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(Eds.)

Advances in Production Management Systems

Innovative Production Management Towards Sustainable Growth

IFIP WG 5.7 International Conference, APMS 2015
Tokyo, Japan, September 7–9, 2015
Proceedings, Part II

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Preface

Modern companies in industrially advanced countries face the low growth of the global economy. Every enterprise makes various efforts to survive in such a severe management environment. Mass production style has disappeared, and manufacturers must provide goods that the customer favors when the customer wants them.

Organizations today cannot do it alone. Most modern enterprises depend on the collective efforts of a group of trading partners to stretch a supply chain from the raw material supplier to the end customer. A trading partner in this context means any external organization that plays an integral role in the enterprise and whose business fortune depends wholly or partly on the success of the enterprise. This includes factories, contract manufacturers, sub-assembly plants, distribution centers, wholesalers, retailers, carriers, freight forwarder services, customer broker services, international procurement organizations, and value-added network services. Building such resilient global value-chains is needed.

Current enterprises also face global environment issues. Saving energy, reduction of industrial waste, and reutilization of natural resources are required in all operational stages to realize environmentally friendly production and logistics systems. Modern manufacturing enterprises should cope well with such issues as enterprise management responsibilities.

This book collects suggestions of leading researchers and practitioners from all around the world, including conceptual frameworks of new approaches, developments of novel technologies, and case studies of practical issues. The book comprises five main categories, including specific subtopic themes as follows:

- Collaborative networks
  - Collaborative tools in production management
  - Collaborative design
  - Distributed systems and multi-agent technologies
  - ICT for collaborative manufacturing
  - Innovation for enterprise collaboration
  - Collaborative information networks
  - Performance measurement and benchmarking
  - B2B, B2C
- Globalization and production management
  - Inventory management in large supply chains
  - Global supply chain systems
  - Mass customization
  - Social and cultural aspects of global supply chains

  - Worldwide procurement
  - Logistics and distribution management

- Knowledge-based production management
  - Computational intelligence in production management
  - Intelligent manufacturing systems
  - Knowledge engineering
  - Knowledge-based PLM
  - Production planning and control
  - Scheduling
  - Automatic learning systems
  - Modeling and simulation of business and operational processes
  - Supply chain simulation
  - Social networks for manufacturing
  - Virtual factory
  - Agile and flexible manufacturing systems
- Project management, engineering management, and quality management
  - Closed loop design
  - Highly customized products and services
  - Quality management
  - QFD
  - Six-sigma
  - New products development
  - Engineering management
  - Engineering and management education
- Sustainability and production management
  - Eco-design and eco-innovation
  - Energy efficiency in manufacturing
  - Green manufacturing
  - Life cycle assessment
  - Remanufacturing
  - Disassembly and recycling
  - Sustainable supply chains
  - Sustainability in global supply networks
  - Smart factory

The papers in this book were peer reviewed and presented at the advanced production management systems conference – APMS 2015 – which was held in Tokyo, Japan, September 7–9, 2015. The conference was supported by Working Group 7 of Technical Committee 5 of the International Federation for Information Processing called Advances in Production Management Systems (APMS) and was hosted by Musashi University, Tokyo, Japan.

There were 185 full paper submittions, and 163 of them were accepted through peer review. Thus, the acception ratio is about 88 %. As the book editors, we would like to thank all the contributors for the high-quality presentation of their papers. We would also like to thank the members of the international Program Committee for their work in reviewing and selecting the papers.

June 2015

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Facilitating Organizing in Business Processes

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Abstract. The paper studies the role of co-orientation, i.e., the alignment of attitudes and activities, in the development of collaborative business processes and how a facilitator can support the emergence of co-orientation and the organizing of collaboration. The development of collaborative business processes is seen as a communicative process of collaborative organizing. Conversations in a co-creative workshop are analyzed to understand the process. The paper sheds light on communication tactics that a facilitator can employ to enable collaborative organizing of inter-organizational business processes towards sustainability.

Keywords: Communication · Organizing · Facilitation · Business processes

1 Introduction

Organizing collaboration in inter-organizational context is often achieved through the development of inter-organizational business processes [1]. The development of collaborative business processes requires a participative approach [2, 3] and application of co-creative methods [2, 4]. Co-creation also enables sustainability [5]. External facilitators can provide an important support for the collaborative development effort [6]. However, little is known about the communicative process of organizing in this context and how it can be managed and facilitated. This paper reports the findings of a study analyzing facilitators' activities in this context and how these activities contribute to organizing and sustainability. Insights from the communication as constitutive of organization (CCO) view are brought into the context of collaborative development of business processes.

2 Theoretical Background

The role of communication in organizing has gained an increased attention of organization scholars during the recent years. The constitutive view of communication maintains that organizing is a communication process and that this process produces enduring patterns that constitute the organization as a whole [7]. According to the Montreal School, organization is achieved through co-orientation, i.e., actors tuning in to one another and a mutual objective [8, 9]. This alignment is produced through interplay between conversations and textual objects [8, 10]. Eventually, collaborative dialogue produces the alignment of interests which can be inscribed in joint textual

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objects. These objects can become distanciated through reification and abstraction and as a result, gain authoritative power in the relationship [10, 11].

According to Vásquez and Cooren [12], three kinds of spacing practices take a central role in the communicative process of organizing by constructing spatial and temporal relationships between actors and elements: presentifying, ordering, and maintaining coherence. Presentifying refers to making an organization and various interests present in a time and space through different materialities. Ordering refers to defining relationships between actors, activities, and responsibilities as well as creating temporal frameworks. Maintaining coherence refers to setting goals and criteria for consistent actions [12]. All these three practices are supported by conversations and textual objects that represent the organization. Through materialization of the organization, representational objects help reveal gaps in alignment and create alternative modes of organizing [13].

Organizing inter-organizational collaboration is a challenging process that sometimes requires an intervention by a neutral facilitator. Facilitation can be defined as a process in which a neutral person diagnoses and intervenes to help a group improve how it identifies and solves problems and makes decisions to increase its effectiveness [14]. In this paper, facilitation is understood as an outside intervention to the communicative process of organizing collaboration between companies. Facilitation itself is also understood as an essentially communicative endeavor. It consists of communication activities aimed at creating conversations and textual objects that support the creation of co-orientation and organization.

Cooren et al. [15] showed how a facilitator can support structuring of an event by enabling dialogue and the agency of nonhuman textual objects as well as interplay between them. We continue the study of facilitator practices from this and focus on the ways facilitators can support organizing by enabling the production of elements that constitute an organization. By elements we mean definitions of relationships between actors, activities, and objectives that are produced through spacing practices [12] and that are inscribed in textual objects and intended to produce collective action [10]. In our study, we focus on business process charts and process discussions, because we are interested in the organizing of business processes.

The main research question of this study is what kinds of communication tactics a facilitator uses to support organizing in business processes?

3 Methods

The study uses qualitative data gathered from a participatory action research [16] project conducted for an airline company that produces flight dispatch and preparation services together with other service companies at the airport. An introduction of centralized load control and a supporting IT system required the development of the collaborative service process. A facilitated workshop was organized for the companies to support the collaborative development of the process by applying a process simulation method [3]. The data consists of the transcriptions of video-recorded conversations that focused on describing and developing the collaboration process with the help of as-is and to-be process models (textual object). The author of this paper did not act in a facilitator role in this workshop but as an observant. However, she participated in the planning of the PAR project which helped her understand the context of the study.

The transcribed conversations were analyzed using discourse analysis, specifically a method called speech act schemas (SAS) that combines speech act analysis with narrative analysis to study episodic structures formed by speech acts [17–19]. The method defines 6 different types of speech acts (assertives, commissives, directives, declaratives, expressives, accreditives) and a narrative schema of 5 phases (manipulation, commitment, competences, performance, sanction) that are used to interpret coordination of action. SAS focuses on analyzing the performative character of discoursive interaction and the organizing effects of speech acts and textual objects [18].

In this study, the analysis focused on the communication practices of the facilitator: how the facilitator guided the conversations and used process models for organizing collaboration and how the participants responded. In the following section, the findings are illustrated by excerpts from the data.

4 Results

The facilitated workshop started with the presentation of the project, greetings from the management, the objectives and agenda of the workshop, and the presentation of the participants. The first discussion topic for the workshop was the current collaboration process and the experienced challenges in it. This was followed by the discussion about the future collaboration process. In the end of the workshop, some group work was conducted on important development challenges but since the role of the facilitators was minor in them, the analysis focused on process discussions closely guided by the facilitators.

The first process discussion started with the facilitator introducing the objective of the discussion and the as-is process model that the facilitators had prepared for the workshop based on interviews. After this, the facilitator encourages participants to describe the collaboration process by explaining each role and activity depicted in the process model.

Manipulation	*Facilitator*:	During the last couple of months, we have prepared together with your representatives a digital model of the flight dispatch process… At first, I could explain the notation so that everybody has an understanding how the model is read. [Explains the notation] Would somebody have something to ask about this notation?	Directive
Performance	*Participant*:	Maybe a small clarification that all the systems are not taken into account in it…	Assertive
Sanction	*Facilitator*:	That was a good clarification. Only the most essential actors and systems are depicted here…	Expressive

As we see in the above excerpt, the facilitators have materialized the collaboration process into a textual object that they claim representing the process. The participants accept this claim with certain conditions confirmed by the facilitator. Right after this, the facilitator asks the participants to describe the actual process depicted.

Manipulation	*Facilitator:*	Could you tell briefly with a few sentences in your own words what is the role of pilots in this process?	Directive
Competence	*Participant A:*	I could try to comment the part that I can but all the others, put an effort into this…	Commissive
Manipulation	*Facilitator:*	What is the role of the pilot?	Directive
Performance	*Participant A:*	The pilot takes the flight under his execution…	Assertive
Performance	*Participant B:*	There emerge also the major problems that we need to come back to, that we discuss in our [unit].	Assertive
Manipulation	*Facilitator:*	Well, next is [this unit]. Could someone tell, … what is the role of [this unit] in this process?	Directive

The excerpt above consists of one episode and the beginning of a second. Here the facilitator encourages the participants to dematerialize the process model by explaining the roles of the process actors. The discussion continues with the facilitator asking the participants describe step by step the activities performed in the process. As the first episode above shows, the participants start also to bring up the challenges in the collaboration process in the discussion. In this way, problems in the alignment of collaborators are brought to light.

The above examples illustrate the ways facilitators can support the organizing of collaboration through presentifying. They prepare objects that represent the organization and use them to create conversations describing the organization and to support the revealing of gaps in the alignment of actors. The findings suggest that facilitators materialize alignment for conversations, support contextualization of the objects, and enable focusing on points of disalignment.

As the discussion continues, new kinds of episodes appear in the data. In the following excerpt, the facilitator realizes that the process model does not correspond to the actual process.

Manipulation	*Facilitator:*	Does the pilot take contact to dispatch at this phase?	Directive
Performance	*Participant:*	It goes so that after the pilot has received this briefing package, they go through it and can ask for replanning… And in case of long distance flights they often take contact and ask for more information.	Assertive
Sanction	*Facilitator:*	So, some kind of contact making could be depicted also here.	Assertive
Performance	*Participant:*	Yes, indeed.	Assertive

The above episode is exemplar in respect to similar episodes in the data that the facilitator suggests the process model be corrected. As the discussion continues, the participants start to bring up deficiencies of the model spontaneously and the facilitator translates the observations into modifications of the model.

New kinds of interaction appear in the data as the discussion moves to the future collaboration process. The process model prepared by the facilitators describes the to-be process which has not yet been completely agreed on. This time the deficiencies in the process model generated discussion about the actual process and how to improve that. Since the future process was still partly open, the result was an understanding that negotiations between partners should be conducted in the near future in order to align activities.

Performance	*Participant A:*	In fact, it should be added… that cargo is responsible for cargo only, and can there be notoc-articles in the mail?	Assertive
Performance	*Participant B:*	No, we do not accept.	Commissive
Performance	*Participant A:*	But then new information can come from the check-in and then catering… That information has to be fed into the [system].	Assertive
Sanction, manipulation	*Facilitator:*	Yes. Is there yet any alternative to how this information is fed?	Directive
Competence, commitment	*Participant A:*	Well, with catering we have not yet agreed on this, nor even negotiated about this. They have quite detailed process nowadays… but the system changes and we have to negotiate on this at a more detailed level.	Commissive

The above excerpts from the conversations show how the facilitators can support the organizing of collaboration through enabling ordering. They help define the collaboration process by capturing modifications to the model as well as encourage alignment where missing. The findings suggest that a facilitator can support ordering by helping define an organizational structure or by encouraging improvement in the organization.

The discussion about the future collaboration process was preceded by a presentation of the goals of the company and reasons for change. This presentation was given by a representative of the airline company. This presentation can be considered as an effort to set goals and create criteria for performance, i.e., to create and maintain coherence. The role of the facilitators in this effort was to give space for discussion about the goals and to mobilize commitment.

Manipulation	*Facilitator:*	…I have asked [F.L.] to tell about the centralized load control and the [new system] at this point.	Accreditive

Performance	*Participant F.L.:*	Now, we have this [new system] coming …Now, in this connection there could be a good opportunity to move into a more centralized model… So, there is a will to achieve a more centralized model…[Q&A]	Directive
Sanction, manipulation	*Facilitator:*	Yes, thank you very much. Keep in mind what came out and emerged in this presentation and now, let's continue the discussion about the future flight dispatch model…	Directive
Manipulation	*Co-facilitator:*	So, we have modelled also this future model during the project… Now, the purpose is to start developing it together… The changes have been marked with pink in here… How does it sound to the cargo is it a good thing that you get this information automatically?	Directive
Commitment	*Participant:*	Yes, it is if it comes automatically, why not.	Commissive

In this excerpt, the facilitator gives the floor to company representative who explains the aims of the management in the change process. After discussion about facts and reasons, the facilitator expresses her gratitude for the speaker and asks the participants to continue the discussion and development of the future collaboration process by committing to the goals set by the management. After this, a co-facilitator introduces the future model and starts asking questions about it from the participants who commit to the changes. The findings suggest that a facilitator can support the creation and maintenance of coherence by providing goals and motivating and by engaging people in a joint effort.

5 Discussion

The findings of this study show how a facilitator can support organizing by communication activities. First, a facilitator can support presentifying by materializing the organization, by supporting contextualization of the objects, and by focusing attention. As previous research has found strategy development to be supported by the processes of decontextualization and recontextualization [20], our findings reveal how a facilitator can support these processes. The function of objects in revealing gaps in understanding has been recognized earlier [13], but we show how facilitators can make use of it. Second, our findings indicate that a facilitator can support ordering by helping define the organization or by encouraging improvement in the alignment of actors and activities. Research in the development of work practices has recognized the role of collaborative modification of objects in supporting development [21] and we reveal the role of conversations in this process and how a facilitator can enhance the interaction.

Third, our findings suggest that a facilitator can support the creation and maintenance of coherence by motivating and by mobilizing commitment. Innovation research has previously shown the importance of change vision for development [3] and activity theory emphasized the role of object-orientedness of human activity [21, 22]. We show how facilitators can provide a purpose for collaborative development.

Altogether, our findings indicate that the role of a facilitator can be important in creating and modifying objects that help define the organization and maintain coherence. They also show that a facilitator can create conversations that help create alignment between actors and activities. Furthermore, a facilitator seems to enable effective interaction between these objects and conversations to advance organizing. The observations confirm the findings by Cooren and his colleagues [15] that the facilitator enables the agency of both human and non-human elements. Our findings contribute to CCO theory and organization theory by presenting activities a facilitator can use to support organizing.

The findings contribute to literature on the co-creation of inter-organizational business processes by describing collaborative business process development as a communication process that supports organizing and can be facilitated, managed and influenced by different human and non-human agencies. The findings help understand how business processes can be defined through the interplay between process models and conversations and how a facilitator can support this through communication activities. The findings give support to the observation by Lavikka et al. [6] that interventions can support the creation of shared understanding about a collaboration process and the co-development of coordination mechanisms. We looked at the phenomenon on a micro-level and add that facilitation of conversations can support organizing by helping collaborators to align attitudes and activities and to define the collaborative business process. Organizing through co-orientation also helps create sustainability. Through presentifying various interests are given voice; through ordering the alignment can be improved; and through purpose creating activities, sustainability as a goal can be brought in.

This study focused on analyzing data from a facilitated workshop but indicated that more research is needed on the role of the facilitator before and after a workshop when textual objects are created and organization enacted.

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Interventions for the Co-creation of Inter-organizational Business Process Change

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Abstract. This paper increases scientific knowledge about developmental interventions in inter-organizational processes by applying coordination theory. The interventions interfere intentionally with the process they aim to develop, reveal interdependencies between the participants, and coordinate their interaction for knowledge creation. The three elements of the developmental intervention are: (1) the participants from the different organizations, (2) the boundary objects that represent the inter-organizational business process, (3) the external facilitator, responsible for designing the other two elements, and for establishing among the participants the knowledge-creating conversational interaction mediated by boundary objects. In a successful intervention, the facilitator and the participants co-develop the necessary coordination mechanisms to support the knowledge co-creation of the participants from the different companies towards the common goal, i.e. the shared knowledge about the inter-organizational process.

Keywords: Intervention · Coordination · Co-creation · Process · Change · Business ecosystems

1 Introduction

The current digitalization of industry drives companies to develop their inter-organizational networks and create new networks for business innovation. The increasing amount of information content as part of products and services opens new business possibilities for companies to serve their customers and end users in novel ways as part of a larger service offering network. This means a huge innovation potential in networked business processes and models [1]. Creating new ICT-enabled business ecosystems is a growing necessity for the survival of many companies nowadays.

Also innovations develop more and more in collaboration between organizations. Collaboration in networks enables individual companies to create solutions to complex problems they cannot solve on their own [2]. Collaboration is required also because networked innovation requires significant adjustments in other parts of the business system than the individual companies are embedded in [3]. However, the creation of networked innovation is challenging because networks are hybrid forms of organizing, and their structures emerge in competitive settings of specific industries [4], and more

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and more also crossing over the borders of traditional industries [1]. Thus, no company alone can be responsible for managing the network towards innovation.

This paper argues that networked innovation can be supported by developmental interventions. Specifically, an intervention can coordinate the collaborative action between companies to enable knowledge creation across company boundaries. The intervention involves purposeful action by an 'external' agent to create change [5]. In this study, the intervention takes place in a network of companies and the agent acting and executing the intervention is a group of researchers external to the companies.

The concept of developmental intervention originates from organizational development [6] and participative action research [7], where interventions are seen as learning and action processes, consisting of the phases of planning, action, and results [8]. The intervention aims at improving the functioning of the participating organizations. The theoretical understanding of interventions is however limited due to the fact that most work on intervention methods and strategies is instrumental in nature, and is decoupled from mainstream organization science [9].

This paper aims at increasing scientific knowledge about interventions for inter-organizational process development by theorizing interventions through the lens of organizational coordination. Interventions interfere intentionally with the organizational process they aim to develop, by revealing the interdependencies between the participants, and coordinating their interaction for knowledge creation and innovation. The question becomes, how to coordinate these interactions over the whole intervention process, so that new inter-organizational knowledge is created, i.e. the intervention succeeds?

When asking this question about the coordination of interaction for inter-organizational process development, we have to bear in mind that the object of the intervention is the inter-organizational process, with a new basis for the differentiation and coordination of tasks [9]. Thus, the knowledge created via the intervention concerns centrally the coordination of the emerging inter-organizational process.

We discuss a preliminary empirical study of an inter-organizational business process development intervention to support the applicability of coordination theory in theoretically describing developmental interventions.

2 Theoretical Viewpoints

In a facilitated intervention that aims to develop an inter-organizational process, the facilitator brings together the participants that co-create knowledge about their interdependencies and ways of collaboration. The successful creation of new inter-organizational practices (process innovation) requires that the participants have the necessary expertise and capabilities to produce innovative solutions. Thus, it is important to engage all relevant stakeholders to the co-creation process [10]. Together they form a shared space, "ba" [11], a virtual community of practice [10, 12] or an innovative knowledge community [13] for knowledge co-creation.

The interactive knowledge creation includes mediating artefacts, often called boundary objects that visualize the object that the participants co-develop. The boundary objects reveal gaps in current understanding [14], and help he participants to cross their knowledge boundaries and create of common understanding [15]. The representational objects are particularly useful in developing collaborative work processes [16]. They help participants to create a holistic understanding of the collaboration process [10], to co-orient towards common objectives, and organize collaborative activities [17]. In addition, these kinds of objects can be collaboratively modified to improve current practices [13]. The possibility to collaboratively modify the boundary objects is essential for knowledge co-creation.

During the co-creation process, the collaborative sharing and creation of knowledge requires conversational interaction between participants. The participants bring in the discussion new observations concerning collaboration, reflect these observations against the current practices, and can produce jointly accepted conceptual change that constitute new knowledge [18]. After this, new ideas produced can be ascribed into boundary objects [19] that represent the process to be developed. The dialectic between conversations and boundary objects produce legitimate representations of the collaboration that gain authority in the relationship, and help coordinate collaboration [20, 21]. The dialectic, collaborative creation of knowledge via modifying the boundary object can be called trialogical learning [22, 23].

Coordination can be defined as the management of interdependences [24]. The need for coordination stems from the need to integrate the interdependencies between differentiated tasks. Successful coordination ensures that the differentiated tasks contribute towards a common goal. The task interdependencies, in increasing order of task uncertainty, are pooled, sequential, and reciprocal, and the corresponding coordination mechanisms are standards and rules, planning, and mutual adjustment [25, 26]. The coordination mechanisms are additive; thus, with increasing task uncertainty, all previous coordination mechanisms are often used, and new ones added.

As environmental uncertainty, level of task interdependence, and time constraints increase, task coordination is not enough but relational coordination is also needed [27]. Relational coordination refers to coordinating work through relationships of shared goals, shared knowledge, and mutual respect. These relational ties reinforce and can be reinforced by communication which is frequent, timely, accurate, and oriented at problem-solving [28].

3 Empirical Developmental Intervention Project

We conducted a developmental intervention project to support the co-creation of a networked process innovation. We applied a participative action research approach where the participants took part in the research process [7]. Action research applies action and reflection, theory and practice, to enable the creation of practical knowledge for the participants of the process [29].

The intervention took place in a network of companies, and the facilitator executing the intervention was a group of researchers. Following the participative approach, the employees of the companies were involved as participants in the intervention. The developmental intervention consisted of three activities: (1) mapping the inter-organizational activities, (2) guiding social interaction for promoting participation, and (3) using mediating artefacts for co-creating knowledge.

The intervention was part of a consortium project of the Finnish Strategic Center for Science, Technology and Innovation for the Built Environment. Eleven companies from the architecture, engineering, and construction industry and two universities developed in the project new, more efficient and innovative inter-organizational project processes and business models, based on the successful use of digitally enabled Building Information Modeling (BIM).

The successful use of BIM in construction projects enables, even requires more intensive collaboration between companies across the traditional professional and sectoral borders. With the use of BIM, the division of work and the interdependencies between the organizations change, and new forms of digitally enabled construction project processes become possible. This necessitates that all parties in the network collaboratively develop new ways of working together. No company can alone be responsible for the process changes. Instead, development has to take place collaboratively and concurrently between the companies in the network.

The intervention was conducted between January and October 2012. The intervention consisted of three phases: (1) collaborative planning of the intervention, (2) a three-day co-creation workshop organized in a relaxing conference center surrounded by Finnish nature, and (3) the further development of ideas into concrete ways of working during a real construction project. In this paper, we will focus on the first two activities.

3.1 Collaborative Planning of the Intervention

In January 2012, a group of researchers and company representatives collaboratively planned a co-creation workshop that should develop a future BIM-based inter-organizational process for the design and development of infrastructure. Three planning workshops á 3 h, and lots of collaborative spirit, were required to develop the plan for a co-creation workshop of three full days, where three parallel groups would approach the development of the BIM-enabled collaboration process, each from their own viewpoint: (1) value creation, (2) the beginning of the process, and (3) the ending of the process.

According to knowledge co-creation theories, the co-creation workshop participants would need a lot of facilitation, and boundary objects, to be able to co-create new practical knowledge about working together in a future BIM-enabled design and development process. During the planning phase, a first "prototype" model of the future BIM-based collaborative process was thus developed, to be used as a boundary object to help the participants share and co-create their practice-based knowledge.

3.2 The Co-creation Workshop

Six Aalto University researchers acted as facilitators during the three-day co-creation workshop. During the first workshop day, the participants had difficulties with getting started. In spite of all the preparatory planning, the participants used the whole day to understand what they should collaborate on during the workshop. It seemed that the participants had problems in trusting each other. However, in the facilitated conversation mediated by the pre-modelled BIM-based process, the participants were able to discuss difficult issues that they thought were hindering collaboration in the present-day construction industry. These issues concerned the companies' different business models and the 'traditional' ways of doing business. These hindrances could now be used as starting points for creating new ideas. The facilitators made sure that each participant could share her/his ideas and could contribute to the shared discussion.

The second day was more successful in terms of co-creating new knowledge. The participants started drawing new ideas on sticky notes that were put on white boards. At the end of the workshop day, the participants co-created an idea of an agile co-working method which would enable the participants to collaborative work with BIM. This idea turned out to be a successful process improvement which was later on tested in the design phase of a potential construction project [30].

During the third workshop day, the participants focused on more thoroughly understanding their new work interdependencies to further develop the idea of the agile co-working method. They wanted to understand when and how they should use the agile co-working method in their BIM-based collaboration process that had been developed for an earlier reference project. The facilitators helped the participants to reveal their work interdependencies in the collaborative BIM-based process, and used process models and other boundary objects to support the conversation. Table 1 presents the tasks of the facilitators during the planning and the three-day co-creation workshop.

Table 1. The participants, boundary objects, and tasks of the facilitators in the intervention.

	The planning of the co-creation workshop	The three-day co-creation workshop
Participants	- 5 voluntary participants from 5 companies - 6 researchers from 2 universities	- 25 voluntary participants from 9 companies - 13 researchers from 2 universities
Boundary objects	Process model and process specification documents enabled the planning the of co-creation workshop and provided a common object of development.	Process model, power point presentations, specification documents to discuss about common objects of development, and as platforms for creating new ideas.
The tasks of the facilitators	- Idea collection for the co-creation event - Deciding on the facilitation techniques - Manuscript for the co-creation workshop - Detailed plans of the group assignments - Implementation of Online group work tool - Design of web-based survey for feedback	- Keeping the schedule - Pre-planned material for the group work - Challenging the participants' views - Making sure that progress takes place - Suitable climate for knowledge creation - Writing down ideas - Ensure the free presentation of ideas

4 Results and Discussion

In this paper, we have aimed to increase scientific knowledge about developmental interventions in inter-company business processes by theorizing interventions through the lens of organizational coordination. We have shown that interventions interfere intentionally with the inter-organizational business process they aim to develop, show the interdependencies between the participants, and coordinate their interaction for knowledge creation and innovation.

The paper finds three key elements of the developmental intervention that are crucial for the coordination of shared knowledge creation: (1) the participants from the collaborating organizations, (2) the boundary objects that represent the participants' interdependencies in the inter-organizational business process that is to be developed, and (3) the external facilitator of the intervention, responsible for establishing the conversational interaction of the participants, mediated by the artefacts, to support the creation of shared knowledge concerning the business process.

The intervention consists of a sequence of phases: planning, co-creation events, and implementation (Fig. 1), and the facilitators can plan the intervention to some extent in advance. The facilitators collect a lot of data from the participating organizations before the co-creation event, and design the co-creation event in collaboration with key representatives of the participating organizations. More precisely, the facilitators (1) set the goal for the intervention in collaboration with the key participants; (2) collect the data and select the participants using interviews and snowball sampling; (3) design the boundary objects in collaboration with the key participants; (4) prepare a 'manuscript' and schedule for the co-creation event.

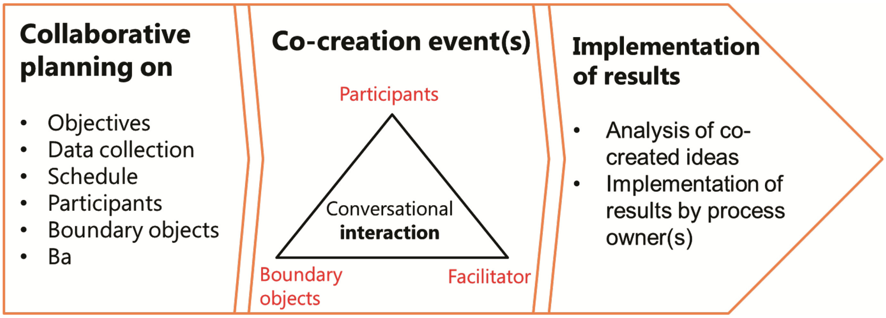

Fig. 1. The phases of a developmental intervention and its three elements that are crucial for the coordination of shared knowledge creation.

In the co-creation event, the boundary objects, often visual maps or scenarios of the inter-organizational process to be developed, provide some "rules" that help the facilitator to guide the conversational knowledge co-creation, and the manuscript acts as a plan and schedule to steer the highly interactive conversational process.

The results of this case study confirm that the participants of the co-creative events, the boundary objects, and the facilitators are required to coordinate the co-creation of shared knowledge concerning the future inter-organizational process. However, the object of the development is highly uncertain: an emerging inter-organizational process. Therefore, not all participants are even known at the beginning of the intervention, not to speak of their interdependencies that will become the object of co-creation. Interaction and mutual adjustment between the facilitator and the collaborating organizations are therefore needed throughout the intervention project.

The paper suggests that in highly uncertain and complex inter-organizational business process transformation, such as in the BIM-enabled project process change, the facilitator and the participants can co-develop the coordination mechanisms to support the necessary knowledge co-creation of the different organizations towards the common goal, i.e. the shared knowledge about the future inter-organizational process. The important coordination characteristics of a successful developmental intervention include both task coordination and relational coordination. The intervention (1) helps to identify and co-develop novel task interdependences [25, 26] and (2) the intervention helps to create common understanding about how to manage them [27].

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Open Cloud Computing Architecture for Smart Manufacturing and Cyber Physical Production Systems

Digital Manufacturing in Smart Manufacturing Systems: Contribution, Barriers, and Future Directions

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Abstract. Today, smart manufacturing systems (SMS) are being developed to improve manufacturing competitiveness. Digital manufacturing (DM) is a technology that supports the carrying-out of tasks and decision-making based on digital models and simulation in a virtual environment, without physical prototypes or experiments. A DM system helps in the design and redesign and analysis of a factory, sustainably and efficiently, to optimize its performance in an SMS. In this paper, the contributions of DM systems in SMS and the application barriers of DM systems are described. A real case that has been developed to overcome the barriers is introduced. Finally, future directions of DM systems in SMS are discussed.

Keywords: Cyber-physical system · Virtual manufacturing · Factory performance optimization · Modelling and simulation

1 Introduction

Leading research institutes and global companies are developing and implementing smart manufacturing systems (SMS) to improve manufacturing competitiveness [1, 2]. Digital manufacturing (DM) is a technology that supports the carrying-out of tasks and decision-making based on digital models and simulation in a virtual environment, without physical prototypes or experiments [3].

A DM system is based on computer-aided design (CAD), simulation, and an information-sharing model. It makes use of legacy systems such as product lifecycle management (PLM), enterprise resource planning (ERP), manufacturing execution systems (MES) and supply chain management (SCM) [3, 4]. DM is an essential system in the design, redesign, and analysis of a factory in SMS [5, 6]. DM is being implemented and developed into various manufacturing industries.

This paper is structured as follows. In Sect. 2, the contributions of DM in SMS are explained. In Sect. 3, application barriers of DM are described. A case that has been developed to overcome the barriers is introduced in Sect. 4. Finally, future directions of DM in SMS are discussed.

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2 Contribution of DM in SMS

SMS connects all manufacturing elements such as procurement, production, product, logistics and service. It controls the process of production by a cyber-physical system (CPS) [7] as a unified environment. CPS enables not only the exchange of all necessary information for the manufacture of optimized products, but also the control of the entire production process in the factory, based on the “internet of things” (IoT) [8]. DM in SMS is located as a virtual factory for the manufacture of products in a cyber-area, as shown in Fig. 1. DM in a SCOR model [9] covers the Plan as it is related to the Make process, and those parts of the Source, Delivery and Return processes that are connected with Make.

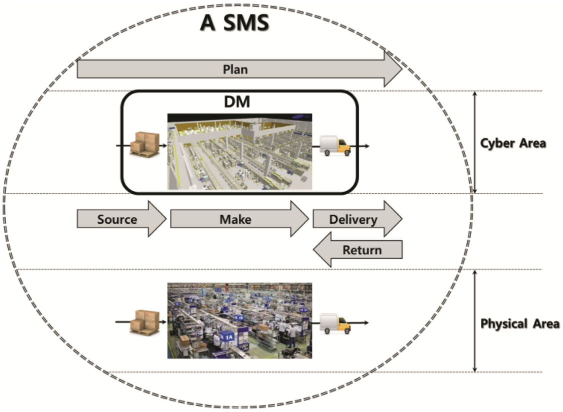

Fig. 1. DM coverage in a SMS

There are three types of DM: design-centered, production-centered, and control-centered, according to the application field and the purpose, as shown in Fig. 2 [3].

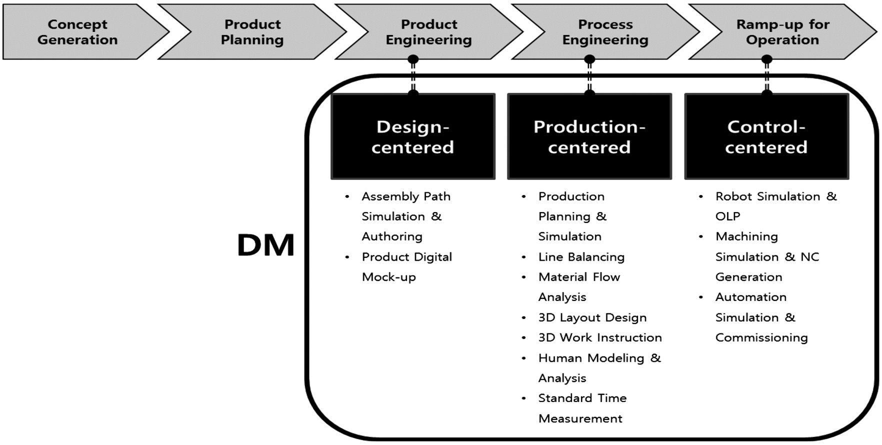

Fig. 2. Functional classification of DM

Design-centered DM has functions of assembly path simulation and authoring, and product digital mock-up, for support of design and engineering tasks [10, 11]. Production-centered DM supports manufacturing preparation tasks related to the functions of production planning and simulation, line balancing, material flow analysis, 3D layout design, work instructions, human modelling and analysis, and standard time measurement [10, 11]. Control-centered DM focuses on monitoring and controlling by direct interface with production systems and machines on the shop floor. It includes functions of robot simulation and off-line programming (OLP), machining simulation and numerical control (NC), and automation simulation and commissioning [10, 11].

3 Barriers of DM Application

We have built over 40 virtual factories based on DM for automotive, electronics, machinery, and shipbuilding companies in Korea for 15 years. The barriers were analysed based on the experiences [15, 27–29].

3.1 The Approach Based on Functions of DM System (View of DM Vendor)

Consultants and engineers in DM vendors [10, 11] have an approach based on system functions. At the time of meeting with the manufacturing company, DM vendors provide solutions by the mapping of system functions according to the customer's requirements. DM vendors usually believe that all requirements will be satisfied and functions supported because they are offering powerful systems.

However, the functions overlap and integration problems often occur because the manufacturing company is already using heterogeneous software packages. In addition, manufacturers will often have employees whose ways of working are based on their own experience and existing methods, and without the use of software packages. They tend to resist the introduction of new software packages and systems. This resistance is higher in engineers than it is in managers.

3.2 The Approach Based on Tasks of Optimizing Factory Performance (View of Manufacturing Company)

Tasks in the factory are complex and have variability [12]. Manufacturing companies often have trouble in explaining accurately and clearly their current problems and their requirements for system development, due to various reasons such as confidential data or unawareness. But a clear analysis of requirements at each manufacturing level, from individual machine to the factory as a whole, is essential for project success.

Then, performance measures and the correlations have to be defined based on the analysis. The person in charge at each manufacturing level tends to care only about his or her particular area of work. Thus, it can be difficult to define performance measures and the correlation analysis for an entire factory performance optimization.

Many researches have been carried out on factory performance measures [12–14]. However, there is a shortage of correlations analyses. In order to develop a DM system successfully, a definition of performance measures and a correlations analysis for the entire factory are necessary.

3.3 Barriers Between Two Approaches

A manufacturing company can develop an over-optimistic view of the effect of a DM system that has fancy 3D visualization. Sometimes, they believe that all the problems in the factory will be identified and solved without any efforts, simply by purchasing such a DM system. Undirected or vague development without determination of factory performance measures and elimination of engineers' resistance can lead to a negative return on investment (ROI). Specific and clear communication, informed decision-making, and role performance between the DM vendor and the manufacturing company lead to success in system development.

Three important factors are summarized which will eliminate the barriers between two approaches as mentioned earlier:

- clear definition of factory performance assurance, performance measures, and their correlation;
- mapping between derived performance measures and functions of DM systems;
- data exchange and integration between heterogeneous software packages and systems (not only heterogeneous DM systems but also other related systems such as PLM, ERP, SCM, MES).

Solicitude and collaboration between DM vendors and manufacturing companies is most important, and is achieved through an understanding of the differences between them in areas such as knowledge, terms, and culture.

4 Case Study

In this Section, a real published case is introduced, in the light of the three important factors mentioned above.

e-FEED [5] is a system to comprehensively design, redesign, and analyse manufacturing processes and lines in the factory. e-FEED serves as a hub that provides knowledge and a standardized engineering process. It enables diverse factory development, with engineers and managers able to access the system simultaneously and make decisions through collaboration [5].

The factory design and improvement (FDI) process in the manufacturing company was analysed as the first priority in developing e-FEED. FDI has four steps: Requirement, Basic Design, Detailed Design and Test, as shown in Table 1 [6].

FDI is a complex process because of the need to determine the manufacturing method, equipment, processes and lines while considering the overall product lifecycle related to the product plan, design, and manufacturing. By analysing FDI using IDEF0 as shown in Fig. 3, performance measures and the correlations were derived and the mapping of DM functions was carried out.

Table 1. Factory Design and Improvement [6]

Step	Description
Requirement	The customer's needs are investigated. General plans relating to infrastructure, environment, budget, sales, production and schedule are established
Basic design	After the production target is set, capacity, equipment and human resources are estimated. The layout is designed briefly as well. Then a more suitable production system is developed
Detailed design	Equipment and inspection machines are designed by analysing manufacturing methods and processes. The material flow between each process, each floor and each factory is designed by referring to the estimated capacity in the basic design step. Material handling such as loading and unloading, transportation, and storage are developed as well. The final layout is determined on the basis of the modules, processes, lines, and material flow design
Test	The manufactured equipment is inspected and the real processes and manufacturing lines are set up. Once arranged on the shop floor, the layout, material handling and material flow are verified. Finally, all processes are standardized under optimum conditions

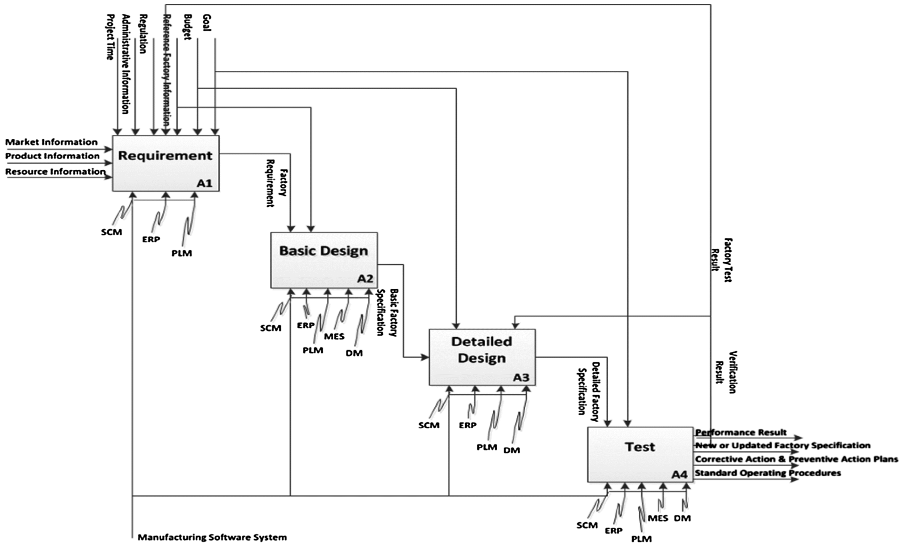

Fig. 3. FDI activity modelling by IDEF0 [15]

e-FEED consists of an advanced factory designer to design the layout easily, a database or library of equipment, processes and lines, and a XML schema [5] to enable an automatic interface between heterogeneous engineering software packages. Such a factory layout can be designed and changed easily. The simulation is run automatically by e-FEED, as shown in Fig. 4 [5].

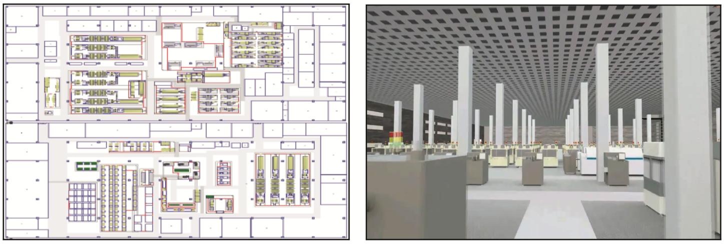

Fig. 4. Layout design and 3D design review [5]

The XML schema contains the Product, Process, Resource and Plant information as shown in Fig. 5 [16, 17]. The schema also has smart-supports rule data for design error verification and object relation information [5]. It was based on the PLM Services 2.0 [18] defined by the Object Management Group for PLM data exchange considering the extensibility, and included the scoring model and the result model for the integrated decision-making result report.

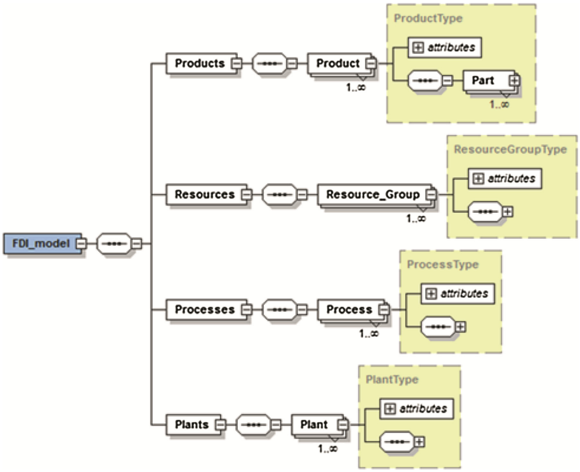

Fig. 5. XML schema structure

The schema-based automatic interfaces between heterogeneous software tools to design, redesign, and analyze manufacturing processes were developed. Figure 6 shows software tools that the target company uses. If there are no ways such as application

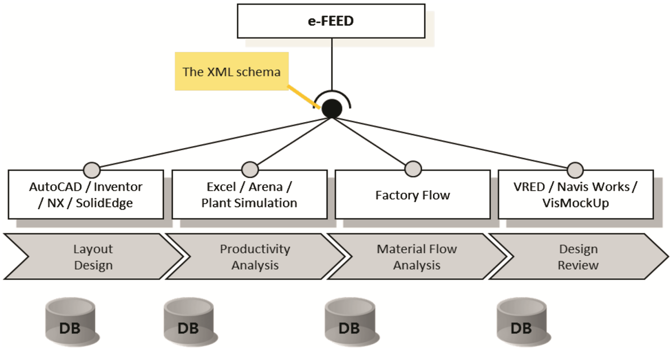

Fig. 6. XML schema based interface between heterogeneous software tools

programming interface (API) or scripts in the software tools in order to exchange data, the task is carried out manually by the persons in charge.

Projects for new factory development and improvement of existing factories were carried out based on e-FEED. Work time for a new factory layout design was reduced from six weeks to 1.5 weeks, and improvement work on an existing factory that previously took four weeks can be carried out within one week [5]. Particularly time-consuming tasks for factory performance optimizing such as data collection, creation of a simulation model and documentation are improved innovatively. The expected maintenance costs to operate the system are reduced as well. Above all, existing work processes that depend on a few experts are eliminated.

5 Future Directions

This paper explained the contributions of DM to SMS, and barriers encountered when DM is introduced at a manufacturing company. And a real case that tries to solve current problems between DM vendors and manufacturing companies is described.

In order to develop a comprehensive system, FDI as an activity model is proposed and an XML schema is developed based on FDI. Tasks of DM development and factory performance optimizing are highly reliant on experts. FDI and the schema help to develop functional mapping of DM and the key performance measures at each manufacturing level, from individual machine to the factory as a whole, instead of experts. FDI is being extended and improved to support not only more specific works in the factory but also various industries. Interfaces to connect various software packages and systems that are already in use in the real company are incorporated into the schema as well.

As mentioned before, tasks in the factory are complex and have variability. Research into performance measures and the correlations between each manufacturing level in the factory have to be carried out actively. Standard reference models and data schemas are required for DM system development. A standard can dramatically reduce the trials and errors of system development. Moreover, once continuous factory design and analysis are executed and optimized, factory performance can be maintained stably and according to a standard. Training in such functions as factory performance, DM functions and project leadership is consistently required.

The future DM system will be improved into the realistic system [19, 20] by adopting virtual reality technology. In addition, control-centered DM connected to the shop floor will be implemented much more widely [21]. For this, an interface between a DM reference model and MTConnect [22] can be considered. The reference model has to be developed with regard to flexible interfaces with reference models of ERP, SCM, PLM and MES in SMS, such as SCOR [9], DCOR [23], MESA [24] and ISA95/88 [25, 26].

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A Formal Process for Community-Based Reference Model Evolution for Smart Manufacturing Systems

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Abstract. Service-oriented manufacturing systems need to be supported by formal reference models for effective service description, discovery, and composition. A reference model should evolve continuously throughout its lifecycle to respond to changing requirements. The objective of this work is to propose a formal process for collaborative and community-based reference-model evolution and identify the computational components required for effective model evolution. The main steps of the proposed process include service registration, vocabulary extraction, evolution triggering, change evaluation and approval, and change implementation. An important feature of the proposed process is the use of a Simple Knowledge Organization System (SKOS) thesaurus for the initial stages of knowledge elicitation and organization.

Keywords: Ontology evolution · Service-oriented manufacturing · Smart manufacturing · Crowdsourcing reference models · Cloud manufacturing

1 Introduction

Distributed intelligence is one of the key distinguishing features of the already emerging, next-generation manufacturing systems. The new factories of the future are supported by *service-oriented, data-driven*, and *knowledge-based* systems [1]. Such factories will be operated and controlled by networks of interconnected devices and processes with embedded intelligence. These embedded intelligent agents will provide and consume a wide range of services such as process selection, production planning and control, inventory management, quality control, and maintenance planning. A service-oriented manufacturing enterprise comprises a network of loosely-coupled processes that can be configured and reconfigured in a timely manner in response to changing needs. This enhances the overall responsiveness, agility, and resilience of the system.

Although the idea of Service-oriented Manufacturing (SOM) has been around for more than a decade, there are still multiple infrastructural issues that need to be addressed before all the benefits of SOM can be realized in practice [2–4]. One of those issues is the development of shared reference models that are used for representation of the services. In the presence of shared and formal reference models, a human user, or an intelligent agent

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embedded in the smart manufacturing system, can (1) offer and consume services, (2) perform inference and reasoning about service capabilities, and (3) participate in automated or semi-automated services composition and system configuration. Several types of reference models, such as information, functional, and resource models, are needed to describe different types of engineering services including engineering information services, cyber-physical system services, and hardware services. Without useful and effective reference models, ambiguity and imprecision ensues in communications among collaborators, stifling their efforts to enable smart manufacturing when using those manufacturing services.

A reference model, like any other ontology, is a living entity that evolves over time due to change in the conceptualization of the domain, business strategy evolution, or new user's needs. A reference model in a large manufacturing domain needs to be collaboratively and evolutionally developed [5]. For managing the evolution of ontologies that are maintained by a single organization and used by homogenous and collocated users, there are established processes based on data-schema evolution that have been successfully adopted and implemented [6]. However, the socio-technical aspects of the community-based, ontology-evolution process have not been adequately investigated and understood [7]. In this paper, we discuss a general framework for evolving a reference model from a service-oriented perspective. We collectively refer to all the necessary reference models as a single service reference model, or simply a reference model (RM).

There are multiple requirements for the model-evolution process in a collaborative and distributed setting. Most importantly, the evolution process should enable detection and resolution of semantic conflicts and ambiguities. Also, it should be a social process driven by community goals and interests. The evolution process should follow a structured methodology that (1) ensures long-term validity and consistency of the model and (2) involves all stakeholders including service providers, service users, and reference-model administrators and developers. The process should be transparent, formal, and timely.

Traditionally, the evolution of a reference model adopted for a data exchange standard is a batch process. The model or standard custodian either updates the model after a certain time period or waits until there are significant new requirements for change. In some cases, the models can evolve sooner, even though the updates will have no impact on existing usages. Conversely, some updates may cause large impact on existing usages. Formalizing the process means that automation could be applied as much as possible. Automation is preferred since manual handling of the evolution can be time-consuming and error-prone – especially as the size and complexity of the reference model increases.

The objectives of this work are (1) to propose a formal process for community-based reference model evolution and (2) to identify the computational components required for effective model evolution. The remainder of this paper is organized as follows. The next section lays out the necessary assumptions and definitions pertaining to the proposed process. The model evolution process is discussed next, followed by an example scenario. The paper ends with some closing remarks.

2 Assumptions and Definitions

Assumptions:

- The reference model contains the classes, properties, and axioms required for describing different types of manufacturing services.
- The proposed evolution process only applies to extensions of the reference model. The evolution of the core of the reference model may call for a different set of procedures and is out of scope.
- The reference model uses Ontology Web Language Description Logic (OWL DL) syntax and semantics.
- Services need to demonstrate Minimal Ontological Agreement (MOA) with the reference model before they can be registered for discovery. In other words, the service description that uses the reference model to formally describe the service must at least agree with the core of the reference model.
- There are multiple sub-problems related to ontology evolution including backward compatibility, change propagation, and consistency maintenance [8]. In this paper, we discuss only the overall process of ontology evolution.

Definitions:

- Service: A service is a complete, self-contained, unit of functionality with well-defined interfaces and possibly quality measures.
- Service Scheme: Service scheme is an ontology fragment describing conceptual-level classes, properties, and axioms used in defining a service. Ontology design patterns may also be part of the service scheme.
- Service Provider: An organization responsible for description and provision of a service.
- Reference Model Evolution: Reference model evolution is defined as a timely enrichment, extension, or adaptation of the model to the arisen changes through subtractions and additions of the classes, properties, and axioms while maintaining the semantic consistency of the model. Propagation of the changes to the depending artifacts (i.e., service descriptions) is also a part of the evolution process.
- RM Admin: RM admin is in charge of overseeing the evolution process and directing the workflow.
- RM Engineer: RM engineer is an expert in ontology development and knowledge modeling.
- RM Community: RM community comprises domain experts in those technical fields related to the concepts in the reference model. Community members may play multiple roles including the service provider and RM engineer.
- Service Registration: Service registration refers to a formal request to add a service to the service registry. Upon registration, the service description is accessible to the service registry user/agent. A service registration event may or may not trigger an evolution.
- Optimistic Service Registration: The service is accessible right away for discovery after registration despite any possible misalignment between the service scheme and

the reference mode (note however that the service scheme still has to align with the core of the RM, i.e., satisfying the MOA). This strategy allows the service to still be used while it may not be easily discovered and composed.

- Pessimistic Service Registration: The service is available for discovery only after its internal service scheme is aligned with the reference model.
- Primitive change: A change that affects only a single OWL primitive.
- Complex Change: A change that affects more than one OWL primitive.

3 Reference Model Evolution Process

The reference model evolution process proposed in this paper is based on the optimistic service registration scenario. Under this scenario, service registration and RM evolution are decoupled, yet related, processes and are modeled in the same flow. In the proposed RM evolution process, the reference model is supported by a SKOS (Simple Knowledge Organization System) [9] thesaurus tool, which provides linguistic and semantic analysis of the concepts and terms used in the model. The SKOS model also makes the link between the lexical (terms for concepts) model and conceptual model explicit. Such features help in harmonizing jargons in a distributed, multi-field environment. The main steps of the service-registration and model-evolution processes are described below.

Service Registration: The registration process starts with a *service provider* submitting a *service registration package* containing multiple components including the service scheme, corresponding description, and, possibly, installation files. By comparing the service scheme with the core RM, the MOA prerequisite is verified and if the service meets this prerequisite, it is queued for registration. This prerequisite ensures that the service scheme is in agreement with the core conceptual model of the RM. The service is then registered and stored in a temporary space of the service registry and is made available for discovery and use by service users. Expiration may be applied to services in the temporary registry. The workflow of the service registration process is shown in Fig. 1.

Vocabulary Extraction: The service scheme included in the service registration package contains the vocabulary of the service - classes and properties. The vocabulary is extracted automatically from the service scheme and saved as a SKOS model under the category of *Candidate Vocabulary.*

Change Process Triggering: The RM change process can be triggered automatically either after a predetermined time has elapsed or after a certain event takes place. Examples of the events that can trigger the change process include (1) a threshold is reached on the number of candidate concepts, (2) a semantic conflict between the candidate concepts and the RM occurs, (3) semantic gap in the RM is identified, or (4) a change in the usage behavior or goal of the system users is observed. While events in #1 can be detected totally automatically, the rest will be detected by a combination of human and computational algorithms. In particular, bottom-up (inductive) change recognition algorithms are frequently used [7].

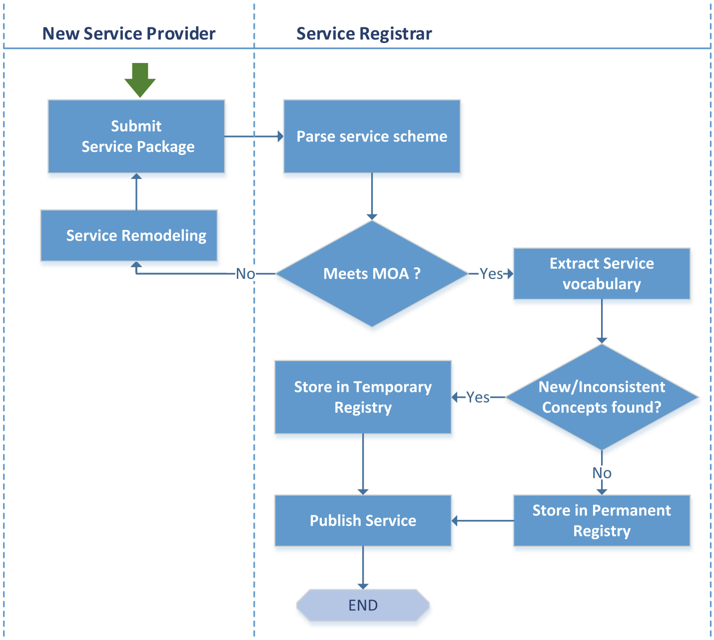

Fig. 1. Service registration process

The RM engineer can also trigger the change process manually to adapt the ontology to new requirements or enhancements. Enhancements refer to the usability of the ontology, which is based on feedback from the end users. In either case, the RM engineer creates the change request centrally and initiates the evolution process. The RM engineer also conducts an impact analysis to identify the consequences of the change. The formal change request together with the impact analysis result is sent to the RM admin for approval. Figure 2 shows the workflow of the change approval process regardless of whether or not the change is triggered automatically or manually.

Change Evaluation and Approval: The proposed change should be first approved by the RM community and then by the service owners who will be affected by the change. The change approval process is administered and managed by the RM admin. The admin first notifies the RM community of the details of the requested change and its nature and scope. The change can be as simple as renaming a class or attribute (*primitive change*) or it can involve adding new ontology constructs composed of multiple classes, properties, and axioms (*complex change*).

The RM community members, who have vested interest in the impacted artifacts, evaluate the requested change with respect to technical and terminological validity and viability. These interested members may come from subscriptions to particular concepts or based on prior services for which they had registered. Once the RM community approves the proposed change, the RM admin identifies the registered services, which will be affected as a result of the change, and submits the proposed changes to providers of those services.

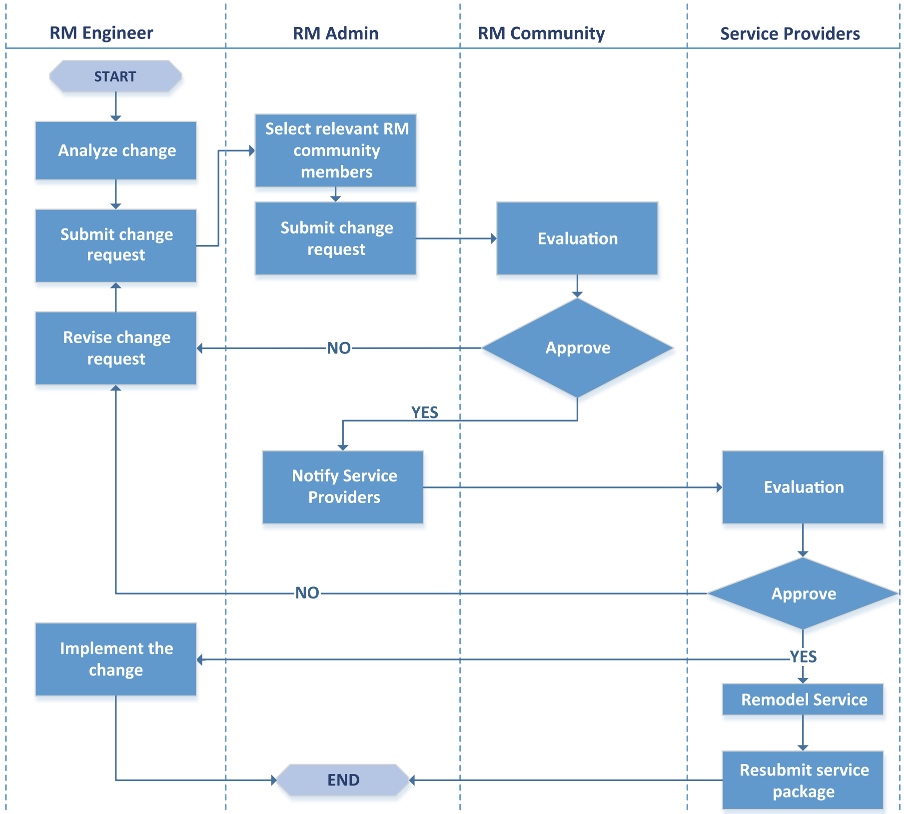

Fig. 2. RM change process

If a majority of the service providers approve the proposed changes, the change is formally approved and implemented in the reference model by the RM engineer. The affected services are moved to the temporary registry space. Service providers then restructure those services based on the proposed change and resubmit a new service registration package, which contains the new service scheme, for registration (Fig. 2). If the proposed change is rejected by a majority of the affected service providers, the RM admin requests the RM engineer to redefine the change based on the feedback received and submit a new request or discard the change request.

Change Implementation: If a change request is approved, the RM needs to be updated accordingly. The RM engineer is in charge of applying the change to the thesaurus and the ontology. The concepts and properties that are approved are moved to the *Approved Vocabulary* scheme of the SKOS thesaurus. Then the corresponding changes are applied to the ontology itself. This involves both required change (directly modifying the ontological entities mentioned in the request) and derived change (discovering new changes based on the explicit changes).

4 Example

In this section, we describe the proposed service registration and model evolution process through an example scenario. The service used in this example receives operational data from an MTConnect [10] agent of Computer Numerical Control (CNC) machines through Hyper Text Transfer Protocol (HTTP) requests and calculates the energy consumption for the given set of machining instructions written in G-code. This service is named Machining Energy Consumption Calculator (Mecca) by the service provider. At the time of registration, the service scheme is extracted from the submitted service registration package as shown in Table 1.

Table 1. The extracted vocabulary for Mecca

`Classes`	`Vertical Milling Machine, Material, Part, Energy, Power, Cutting Tool, Spindle, Machining Operation`
`Object props`	`hasSpindle, acceptsMaterial, hasCuttingTool`
`Data-type props`	`Feed rate, spindle speed, depth of cut, specific energy, machinability rating, cut length in X, cut length in Y, cutting energy`

The extracted vocabulary is then exported to the SKOS tool as shown in Fig. 3. The service scheme is also recreated in the SKOS tool to maintain the relationships between Mecca model entities. Through a comparison between the Mecca service scheme and the reference model, the following discrepancies are detected:

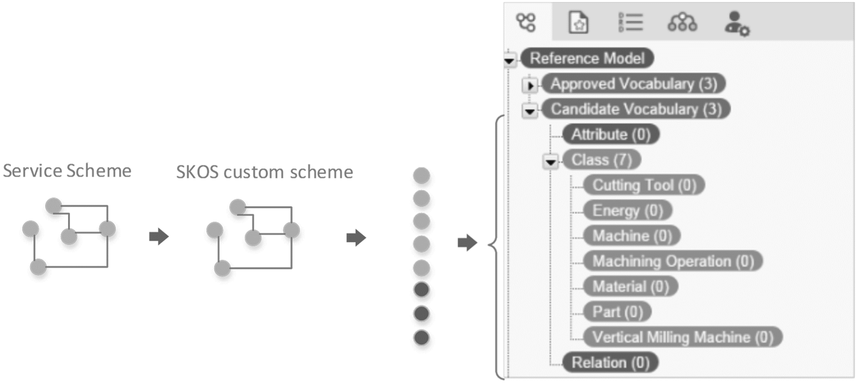

Fig. 3. Vocabulary extraction

- D1: *machinability rating* is an attribute of the Material class in Mecca, but the Material class doesn't have such attribute in the RM.
- D2: *spindle speed* is an attribute of the Vertical Milling Machine class in Mecca, but *spindle speed* is an attribute of the Spindle class in the RM.

In this example scenario, we assumed that the change process is triggered when the accumulated number of candidate entities (class, property, relationship) reaches a threshold. Once the change process is triggered, the RM engineer creates a formal change request and submits it to the RM admin. The RM admin then routes the change workflow to the appropriate RM community subgroups for evaluation and approval. The RM community approves the addition of *machinability rating* as a new attribute of the Material class. A notification is then sent to all providers who use the Material class in their service scheme. Since no conflict arises on the service providers' side, the change receives final approval and the RM engineer updates the RM accordingly.

The RM community, however, maintains that it is more appropriate to keep the spindle speed as a property of the Spindle class rather than a property of the Machine class (note that the Machine in turn owns a Spindle).

The RM community, however, maintains that it is more appropriate to keep the spindle speed as a property of the Spindle class rather than a property of the Machine class (note that the Machine in turn owns a Spindle in the reference model). Therefore, the RM admin notifies Mecca service provider about the need for service description revision. The provider agrees to revise and resubmit the service description. To assure an effective revision, the RM engineer points the service provider to a library of modeling patterns that have been approved for use in the RM development and evolution process.

5 Closing Remarks

In this paper, we proposed a methodical process for community-based reference model evolution and identified the necessary computational requirements. The main steps of the proposed framework include service registration, vocabulary extraction, change request submission, change evaluation and approval, and change implementation. An important feature in the process is the use of a SKOS thesaurus for the initial stages of knowledge elicitation and organization. The thesaurus separates meaning and labels; thus, simplifying the resolution between model developers and service providers. Also its simple semantics facilitates active involvement of community members in the evolution process.

There are multiple issues that need to be addressed before the proposed framework can be fully utilized. Currently, protocols that guide service providers in creating services that are conceptually in agreement with the reference model do not exist. Also, the components of the service registration package should be formally defined. Semantic-and-linguistic analysis and mapping of the incoming service schemes are technical challenges that need to be addressed. The events that can trigger the evolution process also need to be defined more precisely. Developing the machine-learning algorithms and data-mining techniques that support change discovery, based on ontology instances and usage patterns, is another future task. Other areas that need further investigation include impact analysis, change propagation, and change validation.

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Analysis of Standards Towards Simulation-Based Integrated Production Planning

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Abstract. Production planning is carried out at the enterprise, operation, and process levels. Although production plans at higher levels constrain those at the lower levels, the processes for generating those plans are typically not well integrated in practice. Because of that, the schedules at lower levels may not accurately reflect what was planned at the higher levels while the plans at the high level may not be based on prevailing conditions at the lower levels. Simulation models that evaluate the performance of a production plan also need to be integrated with production management systems. This paper provides a background to integration problems associated with simulation-based multi-level production planning by exploring current practices, standards, and tools. We lay a foundation for a standards-based simulation for integrated production planning.

Keywords: Integrated production planning · Simulation · Standards

1 Introduction

The objective of production planning (PP) is to decide on product types and quantities to produce during specific future periods to meet demand. PP is typically decomposed into decisions at different levels in the organization [1]. Bitran and Tirupati [2] identified the PP levels as enterprise, operational, and process levels. Enterprise level planning relies on aggregated estimates while lower level planning uses up-to-date, granulated data. Figure 1 illustrates the conceptual view of inputs and outputs for different PP levels. The input data for enterprise planning are customer and forecasted demands, projected capacity, and inventory. The outputs are the details of production release and sales, also called the master production schedule (MPS). Lower level plan outputs are scheduling policy, work in progress levels, cycle times, and dispatching.

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The aggregate PP problem can be formulated as a linear mathematical model to determine future production levels, capacity, labor force, and inventory [3]. The enterprise resource planning (ERP) tool determines production resources, financial, and delivery of raw materials to execute the plan. The manufacturing execution system (MES) uses the MPS to provide shop floor production instructions. The outputs of the MES including dispatching rules and procedures are often evaluated by simulation taking into account real-time events such as machine breakdowns and part shortages [1]. This typically results in a more detailed and up-to-date situation analysis.

Clearly, the degree of coordination between enterprise-level PP, lower-level PP, and the integrated simulation models plays an important role in the success of PP. In particular, the prediction of shop floor events and anticipated capacity being fed back to enterprise-level level to update the MPS [4]. PP methods such as CONWIP cannot succeed without feedback of shop floor simulation results to enterprise level planning [5, 6]. Moon and Phatak [7] also showed that bi-directional feedback between a stochastic shop floor simulation and ERP improved lead-time accuracy. Kulvatunyou and Wysk [8] demonstrated with a simulation model that decomposition and modular integration of resources, process, and production data led to up-to-date analysis. For these reasons, we propose that simulation-based integrated PP enabling a cyber-physical system approach of combining computational and physical elements to adapt to changing environments be employed. However, there are problems to achieving such integration. This paper provides a background to addressing those problems by reviewing existing methods, PP interface standards, and a sample integration architecture. An extension of the SIMA reference architecture [9] is proposed to define inputs and outputs to activities, and information needs at each PP level.

The rest of the paper is organized as follows. Section two describes the causes of PP and simulation integration problems. Section three discusses a reference architecture that can be adapted for the simulation-based integrated PP to increase accuracy. Section four concludes the paper and discusses future work.

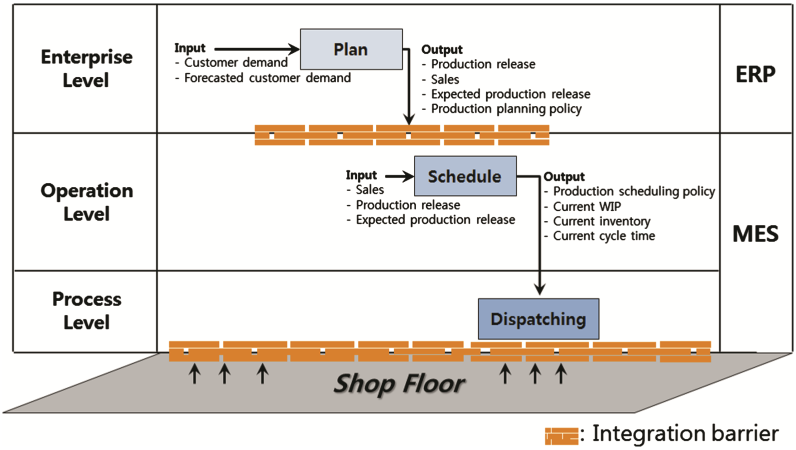


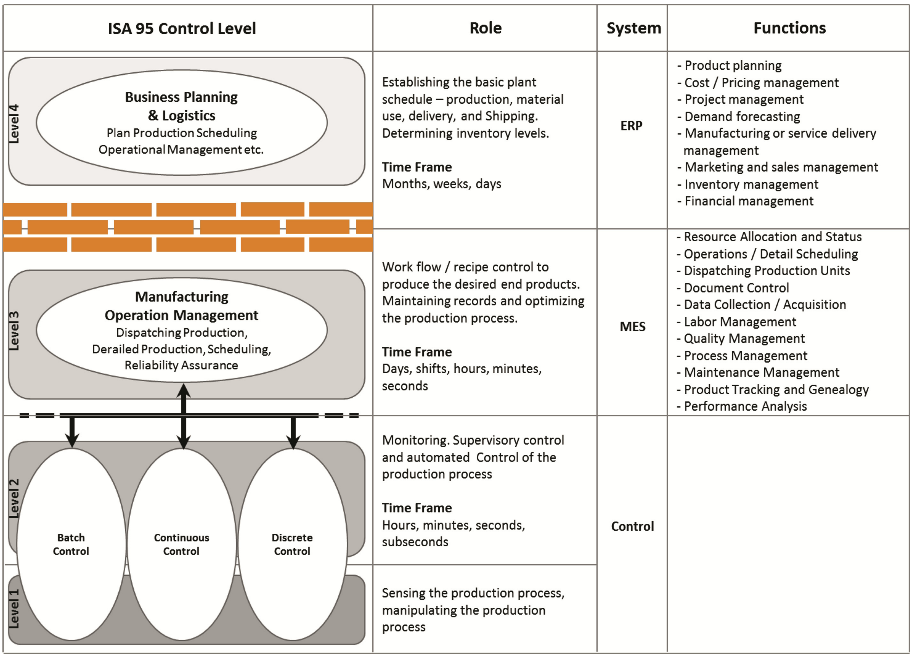
Fig. 1. The input and output data between different PP levels.

2 Analyzing Problem Sources

We describe the PP and simulation integration problems by examining characteristics and the challenges with applying existing standards to the problem.

Temporal Characteristics of the Problem. The decomposition of the PP problem into enterprise, operational, and process levels is consistent with the ISA-95 CIM (Computer Integrated Manufacturing) standard model. ISA-95 activities are classified into 4 levels, shown in Fig. 2. Levels 1 and 2 activities manage manufacturing processes. At level 1, processes are controlled and data is gathered in almost real time (1 ~ 20 ms). The time-scales at level 2 are hours, minutes, and seconds. At level 3, workflows are managed in days, shifts, hours, and minutes. Level 3 activities interface with the shop floor equipment and machines [10]. The MES plays a role mostly at this level. At level 4, enterprise planning, carried out by ERP, has time-scales of months and weeks [11]. These differences in activity time-scales imply different objectives and plans for each level.

Planning and Operation Gap. Level 4 plans are supposed to be realized in levels 2 and 3. However, data aggregations at higher levels and unexpected events such as order change and machine breakdowns result in operational level outputs that differ from original high level plans.



ISA 95 Control Level	Role	System	Functions
Level 4 Business Planning & Logistics Plan Production Scheduling Operational Management etc.	Establishing the basic plant schedule – production, material use, delivery, and Shipping. Determining inventory levels. **Time Frame** Months, weeks, days	ERP	- Product planning - Cost / Pricing management - Project management - Demand forecasting - Manufacturing or service delivery management - Marketing and sales management - Inventory management - Financial management
Level 3 Manufacturing Operation Management Dispatching Production, Derailed Production, Scheduling, Reliability Assurance	Work flow / recipe control to produce the desired end products. Maintaining records and optimizing the production process. **Time Frame** Days, shifts, hours, minutes, seconds	MES	- Resource Allocation and Status - Operations / Detail Scheduling - Dispatching Production Units - Document Control - Data Collection / Acquisition - Labor Management - Quality Management - Process Management - Maintenance Management - Product Tracking and Genealogy - Performance Analysis
Level 2 Batch Control Continuous Control Discrete Control	Monitoring. Supervisory control and automated Control of the production process **Time Frame** Hours, minutes, seconds, subseconds	Control	
Level 1	Sensing the production process, manipulating the production process		

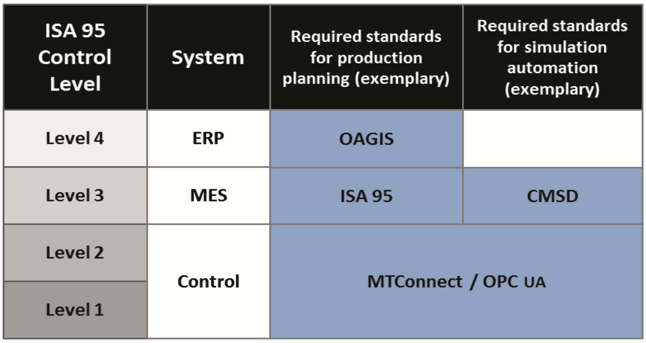
Fig. 2. ISA-95's hierarchy model and associated systems and functions.

System Interface Difficulty. Standards are essential for manufacturing data management and to integrate multiple systems. Figure 3 shows examples of standards and systems. Data is collected at levels 1 and 2. The 4th column of Fig. 2 lists the functions provided in the systems. ERP for enterprise planning and MES for lower level PP do not interface well especially if provided by different vendors. Because of this, the often-required adjustments to production plans may be difficult to carry out.

Data for Simulation. Aggregate PP focuses on maximizing on-time demand satisfaction and minimizing inventory while detailed PP at lower levels focus more on minimizing cycle times, resource utilization, and maximizing bottleneck utilization [1]. As such, simulation objectives are different for each level. The corresponding differences in details, scope, and data complicate the coordination of inputs and outputs with the multi-level simulation models. This problem can be broken down into two aspects: data interoperability and data collection.

An impediment to wide simulation usage is that simulation tools have a very low level of data interoperability among themselves and with other manufacturing applications [12]. Recognizing this problem, the Simulation Interoperability Standards Organization (SISO), in collaboration with NIST, developed the Core Manufacturing Simulation Data (CMSD) [13]. CMSD can facilitate exchanging data across different simulation tools used in the supply chain. But it does not support integrating simulations along a vertical scale, i.e., across hierarchical levels. Its usefulness for multi-level PP simulation is, therefore, limited.

Figure 3 shows other exemplar standards against the PP level. The OAGIS standard, from the Open Applications Group, establishes integration scenarios for a set of applications including ERP, MES, and Capacity analysis [14]. OAGIS defines business messages that allow application-to-application and business-to-business integration. As such, the main emphasis for OAGIS is at the enterprise level while the ISA-95 is more emphasized at the operations levels. Therefore, there are gaps in these standards for modeling the exchange of data between the different PP systems, and between PP and simulation tools.



ISA 95 Control Level	System	Required standards for production planning (exemplary)	Required standards for simulation automation (exemplary)
Level 4	ERP	OAGIS	
Level 3	MES	ISA 95	CMSD
Level 2	Control	MTConnect / OPC UA	
Level 1			

Fig. 3. Systems and data standards for simulation data integration.

The activity that precedes data processing and modeling for simulation is data collection. Jung [15] categorized data collection methods into automated, semi-automated, and manual methods. For automated data gathering, communication interfaces based on standard protocols have been developed. MTConnect [16, 17] has recently emerged as a standard for automated, real-time data gathering from equipment. The current scope is limited to machine tools. An enhancement to cover other kinds of equipment is necessary.

OLE for Process Control - Unified Architecture (OPC-UA) (IEC62541) [18] is a communication protocol for interoperability from the OPC Foundation. MTConnect and OPC-UA support interfaces to levels 1 and 2 (Fig. 3). MTConnect and OPC-UA have collaborated to produce a companion specification called MTConnect-OPC UA to ensure interoperability and consistency [19]. Other OPC UA companion specifications exist that may support data collection from other kinds of equipment.

In order to model interdependencies between PP functions and simulation objectives, a references model is needed. A reference model is an abstract framework consisting of an interlinked set of clearly defined concepts for unambiguous communication [20]. In the next section, we use the System Integration for Manufacturing Applications (SIMA) Reference Architecture to describe entities and relationships involved in the multi-level PP. We propose to extend this model to develop a unified PP function that is enabled by a multi-level simulation.

3 Integrated Production Planning Based on Simulation

This section describes the proposed feedback control mechanism and an introduction to the SIMA reference architecture and proposed enhancements.

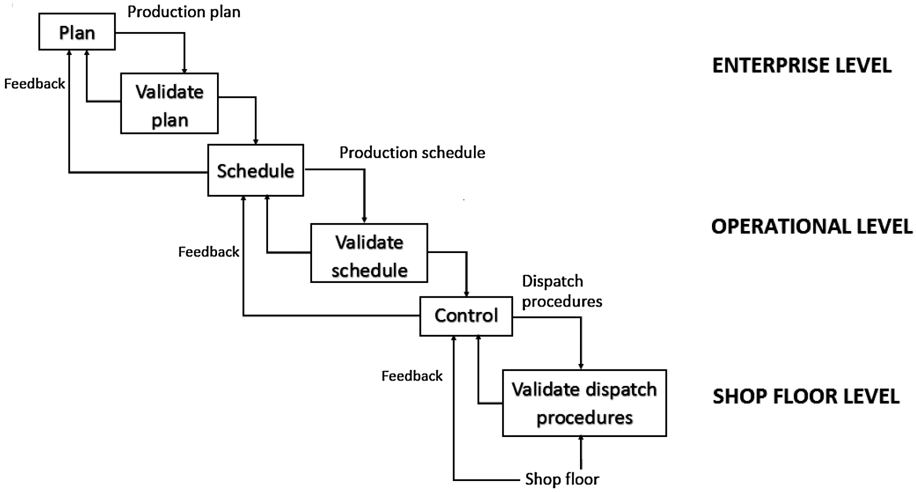


Fig. 4. Feedback mechanism for simulation-based integrated production planning

Feedback Control Mechanism Based on Simulation. The hierarchical decision system relies on a top-to-down approach where decisions at each level being passed down to the level below for execution. The feedback from a lower level to a higher level is used to modify the higher decisions so as to enable feasibility at the lower level. While research in feedback mechanisms including use of simulation has been reported, it has mainly been limited to two levels [21]. Secondly, the results have not included practical implications of implementation by use of standards and protocols. In the proposed simulation enhanced feedback, each level within the PP hierarchy has two feedback inputs, as shown in Fig. 4. First, the outer loop, which represents the traditional method of feedback where upper plans are revised to enable feasibility at lower level. Second, the inner loop that providers the output of simulation as a consideration for PP revision. We assume that lower levels have models that can better process more detailed information. From the shop floor, for example, data is used along with simulation to predict events as well as capacity and project inventory levels. This information along with the schedules passed from the scheduler is used to determine work dispatch procedures to ensure optimized production. These new procedures have to be aligned with schedules. The same procedure is used when revising the production plan at the enterprise level. The simulation models need not be integrated or run concurrently, but during usual events that necessitate production plans revision. In the next subsection, we introduce and discuss the SIMA reference architecture with which the feedback control mechanism can be integrated.

SIMA Reference Architecture. The System Integration for Manufacturing Applications (SIMA) Reference Architecture focuses on standards and technologies to integrate manufacturing software applications in design, fabrication, and assembly of discrete manufactured parts. It was developed at NIST using IDEF0 diagrams [22]. In IDEF0, the activities, shown as boxes, represent functions and operations. The fundamental objects of an IDEF0 model are activities, information flows and resources that include controls and mechanisms. Inputs are arrows into the left side of the activity box. Outputs are arrows exiting the right side of the activity box. Controls are arrows into the top of the activity box, while from the bottom, are the mechanisms or means by which activities are performed. A set of activities, information flows and resources are defined in multi-level activity models that describe the engineering and operational aspects of manufacturing a product from conception through production. The activity model provides a frame of reference for identification and standardization of interfaces between activities through information flows [9].

Within SIMA, the activity model for developing the production plan and coordinating product orders with shop floor activities is the “Develop Production Plan” activity model shown in Fig. 5. Designated as A41 in the reference architecture, this activity model is relevant to developing the integrated PP system. It has four sub-activities, briefed as follows. A411 “Create Master Schedule” determines product quantities to be produced during a future planning period, given customer orders or forecasts. Customer orders are defined by product type, quantities, and due dates. Considering anticipated capacity and capacity restrictions, this sub-activity develops the MPS. This activity takes place at Level 4 in the ISA-95 Control Level.

The OAGIS standard can support this sub-activity. A412 “Define Capacity Requirements” determines the long term capacity requirements based on the MPS, capacity projections and possible adjustments. A413 “Create Production Orders” generates production orders in quantities determined by the MPS and resource requirements. These two sub-activities correspond to Level 3 in the ISA-95 standard. The MES and CMSD standards are applicable. Lastly, A414 “Monitor Production Orders” monitors the status of production orders from the shop floor. Thus, it requires information to be collected from Levels 2 and 1 and fed into Level 3 for aggregation. Level 2 and 1 information may be supported by the MTConnect and OPC-UA communication protocols. In the IDEF0 diagram, activities are interconnected with information flows. This connectivity between activities across control levels identifies the integrated PP requirements.

The proposal is to make the feedback mechanism defined in Fig. 4 as part of the SIMA architecture. The additions are the validation activities to be performed using simulation. Therefore, interfaces need to be defined to integrate simulations, manufacturing applications, and databases. Extensions to the existing CMSD specification will be investigated to support such vertical integration.

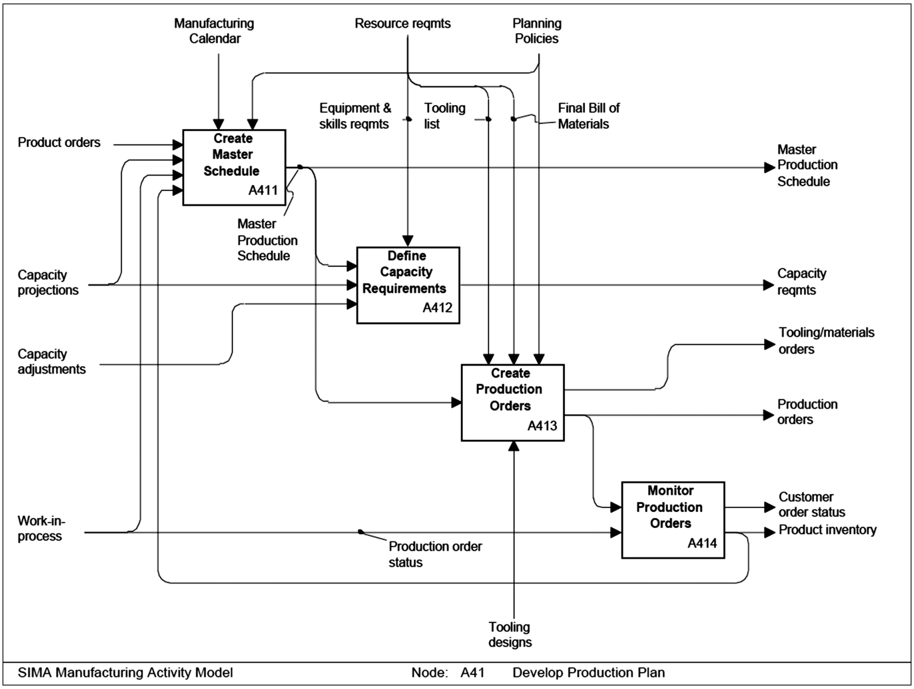


Fig. 5. SIMA manufacturing activity model: A41 develop production plan.

Driven by simulation validation objectives at each level, the new proposed activities can be defined as follows:

Simulate production plan

Inputs: current work-in-progress and inventory, master production schedule, cycle time, takt time, required inventory levels, expected capacity variation,

Outputs: production levels, sales, finished products inventory, backlogs, fulfilment rate

Control: strategic policy to control demand, inventory, capacity, variability, demand satisfaction

Mechanism: production plan simulation model

Simulate schedule

Inputs: production order sequence or schedule, lead times, due dates,

Outputs: production order release, production order completion, work in progress levels, number of orders filled, number of orders missed

Control: resource (people and machine) levels, batch size, target performance levels such as resource capacity utilization levels, work-in-progress level, and safety stock

Mechanism: scheduling simulation model

Simulate dispatch rules and procedures

Inputs: job sequence,

Outputs: resource utilization, throughput rate, actual cycle time,

Control: dispatching rules, resource production rates, target utilization level, upper and lower stock limits,

Mechanism: real-time control simulation model.

4 Conclusion and Future Work

This paper has pointed out the need for increased concurrency among production planning at different hierarchical levels in a manufacturing organization. This paper first described the PP planning function at different hierarchical levels followed by an overview of PP integration challenges. Simulation based prediction of shop floor events, inventory levels, and capacity by using real-time events can reduce the potential infeasibility and accuracy of the multi-level PP process. However, these simulations also need to be integrated with production management systems. To that end, exemplar standards and their limitations to integrating simulations and production management systems have been discussed; and a framework based on the SIMA reference activity model to extend those standards have been proposed.

While automated tools with tasks from data collection, analytics, and scheduling have been developed, employing a cyber-physical approach that integrates these methods and standards at different levels with simulation assisted human decision making will result in a more accurately responsive PP system. Future work will include the description of data requirements for inputs and outputs at multiple levels. Within the SIMA architecture, the additional activities, i.e., simulate to validate production plan, simulation to validate schedule, and simulate to validate dispatch and production control procedures will be validated against the specific needs and environments of individual manufacturing organizations.

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Challenges for Requirements Engineering of Cyber-Physical Systems in Distributed Environments

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Abstract. Engineering of systems is highly influenced by rapid technological changes, such as the emergence of Cyber-Physical Systems (CPS). These are interconnected embedded systems enabled by human-machine interaction. Realisation of CPS require a collaboration between mechanical engineering, electrical engineering, and computer science since different components are delivered and developed by different disciplines. Consequently, the Requirements Engineering (RE) process needs to consider multi-disciplinary perspectives. The objective of this paper is to elaborate the specific challenges of RE for CPS in a distributed environment and to identify knowledge sources and targets in CPS engineering. It describes the relevant types of knowledge and defines appropriate exchange mechanisms and standards.

Keywords: Requirements engineering · Cyber-physical systems · Collaborative network

1 Introduction

Manufacturing is often a complex process based on economy of scale principles [1] and involving globally distributed partners [2]. The supply chain can be seen as an ecosystem of different actors with different needs, acting and interacting in a dynamic environment [3]. New levels of human-machine interaction have become possible and more widespread, paving the way for reliable, sustainable, technology-driven ecosystems. Follett [4] enlists as significant emerging technologies a networked, intelligent world connected by IoT: more efficient and effective manufacturing aided by advanced robotics and customised, just-in-time manufacturing, driven by additive fabrication/3D printing. The growth, maturity, and widespread adoption of these technologies have the potential to disrupt and innovate. Intelligent materials, wearable technologies, tangible interfaces, human-robot collaboration, evolving tools, processes and interactions in neuroscience, avatar-quality VR, ubiquitous usage of machine learning and deep learning algorithms will increase the added value of technology and open the way towards technical breakthroughs as a result of synergies of near-simultaneous events.

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The relevance of these technological advances has been recognised by being implemented in several governmental programmes like the German “Industrie 4.0” paradigm [5] and the United States Smart Manufacturing Leadership Coalition (SMLC) [6] aiming at introducing Cyber-Physical Systems (CPS) into manufacturing [7]. Such systems emerge through the complex networking and integration of embedded systems, application systems, and infrastructure, enabled by human-machine interaction. Contrary to conventional production or logistics systems, CPS follow an holistic system approach and can thus be seen as systems of systems, requiring the collaboration of different disciplines such as mechanical engineering, electrical engineering, and computer science for their realization [4]. Rapid technological changes combined with a highly competitive market have induced a need for implementing new processes and production methods for reducing “time to market” [8, 9] as well as in order to be both appropriate in terms of quality and cost effective [10] and meet the customers’ expectation. Customers nowadays demand integrated solutions and services, covering the whole system life cycle. Consequently, understanding the underlying needs, and the thus the requirements on a product or service throughout the entire life cycle is a prerequisite for successful systems engineering and the provision of cost-effective solutions [11–13], also contributing to an improved usage of resources. From a technical point of view this can be realized today focusing on reusability of components [14] as well as through better collaboration across different process steps [15]. What does this mean for Requirements Engineering on CPS however? The main challenges, which increase the complexity, are the dynamical aspects of CPS as well as the increased number of stakeholders and system components involved covering the whole life cycle [15]. Operating in a dynamic environment requires high flexibility, re-configurability etc. as well as evolutionary changes in the requirements.

Inadequate Requirements Engineering (RE) is one of the main sources for the failure of development projects and culminates in exceeding budgets, missing functionalities or even the abortion of the project [16]. Consequently, for dynamic systems with evolutionary requirements, the need for continuous interaction between the development process and the requirement elicitation process is inevitable for ensuring a consistent and traceable elicitation and management of requirements [17]. However, what do actually dynamical changes mean for the RE, and how do the rapid advances in technology and sensors (f. ex. regarding the data analysis, used sensors etc.) actually influence the process? The next Sect. 2 will first describe the research approach. Section 3 will cover the foundation of CPS and RE, before in Sect. 4 the major gaps are outlined and the research questions are derived. Section 5 will present the initial findings for a RE framework for CPS, whereas Sect. 6 will conclude and present next steps.

2 Research Approach

The main objective of our study is two-folded (i.e. how can we improve RE for CPS, and how can this be done based on existing approaches with best possible quality). For this we first need to know what characterises CPS systems and which characteristic are relevant for the RE process. Secondly, which RE approaches exist and which limitation do they have. Based upon such analysis, we can develop or change existing tools and framework for CPS, thus in order to address these points, our methodological approach is based on combination of the research methods literature review and action research.

A literature review was carried out targeting knowledge processes, and information on CPS and supporting technologies. Scientific papers were accessed through Google Scholar searching for key words (sensors; CPS components, SOA, actuators, communication and network; Requirements Engineering + dynamic systems, RE + CPS) [18]. The relevance of the downloaded papers for this article was based on assessing the abstract, as well as by searching for the combination of RE and CPS in the full papers.

The work with the specific RE process for CPS had a different methodical approach. The researchers have been involved in the specifications and development of the scenarios. Design Science was the overall scientific approach in this work [19, 20]. More specific, action research was applied [21].

Section 3 outlines the key findings from the literature review, Sect. 3.1 focusing on CPS, Sect. 3.2 on RE.

3 Theoretical Background

This chapter identifies the specific characteristics of Cyber-Physical Systems related to systems engineering. This allows to derive challenges for the Requirements Engineering of CPS. Based on the results, in Sect. 3.2, existing RE approaches are examined, in order to investigate to which extent the identified gaps are addressed.

3.1 Engineering of Cyber-Physical Systems

CPS integrate physical capabilities and require new ways of human-machine interaction using advanced sensors and actuators. They rely on knowledge and engineering principles from computational and engineering disciplines [7]. Additionally, for reaching the full potential of CPS, the system will also comprise the logistics and management processes, as well as internet services receiving, processing and analysing data from the sensors and controlling the actuators, connected by digital networks and multi-model human-machine interfaces. As such, CPS are open socio-technical systems with a functionality far exceeding controlled embedded systems [22].

3.2 Requirements Engineering Approaches

As already mentioned in the introduction, RE for CPS has to define requirements for a rising amount of tangible and intangible components from a growing number of distributed stakeholders from multiple disciplines and consequently only RE approaches being able to deal with the complexity of the system, its openness and evolutionary nature can be considered as suitable. Furthermore, due to the complexity of the systems, they also have to enable direct involvement of the user and information exchange between different stakeholders. Finally, the different formalisms and tools of the involved disciplines have to be considered and integrated or replaced.

Hauksdóttir et al. [16] investigate the management of requirements for complex systems or products. They recognize requirement reuse as an enabler to increase efficiency and quality of Requirements Engineering and propose a structure for a reusable requirement specification. The proposed structure has five groups of requirements (business requirements, standards and laws, product properties, life phase requirements, design constraints) that are applicable to different products. Each group contains several sub-groups that have to be defined for each product individually and contain different requirement types. The structure has been tested with embedded products but not with CPS and the authors argue that it has to be tested with other product types and might require different categorization.

Penzenstadler and Eckhardt [24] agree that ensuring communication and consistency of requirements for CPS is a challenge due to the variety of stakeholders involved. The authors propose a RE content model for requirements elicitation and documentation at different levels as a solution. The model originates from a research project (ARAMiS) with stakeholders from 30 companies and defines the artefacts that have to be defined during RE instead of a specific RE process. This leaves the organisation of the RE activities in the hand of each stakeholder. The content model features five levels (context, system, subsystem, architecture) with several items. It has been implemented in the Enterprise Architect tool based on SysML and UML diagrams. However this requires the adoption of the content model by all stakeholders involved.

Wiesner et al. [23] also address the problem of information exchange between the different disciplines. They propose Natural Language Processing (NLP) as a way to translate non-formal requirements to formal descriptions in different disciplines, thus enabling automated information processing. Natural language is a universal format, understood by the end user and stakeholders from all involved disciplines. NLP techniques can assist requirements engineers when writing specifications. The application of NLP could establish a dialog system, which supports resolving ambiguities and semi-automatically transform requirements in natural language into discipline specific models. However this theoretical approach has not yet been tested for CPS development in practice.

4 Gap Analysis and Research Questions

In systems of systems like CPS, the independence of the constituent systems and their evolutionary nature lead to exceptionally distributed RE activities for a multitude of stakeholders with isolated RE approaches in several disciplines. In the next step we are therefore looking at how existing approaches contribute to that and which gaps we can identify.

Regarding managing the complexity of CPS, a modular approach would lead to a better usage of resources. From a technical point of view this can be realized today focusing on reusability of components [14] as well as through better collaboration across different process steps [15]. For Requirements Engineering, this demands for a requirements structure that allows the specification of the CPS components from different domains and their interaction, as well as the reuse of requirements from previous CPS projects in a modular way. Hauksdóttir [16] defines a reusable requirements structure in a generic way, not focused on the specific characteristics of CPS, while Penzenstadler and Eckhardt [24] primarily focus on fostering information exchange between stakeholders.

For the inclusion of all distributed stakeholders, it has to be ensured that participatory approaches can be used with the limitation that knowledge specific CPS models and components should not be required. Furthermore, a common basis is needed to dynamically exchange requirements between a multitude of stakeholders. The content model from Penzenstadler and Eckhardt [24] provides a framework for the specification of the targeted CPS on different levels in SysML and UML. This is a suitable approach to exchange information between the technical design departments of stakeholders, if they agree to adhere to a common standard. At the same time it might be too difficult to be used by non-technical stakeholders, such as the user. Wiesner et al. [23] offer a way to transform requirements between natural language and formal models, which might be a good extension to bridge this gap.

The information exchange between different disciplines is partly addressed by two approaches described above. However, they either require to implement a common standard for all stakeholders instead of the domain specific models, or use natural language for information exchange which produces ambiguity problems. However, as it might not be feasible to implement a common standard on all levels for the stakeholders, a translation might be needed between domain specific models on lower levels and a common model on higher levels. Based upon this analysis our research questions are:

1. How can existing tools and frameworks be adapted to take the the distributed environment, dynamic evolvement and the need of flexible integration of new, not existing components into account?
2. How can a new framework look like if no existing approach is applicable?

5 Initial Requirements Towards an RE Framework for Cyber-Physical Systems

Section 5.1 identifies three main challenges in the Requirements Engineering process for CPS systems, while in Sect. 5.2 first requirements for a CPS RE framework are derived.

5.1 Challenges Identified for RE for CPS Based on the Literature Review

Geisberger and Broy [22] give RE a central role for CPS development, integration, maintenance and evolution. However, several challenges for engineering of CPS could be found in literature, which have to be addressed by a suitable RE approach. In summary, three main areas were identified: the complexity of the CPS itself, the distributed stakeholder environment around the CPS and the different disciplines involved in CPS development.

CPS consist of a large number of different cyber and physical components that create the desired functionality through emergent behavior. Furthermore, they are open systems that have to be interoperable and can evolve. According to Ncube [25], for interoperation between systems that have been separately developed, RE has to be able to identify the key interoperation influencing requirements. Due to the complexity inherent to systems of systems, such as CPS, requirements are distributed among many disciplines and can be conflicting, unstable, unknowable or not fully defined. Schätz [26] describes three dimensions of CPS complexity: cross (application domains, engineering disciplines, technologies, organizations), live (reconfiguration, redeployment, update) and self (documentation, monitoring, adaptation). The joint presence of these dimensions is typical for CPS and has to be considered already during RE.

CPS have a large number of stakeholders that are typically separated spatially and organizationally. In addition to the user, who defines the scope and purpose of the CPS, specialized partners with distinct processes develop the individual system components. Following Geisberger and Broy [22], users and other stakeholders from different domains have to be actively involved into the development from the start. The CPS has to be adapted to the needs and competences of the users.

The stakeholders are not only distributed, they also stem from multiple disciplines with own formalisms and tools. During CPS development, information and requirements have to be exchanged between the disciplines in order to create a common view of the targeted system. Baheti and Gill [7] emphasize the need for theories and tools to design, analyse and verify the components at various levels, understand the interactions between systems and ensure safety and performance with minimal cost. Currently, CPS components are handled by isolated disciplines with their own formalisms and tools, which either represent the cyber or physical process. This hinders the verification of the overall system design and component-to-component interaction. Broy et al. [27] demand the synthesis of knowledge across different domains of application, including methods of requirements analysis and modelling.

5.2 Requirements for a CPS RE Framework

Based on the gaps identified in the analysis carried out above, we can identify three main requirements on RE methods for CPS:

- The development of a reusable requirements structure for CPS, which allows the definition of modular components, which can be combined to the overall system. To support modular design and interoperability of CPS, standardized abstractions and architectures are needed. This also refers to verification and validation of the system at the design stage. This requirement addresses the challenge to manage the complexity inherent to CPS.
- Definition of a CPS content model that is formal enough to describe the targeted system unambiguously and in a verifiable way, but has the flexibility to include non-formal inputs. The different stakeholder needs and changing requirements must be managed by RE processes and tools, which have to be able to manage emergent effects with predictable results. This requirement addresses the challenge to involve all stakeholders, including the final user, into CPS development.

- The inclusion of the most relevant domain specific models into the CPS content model, e.g. using semantic mediation. It needs to integrate mechanical and software engineering models for the formal description of requirements, which have to be mapped to the system elements and communicated between stakeholders from different disciplines. This requirement addresses the challenge to integrate all domains involved in CPS development.

5.3 Initial Outline of a CPS RE Framework

Based on the requirements identified in the previous section, a CPS RE framework can be outlined. Requirements in the CPS development process can be assigned to two distinguished areas: the problem domain and the solution domain. The problem domain includes the needs and business goals for system development and their formulation into stakeholder requirements, without preselecting any specific CPS characteristics. The solution domain contains the system requirements describing the targeted functionalities of the solution and subsequently the architectural design, which specifies how the CPS will meet the system requirements.

Business requirements are derived from the business goals or objectives of the organization, which interpret the underlying business vision. They are mostly given in natural language. Methods for documentation of business requirements can be Business Process Model and Notation (BPMN) or data flow diagrams, showing the difference between "as-is" and "to-be" business processes. Stakeholder requirements in general are derived from the statements of need, using various methods like use scenarios, and are stated in non-technical terms normally not adequate for design purposes.

Describing the targeted CPS behavior in terms of conditions or capabilities of the envisaged solution can be done through developing system models describing functionality and then documenting system requirements that capture the vision of the customer in technical terms, enable the definition of the scope of the system and allow estimating the cost and schedule required to build the system. The description of the architectural design of a system identifies the different system elements and shows how they work together through their relationships to meet the system requirements. In the case of CPS, this can be the interaction between product and services, or between software and hardware. These models can be documented in SysML or domain specific notation.

As it is often not possible to use a common notation, such as SysML, for all involved stakeholders, a mediation or translation has to be established between the different domain models. The framework covers this in two different ways: For the semi-automatic translation between non-formal (natural language) and formalized notations, Natural Language Processing [23] can be implemented. Transformation between the different formal domain specific models can be achieved using methods such as semantic mediation, which enable conversion between model using ontologies. In this way, domain barriers can be greatly reduce or fully removed.

6 Conclusion and Future Work

The scale and complexity of the objects targeted by systems engineering is constantly growing, reflected by the emergence of CPS. Current methods and tools, in particular for requirements engineering, do not provide full support for these new challenges. The realization of CPS usually requires the temporary collaboration of a multitude of stakeholders from different domains, such as hardware, software and services. Besides the customer/user and the system integrator, there are stakeholder groups for the system components, life cycle services and system environment, each with their own objectives and context.

In the paper, it could be shown that CPS have special characteristics compared with conventional systems that affect Requirements Engineering. The main points identified are greater complexity, multiple distributed stakeholders and the involvement of several disciplines with their own formalisms and models. At the same time, first approaches to address these issues for Requirements Engineering could be found.

Complexity can be addressed with a suitable management structure that supports the reuse of requirements from earlier projects and thus enables modularization of CPS. Future work in this area should include the specification of such a requirements structure, which also helps to manage changing requirements and predicts the emerging properties of a CPS.

Multiple distributed stakeholders for the system as a whole may have limited knowledge of the needs and constraints for the individual components, and vice versa. They can be included by implementing a universal content model for CPS that helps to exchange unambiguous information about the targeted system requirements. Non-technical stakeholders, such as the user of the CPS could participate in system development using NLP technology. Future work should extend such a content model with interfaces to natural language and domain specific models, where necessary.

The involvement of different disciplines requires the implementation of a common standard, as either described above or appropriate interfaces between domain specific and common models. As it might not be possible to replace domain specific models in all cases, future work should deals with the implementation of such interfaces that are able to translate between different models without information loss or delay.

Systems engineering is evolving from a centralized development process for individual systems and components towards the orchestration of distributed software, hardware and business processes for a common purpose. Addressing the identified requirements with a CPS Requirements Engineering framework would help to make the development of CPS more cost effective and faster, while retaining a high system quality.

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Industry IoT Gateway for Cloud Connectivity

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Abstract. New approaches and technologies like Internet of Things (IoT), cloud computing and Big Data are giving rise to another industrial revolution. We propose here an implementation of an industrial gateway architecture adopting the idea of IoT, intelligent methods, Machine-to-Machine and Cyber-Physical Systems. The proposed gateway creates a virtual representation of the physical world scanning the technological layer's devices in real time. It creates a uniform communication interface for the heterogeneous technological layer, enables self-management of devices, diagnostics and self-reconfiguration to improve Quality of Service aided with cloud SCADA and MES services. We have tested the proposed gateway in an experimental setup with a programmable logic controller.

Keywords: Cyber-physical system · Gateway · Internet of things

1 Introduction

Industry is a heterogeneous system consisting of various heterogeneous subsystems [1]. The subsystems must be interconnected to reach the complexity needed for an optimal performance of a plant [2, 3]. This need for interconnection leads to the next industrial evolution step defined as the Industry 4.0. The term "Industrie 4.0" (German for "industry") refers to the fourth industrial revolution. It originates from a project in the high-tech strategy of the German government, which promotes the computerization of manufacturing. [4, 5]. The first industrial revolution increased production and decreased difficulty of manual work by using steam power. The second revolution did the same with the help of electric power and the third revolution brought electronics and IT to further automate production. The idea of the latest industrial revolution was presented at the Hanover Fair in 2011 [2].

Prof. Dr. Ing. Detlef Zühlke (Scientific Director of Innovative Factory Systems at the German Research Center for Artificial Intelligence) is sometimes called the "Father of Industry 4.0". The goal is to create more successful companies quickly capable to endure in the global competition [5].

Improvement of the interconnection of the industrial subsystems is related to the concept of the Internet of Things (IoT) [5], especially because of IoT aims to improve the interconnection of the digital and the physical world. Industry 4.0 in the contrary to the typical industry architecture significantly improves management of processes. IoT improves the processes of collecting, analyzing and processing the valuable and now

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easily accessible information originated in every part of the plant. The industrial IoT changes the machine-machine and machine-human interactions, comprehensive interoperability and intelligence aids to improve analytical description of the environment and better decisions can be taken. [4, 6] (Fig. 1).

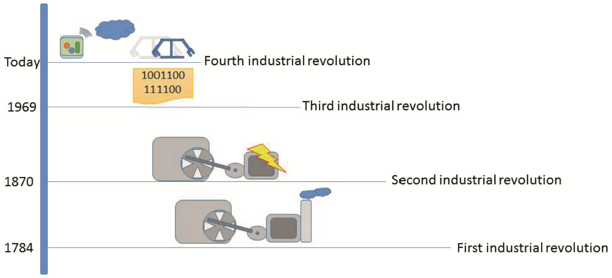


Fig. 1. Chronology of the industrial revolutions

Plants are comprised of different subsystems, modules, devices, machines operating with various communication protocols and interfaces. The problem is that the subsystems do not provide a unified connection to the technological layer and to the higher layer of the industrial hierarchical model. We propose implementation of the IoT in the Supervisory Control and Data Acquisition layer (SCADA). Typically the sensors of the technological layer produce large amounts of data; the SCADA layer collects it and provides the data to the Manufacturing Execution System (MES). This decreases interoperability between the technological layer and MES. The plants typically use strictly defined fixed interfaces for the communication within each layer between the layers of the hierarchy. This constraint does not allow ad hoc behavior of the plant. Our goal is to create ad hoc environment connecting technological layer with higher layers. The connections will be not constrained by fixed interfaces between the layers but automatically ad hoc included and ad hoc accessible for every layer.

2 Industry 4.0 and IoT

Industry 4.0 brings greater flexibility, adaptability, self-organization, self-optimization, self-diagnostics and leverages interaction between business and customer relationship, increases safety, reliability, autonomy and efficiency. The technological part is represented by a cyber-physical system [6]. Every product is individually described by the connection to business and customer layers. Integration of intelligent autonomy and monitoring with increasing automation into industry was important. It is represented by Cyber-Physical Systems (CPS) and IoT [3].

Modern factories exceed the boundaries of the traditional ones. The factories are able to react to unpredicted situations autonomously and to select the optimal responses with regard to the plant or the market. The interconnection of the processes and plants is improved and the network security is better. The boundaries of the new industry are exceeded between the regions and between the different plants.

3 The Concept of Industrial Connection with IoT

Industry 4.0 connects machines, workers, and factory systems into a network. New technological approaches of IoT, cloud computing, M2M (machine-to-machine), CPS and Big data are implemented into the network. Each of the technologies increases productivity [7, 8]. We focus on IoT facilitating the interconnection of heterogeneous factory environments. The communication within the factory and the digital model of the real factory states are improved. The proposed interconnection enables better analysis and decision making. The position of IoT in the hierarchical model is depicted in Fig. 2.

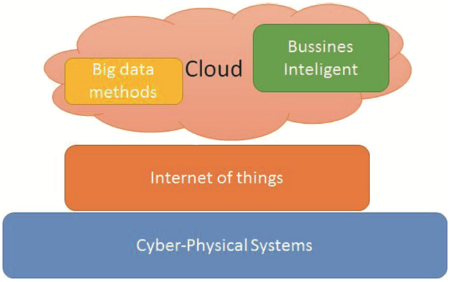


Fig. 2. Industrial connection with IoT, CPS, cloud, and Big data

IoT creates a virtual (digital) representation of the physical world. The software applications access the virtual representations of the devices only. This solution is more suited for the world representation management when using various physical devices [9, 10]. This layer must implement ad hoc behavior and it must be manageable by central or distributed nodes [11, 12].

The IoT layer runs a software surveyor for detection and identification of new devices. It enables adaptation of any physical layer and its integration into the factory architecture. Data/information is accessible to every application inside the plant or inside/outside the plant respectively. The devices detected for the first time are looked up in a devices database and included into the device ontology [4]. Measurement frequency, measurement range, device position etc. describe the device.

The connection to the technological layer is crucial and it influences the plant's Quality of Service (QoS) significantly. The technological layer of a heterogeneous system will not feature composite communication interfaces in Industry 4.0. The technological layer consists of CPS and smart products. These enable easier but not uniform connection to the technological layer. We propose a solution for the IoT connection to the technological layer here. We have designed a concept of IoT gateway that is described below. The proposed gateway supports communication with a cloud. SCADA and MES services may be implemented in the cloud as we have described in [13].

4 Concept Definition of the IoT Gateway

The important part of SCADA is the connection to the technological layer. This connection is crucial for data forwarding to the higher layers of the factory architecture. Therefore, we propose an IoT gateway connecting the physical devices and the higher layers of the Information and Control System (ICS). Regular and stochastic changes occur in a real word environment and the IoT gateway must adapt to the changes. The gateway's main role is the development of a virtual representation of the physical world enabling data collection and forwarding. The gateway's functionality must be robust to fulfill the requirements of all layers in the factory architecture (Fig. 3).

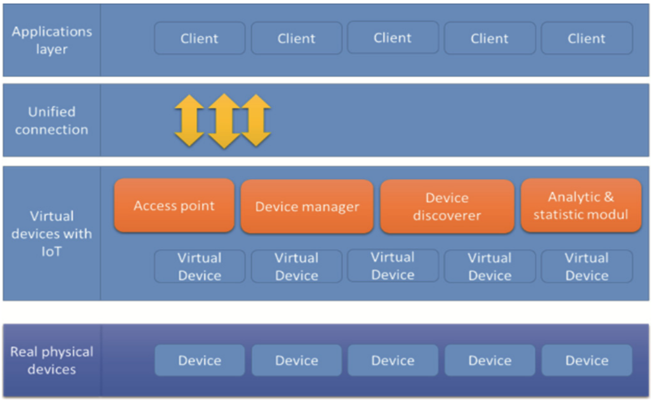


Fig. 3. Concept definition of IoT in the industry.

The IoT gateway distinguishes between the physical device and its virtual representation. That enables implementation of device management in the cases of failure or for saving energy when redundant measurements are taken. Additionally the virtual representation of the devices simplifies the connection between the cloud application and the physical devices (sensors/actuators). The gateway offers a unified connection to the virtual representations of the devices so that any application may use it.

The virtual representation of a device does not simply mirror the state of the device. Functionality for enhanced description of the device, its properties and measurements is added. [9, 10]. The IoT gateway provides a complex representation of the instances.

We have defined the main tasks the IoT gateway will perform to reach the best QoS:

- **Data forwarding** – the gateway is responsible for data forwarding from the technological layer to the higher layers of the factory architecture [11].
- **Gateway management** – the gateway is a key integration element in the entire factory architecture. A fixed and no-manageable gateway will cause fewer problems with adaptivity and implementation [11].

- **Device management** – enables runtime configuration of devices, setting the statuses, functionality modes, errors acknowledgements and other [11].
- **Data analysis** – the IoT gateway monitors and analyses data in real time using statistics and artificial intelligence. This module cooperates with the device management to maintain QoS, reliability and fault tolerant operation. The faults are detected and the faulty devices are substituted by the available redundant devices. Data analysis with the device management enable self-configuration, adaptive and robust behavior with regard to the technological layer connected to the IoT gateway. The goal is to achieve autonomous management of devices without the need of human intervention aided by M2M communication.
- **Diagnostics** – the IoT gateway detects errors and faults in the entire technological layer and in the IoT gateway itself.

The operation of the proposed IoT gateway is divided into the management and runtime parts.

4.1 Management Part of the IoT Gateway

Management part of the IoT gateway detects, identifies and networks new devices in real-time. The IoT gateway creates a virtual instance of a device after having detected it. A definition of the device is needed to create the virtual instance. The definition may contain measurement ranges, device's location and power management information, lists of fault states, error states and error messages. If the definition of the virtual instance is inferred from the physical device it is uploaded to the device database [10]. The device manager will then create the virtual instance and forward it to the runtime.

The virtual instance communicates with the device in the runtime. The data exchanges are based on events to reduce the communication load. However, the devices in Industry 4.0 should be manageable; at least the device's status must be settable.

This industrial solution enables to contact new devices. The contacted devices must provide metadata describing themselves to be correctly recognized. The IoT gateway creates the virtual instances based on the metadata. The virtual instances are frequently refreshed based on the corresponding events. The inactive physical devices are set to idle state by the device manager. Additional functionality is the management of the running virtual devices. This implies additional ability to update the physical and virtual instances in real time. The management part provides additional information to the data access point of the IoT gateway and the access point provides it to the higher layers (to MES, for example). The access point also collects information on configuration of virtual and physical instances from SCADA layer.

The diagnostics module enables management of the physical devices, the virtual instances and of the IoT gateway to ensure reliable control of the devices and data transfers from and to the technological layer. The diagnostics module also enables problem identification and invokes events describing the critical or the alarm states (Fig. 4).

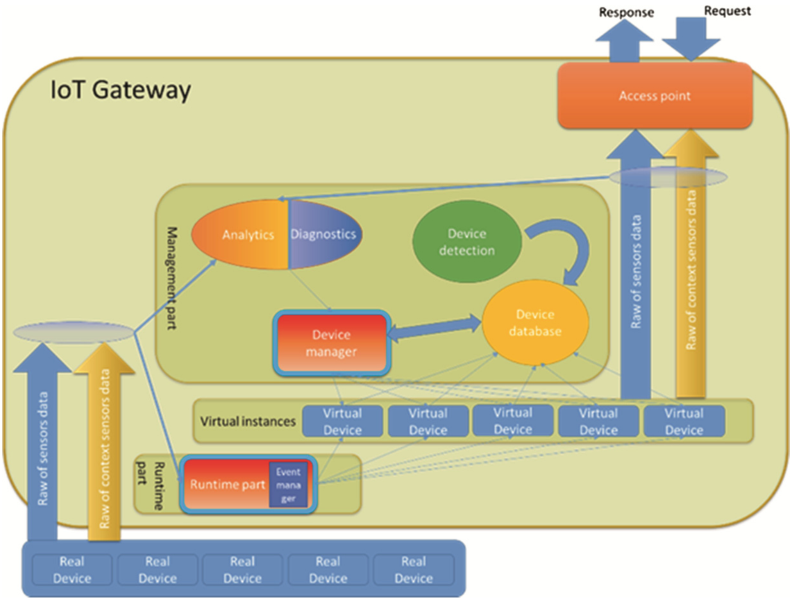


Fig. 4. Management and runtime parts of the IoT gateway

4.2 The Runtime Part of the IoT Gateway

Runtime part operates with the virtual instances created for the physical devices by the management part. Runtime part is responsible for finding new devices and updating the virtual instances. The virtual instances are easily accessible via the unified connection interface of the IoT gateway.

In the case of a fault occurring on the physical device the virtual instance may link itself to another redundant physical device or self-reconfigure. The functionality of the faulty device is substituted by functionality of another device. The runtime part runs an event manager that keeps the physical devices and the virtual instances synchronized.

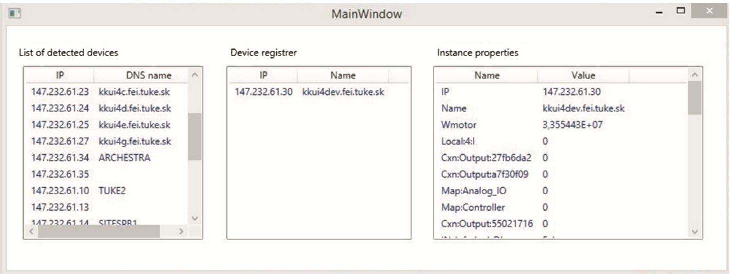
5 The Implemented Solution

We have not implemented the full functionality of the above described concept so far. We are try to identify and to use progressive approaches to improve the interconnection of the heterogeneous technological level and the cloud SCADA and MES services. We have designed a clustering method for grouping redundant devices. Substitutes for the faulty devices are easy to find and robustness is increased.

We have developed the management and the runtime parts of the IoT gateway. We have implemented the software agent scanning the defined subnets and identifies all the connected devices. The implemented management part selects the devices with the known communication interfaces and stores them in the device database. After that virtual instances for the devices are created and a synchronization interval is set up.

We have used PLC CompactLogix L23E from Rockwell Automation in our experiment. The PLC has been detected and identified by IoT gateway. An industrial IoT gateway must communicate via various communication protocols. The proposed IoT gateway uses a wide scale of industrial communication protocols; CIP (Common Industrial Protocol) was used for communication with the PLC in our experiment.

We have developed a GUI showing the IoT gateway processes using WPF and MS Visual Studio 2013. A list of the available devices found by the IoT gateway is shown in Fig. 5. The IP address of the PLC is shown in the *Device register* tab. Its virtual instance properties are displayed in the *Instance properties* tab. The virtual instance was automatically created upon reception of the metadata downloaded from the PLC.



List of detected devices

IP	DNS name
147.232.61.23	kkui4c.fei.tuke.sk
147.232.61.24	kkui4d.fei.tuke.sk
147.232.61.25	kkui4e.fei.tuke.sk
147.232.61.27	kkui4g.fei.tuke.sk
147.232.61.34	ARCHESTRA
147.232.61.35	
147.232.61.10	TUKE2
147.232.61.13	
147.232.61.14	SITESPR1

Device registrer

IP	Name
147.232.61.30	kkui4dev.fei.tuke.sk

Instance properties

Name	Value
IP	147.232.61.30
Name	kkui4dev.fei.tuke.sk
Wmotor	3,355443E+07
Local:4:I	0
Cxn:Output:27fb6da2	0
Cxn:Output:a7f30f09	0
Map:Analog_IO	0
Map:Controller	0
Cxn:Output:55021716	0

Fig. 5. Graphic representation IoT gateway processes

6 Conclusions and Future Work

New industrial revolution based on CPS, IoT, cloud computing, and Big Data is on the way. [4, 12]. We have focused CPS and IoT for increased industrial autonomy, flexibility, efficiency, self-configuration, self-adaptiveness and robustness. Important part is communication in industry. Heterogeneity of the technological layer makes communication problematic. We have designed and implemented an IoT gateway creating a unified connection to the technological layer aided by IoT. This proposed gateway allows management of devices, identification of new devices, reading context data of the devices, self-reconfiguration, diagnostics and fault tolerance by creating virtual representations of the physical devices.

The future work includes implementation of artificial intelligence methods for classification of devices and their communication interfaces, for analysis of their behaviors and implementation of M2M to achieve self-managing behavior of the IoT gateways and their cooperation.

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A Proposal of Value Co-creative Production with IoT-Based Thinking Factory Concept for Tailor-Made Rubber Products

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Abstract. Production companies are required to notice the importance of the paradigm shift from "use value" into "value in use" about their products and services. Value co-creative activity between the producers and consumers is essential to realise the paradigm shift in practical business case. The IoT(Internet of Things) is a powerful infrastructure to digitalise and increase the integration of vertical and horizontal value chains in the business process. We propose a value co-creative production system model under IoT environment with an innovative "Thinking factory" concept. Our current target is the rubber industry which is required to provide tailor-made products as human-machine delicate interface.

Keywords: Value co-creation · Smart factory · IoT · CPS · Multiagent system

1 Introduction

Nowadays production companies are required to pay attention into the importance of the paradigm shift from "use value" into "value in use" about their products and services. Value co-creative activity between the producers and consumers is essential to realise the paradigm shift in practical business case. The IoT(Internet of Things) is a powerful infrastructure to digitalise and increase the integration of vertical and horizontal value chains in the business process. Therefore smart production concept is now paid great attention in accordance with the development of ICT. Industry 4.0 in Germany [1] and Industrial Internet Consortium (IIC) initiative in USA [2] are the most famous projects focusing on the smart factory. IoT (Internet of Things) and CPS (Cyber Physical System) are their key technologies to support the realization of Smart factory.

On the other hand, Kobe area is the birthplace of the rubber industry in Japan and the country's largest base of chemical shoes. It is utmost important for Kobe area to realize an innovative outcome of the rubber industry under the global competition. This innovation is expected to enhance the competence of Japanese manufacturing technology. We focus on the shoe industry with rubber

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materials as consumer products, because it is one of very important production businesses in Kobe area as mentioned before.

Currently because of current modern life and life longevity, it has become common to put on shoes daily for long time. Shoes have become very important to support the total body weight of its own. Consumers pay much concern to "foot comfor" or "shoes fit feeling" in various life scenes, such as health promotion, rehabilitation, running or other sports, business use, and so on. Thus the shoes industry is one of the most suitable target to try to implement the value in use concept with the idea of tailor-made rubber products.

In this paper we introduce our research activity as a part of the "Innovative Design and Production Technology Project" under the cross-ministerial SIP (Strategic Innovation Promotion) program [3] supported by Cabinet Office, Government of Japan [4]. We propose design/manufacturing systems targeting value-co-creation for our life innovation focusing shoes as pioneer model in the rubber industry as well as realising tailor-made rubber products with reactive 3D printer in our R&D activity.

2 Thinking Factory Concept Under IoT

As we mentioned before, smart production concept is now paid great attention as IoT environment is spreding. Industry 4.0 and IIC are the most famous projects focusing on the smart factory. The technological map between Industry 4.0 and IIC is illustrated in Fig. 1.

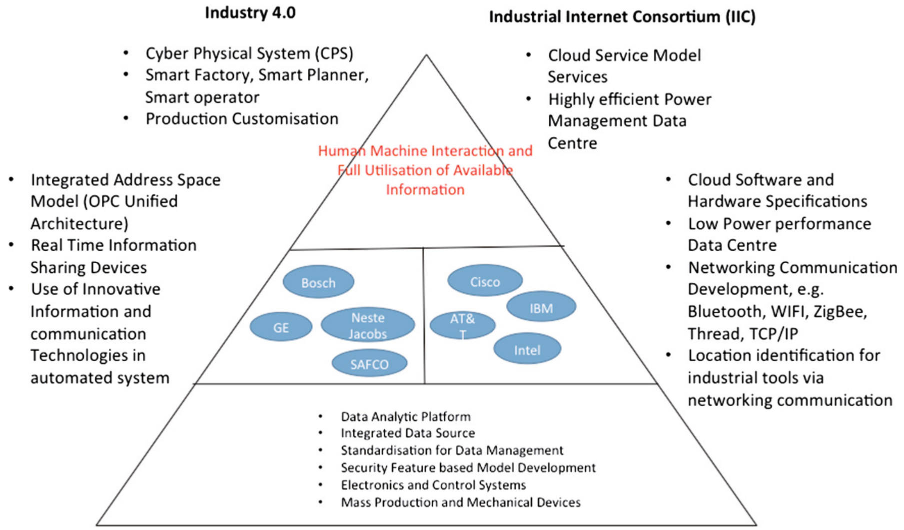

Fig. 1. Industry 4.0 and IIC

Industry 4.0 is based on CPS and IoT, and tries to facilitate the smart factory in terms of automation and integration amongst supply chain. On the other hand

IIC is more based on Cloud computing and tries to enable stakeholders in the manufacturing industry to form collaborative R & D via IoT.

Industry 4.0 was first introduced by the German Government in order to increase visibility of the operational activities in the factory by use of advanced manufacturing technologies and promote decentralisation management [5]. The key focus is on the development of cyber physical system (CPS) [6]. CPS is defined as the advanced manufacturing technologies for controlling and handling inter-operative systems, where physical assets is associated with computational capabilities and elements. In this context, Lee et al. provides the 5 C architecture guideline for Industry 4.0 in which the data sources are based on sensor, controller and networked systems. This proposed architecture includes the smart connection level, data-to-information conversion level, cyber level, cognition level and configuration level [7].

The Industrial Internet Consortium (IIC) was established in March 2014 by an alliance of technology development companies [2]. These partnership companies include AT&T, Cisco, GE and Intel. They are currently working on the focused areas of improvement in software and hardware platforms towards excellent networking by identifying and implement best practices using IoT. Currently, these partnership companies attempt to incorporate new strategy by rectifying the current system weaknesses to ease of implementation by IoT. In addition, the development on networking connectivity via cloud computing is one of the key focuses for the IIC for improving and standardising the core activities for implementation guideline using IoT shown in Fig. 1.

Our thinking factory concept for realizing the value co-creative production is shown in Fig. 2. Several kinds of users are interactively connected with thinking factory under IoT environment. Our concept also contains CPS, cloud computing and big data analysis, and it focus more on uses value creation as well as producers value.

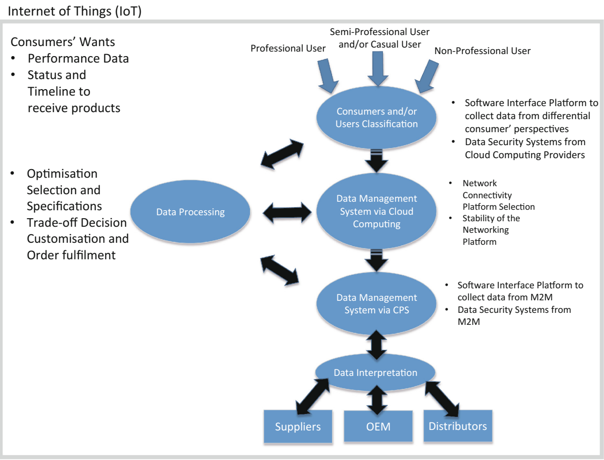

Fig. 2. Thinking factory concept with customers involvement

For sustainable value creation, our thinking factory mutually circulates both traditional producer innovation providing values and user innovation providing values created by users' participation. Involvement of users in design and development evolves wide spectrum of technologies realizing potential needs. Proposal by researchers of new product or service will inspire idea creation of future product or service.

Value co-creative production between value producer and value consumer could be established by our thinking factory concept under IoT environment as illustrated in Fig. 3. Value market is constructed in the "Value in use" production, and the development about both product and customer is carried out under the mechanism.

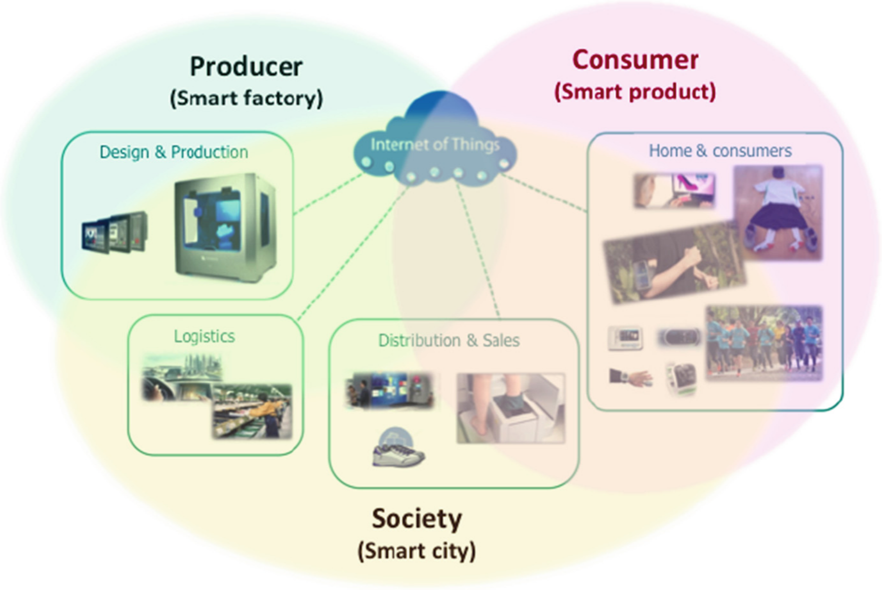

Fig. 3. Value co-creative production under IoT

CPS is a decentralization concept through the intelligent system to arrive at smart production. Several developed technologies for managing computational element between its physical assets and computational capabilities enables CPS with cloud platform. We have already proposed "Real-Virtual fusion manufacturing system" concept [8] which includes CPS characteristics in dynamic production management, and we are now implementing it into our thinking factory model.

Several research activities are carried out in our project, and we will explain consumer-based supply chain for tailor-made rubber products as an example in the next chapter.

3 Consumer-Based Production Model for Tailor-Made Rubber Products

Total business flow in the proposed value co-creative tailor made production system for shoe industry is shown in Fig. 4. All of users, marketing/product design/procurement/ordering departments, production sites, and retailers are connected via IoT. All the related data are circulated, and interactive design & production are executed amongst users, designers, and producers.

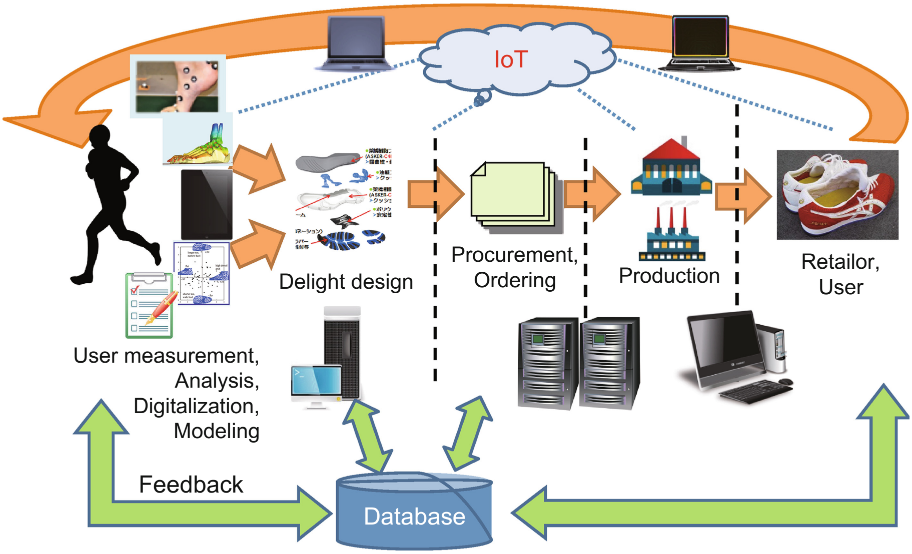

Fig. 4. Value co-creative tailor made production system

Several research activities are executing now in our project, and we will explain consumer-baed supply chain for tailor-made rubber products as an example. The consumer-based supply chain model is proposed to manage and handle the inter-relationship of supplier-manufacturer and manufacturer-distributor parties. In recent literature, the research works on production inventory policy only focus on either supplier-manufacturer inventory or manufacturer-distributor inventory policies in multiple product conditions [9,10]. However, the interaction of all supply chain members for planning inventory policy may have direct impact on cost savings. As illustrated in Fig. 5, both parties (i.e. supplier-manufacturer and manufacturer-distributor) require to work closely in order to achieve cost minimisation for the entire supply chain network. In this modelling, the multiple distributors are responsible for different product customisations and delivery according to the requirements of the consumer segments. In fact, the inventory policy in product customisations for supplier-manufacturer and manufacturer-distributor parties can vary in terms of quantities, ordering size and differential consumer segments. These variations may then increase the operational costs along a supply chain.

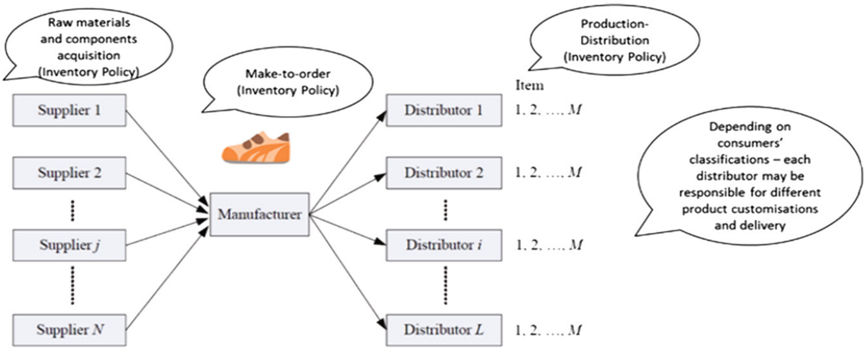

Fig. 5. Supply chain network for product customisation

In our activity the integrated production inventory policy in a supply chain is relatively complex to be planned for 3D printing product customisations. The policy usually needs to incorporate with the demand fluctuation, ordering size, differential consumer segments, and 3D printing machine capabilities. Figure 6 illustrates a schematic diagram of the integrated inventory policy for both parties in 3D printing product customisations. The raw materials and components used can actually move across multiple entities along a supply chain, such as supplying, producing and distributing to consumers.

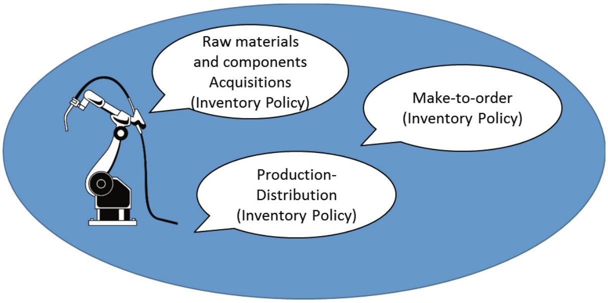

Fig. 6. Integrated inventory policy in 3D printing product customisation and consumer segments

The appropriate supply chain planning in inventory policy from initial acquisition, make-to-order and production-distribution is required to minimise the associated cost along its value chain. This is also known as three echelon supply chain perspective. For optimising the gained profit and added value for implementation, there is a need to develop an integrated system modelling to simulate the complexities of differential consumer requirements in 3D printing rubber product customisations.

4 Conclusion

We introduced our proposed concept on "value co-creative production system model" under IoT environment, which facilitates an innovative "Thinking factory" structure targeted to the rubber industry in Kobe area. Deep involvement of users into the IoT based production system were investigated, and that is an important difference from Industry 4.0 or IIC in the abroad. The framework of users' participation to value co-creation was constituted by Kobe University, prefectural research institute located in Kobe area, and many leading business companies as provider or user. Our activity tries to realise the innovative paradigm shift from "use value" production into "value in use" production in the near future.

Ackowledgement. Our activity is fully supported by the "Innovative Design and Production Technology Project" under the cross-ministerial SIP (Strategic Innovation Promotion) program organized by NEDO (New Energy and Industrial Technology Development Organization) and Cabinet Office, Government of Japan.

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Decomposing Packaged Services Towards Configurable Smart Manufacturing Systems

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Abstract. Smart Manufacturing Systems have the ability to adapt to rapidly changing requirements. Software components of the manufacturing system—services under Service Oriented Architecture—must be configured dynamically to meet such requirements. Currently, software vendors provide packaged services, so they are not easily reconfigurable. Thus, engineers or production managers face difficulty in composing services with the appropriate functionality and quality. The objective of this paper is to discuss high-level requirements for such a unit service concept and provide an initial use case to illustrate how the unit service concept may apply new technologies to improve service. We propose a decomposition of target service according to standard model, and we claim the limitations of decomposed unit services, and new technologies and opportunities for each decomposed services.

Keywords: Manufacturing service · Smart manufacturing · Production planning

1 Introduction

Smart Manufacturing Systems (SMSs) are defined by advent of new technologies that promote rapid and widespread information flow within the systems and surrounding its control [1]. New technologies, such as internet of things (IoT), big data analytics, and predictive analytics, enable collecting and processing of huge amounts of data, rapid and precise physical systems monitoring, and deeper and advanced analysis for those data. New technologies offer chances to develop new manufacturing services, or to improve previous services.

However, previous manufacturing supporting systems, such as enterprise resource planning, material requirements planning, and production planning, have limited availability to apply these technologies. Systems to support manufacturing for enterprises have variety scopes and level of details, but, the lack of a standard industry approach to production management results in customized software or use of a manual approach [2]. The resulting systems have specified structure, low level of modularity and low level of interoperability. In the worst case, the existing system must be reconstructed before it applies new technologies for SM.

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A configurable SMS is a manufacturing support system that dynamically composes unit level manufacturing services to satisfy manufacturing requirements. To be configurable, a whole packaged service should be decomposed into unit level services and be interoperable. Configurable SMS enables service oriented architecture based manufacturing support systems, and these systems can be operated with lower cost and easier management than existing systems, and can provide the most appropriate services to satisfy manufacturing requirements.

To prepare the era of SM, manufacturing services required should be collected and generalized. Thus, in this paper, we tried to start by analyzing one instance. We selected one production planning service as our target service to be analyzed, and discussed its decomposition and applicability of new technologies for SM. Section 2 describes target service details and its decomposition into unit services according to the standard model. Section 3 identifies the limitation of these services and opportunities to improve these services in the era of SM. Section 4 concludes the paper and discusses future work.

2 Target Service Description

2.1 Target Service Details

The target service is Production Planning and Management. This service is performed by three modules: (1) order-processing, (2) production-planning, and (3) production-management. Each module interoperates through a specified interface. The order-processing module is involved in defining the relative importance of order, and selection of orders that will be serviced. The production plan will be based on the customer orders selected during order processing. The production-planning module generates a production plan considers manufacturing capability. The production-management module tracks production and detects abnormal conditions. After detecting an abnormal condition, if the uncommitted production plan (future plan) is affected critically, then the production planning module modifies plan to consider the effect of abnormal condition.

This service covers production planning and revising of the plan when an abnormal situation happens. Specifically, the scope of this service is classified into level 3 and level 4 according to the functional hierarchy model [3]. Production-planning module performs level 4 activities, and the production-management module performs level 3 activities. This functional hierarchy model does not consider order processing (Fig. 1).

In the functional data flow model [3], the target service's scope covers order-processing, production scheduling, and production control functions. The order processing function is enabled by the order-processing module, and production-schedule function is enabled by production-planning module, and production control function is enabled by production-management module (Fig. 2).

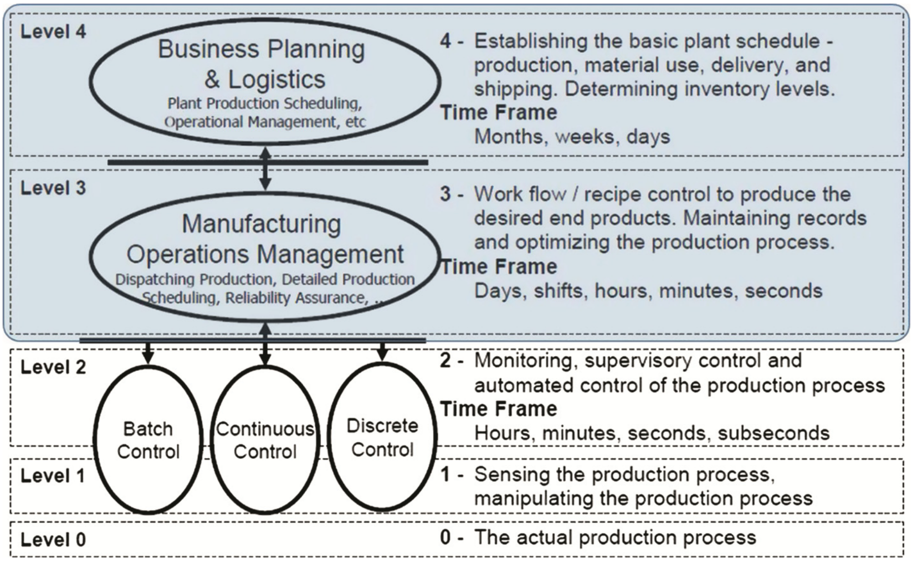

Fig. 1. Scope of target service in the functional hierarchy model

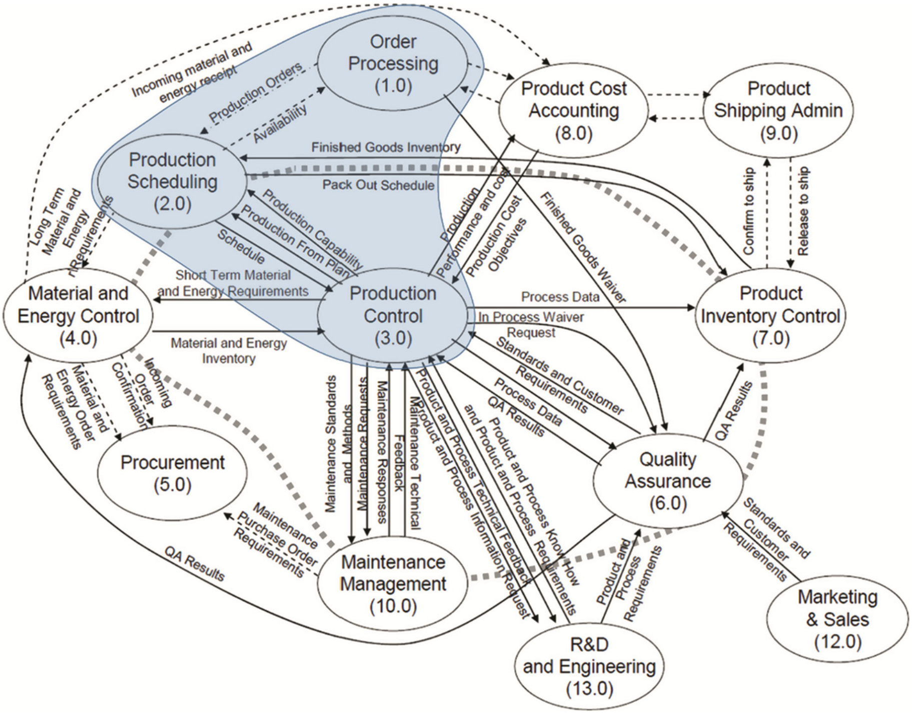

Fig. 2. Scope of target service in the functional data flow model

2.2 Target Service Decomposition

We decomposed our target service into functions according to the functional data flow model, these functions are order processing, production schedule, and production control. Each corresponds to a module of the target service. Each function is decomposed into sub-functions, which are acting as unit services in service-oriented architecture. Detailed description of sub-functions are as follows (Fig. 3).

- Order processing includes order prioritization, order selection, and order consolidation.
  - Order prioritization determines the relative importance of production orders, and uses it when partitioning an order if production cannot be performed. It generates the production order list with each order's priority.
  - Order selection determines which order to be produced in this scheduled period and generates the production order list for production schedule. Order selection should consider many attributes such as due date, production and transportation lead time, order priority, and minimum order quantity.
  - Order consolidation merges orders that have the same attributes such as product model group, due date, and special production requirements. This step reduces the number of variables used in the production schedule.
  - By these functions, the initial orders become production orders which are the input of the production schedule function.
- Production schedule includes product definition reference, capability reference, production request generation, schedule modification, and availability offer.
  - Product definition reference includes shared information between product production rule, bill of material, and bill of resources [3]. The information is related to how to produce this product. The information includes the parts and the numbers of them required to be assembled into this product, the operations required, and other customer-specific requirements. This information ensure production of exactly the required product.
  - Capability reference includes the production resources information including personal resources capability, equipment capability, and material capability. We use this information to prevent our schedule from exceeding the production capability.
  - Production request generation outputs requests for production. After the scheduling, the result of production schedule should be shared to ensure efficient production. The production request includes when and how many items should be produced or assembled, how many materials to be used, and where the items should be delivered. These production requests are generated according to production schedule.
  - Schedule modification adjusts the given schedule according to order and production environmental changes. We should modify our schedule if these changes happen frequently.
  - Availability offer provides availability information on whether components are available. After the scheduling, some orders are fulfilled whereas others are not. Information about availability is conveyed to the customer and the order is mediated.

  - By these functions, requests for production operation and availabilities for the production orders are generated.
- Production control includes production response generation, identification of event and alarm information, and production capability management.
  - Production response generation outputs the production result data from the requests. Production response includes requested production quantity, actual production quantity, produced site, area and facility information, worker information, and start and end time of production operation. This process is required, to track the production requests and to compare the difference between the plan and real production.
  - Identification of event and alarm information identifies special problems that can affect to production; i.e., facility breakdown, drop of quality or yield, material shortage and other abnormal signs.
  - Production capability management manages personal, facility, material and energy capability during production. This component manages the records of committed capability usage and updates the history according to the production. This component also manages available capability information.
  - By these functions, the production responses are fed back to production schedule function to modify the schedule, and the capability is updated according to the real situation.

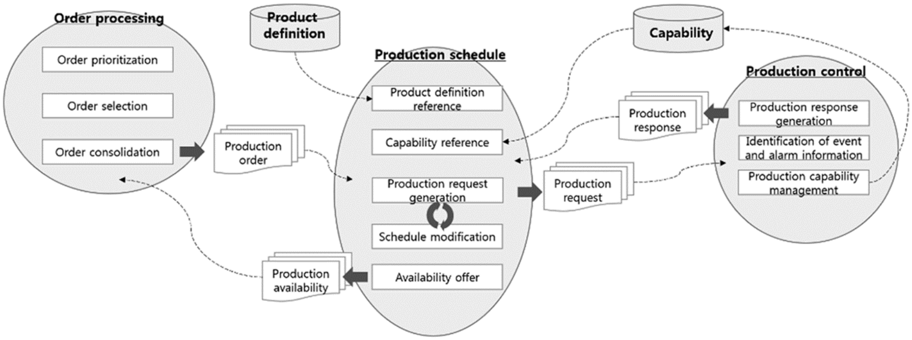

Fig. 3. Target service decomposition into unit level services

3 Limitations and Opportunities

3.1 Limitation of Target Service

The services had limitation when the provided functions depended on the users' decision. Users may fail to make consistent and optimized decisions when they use the production-planning service because of its high complexity [4]. In addition, because sensor and data gathering techniques are advancing, they should make decisions increases at some real-time decision-making points.

Order prioritization is critical to determine which order is produced or not. Improper priority can cause loss of critical customers' business because the priority of their order has been reduced and the schedule is prone to ignore lower-priority orders. However, order prioritization is done manually in many enterprises. Some simple rules were used: the highest priority is given to for the most frequent and most important customers, and the lowest priority is given to for small orders. Manual determination of order priorities causes operational problems, which result from inconsistent prioritization policy, and leads to inappropriate optimization.

For another example, schedule modification was dependent on the planners' decision. After the order or production environmental changes were reported, planners make decisions about the production, including cancellation of committed production request, re-allocation of facilities and materials, and determination of re-scheduling period. These decisions take time, but the planner cannot keep up with all change in order or production environment.

3.2 Opportunity Discovery

New technologies and methods can be introduced to develop new services, or to improve services. Computational components and physical components of manufacturing enterprises are becoming increasingly seamlessly and closely integrated to perceive changes in the real system [2]. Current efforts in the cyber-physical systems-based approach will produce many new value-creation opportunities for future manufacturing [5]. We will describe the opportunities application to our target service (Fig. 4).

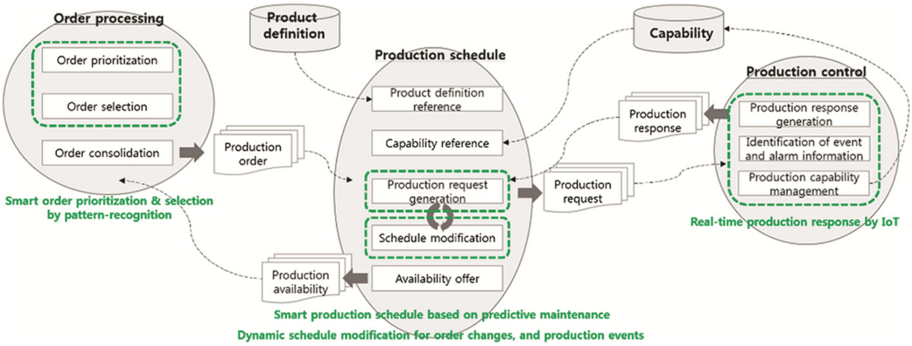

Fig. 4. Target service decomposition and new technologies enabling opportunities

At first, big data and predictive analytics can be used to innovate the services. For example, from the big data and predictive analytics, the past order prioritization and selection history are analyzed and patterns can be recognized. Pattern-recognition-based order prioritization and selection can support consistent and optimized decision-making.

IoT and real-time information can be used to innovate manufacturing services. For example, real-time information gathering and processing enable real-time identification of event and alarm information from various sensors attached to the facilities. According to this real-time information, real-time production responses and dynamic schedule modification are possible [6–8].

In addition, predictive analytics enables predictive maintenance, which in turn enables predictive maintenance-based production planning. Many approaches use fixed or periodic (deterministic) maintenance schedules; this time-based and hands-on equipment maintenance is still the norm in industrial processes, but this practice may be inefficient [9]. Production plan to exclude these unnecessary maintenance events increase their effectiveness.

4 Conclusion and Future Work

This paper described a target service, and decomposed function into unit services. Our target service consists of order processing, production schedule, and production control functions, and each has several sub-functions (unit services). Several methods and new technologies, such as IoT, big data analysis, cyber physical system, and predictive analytics, can be used to innovate current unit services and whole function.

Towards SM, we plan to collect more instances, and we will generalize the set of manufacturing services from these instances. These services will be analyzed, and new and advanced services from their improving opportunities and relationships will be discovered. The services will be decomposed into unit level services to enable the dynamic composition of manufacturing services for specific requirements.

Acknowledgement. This work was partly supported by the ICT R&D program of MSIP/IITP [B0101-15-0650, Development of Smart Manufacturing Operation Platform for Hightech Industry].

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Simulation-Based ‘Smart’ Operation Management System for Semiconductor Manufacturing

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Abstract. Presented in this paper is a framework of a simulation-based ‘smart’ operation management system (OMS) for semiconductor manufacturing. Also described are changes in the semiconductor market environment and key modules in the smart OMS. The proposed smart OMS is being implemented for a couple of IC chip makers in Korea.

Keywords: Simulation-based operation management system · Online simulation · Lot pegging · Fab scheduling

1 Introduction

Online simulation is used in the simulation-based operational management. An *online simulation* starts with the current state of manufacturing facilities at any point in time. A simulation-based operation management system (OMS) provides stakeholders with the ability to evaluate the capacity of the facility for new orders and to predict the expected delivery times and changes in operations [1–3].

In recent years, the semiconductor industry has been forced to become more competitive in pricing and in adopting new technology, while delivering IC chips faster and with an enhanced CPFR (collaborative planning forecasting and replenishment) with their customers. Thus, in order to meet the requirements of competitive pricing, fast-delivery, and CPFR, the OMS for semiconductor manufacturing should be capable of (1) increasing the number of tools per worker for TAT (turn-around-time) reduction, (2) enhancing the visibility of the supply chain, (3) providing reliable RTF (return to forecast) values, (4) minimizing WIP, (5) maximizing resource utilization, and (6) increasing the global efficiency of the IC chip supply chain.

Presented in the paper is an overall framework, together with some technical details, of a simulation-based ‘smart’ OMS for semiconductor manufacturing. Changes in the semiconductor market environment and in the concept of ‘smart’ OMS are given in the next section, and the architecture of the smart OMS is detailed in Sect. 3. Descriptions of the key modules in the smart OMS are given in Sect. 4, followed by a final section on conclusions and discussion.

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2 Semiconductor Market Environment and 'Smart' Operation Management System

Depicted in Fig. 1 are changes in the IC chip market environment. In the case of memory chips, there are only a few major suppliers (like Samsung and Micron) and a few major customers. The customers of IC chips (like Apple and HP) are now producing their products via *mass customization,* which requires low unit costs of mass production as well as swiftness in model changes and new product introduction, which in turn require the IC chip makers to become more competitive in pricing and in adopting new technology, while delivering IC chips faster with an enhanced CPFR with their customers.

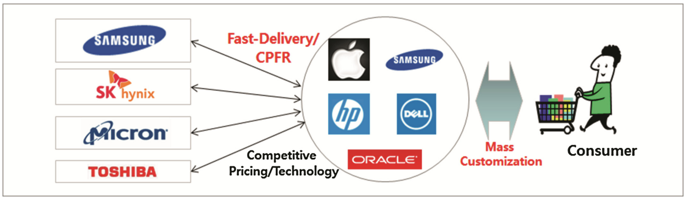

Fig. 1. Changes in the semiconductor market environment

In order to enhance an IC chip maker's competitive power for ***pricing***, its Fab *operation management system* (OMS) should be able to

(1) minimize WIP to reduce TAT and to avoid deterioration defects,
(2) increase the *number of tools per worker* (NTPW) to reduce TAT and labor costs,
(3) maximize resource utilization, and
(4) increase global efficiency of the IC chip supply chain.

For the ***fast delivery*** of IC chips, the OMS should be able to

(1) minimize TAT by minimizing WIP and maximizing NTPW, and
(2) enhance the visibility (or transparency) of the IC chip supply chain.

For efficient ***CPFR*** with customers, the OMS should be able to

(1) enhance the visibility of the supply chain,
(2) provide reliable return-to-forecast (RTF) values, and
(3) minimize TAT.

In summary, in order to meet the three requirements (competitive pricing, fast-delivery, and CPFR), an OMS for semiconductor manufacturing should be capable of (1) increasing the number of tools per worker for TAT reduction, (2) enhancing the visibility of the supply chain, (3) providing reliable RTF values, (4) minimizing WIP, (5) maximizing resource utilization, and (6) increasing the global efficiency of the IC chip supply chain. Such an OMS is often referred to as a 'smart' OMS. It is well observed in semiconductor industry that TAT decreases drastically as the number of tools per worker increases.

Figure 2 illustrates the concept of such a smart OMS. A smart OMS is similar to a smart phone GPS navigation which receives the current car location from the GPS and the current traffic information from the ITS (intelligent transportation system) and provides real-time information and advice to the driver. The smart OMS of a semiconductor Fab (or of the entire supply chain) generates production target values and provides relevant data and advice to stakeholders in ‘real-time’ by making *online simulation* runs in real-time with minimal human intervention.

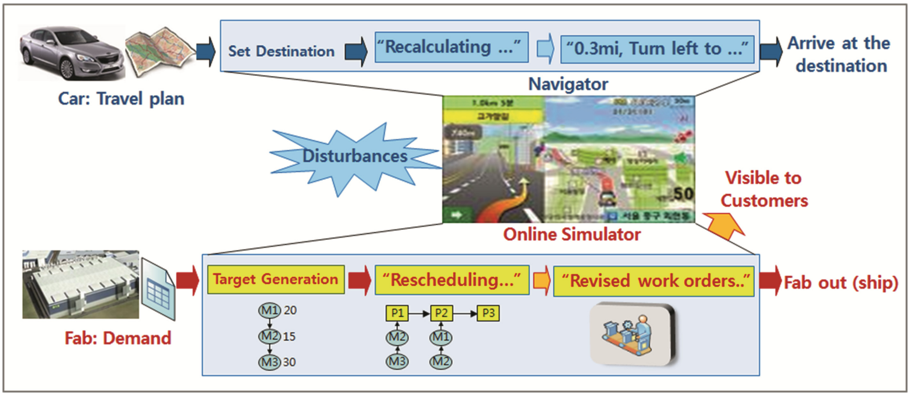

Fig. 2. Concept of a smart operation management system (OMS)

3 Architecture of Smart Operation Management System for Semiconductor Manufacturing

The smart OMS depicted in Fig. 2 is a simulation-based OMS. Perhaps, the concept of a simulation-based OMS was first proposed by the first author of this paper in an IFIP WG 5.7 conference [1]. OMSs were (and still are) often referred to as *manufacturing execution systems* (MES). More recently, a simulation-based OMS for LCD module manufacturing was presented [2]. Figure 3 shows the flow of LCD module manufacturing and the overall architecture of its simulation-based OMS.

When a weekly MP (master plan) is issued by the SCP (supply chain planner) system, the Weekly Planning System performs finite capacity planning to generate feasible daily production plans for the DPS (daily planning and scheduling) system. The DPS system generates detailed loading schedules for the TFT (thin-film-transistor) Fab, CF (color filter) Fab, LC (liquid crystal) Fab, and Module line. The weekly planning system (WPS) receives the weekly MP from the SCP system once a week and performs finite capacity planning to generate feasible daily production plans, purchase orders for the suppliers, etc.

Figure 4 shows the structure of a typical IC chip supply chain (or manufacturing network). A semiconductor wafer goes through a series of fabrication steps in a Fab to form a large number of ICs on its face (for 30–40 days) and stays in a Probe line to be

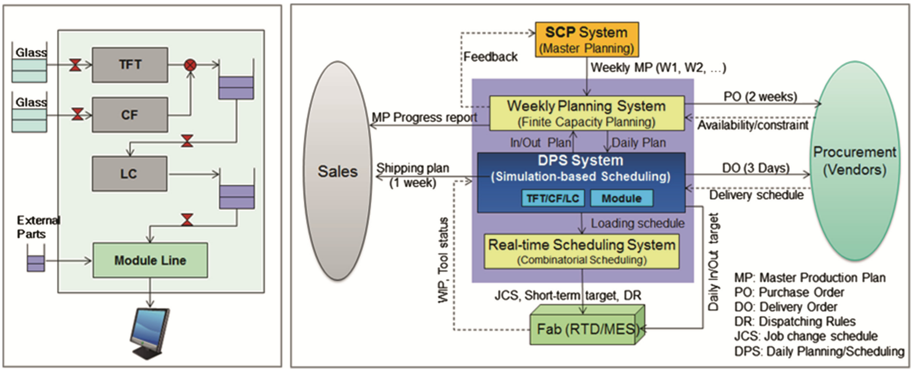

Fig. 3. Architecture of the simulation-based OMS for LCD module manufacturing [2]

probed for possible defects (for 2–5 days). Then, the chips are put into an IC package in the back end lines (for 3–7 days). A group of Fabs that can share resources is called a *site*. IC chips fabricated and probed in domestic Fabs may be sent to an overseas back-end line for packaging, and vice versa.

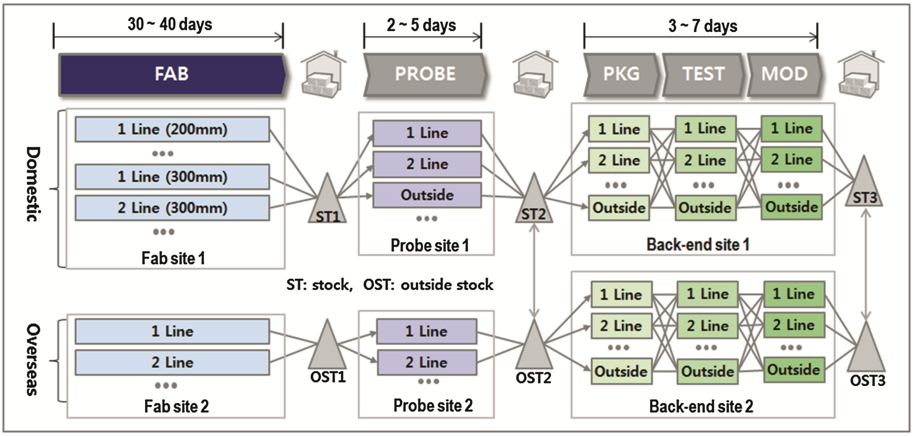

Fig. 4. Structure of IC chip supply chain

Shown in Fig. 5 is the overall architecture of the simulation-based OMS for IC chip manufacturing; this architecture corresponds to the supply chain structure shown in Fig. 4. The OMS consists of four software modules: the *Factory Planner* for generating daily input and output plans, the *Lot Pegging Module* for pegging the lots and generating their step targets and RTF values, the *What-if Simulator* for estimating bottleneck steps and WIP, and the *Fab Scheduler* for generating tool schedules. The Master Planning System (MPS) generates *weekly targets* for the Factory Planner and *demand data* for the Lot Pegging Module based on the firm *orders* and *forecast* values from Marketing and Sales. The key outputs from the OMS are (1) tool schedules to Real-Time

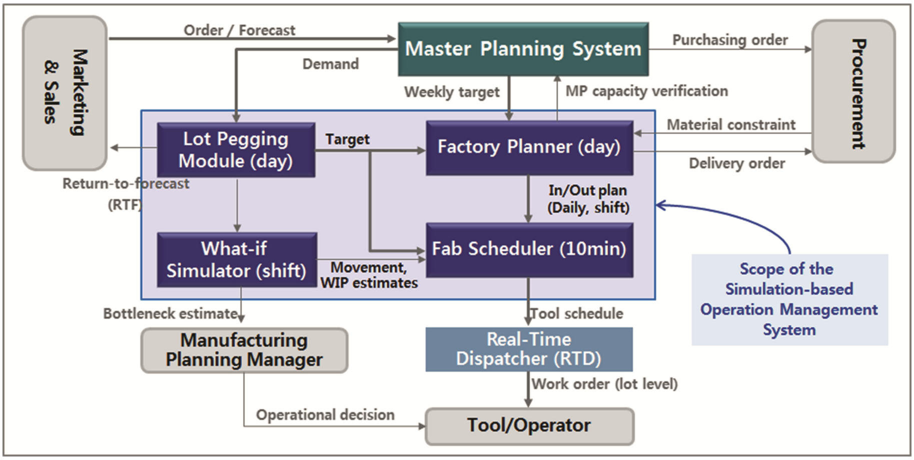

Fig. 5. Architecture of simulation-based OMS for IC chip manufacturing

Dispatchers (RTD), (2) RTF to Marketing and Sales, (3) delivery orders to Procurement, and (4) Master Plan verification back to MPS.

The *Factory Planner* is executed once a day for a simulation time period of 2–7 days at each site (e.g., Fab site 1, Probe site 1, etc., as shown in Fig. 4); the *Lot Pegging Module* is executed daily for all the lots in the supply chain, as shown in Fig. 4. The *What-if Simulator* is executed at the beginning of each shift for a simulation time period of 1–2 shifts at each line (it may be executed every hour if necessary). The *Fab Scheduler* is executed every ten minutes for a simulation time period of one shift for each line. The RTDs generate lot-level work orders (to each of the individual tools and operators) in real-time (less than 2 s).

The simulation-based OMS presented in Fig. 5 is a ‘smart’ OMS in the sense that (1) it is executed with minimal human intervention, (2) the current status and future trajectories of the supply chain are always visible to all stakeholders and (3) ‘optimal’ work orders are generated in real time. ‘Optimal’ work orders should maximize *step movements* and minimize both *WIP* and *TAT,* while also minimizing their variability.

4 Modules in the Smart OMS for Semiconductor Manufacturing

Some details of the individual modules of the OMS depicted in Fig. 5 are described in this section. Topics to be covered here are lot pegging, factory planning simulation, what-if simulation, and Fab scheduling simulation.

As shown in Fig. 6, *lot pegging* is carried out backward starting from the IC chip *Demand* data, through Probe stages, to the final *Fab-in target* stage, in which the blank wafers are released into the Fab. The lot pegging system keeps track of the progress of any given lot: (1) it provides the latest process start time (LPST) for each pegged lot to meet its demand; (2) it detects unpegged lots that have no demand; and (3) it provides

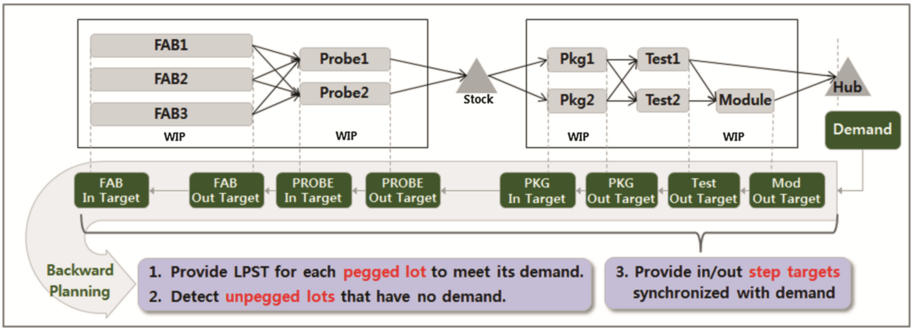

Fig. 6. Lot pegging operation

in/out step targets synchronized with demand. Through this system, any excess WIP without a target can be identified and controlled.

How factory planning simulation is carried out by the *Factory Planner* is shown in Fig. 7. The system generates an optimized plan for each line that ultimately satisfies the customers' demands. To generate the in and out plans for each line, factory planning simulation is carried out in two steps starting from the demand data: Target Generation via backward planning simulation [4] and Capacity Planning via a forward planning simulation [5]. The final outputs from the factory planning simulation are the estimated step completion times, machine (i.e., tool) schedules, and Fab out plans for each and every line in the supply chain.

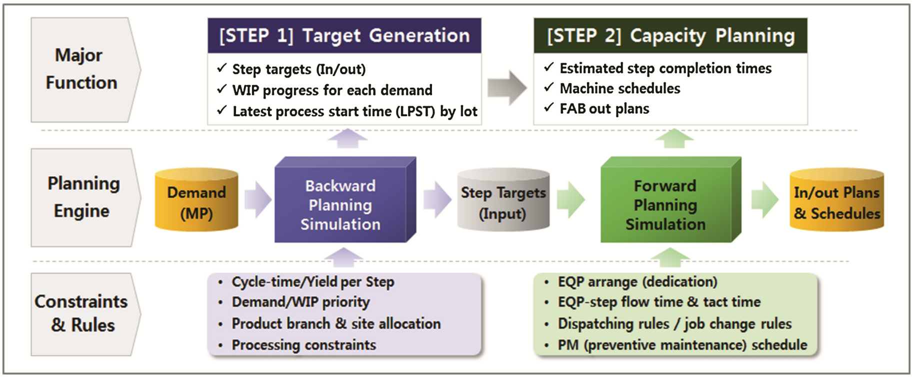

Fig. 7. Business architecture of the factory planner

Figure 8 shows the business architecture of the *What-if Simulator*. The simulation engine receives three types of input: Master data (product/BOP model, equipment model, and job change model); current status data (WIP, equipment, and PM); and production plan data (step targets and release plans). Then, it generates four types of KPI data: step movement estimates, Fab-out estimates, WIP level estimates, and expected bottleneck steps. As shown in the right part of Fig. 8, the system provides various decision-support data to the line managers. It also provides various technical data to the execution modules of the OMS, such as the RTD/MES (manufacturing execution system), Fab scheduler, and PM (preventive maintenance) scheduler. How the what-if simulation is performed by the simulation engine may be found in [6, 7].

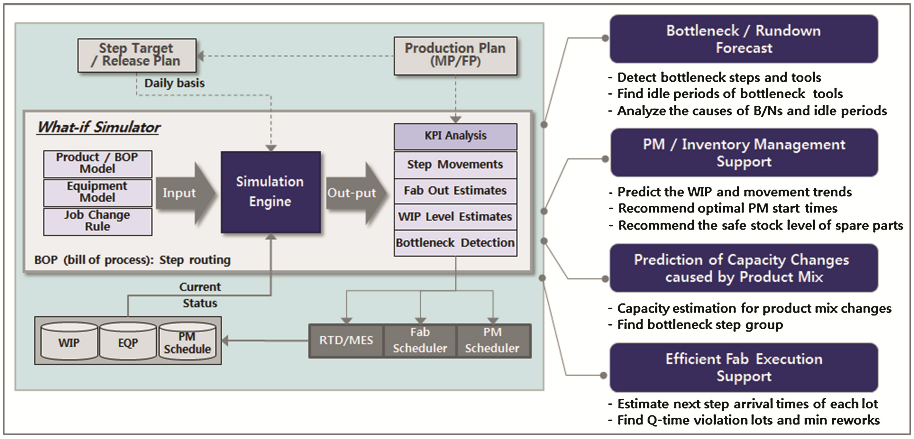

Fig. 8. Business architecture of the What-if simulator

The *Fab Scheduler* generates release plans and tool schedules such that the step targets provided by the Lot Pegging Module and Factory Planner are satisfied. First, the release plan for the line is generated considering capacity constraints, equipment arrangement (i.e., dedication), and operational rules. Then, a loading simulation, which is the same as the forward planning simulation shown in Fig. 7, is carried out to generate tool schedules. Figure 9 shows the major IC-chip processing steps for which tool schedules are generated.

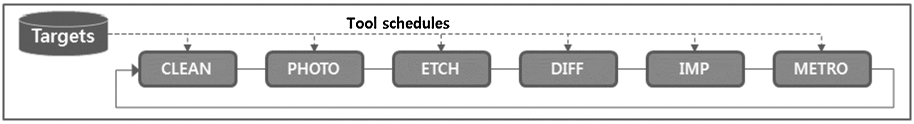

Fig. 9. Major processing steps for IC chip manufacturing

5 Summary and Conclusion

Presented in the paper is a framework of a simulation-based ‘smart’ operation management system (OMS) for semiconductor manufacturing. Also described are changes in the semiconductor market environment and key modules in the smart OMS. The proposed smart OMS is being implemented for a couple of IC chip makers in Korea. IC Chip manufacturing is generally classified into memory semiconductors and non-memory semiconductors. The latter are produced in much more varieties and smaller quantities than the former. Moreover, the overall production consists of numerous production process flows. Non-memory semiconductors especially have a higher rate of sample runs and/or engineering lots in the Fab, and require delivery management on a per lot basis.

The smart OMS architecture presented in this paper is applicable for non-memory semiconductors (often referred to as system LSI) as well. In detail, for non-memory semiconductors, it is critical to manage the delivery of each demand using the lot pegging module and the FAB Scheduler has to use a loading simulation logic that can reflect the variety of process flows of each product on a per lot basis. The proposed smart OMS is being implemented for a couple of IC chip makers in Korea and the prospects so far are quite promising; however, more rigorous analysis and evaluation of the proposed OMS have yet to be made.

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The Practitioner’s View on “Innovative Production Management Towards Sustainable Growth”

Enterprise Web Portals for Supply Chain Coordination: A Case Study

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Abstract. The performance of the supply chains is highly linked with the quality of relationship between partners. Web portals are more and more used for facilitating this relationship, but the consequences of their implementation on real cases are still seldom analysed. Such analysis is provided in this communication, highlighting the interest but also the problems of supplier portals thanks to a questionnaire filled by more than 130 suppliers of a large company.

Keywords: Supplier web portal · Supply chain · Coordination

1 Introduction

The use of the Information and Communication Technologies (ICT) is now quite mature inside companies, with the generalisation of the ERPs (Enterprise Resource Planning) systems), and in Supply Chains (SCs), with EDI (Electronic Data Interchange) and Internet as privileged communication tools [1]. The study of the influence of these tools on the relationships and quality of cooperation between customers and suppliers is as a consequence a field of growing interest. In this context, this communication focuses on the use of supplier web portals in a multi-site company of the high-tech sector, characterised by long cycle times, short series and high need of reactivity, in which each factory has to synchronize many suppliers. In that case, the diversity of size and culture of the partners, leading to quite different maturity levels towards ICT, considerably complicates the coordination between partners [2].

After a short survey on the role of ICT in integration and coordination of Supply Chains, we investigate the case of Inter-Organizational information Systems Infrastructures (IOSI), and more specifically supplier web portals. As a second step, a case study is presented: the use of the supplier web portal of a French large company, "Electra" (fictive name). The methodology of the study and its main results are then discussed.

2 Role of Information Systems in the Supply Chain Coordination

There is an interesting chronological correlation between the development of the concept of SC, appeared in the 80's, developed in the 90's and generalised in the 2000's, the

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evolution of ICTs and the context of globalisation. These three phenomena are indeed intrinsically linked: the strategy of the companies aiming at developing their SC has relied on the new possibilities of information systems, especially linked to Internet, in order to benefit from the ever increasing globalisation of economy. In their survey, Arshinder and Deshmukh [3] suggest a classification of the themes attached to the coordination of the SC: the Information and Communication Technologies are one of the considered mechanisms for coordinating a SC, information systems and contracts allowing information sharing and collaborative decision-making.

The integration of functions inside a company is usually performed thanks to the large functional coverage of an ERP, while with an external point of view, the EDIs have improved the quality and the quantity of information exchanged by the partners of the SC. A study realised on an important panel of French companies [4] shows that the companies using an ERP have a better external degree of integration with their suppliers and service providers (transporters for instance), using tools like EDIs, internet, web portals, than those who do not internally use an integrated information system. In that context, an IOSI is a collection of information technology resources, which includes communication network, hardware, IT applications, standards for data transmission, and human IT skills and experiences. IOSI helps organisations to establish and maintain interfirm relationships such as alliances, partnerships, and buyer-supplier relationship [5].

Four stages of evolution of IOSI may be distinguished [1]:

- stage 1: IOSI using paper supports (order forms, delivery orders…). We suggest to extend this stage to the use of Excel or Word files.
- stage 2: IOSI using EDIs.
- stage 3: IOSI using an ERP.
- stage 4: IOSI using internet portals or platforms.

We shall see that these four stages coexist in the IOSI used by Electra and his suppliers.

Finally, it is possible to characterise IOSI according to the inter-enterprise coordination mechanisms [6], by distinguishing those based on bilateral relationship, e.g. an EDI between two companies; those centred on a partner who is in relation with multiple customers or suppliers (this is the case for the considered portal) and finally IOSI putting in relation multiple customers with multiple suppliers (like electronic marketplaces, but also supplier portals like Boostaerospace[1], providing a unique portal for customers of the aeronautical industry and thousand of their suppliers).

3 The Supplier Web Portal: An Inter-organisational Technological Tool Allowing Coordination of Customer and Supplier

Under different names ("B2B portal", "Enterprise Information Portal", "Corporate Information Portal", or "Corporate Portal") the concept of enterprise web portal appeared in the end of the 90's with the development of Internet [7]. According to [8],

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[1] http://www.boostaerospace.com/.

"Enterprise Information Portals are applications that enable companies to unlock internally and externally stored information, and provide users a single gateway to personalized information needed to make informed business decisions". Enterprise portals can have various contents, aims, technologies or targeted users. It is possible to classify them according to [9]:

- the content provided by the portal: transactional (order entry, facture payment) vs. informational (technical documentations techniques, price catalogue),
- the targeted portal users: wide target and generic purpose portal (horizontal) or more specific target with deep technical content (vertical),
- a public-private dimension, with portals open to a wide audience or restricted to given users.

In the case of Electra, the portal is a transactional, vertical and private one.

In addition, three distinct orientations of B2B portals may be distinguished in SCs: customer oriented portals, supplier oriented portals, and digital marketplaces where customers and suppliers can meet [10]. Most of the existing studies deal with customer portals in the domain of Customer Relationship Management or e-commerce, or with digital marketplaces providing new opportunities to the company through a new marketing channel [11]. In contrast, little research has been conducted on supplier portals with a technical point of view [12]. These supplier portals may be the forefront of an evolution of the customer-supplier relationship and of the integration of the SC information systems, since they allow to streamline and integrate the information flows between partners of the SC. Some examples of integration of the information flows by means of supplier portals have been reported, e.g. in the US Air Force [12] in a Taiwanese company [10], or in the supply chain of a company of the automotive sector [13].

Often imposed by the customers, supplier web portals may create an asymmetry in the customer-supplier relationship, since the supplier is committed to use the customer's tool (the web portal), follow the rules of utilisation of the portal, train on the tool, and provide the information requested by the customer, in the required format.

The supplier hopes in return to consolidate his relationship and obtain a better quality of information, that he will be able to integrate in his internal information system. Moreover, the necessity to be integrated with the customer through a supplier portal creates a "barrier" for new suppliers, which protects as a consequence the "old" ones. In practice, it can be noticed that this barrier increases the feeling of security of the supplier, together with his trust in the customer. After a study on Ferrari's supplier portal, [14] even concludes that the use of a portal more impacts the improvement of the communication and relationships with the customer than the logistic performance or the purchasing process. Nevertheless, Robey et al. [15] analyse the inter-organisational impact of IOSIs, focusing on EDIs, and conclude that the use of EDIs reinforces the power of the customer at the expense of their suppliers, while the quality of the customer-supplier relationship influences the good use of the EDIs, and as a consequence the integration and coordination mechanisms.

4 Case Study

The inputs of the literature summarized in Sect. 3 have been confronted to a real case: the Electra company and its relationships with its suppliers through its supplier portal.

4.1 Context of the Company

Electra manufactures high tech products on several production sites. Its activity is based on contracts on several years; its cycle times are long; the company has long-term relationships with many highly specialized suppliers. The company uses the SAP ERP for many years, and has recently implemented a supplier portal integrated in SAP. Within this portal, the exchanges between the customer and the suppliers are performed according to the process summarized in Fig. 1.

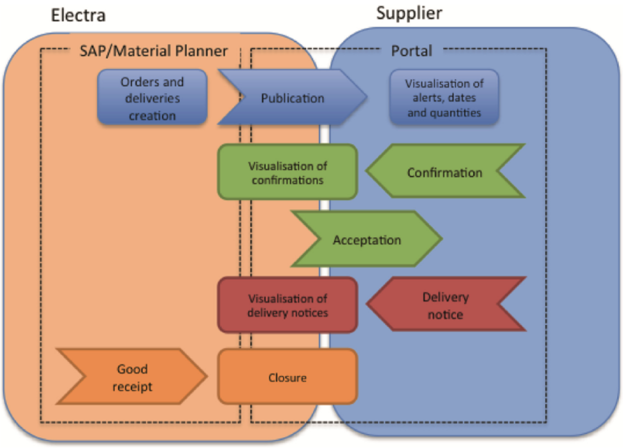

Fig. 1. Information exchange between Electra and its supplier through the portal

The project of implementation of the portal at Electra's was launched in the beginning of 2010, with a progressive deployment since 2011 on pilot sites and pilot suppliers, until the integration of all the sites and a majority of suppliers in 2013. In 2014, all the industrial sites of Electra, and about 450 suppliers, were using the portal. Our case study concerns the post-implementation phase of the project, and studies the appropriation of the portal by the suppliers, from their perspective.

4.2 Methodology

One of the authors has followed the implementation of the web portal in a pilot site during two years, and has had meetings with the project leader on the site, with the supply chain leader and with the project leader in the head office. An investigation has then been decided with two main objectives: for Electra, in order to better understand the modalities of use of the portal by the suppliers and the linked problems; for the authors, in order to analyse how this portal influences the relationship between customer and supplier.

A questionnaire with 45 items has been created using a methodology of investigation based on questionnaires used in social sciences [16]: 38 questions are "closed" while 7 are "open" in order to allow comments and reactions to the closed questions. It has been decided with Electra to keep the questionnaire anonymous but to give to the suppliers the possibility to provide their name if they want a feedback from Electra.

The questionnaire was sent to the supplier user (mainly supply chain user or sales administration user) and addresses four main topics: general information on the supplier and his information system; use of the portal; integration of the information coming from the portal in the IS of the suppliers; evolution of the collaboration with Electra since the implementation of the portal.

The questionnaire has been created using a dedicated web tool, the access link being sent to 450 suppliers by Electra. The questionnaire has been available during five weeks, a reminder being sent after three weeks.

138 questionnaires have been collected, 134 of them being considered as exploitable. This number so that the quality of the answers (nearly all the exploited questionnaires were complete, and included argued answers to open questions), allows to consider that the sample is good, which was confirmed by Electra. This is also shown by the distribution according to company size (25 % having less than 50 employees, 27 % between 50 and 200 employees, 26 % between 200 and 1000 employees and 12 % more than 1000 employees) so that by country (46 % of French suppliers, 54 % from Europe and Asia).

4.3 Results

Even if the answer could be anonymous, 59 suppliers have given their name. Most of the answering suppliers have stable relationships with Electra: 86 % work for Electra for more than 5 years. In the supply domain managed by the portal, the relationships are frequent and intense: the supplier work in average for 5 sites of Electra. Two to three persons use regularly the portal at the supplier's, and log on 14.6 times per month in average. Usage is then regular, almost daily in 33 % of the cases. A majority of the suppliers also use this type of tool with other customers (57 % use other portals, and 32 % EDIs).

Most users benefited from training on the portal. Nevertheless, 18.7 % have not been trained, mostly because they got their position of web portal user after the training period. How new users should be trained is so an important question.

The opinions on the improvement of the relationship with Electra, so that on the quality of the exchanged information, are dispersed: 50 % of the respondents see an improvement while 32 % do not see any change, 18 % estimating that the situation worsened. This may be set in relation with 69 % of the users expecting an improvement of the portal, and 59 % providing their expectations as free comments.

Globally, the users know and use the simple functions of the portal (delivery programs, confirmations, delivery notices), but much less the advanced functions.

They criticize:

- the slowness of the system (26 %) (due to poor web connections),
- its poor user-friendliness (in 44 % of the answers), which does not facilitate its appropriation (complex menus, many manipulations required, missing lines on the screen),
- a vocabulary not always understandable or well translated (12 %),
- non optimized processes: redundancies, necessity of useless back and forth exchanges with Electra (21 %),
- the poor quality of the data, not always reliable (18 %),
- the difficulties for integrating the data in their own system (18 %),
- a deviation of the use of the portal by its users at Electra (11 %), that can be indirectly related with the number of suppliers receiving additional Excel files from their contacts at Electra (45 %),
- marginally, an insufficient training (9 %).

Almost all the respondents use production management tools (70 %). These tools are mainly integrated tools (ERPs) but sometimes specialized ones. Nevertheless, Excel is still considered as a basic tool for forecasting.

72 % of the suppliers integrate the forecasts provided by the web portal, and 64 % the orders. Between a quarter and a third of the respondents do not integrate them at all.

This integration, when done, is mainly performed manually (47 %), often after correction of the data using Excel files (46 %), which is accepted by the portal. This correction of the data can be explained by free comments underlining in 18 % of the cases a poor reliability of the data (presence of null quantities for instance).

The suppliers clearly suffer from difficulties for performing a more systematic and automated integration of the data provided by the portal. The EDI solution can provide an improvement, but only 13 % of the present users ask for such a solution.

45 % of the suppliers receive Excel files from their contacts at Electra, in parallel with the information provided by the portal. These files may concern forecasts, orders, and deliveries, all theoretically provided by the portal. The suppliers complain about redundant, and sometimes conflicting information, the data provided on Excel files being considered as more reliable than the ones provided by the portal.

On the other hand, the reaction of the suppliers when facing a problem also shows unexpected behaviours: 40 % call their usual contact at Electra and 15 % call a colleague, instead of referring to the user manuals (18 %) or contacting the key users (23 %) as recommended. A familiar human relationship if therefore preferred through phone or email, even if it leads to neglect the nominal procedure.

A very positive point of the investigation is that the suppliers do not reject the portal but ask for improvements. 56 % of the suppliers consider themselves as "members of the users' community". The analysis of the correlation between answers shows that this feeling is correlated to a more positive opinion on the portal, and to a better internal integration of the forecasts and orders.

Although the sizes of the companies and sectors of activity and country are diverse, no correlation can be established between the use of the portal, the satisfaction felt and the type of company (especially its size). This may set into question the usual consideration that small companies are more reluctant than large ones to use ICTs.

Technically, it is clear that the portal would need some improvements: better connexion to the portal from some places and better ergonomics (especially in the structuration of the screens) for instance.

In terms of training, tools or training modules should be systematically suggested to the new users, the supported process being relatively complex. An extensive training of all the users on all the functions of the portal could be of immediate benefit.

A better communication with the suppliers on the resources and competences that could support them should be done. The animation of a real “users’ community” using social tools (Facebook or dedicated tools [17]) could be considered.

The reasons for the use of Excel files should be investigated more thoroughly, and solutions inside the web portal should be found.

The suppliers should be helped for finding practical solutions in order to integrate the data provided by the web portal in their information system.

5 Conclusion

Supplier web portals are becoming a key tool of the collaboration between customer and supplier. Through a questionnaire, we have investigated the first results of a recent experiment of such portal in a high tech industry, showing that in spite of high potential, many practical (and sometimes anecdotal) problems may set into question the efficiency of such tools.

This investigation has intrinsic limits that could provide new perspectives for this topic of research. Firstly, the domain of activity of Electra concerns industrial products of high technology. The results can clearly not be generalized to other domains like the automotive sector or mass-market products. Moreover, the study addresses the appropriation of the portal by the users at Electra’s suppliers, but does not analyze its appropriation by Electra’s users. Nevertheless, our study shows that such investigation would deserve some interest. Finally, it would be interesting to deepen the conclusions by meeting some suppliers. In spite of these limitations, we hope to have shown the great potential of these tools for a better integration of the partner’s processes and information systems in nowadays supply chains.

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Manufacturing Research, Innovation, and PhD Education on a National Level – Produktion2030, a Swedish Example

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Abstract. National competitiveness in the manufacturing sector requires continuous investments in innovation, research, and education. Swedish manufacturing industry have joined forces with universities and research institutes to initiate Produktion2030, a successful public-private-partnership research and innovation programme. In this programme, industry is at the helm, to strengthen sustainable production and to increase investments towards advanced manufacturing in Sweden.

Keywords: Production · Innovation · Research · PhD education · Sweden

1 Introduction

A competitive manufacturing industry is vital for Sweden's job market and growth. Similar economic dependencies may be found in most of the European countries, as well as in other global regions. This industrial sector is a foundation for a sustainable society and a key driver for new businesses and services; information and communication technology; and breakthrough manufacturing technologies e.g. additive manufacturing. Not surprisingly, governments globally are launching massive efforts, investing in manufacturing research, innovation, and education (RIE) programmes. Their goals are to increase global competitiveness in the manufacturing sector by stimulating e.g. innovation processes, business development, and technology transfer. In Europe, programmes like Finland's *Fimecc*; Germany's *Industrie 4.0*; Denmark's *MADE;* and the *Smart Industry* from the Netherlands are good examples of manufacturing innovation efforts. In Sweden, national manufacturing strategic research agendas [1] were established in 2008, 2011, and 2013. These initiatives were led by industry, in this case represented by Teknikföretagen[1], together with the Swedish Production Academy and the national Research Institutes. As a result the national research and innovation programme Produktion2030[2] emerged. Its vision is that Swedish manufacturing industry

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[1] Teknikföretagen **(The Swedish Association of Engineering Industries), the main** association for Sweden's export industry, representing 4000 companies. http://www.teknikforetagen.se.
[2] The Produktion2030 research and innovations programme: http://www.produktion2030.se.

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stays a front-runner and innovation leader in sustainable production. This paper presents the challenges, background, and operation of Produktion2030. The two authors of this paper are director and co-director of the Produktion2030 programme.

2 Background – National Swedish Efforts for Manufacturing Research, Innovation, and PhD Education

Fifty percent of Sweden's export goods derive from the manufacturing sector and more than one million people are employed directly or indirectly by this sector. The Swedish reliance on industry has resulted in a long history of governmentally funded research and development programmes in the manufacturing area. In the 1960's and forward, technology- and process-oriented research programs focusing on e.g. machining, welding, assembly, robotics, and materials have supported Swedish industrial excellence. In parallel, excellent organizational and work-science related research put Sweden in a leading position in how to organize and operate manufacturing operations. For practical reasons, the two inseparable organizational and technical strands merged in the 1990's. Also at that time, research projects became highly integrated between industry, academia, and institutes. Industrial co-funding requirements increased and the amount of governmental funding for manufacturing research started to drop, reaching a critically low level around 1995 (see Fig. 1). The drop forced industry, academia, institutes, and research societies to protest strongly. Governmental funding agencies then launched sector-oriented programmes to support more applied research in manufacturing (i.e. automotive, aerospace, etc.). Examples are the aerospace programme NFFP (1994–2008) and the automotive

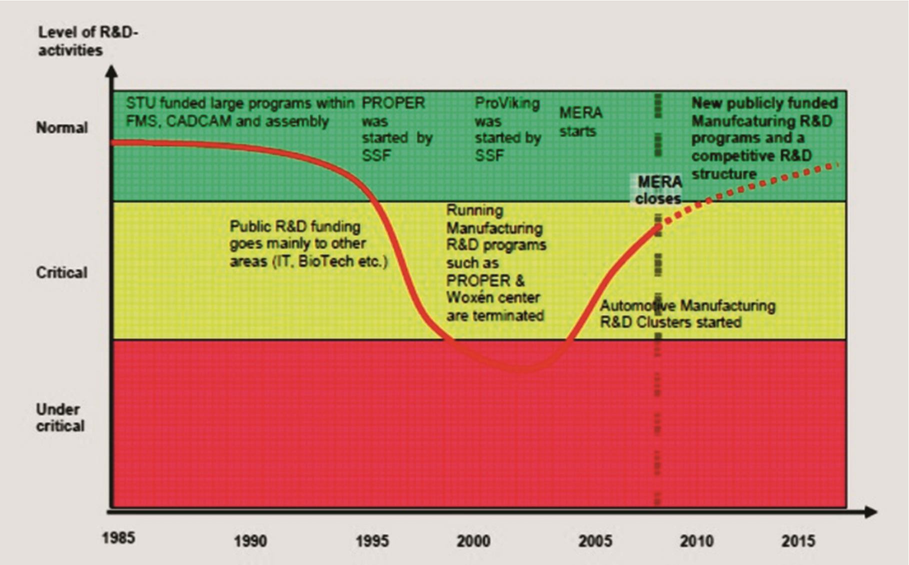

Fig. 1. Swedish governmental research funding in production [3]

programmes MERA (2002–2007) and FFI (2008 – ongoing). In parallel, major Swedish research foundations launched manufacturing research efforts that focused on basic and applied research as well as national PhD education programmes, e.g. for product development (ENDREA 1996–2002) and production development (PROPER 1997–2004) [2] as well as ProViking (2002–2012).

The national project "Produktion för konkurrenskraft" (*Production for Competitiveness*) was launched by The Royal Swedish Academy of Engineering Sciences in 2004. The project was an important contribution to the reestablishment of a strong Swedish community for production research and development. The aim was to map Swedish academic and institute production research; to assess the R&D needs of the manufacturing industry; and suggest actions to increase competitiveness of that industry. In 2007, Teknikföretagen[1] took the lead in disseminating and promoting results from the project through a nation-wide tour, covering more than 100 Swedish cities. Recommendations were also submitted to the ministries Enterprise as well as Education and Research in an industrial request for future research funding to universities and institutes. In addition, The Swedish Production Academy[3], a national network for academic production engineering professors, was founded. All universities with engineering programmes and production research are members and the majority of PhD students are organized in the Production Academy Doctoral Chapter (PADOK). The Academy also hosts a bi-annual academic conference (Swedish Production Symposium) and constitutes a platform for long-term development of research and higher education.

2.1 Consensus for a New Innovation Programme – Produktion2030

The collaboration between industry (i.e. Teknikföretagen), the Swedish Production Academy, and the national manufacturing research institutes was established through joint efforts. Since 2005, these actors had collaborated in promoting and developing national interest in production research, dissemination and education. To influence policy makers and put forward recommendations for research funding and education, these actors have produced national agendas for development in production, aiming to influence industry, academy and government. The first two agendas, "Svensk produktionsforskning 2020" and "Svensk produktion 2025" had impact on the Swedish Research and Innovation Bill in 2008, resulting in a radically increased government funding of 300 MSEK (M€ 30) within the production research area. A third strategic agenda, "Made in Sweden 2030" was presented in 2012.

The agenda described a well-accepted roadmap for further governmental and industrial investments to renew a large number of industries, manufacturing industry included. Thus, the strategic research and innovation programme Produktion2030 was established in 2013.

The manufacturing industry in Sweden represents a majority of the national gross investments in R&D, with more than a third of the total national spending on R&D deriving from the manufacturing industry. This makes Sweden highly dependent on its manufacturing industry for knowledge growth and innovation, as well as for job creation

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[3] The Swedish Production Academy: http://www.produktionsakademien.com.

and growth. Government research and innovation policy directed towards the technology sector (e.g. manufacturing and engineering) has a huge impact on industry's investment's in manufacturing as well as R&D. Regular surveys performed by Teknikföretagen confirms this.

Based on this discussion, Produktion2030 has the potential to fulfill the long-term goals of the programme, with increased investments in production in Sweden as a result. The programme also has a wider scope than its predecessors, encompassing the entire manufacturing sector.

3 Produktion2030 – A National Programme for Research, Innovation and Education

Produktion2030 was one of five national Research and Innovation programmes launched in the first wave of Swedish Public-Private Partnerships in 2013. The government aim with the innovation programmes was to give industry, academy, and institute stake-holders considerable influence on the design and management of the research programme. Industrial leadership is crucial for the programmes' success. Challenges and research priorities are put forward from industry and the research community. Also, activities such as writing call texts, instigating dissemination activities and education programs are managed by the stake-holders through the programme management group.

Further and a bit unusual for this kind of programmes, the responsibility of the project portfolio is in the hands of the programme steering committee. The strategy and operation of the research programme is almost fully outsourced to its stake-holders. Instead, the programme will be assessed by the Swedish Government every three years. Thus, it will be up to industry and the research community in collaboration to make it successful. It should be noted that a continuous and mutual collaboration between Production2030 and VINNOVA, the funding agency, contributes to improvements and quality assurance of the programme.

Produktion2030 is organized in two main dimensions: (1) Six areas of strength, jointly identified by industry, academia, and institutes. (2) Five instruments, providing a scalable organizational infrastructure to facilitate operations.

3.1 The Produktion2030 Areas of Strength

Manufacturing is a wide thematic field with several possible dimensions. Research and innovation content may range from capturing of product customer needs to new ways for production system operation and maintenance. Digital tools for design and development of products have their corresponding potentials in digital visualization of production system for innovation and design. In a national context, there is natural distribution of interests and expertise among industry, academia, and research institutes.

In order to focus Produktion2030, parts of the strategic research agenda efforts were spent on identifying manufacturing areas where Sweden was already strong on research and innovation, and where a good potential for increased national competitiveness could be identified. Produktion2030 should be guided in the most relevant direction to achieve maximum impact in Swedish manufacturing industry. Therefore the scope of the research and innovation was structured into six areas. These areas were chosen through workshops, questionnaires, and bilateral discussions where representatives from research institutes, industry and academia took part. The findings were anchored with a large number of manufacturing companies with extensive research and production in Sweden, e.g. AB Volvo, SKF, ABB, Sandvik, and Saab Group.

After several subsequent stages of analysis done in close collaboration between industry and researchers from academia and institutes, consensus was reached on the following six areas, which were to be developed as national Swedish areas of strength in manufacturing:

1. Environmentally sustainable and resource-efficient production
2. Flexible production
3. Virtual production development and simulation
4. Humans in the production system
5. Product- and production-based services
6. Integrated product- and production-development

The identified areas of strength correspond well to the prioritized research areas within the European public-private partnership (PPP) programme "Factories of the Future" which is aimed at enhancing the competitiveness of European industry [4]. The areas identified by the European PPP organization are: (i) Advanced manufacturing processes, (ii) Adaptive and smart manufacturing systems, (iii) Digital, virtual and resource-efficient factories, (iv) Collaborative and mobile enterprises, (v) Human-centred manufacturing and (vi) Customer-focused manufacturing.

3.2 The Produktion2030 Instruments

The operation of Produktion2030 is based on five "instruments", the second dimension of the programme, which provides a scalable and transparent organizational infrastructure. The vision of Produktion2030 is that Sweden should be a front-runner in sustainable production and that investments in production in Sweden increase. Therefore, it takes more than investments in research and innovation projects to move forward.

The development of education related to national areas of strength, an increase of mobility between industry and research organizations and effective technology transfer to SMEs are important tools to reach the programme goals.

The operations of Produktion2030 are organized through the following five instruments:

1. Research and innovation projects: 0.5–3 year projects with a high Technology readiness level. Projects are initiated through consortia applications based on open calls for proposals twice a year. Sizes and formats of calls vary
2. Knowledge and technology transfer to small and medium sized enterprises (SMEs): captures and transfers method development, new knowledge and technology from the research and innovation projects to SMEs
3. Researcher and Industry Mobility: funding for short job exchanges for researchers in industry, universities and research institutes

4. Education: Produktion2030 has established a national PhD-course programme and will develop courses on masters level as well as platforms for continuous education
5. Internationalization: major efforts to harmonize Swedish R&I&D programmes relevant for the manufacturing industry with EU programmes and funding.

The instruments have been constructed to create highest possible impact of the programme. Further, they are connected and slightly overlap in order to assure programme coherence.

The findings and results from the Research and innovation projects are disseminated through the Knowledge and technology transfer instrument as well as through the Education instrument. The Mobility instrument has as main objective to support knowledge transfer within individual projects, thereby strengthening consortia and endorsing impact. Common to all instruments are the participations from the three types of stakeholders: industry, academy and research institutes. Each instrument has a designated manager (or management group), reporting to the Programme Office.

Sweden is among the leading countries in the world when it comes to investments in research, with typically 3 % of GDP invested annually from private and public sectors. In addition, Sweden ranks among the foremost countries when it comes to innovation. In contrast, only a small portion of these investments in research and innovation are turned over into business creation or added value for industry. The void between research and the private business sector, known as the “Valley of death” [5], is challenging governments all over the world, and great efforts are made to create innovation and research programmes that can minimize this gap and build supporting infrastructures that make more use of research in the business community.

Produktion2030 is aiming to construct a reliable infrastructure that connects research and business through primarily three of its five instruments. The instrument “Research and innovation projects” typically invests in projects that result in test-beds and demonstrators which provides opportunities to try results in an industrial setting. Through this approach an industrial impact is achieved and the companies in the project consortia can attain imminent results to challenges and needs put forward in the project. The instrument “Knowledge and technology transfer to SME’s” is designed to increase the use of test-beds and demonstrators far beyond the limited numbers of companies in a consortia. The instrument aims to extend the reach of each project by re-packaging them to fit a wider group of companies, typically SME’s that are subcontractors to the manufacturing sector. Each project is offered a small top-up funding to create a simplified, shorter version, and already after two years the results are very promising. To support this dissemination, the manager of the instrument is working in partnership with a large number of clusters and SME-associations within the manufacturing sector. The “Mobility” instrument supports the implementation of results from the research and innovation projects by targeting the project consortia. This instrument provides the opportunity to achieve a more thorough testing or implementation of results by making shorter job exchanges between the consortia partners possible (e.g. representatives from industry and research).

The fourth instrument “Education”, is in a way involving industry by directing its offerings of courses and continuous education programmes to members of industry as well as to representatives of academia and research institutes, in this way networks between industry and research organizations are created. Expert Groups as well as the Steering Committee can during the course of the programme suggest topics and knowledge trends that are then addressed by the Education instrument.

Internationalization, the fifth and last instrument directs much of its efforts to increase industry involvement in European funded projects, as well as positioning challenges for Swedish industry and research community high on the agenda for European research programmes and platforms.

Industry commitment is an important KPI of the success of Produktion2030 and the principal organization, Teknikföretagen, together with the funding agency VINNOVA, is expecting a fifty-fifty co-financing of the programme as a whole. To date, after two years in operation, we find that this goal has been surpassed, as every instrument and activity has an average industry participation more than 50 %.

3.3 The Organization of the Produktion2030 Programme

The organization and communication flows in Produktion2030 are shown in Fig. 2. The programme has a bottom up (described in Fig. 2 as a left to right flow) approach where ideas, vision, challenges and project proposals are suggested by members of industry, academy and research institutes, organized in Expert Groups. The groups form communities for national special interest in production, specifically in the corresponding area of strength. The groups have a strong commitment to identify challenges and opportunities in production development and innovation.

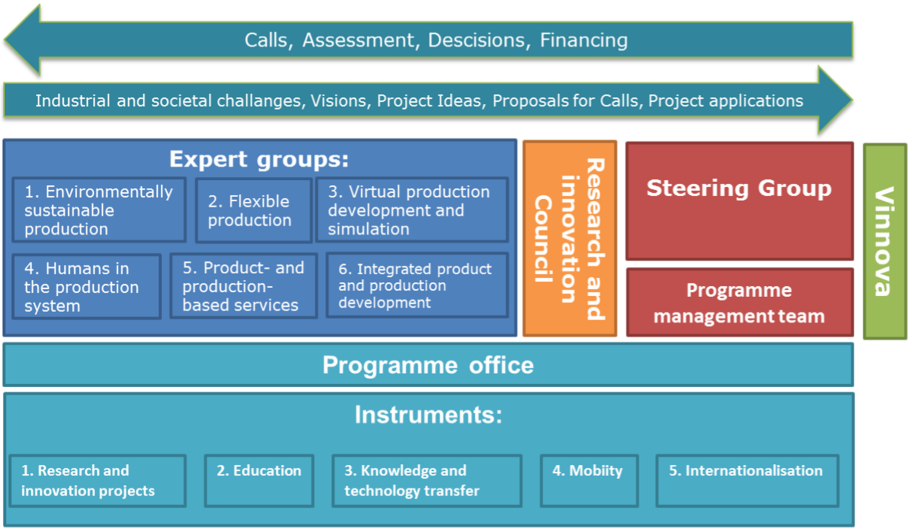

Fig. 2. Produktion2030 Organizational structure

There are currently around 200 persons involved in the Expert Groups. Each Group is managed by two Expert Group Leaders, who have been selected among young (i.e. less than 45 years) and promising academic researchers in each area of strength.

The proposals are passed on to the Research and Innovation Council, a smaller group of 10–12 people representing industry, academy and institutes, with the task to discuss and prioritize the wide range of proposals coming from the Expert Groups. The third level in the decision process is the Steering Committee of 10 people, which has the power of decision, working towards the goals set up in the programme. The Expert Groups gather at least two times per year with the assignment to identify challenges related to production industry, including needs in education, test beds and demonstrators.

4 Discussion and Conclusions

Manufacturing excellence is of vital importance for an export-dominated country like Sweden. Being a nation of only close to 10 million people, strong national collaboration and consensus between industries, universities, institutes, Government, and funding institutions need to be sought to maintain a high level of excellence in the research and education and to attract increased investments in production activities.

The aim of the Produktion2030 public-private partnership (PPP) programme is to invest and leverage a limited amount of government funding towards a maximum impact on the manufacturing industry, production research, and education. The results in technology developments and innovations production will have an influence on investment in production in Sweden as well as supporting Swedish efforts to be a front runner in production.

This paper has presented a series of national Swedish programme efforts. It has also exemplified how a national programme for research, innovation and PhD education can be designed and operated to achieve a high level of national involvement and consensus on aim, vision and direction.

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Linkage Between Delivery Frequency and Food Waste: Multiple Case Studies of a Norwegian Retail Chain

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Abstract. The main objective of this paper is to investigate linkage between delivery frequency and food waste of chilled products by testing the hypothesis – the higher the delivery frequency, the lower the food waste. Multiple case studies have been used to test the hypothesis. Food waste ratios of five product groups have been compared in three delivery frequency scenarios, namely low delivery frequency, medium delivery frequency and high delivery frequency scenario. Moreover, food waste ratios of different product groups have been compared to each other within each delivery frequency scenario. The findings show a strong negative correlation between delivery frequency and the food waste ratio for each investigated product group, which supports the hypothesis. On the other hand, food waste ratios among different product groups within the same delivery frequency scenarios vary significantly.

Keywords: Food waste · Delivery frequency · Retail · Logistics · Chilled products

1 Introduction

There are substantial levels of food waste at retail stage of the food supply chain in Nordic countries, as uncovered by recent studies, especially for fresh and chilled product groups [1–3]. Reduction of such food waste has, therefore, got an increased attention from research community, as well as practitioners in retail chains.

Studies by Mena et al. [4, 5], Beretta et al. [6], Darlington et al. [7], Taylor [8] or Kaipia et al. [9] have presented various causes of food waste where several were related to logistics and supply chain processes, such as long lead times, low delivery frequencies, high inventories and safety stocks, inaccurate forecasting or inefficient order management. However, there is still a limited number of studies investigating the causes and collecting the empirical evidence on linkages to food waste, or comparing their relative impact on food waste. Such studies are necessary in order to become effective and efficient in identifying and minimising food waste.

Among the afore-mentioned causes, the linkage between delivery frequency and food waste has been partly investigated by van der Vorst et al. [10]. Delivery frequency

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can be defined as the number of deliveries per certain period of time. In their study, delivery frequency is defined as the number of deliveries per week [10]. They simulated scenarios with different delivery frequencies per week for chilled salad and observed how throughput time and inventory levels change. Their simulation indicates that the higher the delivery frequency the lower the throughput time and inventory levels, impelling higher product freshness, which could be interpreted as less food waste. The limitations of the simulation approach are that it usually considers only a few factors what can significantly modify the findings from the real life situation. Based on their indications, we therefore decided to test the hypothesis:

> *"The higher the delivery frequency, the lower the food waste."*

The hypothesis is tested by investigating the linkage between delivery frequency and food waste in practice by using data from 4 stores. Moreover, different product groups have been considered in order to see whether the hypothesis is valid for several product groups, and what the potential deviations are between the groups.

The reminder of the paper describes the data collected in the case companies and methods used for data collection and analysis. Further, the description of cases and findings are presented and discussed in terms of the hypothesis. Finally, concluding propositions and topics for further research are highlighted at the end of the paper.

2 Methods for Data Collection and Analysis

The purpose of the study is to provide empirical evidence about linkage between delivery frequency and food waste, as formulated in the hypothesis. Multiple case studies have been selected as one of the methods recommended by Yin [11] for testing hypotheses. The advantage of using case research is in its ability to investigate a research problem within the complexity of real-life [12], thus testing the hypothesis against empirical data [13].

The case study protocol has been developed for collecting and analysing the data across the case companies. Data on sales, food waste and delivery frequencies per different product groups has been collected in four Norwegian stores. The main sources of data were interviews, point-of-sales data and insights to internal documents of terms and conditions between the wholesaler and stores. Data on delivery frequencies has been verified with the stores and the wholesaler. The sum of the sales and food waste data aggregated per period of one year, and has been used to calculate the number of delivered products which in turn has been used to calculate a food waste ratio. The food waste ratio is expressed as a percentage of a quotient between the amount of food waste and delivered products, as proposed by Eriksson et al. [1]. When selecting product groups for analysis, the main focus was on top five product groups with the highest food waste ratios in selected stores.

Data analysis consists of two parts. In the first part of the analysis, food waste ratios have been observed in low, medium and high delivery frequency scenarios, for each product group separately. Three delivery frequency scenarios are represented by four stores, where two stores are considered to have low delivery frequency per week, one is considered to have medium number of deliveries per week, and one is considered to have high number of deliveries per week. More details about the delivery frequencies are described in Table 1. The food waste ratio of each product group has been analysed in each scenario in terms of the hypothesis. It is important to note that in order to simplify the analysis, food waste ratios of product groups in low frequency scenario are average values of the two stores. Moreover, the Pearson coefficient of correlation has been selected due to its suitability for investigating the linear correlation between delivery frequency and food waste in terms of the hypothesis.

In the second part of the analysis, food waste ratios are compared among different product groups within the same delivery frequency scenario. Both parts of the analysis have used graphs and other functionalities of MS Excel 2010 software.

Reliability of data used in this case study is ensured by using the same type and number of products defining each product group in each store. Moreover, methods for capturing and calculating sales and food waste in each store are the same, since they are part of the same retail chain.

3 Case Description and Findings

All stores are part of the same retail chain and are customers of the same wholesaler. They are located within the similar traveling distance from the wholesaler. The product groups discussed are delivered from the wholesaler directly to the stores, and consist of meat, dairy, convenience food (e.g. sauces, tapas), fruits and vegetables.

The stores consist of two small stores with low turnover, one middle store with medium turnover and one large store with high turnover. Delivery frequency from the wholesaler to the stores is based on the turnover of each store, and applies that the higher the turnover, the higher the delivery frequency. Different product groups have different delivery frequencies within each store. For example, product groups of fruits and vegetables have one or two deliveries per week more than product groups of meat, dairy and convenience food. More details about delivery frequency scenarios per different product groups are described in Table 1.

Table 1. Delivery frequency scenarios per product groups

	Delivery frequencies per week		
Product groups	Low delivery frequency	Medium delivery frequency	High delivery frequency
Meat	2	3	5
Convenience food	2	3	5
Dairy	2	3	5
Fruits	3	5	6
Vegetables	3	5	6

The stores with low delivery frequency were placed to the left and the stores with high delivery frequency were placed to the right of the table. Similarly, the product groups with the low delivery frequency were organized on the top while product groups with the highest delivery frequency were placed on the bottom of Table 1. Thus, according to the hypothesis, the food waste ratio should be increasing, as coming towards upper left corner (darker boxes), and decreasing, as coming towards lower right corner (lighter boxes) of Table 1. Table 2 describes the food waste ratios of each product group in three delivery frequency scenarios. Data from both tables are used as an input for further analyses in the next chapter.

Table 2. Food waste ratios of selected product groups in various delivery frequency scenarios

	Food waste ratios		
Product groups	Low delivery frequency	Medium delivery frequency	High delivery frequency
Meat	9,2 %	7,8 %	3,9 %
Convenience food	5,4 %	4,4 %	1,7 %
Dairy	5,4 %	2,1 %	0,5 %
Fruits	4,7 %	3,9 %	2,3 %
Vegetables	4,2 %	3,8 %	1,9 %

4 Analysis and Discussion

Two types of analysis are presented in this chapter. The first analysis compares food waste ratios within three delivery frequency scenarios, for each product group separately. The second analysis compares food waste ratios among different product groups within each of the three delivery frequency scenarios.

4.1 Food Waste Ratios in Different Delivery Frequency Scenarios

In Fig. 1 food waste ratios of each product group are observed in scenarios with low, medium and high delivery frequency. Overall, Fig. 1 clearly indicates that the food waste ratio in high delivery frequency scenarios have lower food waste ratios than the low delivery frequency scenario, and it is valid within each of the selected product groups without exceptions.

For *meat products*, a decrease in the food waste ratio of around 15 % can be observed when delivery frequency increases from two to three days and more than 50 % when delivery frequency increases from three to five days. A very similar pattern can be seen in case of *convenience food*. Correlation coefficient for both meat and convenience food is −0.99 indicating very strong negative correlation.

For *dairy products,* a huge decrease in the food waste ratio of around 60 % can be seen when delivery frequency increases by one day only. Even bigger decreases by around 80 % can be observed when delivery frequency increases to five days a week. This clearly indicates the sensitivity of dairy products to changes in delivery frequency. Correlation coefficient is −0.92 indicating a strong negative correlation.

For *fruits* and *vegetables,* a decrease in the food waste ratio of around 40–50 % can be observed when delivery frequency increases by one day only, from five to six days. This is a much bigger decrease than the decrease of the food waste ratio of around 10–15 % when the delivery frequency increases by two days, from three to five days. This kind of unexpected finding can be caused by factors that are not considered in this study, such as different planning principles or order management processes in particular store which might be significantly more efficient compare to the other stores. The correlation coefficients for fruits and vegetables are −0.92 and −0.84 respectively, and show relatively strong negative correlation. The vegetables group thus indicates to have the lowest correlation between the delivery frequency and food waste among the groups considered.

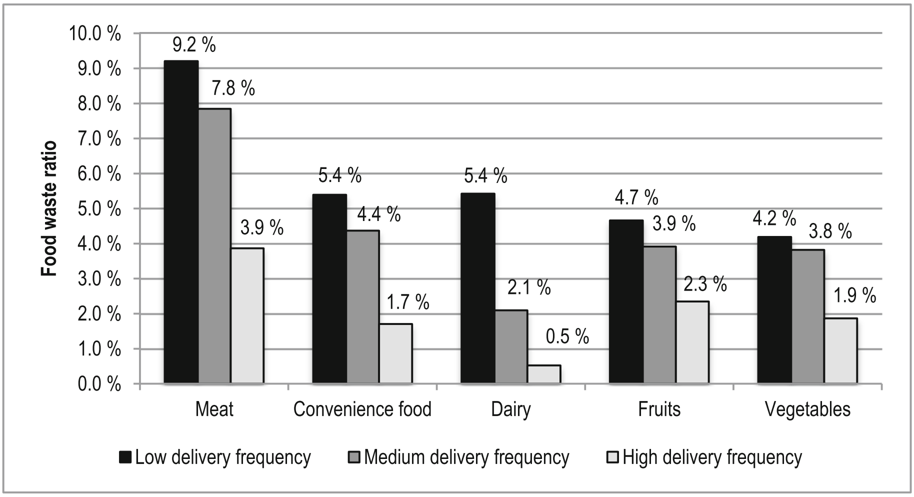

Fig. 1. Food waste ratios per product group in three delivery frequency scenarios

In summary, meat products, dairy products and convenience food strongly support the hypothesis. The fruits and vegetables product groups also support the hypothesis even though with a little lower correlation than the previous groups. These differences highlight the necessity of considering specific characteristics related to each product in order to analyse and explain food waste. The average coefficient of correlation including all product groups is −0.94 what is relatively strong correlation.

4.2 Food Waste Ratios Among Different Product Groups

In Fig. 2 food waste ratios are compared among different product groups within each delivery frequency scenario. Assuming that the hypothesis is valid in this case as well, meat, dairy and convenience food should have similar food waste ratios, and higher food waste ratios than fruits and vegetables. It should be valid in each delivery frequency scenario, since fruits and vegetables have always one or two deliveries more per week in each delivery scenario.

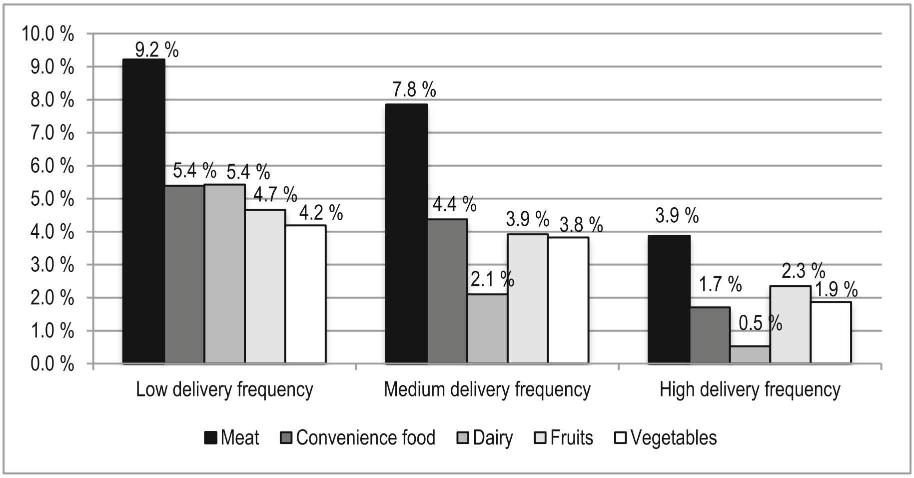

Fig. 2. Food waste ratios of selected product groups in three delivery frequency scenarios

Analysis of the data indicates that the hypothesis is only partially supported in this case and it seems the food waste ratios of each product group behave independently from other groups, in each delivery frequency scenario (see Fig. 2).

Meat seems to be the group that supports the hypothesis most in comparison to the remaining product groups. In each scenario, the meat group has the highest food waste ratios, even in comparison to fruits and vegetables. Comparing with dairy and convenience food which have the same delivery frequencies, food waste ratios of meat are much higher than those of dairy and convenience food across all three scenarios. Since the shelf life and temperature sensitiveness are similar for these three groups, there might be other reasons explaining the deviation, for example different demand and supply pattern, processes and settings in order management or different principles used to decide order quantities, safety stocks or minimum order size.

Convenience food also records a significant decrease in the food waste ratio by almost 65 % in high delivery frequency scenario compared to medium one. This decrease is so low that the food waste ratio of convenience food is below the ratio of fruits and vegetables groups even though they have one delivery per week more.

For *dairy products, as* the delivery frequency increases in the middle and high delivery frequency scenarios, the food waste ratio decreases significantly. The food waste ratio decreases by more than 60 % in the medium delivery frequency scenario with one more delivery per week in comparison to the low delivery frequency scenario. Moreover, the food waste almost disappears in high delivery frequency scenario.

The analysis indicates that dairy products are most sensitive to changes in delivery frequency among the other product groups what can be caused by its product characteristics or demand pattern. Another explanation of such a significant decrease in middle and high frequent stores could be explained by different planning and ordering processes among the stores used in the case study.

Fruits and *vegetables* decrease food waste ratios gradually as the delivery frequency increases. It is interesting to highlight that even though fruits and vegetables have always one or two deliveries more per week than dairy products or convenience food, their food waste ratios are quite similar or even lower than food waste ratios of fruits and vegetables, especially in high delivery scenario. This paradox again indicates that some products have different product or market characteristics, or different methods for handling the products which may significantly influence the food waste ratio. It is, therefore, suggested to always consider differences between product groups when performing this type of analysis.

Overall, the lowest variations in food waste ratios among the different product groups seems to be in low delivery frequency scenario while biggest variations can be observed in high delivery frequency scenario.

Furthermore, it is interesting to notice that the rate of decrease in the food waste ratios of fruits and vegetables groups across three delivery frequency scenarios seems to be similar to the meat group. And similarly, the rate of decrease in the food waste ratio of dairy group across three delivery frequency scenarios seems to be similar to convenience food. Both phenomena should be investigated deeper in further research.

5 Conclusion

This paper used a case study approach to investigate the linkage between delivery frequency and food waste in Norwegian food retail chain of chilled products. The findings of the first part of the data analysis show strong linkages between food waste ratios and delivery frequency for each product group separately. The average coefficient of correlation for all five product groups together is −0.94 what can be considered as very strong negative correlation, supporting the hypothesis – the higher the delivery frequency, the lower the food waste. Meat and convenience food product groups showed the highest correlation between delivery frequency and food waste. The second part of the data analysis revealed huge differences in food waste ratios across different product groups even though products had the same number of deliveries. In the medium and high delivery frequency scenarios, fruits and vegetables created more food waste compared to other product groups such as dairy or convenience food, even though they had more deliveries per week.

As a result of this, it is necessary to distinguish between product groups when analysing the linkages. One explanation could be that it is mainly because of the different product and market characteristics such as shelf life, temperature sensitiveness or demand pattern. However, the findings of the second analysis indicate that even the product groups with quite similar product and market characteristics, such as meat and dairy showed different food waste ratios while having the same number of deliveries. This indicates that various stores might be using different processes or principles other than delivery frequency which are specifically used for particular product group in particular store, e.g. batch sizes, package sizes, planograms, or hygiene and safety regulations. These assumptions should be considered and investigated deeper in the future research.

The main limitation of this study is a small sample size which restricts the generalization of the findings. In future research more stores should be added to the case study in order to increase validity of the findings.

The study contributes to theory by testing the hypothesis about the linkage between delivery frequency and food waste. It also discusses the differences between food waste ratios among different product groups within three delivery scenarios. Practitioners might use the findings of the study in order to understand how levels of food waste for the abovementioned product groups behave under various delivery frequency scenarios. Considering these findings they might better adjust their current processes and planning settings in order to minimise costs related to food waste.

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Comparison of Industry-Academia Partnership Projects for the Purpose of Product Development

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Abstract. The Japanese manufacturing industry has sought to increase its international competitiveness by developing higher value-added products. Simultaneously, R&D that exploits external resources – as typified by open innovation – is also taking hold.

Although collaborative product development research between public research institutions and private-sector companies is widely conducted, there are many instances when the results are not achieved due to differing perceptions of the partnership. Under such conditions, especially when the research is publically funded, methods for better managing the projects are being sought at the policy level. Using examples of publically funded industry-academia collaborative projects, this paper considers efficient management methods for projects aimed at such development.

The research focuses on changes to the collaborative research system used in partnership projects and shows that it is more effective to conduct collaborative research that incorporates other companies as needed, without fixating on the original make-up of the collaborative system at the start.

Keywords: Industry-Academia collaboration · Collaborative research system

1 Introduction

It has been shown that profitability among private companies in Japan's industrial sector is on a long-term, downward trend – even in the key industry of manufacturing. This is linked to the economy undergoing globalization as well as other major structural shifts on a worldwide scale, and the rapid rise of China and the rest of Asia exposing Japanese industry to greater competition. In order to address this situation and tap into the growth of the global economy, companies across the board are working to revamp manufacturing processes in their domestic and overseas plants and improve efficiency rates. Further, in recent years, as seen in Germany's national "Industry 4.0" strategy, greater use is being made of Information and Communications Technology to optimize domestic production sites. In addition, there are attempts underway to strengthen international competitiveness by shifting from the manufacturing of general-purpose goods to higher value-added products. This has created a need to focus on product

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development, which consists of pre-production processes such as concept development, design, and research, all critical in generating higher value-added products. Further, integrating R&D and manufacturing processes is an effective way of producing higher value-added products, which are characterized by innovative features and groundbreaking quality. Therefore, policy changes that relate to product development in manufacturing encompass the need for new investment in R&D. However, presently, R&D investment does not necessarily lead to increased company profits, thereby making the improvement of company profits through R&D an issue that needs to be addressed. As a result, in addition to the traditional approach to R&D where companies work individually on basic research through to the product development, a new approach that incorporates the concept of open innovation is being advocated. This enables companies to minimize investment risk by cleverly exploiting intellectual property, R&D know-how, and other technical skills possessed by other institutions, with a view to turning these into a commercial reality. The use of open innovation is being incorporated into manufacturing industries in Europe, the US, and across the rest of the world, and it is a concept that is becoming a common method of creating innovation [1–3]. Since translating basic research results into commercialization generally requires a large amount of time and money, conducting R&D in-house from the basic research stage entails a high level of investment risk. Therefore, importing technology from external institutions in the form of basic research results can be an effective way of reducing this risk. It is widely known that research institutions, such as universities, are knowledge hubs that conduct cutting-edge and creative research. It is for this reason that industry-academia partnerships involving collaboration between universities and private companies are seen as classic examples of open innovation [4–8]. In Japan, since 1983, when collaborative research between state-run universities and private-sector companies was institutionalized, the number of agreements has increased yearly, and the number of companies attempting to introduce ideas from public research institutions into their own product development is on the rise. A particularly rapid rise in collaborative research was seen after 1990, accompanied by steady increases in the budget to support public funding of such research. A similar trend in government policies promoting industry-academia partnerships has been seen not only in Japan but also across Europe and the US [9–11]. To date, there have been many case studies of effective approaches to managing industry-academia partnerships, which are considered important in raising the competitiveness of individual companies as well as strengthening the country's international competitiveness [12–17]. Some of these previous studies also relate to intellectual property [18] and look at funding for institutions involved in industry-academia partnerships.

Thus, while industry-academia partnerships are considered critical, they also present a challenge since the results of such partnerships often do not lead to the development of any specific products. Particularly in Japan, a major factor thought to cause this lack of success is the different perspectives of university researchers and researchers at private companies towards these joint research projects. This paper aims to demonstrate strategies for overcoming these challenges where such differences between researchers exist and effectively translating the results of joint research projects into product development.

2 Program Introduction

2.1 Program Overview

The program used for the analysis here is one of the industry-academia partnerships run by the Japan Science and Technology Agency (JST), which is one of Japan's funding agencies. JST handled this program from 2001 to 2010.

The system and structure of this program is largely characterized by three elements. First, it targets R&D projects that are expected to translate, within a few years, research results from universities and other public research institutions into either a commercial reality or product development premised on subsequent commercialization, with the aim to build a laboratory-level prototype by the time of completion. Second, it involves three entities collaborating in the research – universities, private companies, and JST – with the university-affiliated researcher taking the lead role in the project. Third, JST provides funding to the amount of approximately 30 million yen per year over approximately three years. In addition, the JST program officer (PO) managing the overall program participates in the funded projects as a third party, and provides advice, information and other support from the perspective of commercial feasibility to efficiently advance the research. In some cases, it may be possible to change the collaborative research structure of the project, if deemed appropriate by the PO (Fig. 1).

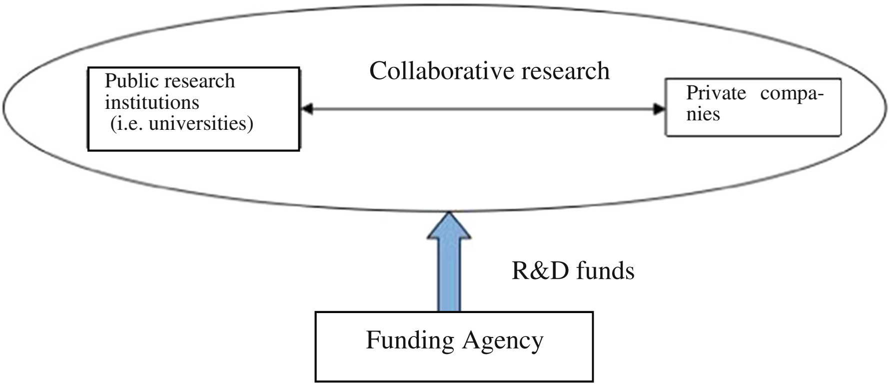

Fig. 1. Support system for collaborative research

2.2 Ex-ante Evaluation

The ex-ante evaluation is conducted by a technology evaluation committee made up of eight external experts, based on the following three indicators: (1) novelty and superiority of the project, meaning the technological content of the research project is innovative and has a high level of superiority compared with other technology; (2) the usefulness of the results in terms of marketability and envisaged for potential commercialization; (3) appropriate research plans with a view to commercialization. Specifically, precise research plans aimed at practical applications are designed for a funding period of approximately three years. They are evaluated from the perspective of whether they have a high potential to succeed, whether the participating companies possess the technical skills required to advance the project and have clear roles, and the companies are suitable for yielding practical applications from the results. The adoption rates vary from year to year, but the trend is between 14 % and 18 %.

2.3 Ex-post Evaluation

The ex-post evaluation is conducted after the end of the funded period, again by a technology evaluation committee of eight external experts. The success achieved by each project is classified according to the following five indicators: (1) corporatization (including those still in preparation); (2) ongoing product development within a company; (3) venture establishment; (4) ongoing operation and the acquiring of other competitive funds; and, (5) ongoing collaborative research with a focus on universities, etc. The research project results are then evaluated based on project reports and comments received, examining, for example, the extent to which the plan was implemented, expected commercial viability, and acquisition of intellectual property rights.

3 Method of Analysis

3.1 Projects Investigated

The projects analyzed in this study are concluded projects that received funding between 2001 and 2004 (with collaborative research agreements from 2004 to 2007). According to project guidelines, there is no limit to the number of companies that can participate in each collaborative research project. Therefore, there are projects with a varied number of participating companies, from projects with only one to projects with multiple ones. Further, in some instances, the collaborative research systems adapt and change during the project, with other private companies joining the project or new companies being swapped in. Thus, as a method of expanding R&D results, with an eye to effective practical application, this study analyzes the relationship between collaborative research systems and actual project achievements.

3.2 Method of Analysis

The analysis matches the status of each project, following the conclusion of funding, to the steps of a general linear R&D model: applied research, product development, and commercialization. Further, it assigns point values to each step of the linear model to conduct a quantitative evaluation. The specific point values are as follows: 0 points for applied research as the initial value; 1 point for product development, which is considered one step up; and 2 points for commercialization, which is considered two steps up.

Meanwhile, although the status of each funded project immediately after conclusion differed, these were classified according to the following five shared indicators to demonstrate their status in greater detail: (1) corporatization (including those still in preparation); (2) ongoing product development within a company; (3) venture establishment;

(4) ongoing operation and acquiring other competitive funds; and, (5) ongoing collaborative research with a focus on universities, etc.

The study associated the steps and the status of each project, shown above, and quantified the performance of the projects (Fig. 2).

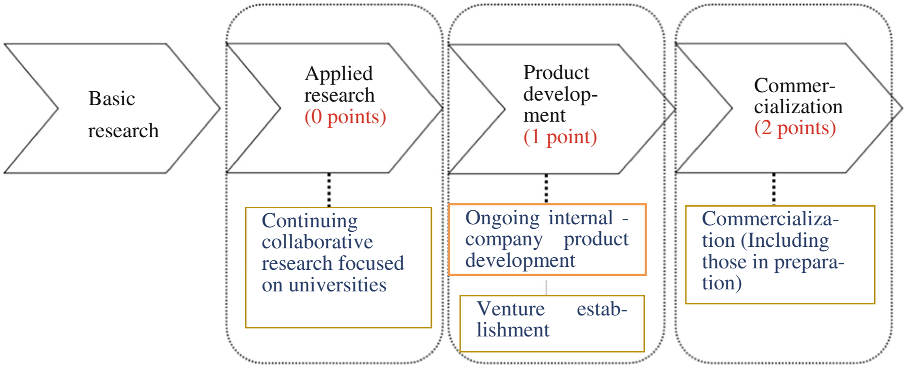

Fig. 2. Project status correlation diagram

4 Results

4.1 Results by Project Structure

Projects were separated into two groups: one group of projects that did not change their collaborative research systems by the time their support had ended and another group of projects that did change their systems. An average point value based on this status was calculated (Table 1). Furthermore, projects were compared based on the following

Table 1. Points by project structure

	Average point by project structure	Collaborative research system at the start of support	
		Project group with one company participating in collaborative research (a)	Project group with two or more companies participating in collaborative research (b)
Group with no changes to collaborative research systems (A)	0.84 (62, 0.54, 0.30)	0.76 (37, 0.54, 0.29)	0.96 (25, 0.53, 0.28)
Group with changes to collaborative research systems (B)	1.37 (19, 0.48, 0.23)	1.29 (7, 0.45, 0.20)	1.42 (12, 0.49, 0.24)

Inside each cell, the top row shows the average points by project structure and the bottom row shows the sample size, standard deviation, and variance.

grouping: projects that had only one company participating at the start of funding and projects that had two or more companies participating at the start of funding.

The analysis was established with two factors: changes or lack thereof to project structure (Factor 1), and whether or not only one company was participating at the start of the support (Factor 2). Accordingly, although the main findings are similar for Factor 1 and Factor 2, performing a two-factor analysis of variance guarantees that there is no interaction (Table 2).

Table 2. Analysis of variance table

Factor	Sum of squares	Degrees of freedom	Mean square	F	Notes
Factor 1	4.13	1	4.13	14.58	$p < 0.005$
Factor 2	1.43	1	1.43	5.06	$p < 0.05$
Interaction	0.00	1	0.00	0.00	
Residual	22.12	78	0.28	–	
Overall	27.68	81	–	–	

4.2 Effects of Restructuring Collaborative Research Project Systems

In order to confirm the effects of changing collaborative research systems and bringing in companies from outside the projects, we compared projects that did not change their collaborative research systems to projects that did change their systems. From those results, the high numbers in the group that changed collaborative research systems revealed this as an effective method to create successful outcomes during the timeframe analyzed (i.e., finding new companies and incorporating them into the collaborative research systems).

5 Case Study

For our analysis, we examined a case study of a project that began as an industry-academia partnership, with a single development company, but went on to add another company later in the funding period to help advance to the product commercialization stage. The aim of this project was to develop a general-purpose device capable of nanofabrication. However, since the initially participating company produced special-specification devices to order, it did not have the capacity to expand its production and business operations to develop general-purpose products. This weakness in the collaborative research structure was identified at the start of the funding period. Two years into the project, with verification results at the prototype level positive, the PO and lead researcher reconfirmed the strategy for capitalizing on future results and began to search for another private company to participate. The lead researcher approached a company that had been involved in collaborative research as part of a separate project and had sufficient technology and business-related capacity for the needs of this project. The company evaluated the project's current research results and investigated whether or not its business strategy was compatible with the project. Based on a positive assessment, it decided to participate. This enabled the project to move forward towards its aim, which was to commercialize a general-purpose device capable of nanofabrication. For the original company, another company with a different business structure joining the project was a good opportunity to build collaborative relations with the new company. Specifically, the development company was tasked with the core parts for the general-purpose device under development.

6 Conclusion

For projects that did not change their collaborative research systems during the research process (i.e. add new companies or change the companies involved), having multiple companies participate at the start, (identifying practical applications within the technological scope of each company), was more effective than having a collaborative research system with only one company participating. Moreover, collaborative research systems that did change were highly effective from a product development standpoint, irrespective of the number of companies participating in the project at the start. One primary cause of this is that as R&D progresses, the societal value of the potential results becomes clearer, which then clarifies which private companies should actually carry out the product development. This is not necessarily a disadvantage for the private companies already participating but rather could be considered favorable for future business, as technology can be licensed to other companies that may participate, bringing in profit from licensing and the transfer of intellectual property.

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The Role of Additive Manufacturing in Value Chain Reconfigurations and Sustainability

The Role of Additive Manufacturing in Improving Resource Efficiency and Sustainability

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Abstract. Additive manufacturing is heralded as a revolutionary process technology. While it has yet to cause a dramatic transformation of the manufacturing system, there are early signs of how the characteristics of this novel production process can improve resource efficiency and other sustainability aspects. In this paper, we draw on examples from a wide range of products and industries to understand the role of additive manufacturing in sustainable industrial systems. We identify four main areas in which the adoption of additive manufacturing is leading to improved resource efficiency: (1) product and process design; (2) material input processing; (3) make-to-order product and component manufacturing; and (4) closing the loop.

Keywords: Additive manufacturing · 3D printing · Sustainability

1 Introduction

Advanced manufacturing technologies are leading companies to rethink where and how they manufacture products. Adopting these technologies heralds a future in which value chains are shorter, smaller, more localised and more collaborative, and offers significant sustainability benefits [1]. Such value chain reconfigurations for sustainability will require a better understanding of the relationships and interactions between stakeholders along the product and material life cycles [2] (Fig. 1).

Additive manufacturing (AM) is one of these advanced manufacturing technologies. To date AM and sustainable industrial systems (SIS) have been viewed from different perspectives. In this paper we explore these two topics through a single lens to better understand the implications of AM on the sustainability of industrial systems. More specifically, we address the following question: How can the adoption of additive manufacturing improve the resource efficiency of industrial systems? First we review the characteristics of AM and prior work at the intersection of AM and sustainability. Then we provide examples that led to resource efficiency and other sustainability benefits. These benefits include allowing companies to redesign and simplify components, products and processes for dematerialisation; be more material, energy and cost efficient in various life cycle stages; customise products according to customer preferences; extend product life through repair and remanufacturing; move towards service-based business

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models; decouple social and economic value creation from environmental impact; and embrace circular economy concepts.

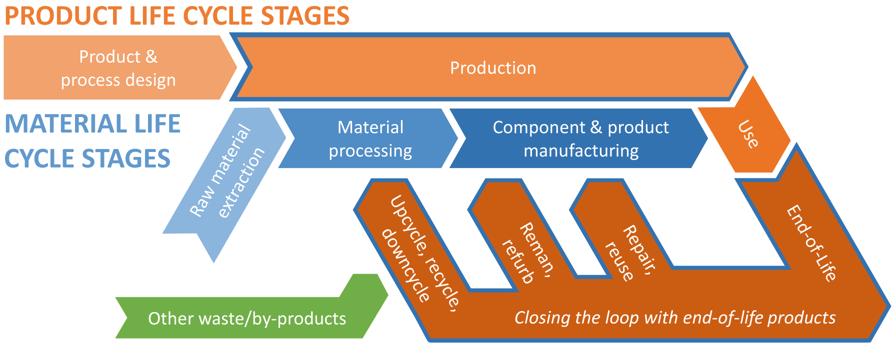

Fig. 1. Product and material life cycle stages

2 Additive Manufacturing

AM, also known as 3D printing, allows objects to be fabricated layer by layer, enabling three dimensional objects to be 'printed' on demand [3]. It is gradually being adopted as a direct manufacturing approach in sectors such as aerospace, motorsports, toys, jewellery, along with a number of medical applications where personalisation is key (e.g. hearing aids, orthodontics, prosthetics, implants). These are at various stages of maturity and adoption, and new applications continue to be found as the technology performance improves.

A number of advantages arising from the adoption of AM have been identified [3–5]. These advantages include the digital nature of the fabrication process. Direct production from 3D CAD models means that no tools and moulds are required, and small batch sizes are more economically attractive relative to traditional manufacturing methods because there are no switch-over costs. Furthermore, these digital files can be easily shared and modified on a distributed basis. Designers also have greater freedoms to create novel structures with AM due to the layer-by-layer deposition of material. The additive nature of the process meaning that less waste material is created and this provides cost savings on material inputs. Direct interaction between the producer and consumers becomes more important through the customisation process. Finally producing goods on demand through AM also reduces inventories and the risks associated with oversupply and obsolescence.

3 Links Between Additive Manufacturing and Sustainability

As adopting AM technologies will radically transform manufacturing systems, policy makers have begun to consider how they can best support their development and implementation. In the UK, the Additive Manufacturing Special Interest Group of the Materials Knowledge Transfer Network identified a number of potential contributions that AM could make to support future needs in sustainable, high value manufacturing. These included improvements to resource efficiency, more efficient manufacturing systems, integrating new materials, implementing new manufacturing processes, and adopting new business models [6].

Life cycle analyses have shown that the adoption of AM could have significant savings in the production and use phases of a product. Estimates for 2025 are in the ranges of $113–370 billion and $56–219 billion respectively in each of these phases. The savings in the production phase stems from reduced material inputs and handling, along with shorter supply chains. In the use phase, lightweight components enable energy consumption to be reduced [1].

3.1 Examples

There is a growing number of component and product redesign examples [7]. In this section we provide examples in which AM has delivered sustainability benefits at various stages of the product and material life cycles. These are summarised in Table 1.

Table 1. Identified benefits in various life cycle stages for the examples provided

	Product & process design	Material processing	Manufacturing	Use & service	Repair & reman	Recycling
GE	✓		✓	✓		
Metalysis		✓				
Bewell Watches		✓	✓			✓
Salcomp	✓		✓			
Home 3D printers	✓		✓	✓		✓
3D Hubs	✓		✓	✓		✓
Rolls-Royce			✓		✓	
PPP		✓	✓			✓
Filabot		✓				✓
EKOCYCLE Cube	✓	✓	✓	✓		✓

Product Redesign. Through its collaboration and subsequent acquisition of Morris Technologies, General Electric (GE) developed capabilities in AM. These capabilities have been implemented in the redesign of a fuel nozzle for the LEAP engine that enters production in 2016. The new fuel nozzle is five times stronger to aid its durability. Its design provides the best fuel flow geometry to improve combustion efficiency. GE reduced the nozzle's weight by 25 % through using cobalt chrome and simplifying the design from 20 separate components to a single component [8].

Raw Material Processing. Significant energy is consumed during the refining and processing of metal ores in preparation for manufacturing. The UK-based firm Metalysis has commercialised a process for producing titanium powder directly from titanium ore.

This new process requires significantly less energy to produce the titanium powder than the established process [9]. Furthermore, the process uses a non-toxic reactant, calcium chloride (CaCl), during refinement and any leftover CaCl can be reused.

Conversion of By-Product into Product. Wood flour and dust are by-products of timber and wood processing. They have traditionally been discarded but have found application in several markets. It is most commonly used as a filler in thermosetting resins, along with wood-plastic composites and building products. Recently, these by-products have been combined with binding agents to create a wood filament that can be used in AM equipment. One company that has taken advantage of this new material input is Bewell Watches, which produces customised wood watches.

Production Process Redesign. To improve the efficiency of power supply casing production, Salcomp aimed to reduce the cooling time in its injection moulding process. Using AM technology, engineers were able to redesign the vent structure of the moulds to dissipate heat more quickly. As a result, cooling time was reduced from 14 to 8 s, enabling increased production. A secondary benefit was improved quality, with rejection rates reduced from 2.0 % to 1.4 % [10].

Manufacturing System Reconfiguration. The adoption of consumer 3D printers such as the Makerbot Replicator, Ultimaker and Cube are leading to a more distributed and localised manufacturing system. The user becomes both producer and consumer, a prosumer. Individuals with 3D printers are able to design and manufacture the products they require, on-demand and to their own specifications. Logistics are still required for raw material flows but the need for the transport of final products and product inventories is removed. Furthermore, manufacturing locally in the home also makes it possible to create in situ recycling systems for products made from 3D printed materials.

Networks such as 3D Hubs provide an online platform that links owners of 3D printers with customers. The owners are typically prosumers who have spare printing capacity and want to increase utilisation. This provides access to local manufacturing. It delivers the same benefits as described above but without the customers needing to own and operate their own equipment. The number of hubs in the network is rapidly growing. At the time of writing, there are 14,300 3D printers accessible within the 3D Hubs network.

Manufacturing and Remanufacturing for Maintenance. The production of the bladed disks (‘blisks’) used in aero engines has a high environmental impact, with significant material waste. Material input to final component ratios of 4:1 are common using traditional 5-axis milling processes, with some components having a ratio as high as 20:1. In the EU FP7 MERLIN project, Rolls-Royce, Turbomeca, MTU, and Fraunhofer ILT collaborated to address this environmental impact. Early demonstrators showed that AM can be used to manufacture and maintain the blisks and reduce waste with ~60 % material savings and ~30 % time savings [11]. AM can also be used for the in situ repair of damaged blisks and thereby extend their operational life.

End-of-Life Product Recycling. The Perpetual Plastic Project (PPP) investigated how plastic waste could be used as an input for 3D printing. The materials tested are used in everyday products such as cups, bottles, caps and carrier bags; i.e. polylactic acid (PLA), polystyrene (PS), low density polyethylene (LDPE), polyamide (PA) and polypropylene (PP). The project demonstrated the feasibility and relative ease of plastic recycling for 3D printing applications, some more successfully than others.

The bio-polymer PLA can provide a wide range of material properties and thus substitute for different plastics. Through the greater use of PLA and less diversity in the range of plastics consumed, simpler recycling systems may be realised. For example, the Filabot reclaimer grinds plastic goods into granules, which are fed into a Filabot machine to create new 3D printing filament. In addition, PLA has the ability to be recycled with no quality loss when treated by specialised companies (e.g. Plaxica). It can be fed back into the same system and thus enable a closed-loop circulation of material.

Another example is the EKOCYCLE Cube. It uses recycled polyethylene terephtalate (rPET) in its cartridges with 25 % recycled PET content. Higher recycled content is possible but limited by aesthetic requirements. The EKOCYCLE Cube is branded as a lifestyle product that enables creativity in the design and realisation of fashion and music accessories.

3.2 Barriers and Opportunities

In this section we discuss the potential benefits of AM to improve the sustainability of products, processes, manufacturing systems and personal lifestyles. We use the different stages shown in Fig. 1 as a guiding structure for the discussion.

Product and Process Design. Traditional manufacturing techniques can be wasteful as they are subtractive. Nature follows an additive process that is more efficient. Components and product assemblies designed for AM mimic nature in the way they are built up. As shown in the GE example, they have fewer parts and more optimised geometries, often unachievable using other manufacturing techniques. Harnessing this freedom in shape and geometry in the design stage achieves novel, more complex (or simpler) structures, including free-form enclosed shapes, channels and lattices.

Just as product design can be improved, so can production process design. As demonstrated by Salcomp, the production process can become more resource efficient by incorporating AM-produced components (e.g. moulds, tooling). This is achieved through a combination of lower energy consumption, and higher quality to reduce rejection rates during the production stage.

In other stages of the product life cycle, AM can improve resource efficiency in manufacturing, improve operational efficiency, functionality and durability in use, and enable reuse, repair and recycling at the end-of-life. Overall, it leads to the decoupling of the total value delivered per unit of resource consumed, as illustrated with the Rolls-Royce blisks.

Current barriers to the adoption of AM include how the technology is perceived by designers and the performance limitations of the technology. The first of these barriers stems from the perception held by engineers and designers that AM is only for rapid prototyping and not fit for direct component and product manufacture. Changing the way that designers think about AM is a challenge. Without a mindset shift, the full benefits of AM won't be harnessed in the design stage. The second barrier arises from the performance of AM technologies. Current technologies can only produce novel forms; they cannot embed functionality such as microelectronics into components and products. It is likely that a second mindset shift within the design community will be required when AM technologies become more advanced and this functionality can be embedded during the manufacturing process.

Material Input Processing. As the example of Metalysis showed, there is potential to rethink how raw materials are processed to minimise the resources needed to bring them into a usable form as inputs for AM. However, few materials can currently be produced using these novel processing technologies. The processes are immature and the input materials for AM have yet to be standardised. To identify the most resource efficient standards and enable this standardisation to be achieved, further research is required to explore and validate the mechanical and thermal properties of AM technologies and materials.

Regarding the conversion of by-products into products, AM can enable the direct reuse of by-products, such as waste in granulated or powder form, as a material input for production, e.g. Bewell Watches. Using waste as an input to produce personalised products is commonly known as waste upcycling and is advocated by the cradle-to-cradle community [12]. However, limitations on the material quality and purity could prevent these products from being recycled when they reach their end-of-life. This is the case with current wood-polymer composites as the technology for material separation and thus recycling does not exist yet.

Make-to-Order Component and Product Manufacturing. AM allows products to be manufactured on demand. This make-to-order model can help eliminate or at least minimise inventory waste, reduce inventory risk with no unsold finished goods, while also improving revenue flow as goods are paid for prior to being manufactured. It allows direct interaction between local consumers and producers, collaborative learning, and user innovation [13]. However, non-linear, localised collaboration between actors with ill-defined roles and responsibilities can result in conflicts and incompatibilities.

Looking at the overall manufacturing system configuration, AM enables a shift from traditional mass production methods and economies of scale to small batch production of customised goods at more affordable prices. Moreover, AM can lead to the reconfiguration of the supply chain as fewer components within product assemblies means that fewer actors, stages and interactions may be needed within it, along with a potential reduction in the environmental impacts of logistics.

As previously described in Product and Process Design section, the additive nature of AM means that less waste is generated during the production process. While AM can be more energy intensive per unit produced (relative performance), it allows units to be produced to exactly match the demand (make-to-order) and thus reduces the overall amount of resources consumed (absolute performance). In other words, AM can enable dematerialisation and lower energy intensity across the whole system.

Furthermore, automation is needed if AM is to become more resource efficient. For instance, automated post-processing is needed to achieve desired aesthetic finishes and to eliminate the 'stair stepping' effect arising from the incremental layer-by-layer build-up of material.

Closing the Loop. During repair, maintenance and remanufacturing, a make-to-order model can be applied to minimise inventory waste as spare parts can be produced locally only when needed, with lower energy intensity processes. This is even more the case with modular and upgradable components. Products can be maintained in situ using AM repair technology, thereby maximising their use and extending their lifespan.

In addition, the availability of AM technologies for repair creates incentives for companies to adopt service-based business models. Such business models have proven highly profitability for companies in the aerospace sector where providing maintenance services allows the manufacturer to satisfy its customers' needs for a high level of flight utilisation.

The AM process has the potential to increase the recovery of value embedded in waste. At the product end-of-life stage, in situ recycling systems can be linked to AM, diverting material from waste streams into new applications. Closing the loop through recycling can be achieved at various stages and scales in AM. The highest value recovery possible is achieved locally during the manufacturing process when the unused AM material is reclaimed.

Initiatives such as PPP help raise awareness and educate the public about small-scale plastic waste recycling and AM. As AM technology and 3D printed products becoming more attractive, companies are attempting to harness this 'coolness' and enhance their brand identity. This can be seen in approaches such as the EKOCYCLE brand, where an attempt is being made to make recycling more fashionable, overcoming traditional negative perceptions of recycled materials being of lower quality than virgin ones, in particular for certain plastics.

4 Conclusions

While AM has yet to dramatically transform industrial systems, there are early signs of how the characteristics of this advanced production process will lead to advances in industrial sustainability. In this paper we have explored the opportunities in the product life cycle for sustainability improvements through the implementation of AM technologies, providing illustrations from practice of the ways in which such improvements are being made.

There are numerous cases of product redesign arising from the application of AM. While the majority of these remain demonstrations that have not entered actual production, high profile examples of AM-based redesign such as the General Electric LEAP engine are bringing about real change and altering industry perceptions of the potential application of AM.

As an emerging technology and industry, there remains significant scope for further adoption and sustainability benefits to be realised. Currently the technology is being adopted by user innovators and early adopters and it is far from becoming mainstream practice. While we have provided examples from other phases of the product lifecycle, the number of documented cases is more sparse across these phases. AM can create new business opportunities for reuse, repair, refurbishment and remanufacturing but companies are only just beginning to discover that AM can extend product life cycles and close the loop. This may be best exploited through the adoption of service-based business models and can result in the decoupling of the environmental impacts from the social and economic value created thereby increasing the companies' sustainability performance.

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The Role of Additive Manufacturing in the B2C Value Chain: Challenges, Opportunities and Models

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Abstract. Additive manufacturing is shifting business models towards mass customisation and responsible production paradigms. Such a technology is fostering re-localisation and value-added approaches in order to increase customer involvement into a more flexible and sustainable production process. This paper provides both theoretical tools and case studies to frame the additive manufacturing realm and the distributed fabrication background.

Keywords: Additive manufacturing · Value chain · Business model · Sustainability · Glocalization · Distributed manufacturing · Co-production

1 Introduction

During the last 20 years, the manufacturing world has been undergoing some disruptive innovations that have changed the way production is conceived. A shift toward its intangible side has been driven by both digitalisation and servitisation. Overcoming the traditional distinction between labour and capital-intensiveness, many businesses can be termed as data-intensive, since several steps along their value chain rely on ICT and digitalised resources in order to provide better responsiveness and cost-effectiveness.

To face with the more stringent market requirements, traditional production approaches based on make-to-order transactional strategies have to cope with mass-production principles and an intimate relationship with the customer. This means managing small and diversified batches [1] and giving rise to a "make-to-individual" relational-based paradigm with an increase of management complexity and, therefore, a potential upsurge of production and service provision costs and risks. Service-driven processes, such as design, support and maintenance, are now crucial to the customer, and can ensure a competitive advantage for enterprises, regardless of their dimension.

The combination of these trends is pushing companies to rethink their value creation mechanisms by changing from a global to a local perspective – from a standardization to a customization approach – and therefore becoming a "good and reliable neighbor" for the final customer [2]. A *glocal* strategy is supposed to find the right balance between a global approach (typically related to efficiency) and a local perspective (related to responsiveness) [3].

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Firms with global brands and technologies are now considering to meet local customisation needs and to endorse nearby resources and expertise. They shift "from primary producers and distributors to aggregators" [4] to coordinate a network of trade and commerce across the value chain, playing the role of logistic orchestrators, decentralising their operations and digitalizing their structures. While raw materials and data flow into a global network, skills and production sites can be managed by proximity, thereby reducing the complexity typically related to the scale [5]. Factories have to be conceived as modular, easily reconfigurable, adaptive and evolving, capable of small scale production to create new customized products and services, environmental friendly and able to respond to the continuous change of the market [6].

To tackle all these challenges and maintain the competitive leadership in different markets, technology can play an important enabling and boosting role in developing value by providing innovative ideas to be turned into new customer-oriented production systems allowing also to balance uncertainty along the supply chain [7].

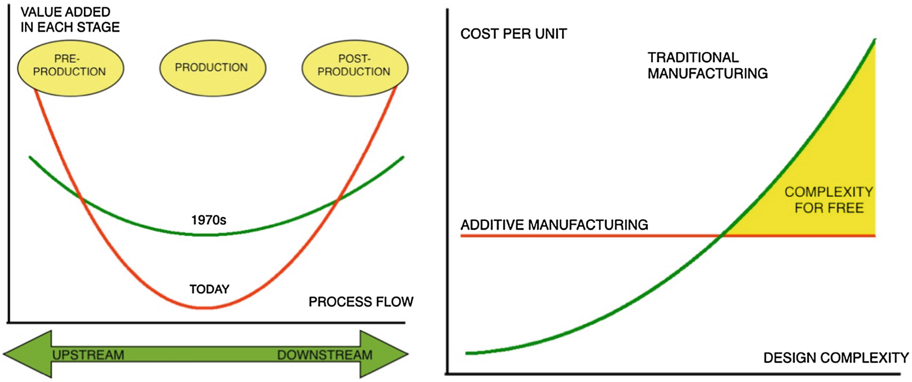
In such a context, this paper addresses specifically the role of Additive Manufacturing (AM) as a key enabling technology for the dynamic reconfiguration of "customer-oriented value" constellations of manufacturing companies and solution providers, capable to operate at multiple locations in proximity with the customer. Through the description of relevant case studies, the paper provides a descriptive framework, which identifies different structures of value chains according to the combination and consistency of strategic, managerial and operational dimensions.

2 Value Chain Reconfiguration: The Case of Additive Manufacturing

To properly drive the manufacturing change, firms should consider what is more valuable for their customers and partners. Cost-cutting is no longer the main concern in creating value. Moreover, digitalisation is changing the rules of the game such that it soon may allow customisation with negligible costs [8]. The Shih's "Smile Curve" [9] (Fig. 1a) helps in understanding the shift of the contribution to the added value coming from different value-chain stages: while in the past, pre-production (R&D, design, subcontracting) and post-production (logistics, marketing, aftersales) stages were slightly more important than production (manufacturing, assembly) itself, nowadays upstream and downstream stages are becoming crucial to the value chain. Co-designing the product with the customer or providing availability contracts and maintenance can really generate the willingness to pay for a premium price.

To build such commendable value chains, enabling technologies are required, like for instance Additive Manufacturing. AM, often referred to as 3D-printing, is a manufacturing process operating through deposition of material layer by layer onto a substrate; such a process enables the creation of complex structures starting from a 3-D CAD model, without the additional costs that traditional subtractive technologies usually require (Fig. 1b). More importantly, design complexity is often correlated to flexibility, customisation and energy efficiency.

An AM-based process can use different materials and deposition techniques, and is particularly suitable for small series and personalised products manufacturing, spare parts and prototyping. The latter was noticeably the first application of such technology dating back in the 1980s, when AM was still named “Rapid Prototyping”. Today, AM is widely used in aerospace, defense, automotive, healthcare, consumer products and retail.



(a) The Value Chain Smile Curve (b) Cost of design complexity

Fig. 1. (a) The value chain smile curve. (b) Cost of design complexity

Since with AM labour is no longer a critical source, the advantage of locating production in countries where its cost is lower will be eroded soon, fostering re-localisation and customer proximity. Moreover, since products could travel along the value chain mostly as digitally stored data, thereby tearing down the wall between production and delivery, the sustainability trait of AM (summarised in Table 1) is starting to threaten traditional subtractive techniques.

Table 1. Sustainability traits of additive manufacturing

Economic sustainability	Social sustainability	Environmental sustainability
Flexibility	Democratization	Waste reduction
Lower time to market	Local expertise endorsement	Energy efficiency
Complexity for free	Regional availability	Customer proximity
Lower production costs	Customer involvement	Digital movement

3 Additive Manufacturing-Driven Value Networks

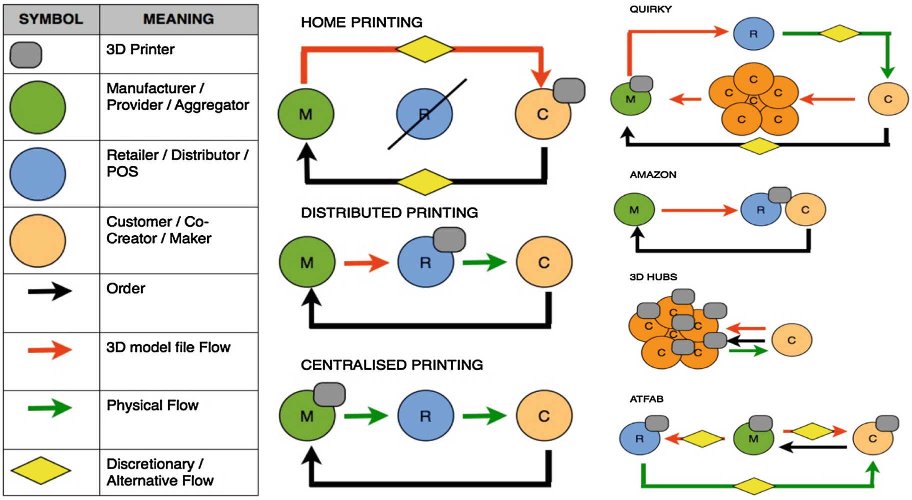
In order to ensure a successful implementation of AM, proper configurations of value networks must be identified. In this section, three Business-to-Consumer scenarios are presented: Home, Distributed and Centralised Printing. The following models, represented in Fig. 2, are drawn and adapted from previous literature [10–12] without any claim to completeness.

In the *Home Printing Scenario*, the customer sends a request to a service provider that supplies her with a 3D-printable CAD model. Alternatively, in the "Maker" case, the customer is also a designer and does not need the service provision of a third party to print her creations. This scenario is unlikely to scale up in the short term, since makers and enthusiasts are just a small niche of the market. According to many scholars, the "Desktop Manufacturing" requires design skills that normal customers are unwilling to develop or unlikely to learn.

In the *Distributed Printing Scenario*, the customer sends the products specifications to an aggregation platform that outsources local 3D printing retailers (typically, but not necessarily, the printer owners) who can ship the finished product to the customers after printing it. This model can be declined in many ways and relevant cases are further discussed.

In the *Centralised Printing Scenario*, the printing stage is "behind the scenes" and does not affect the configuration of the logistic chain, since the impact is solely on the production process. In this model, the environmental concern trait is weakened, thus making it unlikely to be adopted in re-localisation contexts.

It is not in the purpose of the paper to show exhaustively the differences between the aforementioned models, but instead providing real cases for the Distributed Printing Scenario, where AM is the major (but not the only) enabler for a decentralised fabrication paradigm. Four noteworthy models are presented below and summarised in Fig. 2c.



(a) Legend (b) Scenarios (c) Case studies

Fig. 2. (a) Legend. (b) Scenarios. (c) Case studies

3.1 Crowdsourcing and Collaborative Platforms: Quirky

With the rise of the digitalisation and social networks, end users have started to go beyond the consumption status and become more and more involved in the production world. More specifically, innovation is now within the range of everyone thanks to the so-called crowdsourcing platforms. The name stresses both participation and engagement that people can show in new product and service development, simply by submitting ideas, evaluating proposals and finding suppliers and partners for something, which is not yet in the state of the art [13]. Even larger businesses are turning to crowdsourcing instead of relying on internal R&D [14]. With Quirky [15] for instance, anyone can be a designer and submit her idea, which is evaluated and even improved by the community and, if successful, manufactured by internal experts and sold in retailing shops. Needless to say, the manufacturing stage can be performed by AM machines that disclose complex designs and allow performance-based continuous adjustment – based on community feedbacks – at low costs. Note that Quirky manages all the product supply chain and IPR, which is no longer in the hands of the creator as soon as she decides to submit her idea.

3.2 En Route Fabrication and Localised Manufacturing: Amazon 3D-Printing Trucks

As mentioned before, AM makes the discrimination between production, delivery and consumption quite subtle and fuzzy, and new localised manufacturing models are arising in the light of cost-effectiveness. While UPS is expanding its 3D printing in-store services in collaboration with Stratasys [16], a world-class leader in the AM realm, Amazon is thinking outside the box [17]. As a matter of fact, the company has recently filed a patent application about a business model where the printing stage is performed in travelling trucks. The customer submits the order and the nearest truck starts its route, producing the goods *en route*. This model can be purposeful for B2B contexts too, where spare parts availability is a major concern. Thanks to this configuration, where the glocal trait is undeniable, trucks will soon carry solely raw materials on board and become fabrication “movable” points with both additive and subtractive technologies equipment. The intrinsic risk of such a patent is the robustness of the production process. Interesting enough, while the world of manufacturing is experiencing servitisation, the world of retailing is approaching what can be defined “productisation”: AM technology turns out to be so disruptive that two previously sequential steps are now becoming overlapped.

3.3 Sharing Economy and Community Crafting: 3D Hubs

Recently the tags “B2B” and “B2C” have become unsatisfactory in labelling business models comprehensively: as a matter of fact, a new paradigm defined “C2C” (i.e. Customer to Customer), often referred as to peer-to-peer or sharing economy, has changed the business rules [18]. Completely compliant with the servitisation trend and “post-scarcity” economy, customers are no longer interested in owning an asset, but rather in using it for a certain amount of time by paying a predetermined fee. A noteworthy example is 3D Hubs [19], a community made of printer-owners and users who meet both physically and in a virtual marketplace. The customer orders a product or uploads her design through a marketplace and chooses the closest printer owner – typically within 10 km – willing to provide the service. 3D hubs then charge the user with a 15 % commission on the final price set by the service provider, who can even be a user of the marketplace at the same time. According to [19], the hub is now made of more than fourteen thousand peers worldwide with a 3D printer. 3D Hubs does not only provide an on-demand customisable service, but also creates a community of enthusiasts and curious gravitating towards AM with a sustainable incentive mechanism: the users are willing to explore new design solutions at accessible prices, while the printer-owners are keen on shrinking the idle time of their equipment through its rental. The underlying issues are firstly preventing users to bypass the platform once they know each other to avoid the commission and secondly managing complaints.

3.4 Co-configuration and Adaptive Factories: AtFab

Another major trend driving the manufacturing revolution is the Open Source approach, where producers give away their IP to customers and encourage them to experiment or suggest improvements, thereby spurring a bottom-up empowerment. The customers take part to the configuration of a product by either producing it directly, deciding where and how it should be manufactured or just even editing a design provided by the supplier and outsourcing its production. The end user is no longer a mere co-designer but a co-configurator [20] arranging not just the product itself, but its production process, sourcing, delivery and reuse (disassembly). The case of AtFab [21], a design firm co-founded by two architects, is noteworthy in this regard, given its higher degree of adaptation with respect to customer needs. The customer is free to choose whether to edit online models and print them on her own, to choose the nearest fabrication point to make that for her, or even to order a finished product directly from the marketplace. Although AtFab is linked to subtractive manufacturing techniques, the CNC routers and milling machines are completely consistent with the supply chain digitalisation and disintermediation that AM is driving. The social challenges of such mechanism are finding designers/negotiators willing to give away their expertise and IP and ensuring that local fabrication centres are quality-compliant.

4 A Descriptive Framework

The previous cases can be framed into a comprehensive matrix, reported in Fig. 3. On the bottom x-axis we discern between product- and solution-based approaches, while on the top x-axis a Wortmann-based taxonomy is proposed. On the left-hand y-axis we distinguish two different settings: one where there is a focal company delegating production to local factories, and the other where there is a peer-to-peer constellation of firms, based on sharing economy or feedbacks collection. On the right-hand y-axis we differentiate a customer-oriented (one to one) from a community oriented (many to many) outcome. Note that risk sharing increases going through the x-axis, running parallel to the degree of intangibility in the value proposition and to the customer commitment required. Going down instead along the y-axis, a manufacturing democratisation trait emerges, as well as a bottom-up engagement.

The proposed matrix pinpoints four archetypes and their issues; it serves as a sense-making tool to structure and characterize the state of the art and to establish recurring principles, triggering factors and primary concerns. It provides clarity and can even guide implementation of pertaining initiatives and research.

- The *Localised Manufacturing* context, enabled by timely technology supported by end-to-end marketplaces, offers to customers real-time order traceability and high performances on the delivery, but requires a robust logistic optimisation.
- The *Adaptive Factory* is grounded on an open source mind-set and provides demanding customers with an extreme flexibility along the product life cycle, but requires suppliers who are willing to take part of a discretionary - or even opportunistic – relationship.
- In the *Community Crafting* circumstance, the “value proposition” is the recreational aspect of the transaction. Still, sharing economies and disintermediation initiatives encompass different issues related to quality, complaints, logistics and critical mass.
- *Collaborative Platforms* entangle crowdsourcing and community feedback systems, display basically no entry barriers and disclose user innovation. Sometimes the creator may experience a loss of IP or a long gestation before the actual implementation/manufacturing of her idea that could even be far from the original submission.

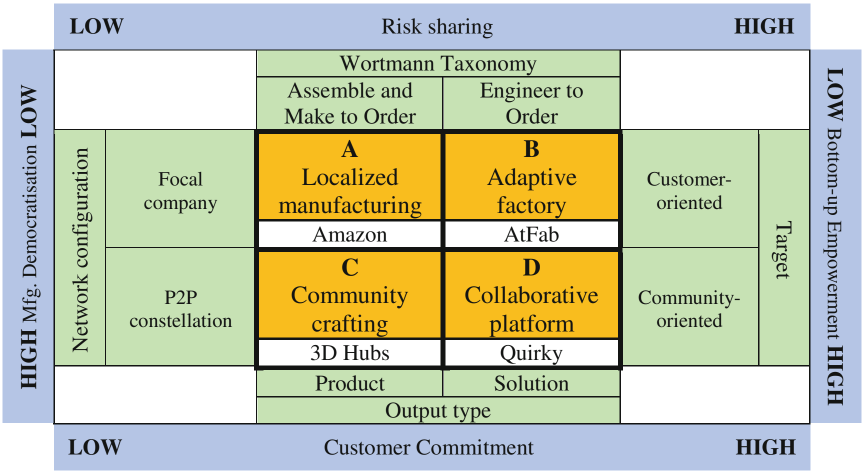


Fig. 3. The four-quadrant descriptive framework

5 Conclusions

Reluctance towards Additive Manufacturing is motivated by its constraints and yet unsolved issues (production time, volume, material, safety conditions, etc.). Those drawbacks will soon be ridden out and, most importantly, the social connotation of such technology – sometimes referred to as “democratisation of manufacturing” - will be recognized and endorsed.

Regardless of the value chain configuration, a thorough digitalisation of production processes is ongoing. Digital platforms manage order purchase and co-development, they enable partner contracting and an easier supplier selection problem, facilitate project planning and monitoring and even collect real-time feedbacks. The digital infrastructure underlying the manufacturing realm will facilitate both imitators and innovators to fast new product development through disruptive technologies such as 3D Printing. Still, this “digitalised” situation will be completely consistent with the endorsement of human expertise in designing high-performing goods: “the artisan production worker will return to prominence” [22]. AM seems to be the proper technology to overcome even the mass customisation and to devise new responsive and responsible models of production, distribution and consumption. Especially for high-value industries in which rapid innovation is much more crucial than cost efficiency, AM could access to highly skilled talents, more important than hourly labour rates in production location decision making. As afore mentioned, proximity to customer concurrently means value increase and sustainability opportunities.

This paper represents a first attempt to frame some relevant arising business models related to advanced manufacturing techniques. Strategic and operational issues related to demand volatility and result-oriented provisions are highlighted and discussed. Distributed manufacturing and servitisation are now endorsing re-localisation of businesses and re-integration of the customer in the value chain, outlining new sustainable and participatory models.

Further research is solicited to devise dialogical expertise and intuitive tools that can help customers, designers, producers, distributors and retailers devise the next industrial revolution.

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An Economic Insight into Additive Manufacturing System Implementation

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Abstract. With an ever growing diffusion of Additive Manufacturing (AM) system in industrial and commercial level, as well as the direct and indirect dynamics which are being introduced resulting from its inclusion as a possible production technology on companies' portfolio, the need to reconfigure production system and adapt the production strategy becomes even more relevant than before. There are several studies which have emphasized on the importance of a paradigm shift in order to exploit advantages of AM, not only considering changes within design and functionality of the product, but also concerning AM's impact on the entire value chain (re)configuration. Thus, it is of crucial importance to take into consideration that for this shift to be feasible and manageable, there is a need to include both technical and managerial aspects of manufacturing. This work proposes an economic insight in order to provide a guideline for the proper evaluation of AM system implementation.

Keywords: Additive manufacturing · Economic assessment · Implementation guideline

1 Introduction

Considering their evolution rate, Additive Manufacturing (AM) technologies are becoming more interesting for a growing spectrum of industries, and the applications will soon impact the production activities of components and products [1] as well. The authors have found that the scarce available literature is not aligned with companies' requirements. They are focusing mostly on technological aspects, and do not provide an holistic view to ensure the evaluation of all the benefits and limitations of AM. In order to highlight the main limitations, three categories have been identified: (i) The data provided are often not up to date (and generally refer to a particular technology or even to a particular machine); (ii) The majority of the works consider a specific technology, and do not provide a priori analysis for identifying which is the most suitable for the context of application; (iii) As a consequence of point *ii*, the economic analysis generally does not compare different AM technologies to evaluate which is the best one and thus, no investment decision analysis is considered.

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In order to overcome the shortcomings described above, this work provides an holistic guideline; deploying an economic analysis to properly investigate the use of AM technologies within an industrial sector. The main objectives can be summarized as the following:

- To define a guideline to support manufacturing companies to understand whether AM techniques are suitable for their context and products; proposing criteria for implementing an a priori analysis, and providing a list of the (eventual) appropriate technologies and related machines,
- To provide a model to include economic implications resulting from AM application, facilitating a comparison between conventional subtractive techniques.

2 AM System

In order to have a better understanding of AM, it is necessary to look at it from the system point of view. This is due to the wide range of impacts that is accompanied by its implementation: extending from raw material suppliers and procurement, towards production level, distributors and even customers. Furthermore, a systematic analysis is able to characterize AM in a more comprehensive way. AM is a term applied to a technological class which consists of multiple subsets that make up the technological variations. Each of these technologies could be applied in various industries ranging from electronics to medical, automotive, armament and aerospace.

2.1 AM Characterization

One of the most remarkable aspects of AM which has enhanced its position among other manufacturing techniques is the flexibility, not only enabling economical low volume production [2] by eliminating the need for tooling, but also providing designers with a degree of freedom that no more limits functionality in favor of feasibility of the process. This feature provides manufacturers with two remarkable opportunities regarding the design: faster time-to-market, and almost real-time design changes that happen as improvements and optimizations are made to the original design. According to [3], special features of AM would result in the following benefits:

- Tool independency, since no tooling is required,
- Economic production of small batches becomes feasible,
- High flexibility for changing the design of the parts/products,
- Optimization for product functionality would be achievable,
- Customization of products which are based on individual customers' needs,
- High possibilities of wastes elimination during production phase,
- Possibility of having simpler and shorter supply chains.

Another study [4] characterizes AM by highlighting its distinguishing features. High automation and part consolidation which provides the possibility to build parts as a single piece and therefore eliminate the assembly would consequently lead to a great reduction of the labor, storage, handling and logistics costs. Economies of scale are one of the most remarkable properties of mass manufacturing. Manufacturing in large volumes allows for reduction of cost per unit as a result of the fixed-cost proration. However, since AM machinery requires no setups, production in small batches becomes economically feasible and this is a direct result of "economies of one".

Economic inefficiency in large volume production, inability of processing large parts due to the chamber size limitations [5], process variability [4] and lack of consistency among produced parts to ensure mechanical properties of the parts [6], incompetency of the companies struggling with process automation and digitalization, limited range of raw materials and lack of international standardization are amongst the most important barriers towards considering AM as manufacturing method.

2.2 AM Technology Variations

Different approaches have been introduced to classify AM processes. One classification is based on the raw materials feed. While it classifies processes according to four types of input raw materials, another type of classification is based solely on the working principle of process [6]. Amongst the others, the most comprehensive classification is presented by the AM subset of *American Society for Testing and Materials (ASTM F42),* categorizing AM variants into seven broad groups [6].

The notable areas in which AM has been deployed with high rates of success are currently limited to medical devices, consumer goods (e.g. electronics), aerospace, automotive, jewelry, architecture and defense [2]. Although various studies have considered the issue of energy usage in AM machines, a unified and standard procedure to measure energy consumption is still lacking and there needs to be more data for making comparisons among conventional technologies and AM. However, there are multiple studies [7] which show when it comes to the environmental aspects and carbon footprint, AM has a positive impact. Needless to say that a majority of these researches would still pinpoint the focus of their investigations into the lack of detailed information regarding wastes, energy consumption and environmental impacts.

3 Impactful Dynamics of AM

As it was mentioned earlier, AM is a system which is attributed by a variety of dynamics. One of these attributes which directly impacts the value chain is the supply chain management. The ability to redesign products with fewer components and the possibility of manufacturing products near customers' physical location are two valuable opportunities offered by AM [5]. This would not only reduce the need for warehousing, transportation and inventory, but it would also make the supply chain simpler by reducing time-to-market and lead-time. Design for Additive Manufacturing (DFAM) is a term which is used to emphasize on the flexibility of AM; meaning that since there are no limitations imposed by the design of the product to reduce its functionality, parts can be redesigned into single components and thus, AM's capabilities would be exploited in a more efficient way. By doing so, a reduction of the materials, energy and natural resources would take place which would eventually result in significant sustainable and economic benefits. An exciting area for AM to implement is in the spare parts supply chain. A thorough investigation [8] of spare parts supply in aircraft industry shows that rapid manufacturing (a term used for AM of individual parts/small lot sizes) can be used for low volume production of parts in a centralized location and at the place of consumption, if inventory holding and logistics costs are high in comparison with the production costs. This strategy would keep stock level down and AM capacity utilization high. In another study [9] four scenarios were studied in two dimensions of supply chain configuration (centralized and decentralized) and AM machine technology (current and future technology). One significant outcome of the study showed that with the current maturity of AM in which machines are both capital- and labor-intensive, centralized production is more efficient, while with the evolution of technology in the future, characterized by cheaper and more automated machines, distribution of production would be a better choice for the spare parts supply chain.

Although the lack of comprehensive data to assess sustainability aspects of AM is a big impediment, some researchers have tried to identify the key concepts of AM which are relevant to sustainable manufacturing [7]. These are the same advantages that distinguish AM from conventional and traditional manufacturing processes. Considering the current legislation and regulatory laws that exist on the environmental aspects of manufacturing processes, and manufacturers' tendency towards moving to cleaner and more sustainable production, the environmental impacts of AM is part and parcel of any analytic assessment. An analytic model on the evaluation of environmental impacts in AM [10] which considered the whole environmental flows, shows that in order to study the global environmental impacts, not only the electricity power consumption, but also the materials, and fluid consumption need to be taken into account.

4 State of the Art of AM Adoption Frameworks

One of the first contributions in this research stream comes from [11] that provided a model for cost estimation of AM applications. It analyzes the direct cost of production considering the machine, labor, and material costs, omitting the overhead costs, as well as the energy consumption. One of the most relevant outputs of the work is evaluation of the typical 3D printing cost profile, which is independent from quantity of the production. In the subsequent studies, the results are discussed in detail and then confuted, especially for small production batches.

The use of activity-based costing for the economic analysis of an AM alternative is provided by [12], however the proposed model has strong limitations since it considers only one single technique. Nevertheless, [12] confirmed previous assumptions, meaning that the more production chamber is saturated, the more the unit cost production is reduced. The models provided in the following years [13] try to evaluate cost of 3D printing application in an holistic view, considering a life cycle approach. In these works, the authors encompassed also re-designing activities which are required for a full exploitation of 3D printing capabilities, while incorporating full advantages enabled by AM. The approach considered by [14] is one of the most comprehensive ones. First, they identify a list of possible products that may be revisited by AM, for each of which, they then evaluate the most appropriate technology that matches the firm's requirements, and only at the end of this evaluation process, do the authors develop an economic analysis.

Considering a more consultancy-oriented approach, one has to notice Senvol (included in [1]), the company which experts in AM machinery and applications based in the US. In the paragraph titled "*Cost-Benefit Analyses for Final Production Parts*", the authors explain applications of their cost evaluation model. Contrary to the previous works cited earlier (e.g. [11, 12]), and due to the inefficiencies caused by print batches, their model does not provide a constant production cost. Thus, until the printing chamber is not completely saturated, the production cost per part provided is not constant. Considering the assumption that the more the machine is saturated, the lower the final production cost per part, previous scientific works that hypothesize to fully load the printer capacity seem more attractive. This assumption is reasonable, taking into account that (due to the absence of setup costs) a given company could saturate the build chamber with other parts/products and hence produce with a fully saturated chamber.

5 Evaluation Guideline and Case Study

According to [15], one of the main requirements of companies with respect to AM is the analytic support in order to evaluate whether or not AM could be suitable for their production processes and products. In this era, academics have to propose guidelines that help "senior management to reconsider whether they will continue using current production technologies, or they could benefit by exploiting the benefits of modern AM technologies". In accordance with this statement, the authors have identified a logical path that a company which is approaching AM for the first time, could follow in order to have a comprehensive evaluation of the AM techniques (Fig. 1).

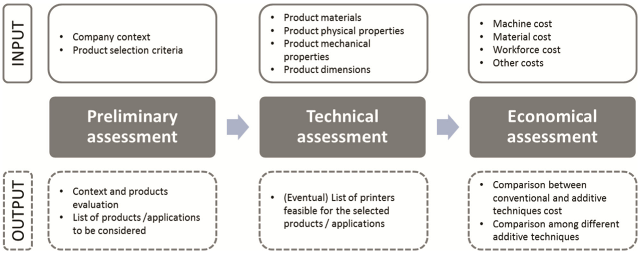

Fig. 1. Proposed AM evaluation framework

Reminding the main shortcomings described in the introduction section, the guideline aims to provide a complete assessment of this new paradigm; considering not only an economic evaluation or a context/product analysis, but also a comprehensive assessment of the alternative AM technologies that can be employed. The text provides an a priori analysis of the AM applications, considering the main features of the company context and products properties, and then proposes a technical and economic model to provide data for a quantitative assessment.

5.1 Preliminary Assessment

The first step that a company should take to understand whether these technologies may bring advantage to its business is a *preliminary* (*qualitative*) *assessment* of the context in which it operates. A framework provided by [16] encompasses three key attributes: production volume, customization, and complexity of the products.

The cited works do not provide quantitative drivers for an easy evaluation of which products are more promising for AM. Indeed, it is argued that already in this preliminary step a company should consider indicators related both to product and supply chain features for identifying which products (or range of products) could be encompassed in the following evaluation steps. For this reason, four different quantitative drivers are introduced that permit a selection of the most promising products for AM:

$$Cost\,weight\,intensity = \frac{Product\,overall\,cost[€]}{Product\,weight[kg]} \tag{1}$$

$$Buy\,to\,fly = \frac{Total\,material\,consumption[kg]}{Product\,weight[kg]} \tag{2}$$

$$Mould\,cost\,intensity = \frac{Cost\,of\,the\,mould\,allocated\,to\,the\,product[€]}{Product\,overall\,cost[€]} \tag{3}$$

$$CNC\,time\,intensity = \frac{CNC\,time\,consumption[h]}{Product\,volume[dm^3]} \tag{4}$$

In which, the higher the ratios, the more appropriate AM alternative would be.

Technical Assessment The next evaluation phase takes the input from selected products of the last part, aiming at the evaluation of the technological feasibility to manufacture them through AM. A more quantitative analysis is performed in order to map some relevant product features that have to be considered in this technological assessment; including dimensions, materials, physical and mechanical properties etc. The comparison of these parameters with a machines' database ensures to identify the (eventual) technologies and the related machines that are suitable for the company's products and needs. The output of this step is a list of (technology and) machines that fulfill the company's requirements, along with information about the machinery price as well as the retailers that could provide them.

Economic Assessment Having identified the list of suitable machines, it is possible to perform a preliminary evaluation of the costs incurred by the company. The developed model ensures two different types of analysis: one for evaluating whether products or components made by AM are more cost-effective than the same products or components realized through conventional subtractive techniques (e.g. injection molding or CNC machining), and the other one for evaluating which of the AM technologies that fulfill company's needs is more cost-effective, overcoming a general limitation of the literature.

According to [11], the provided model computes the direct costs of the AM application in terms of machine, materials and workforce. Indeed, thanks to the rigorous data collection, the costs related to the maintenance activities that [12] took into account as indirect cost, is considered to be a direct cost.

5.2 Case Study

The proposed case study considers a company that has exploited AM since 2001, and reached a high level of expertise, especially in SLA [6]. The company belongs to the automotive sector (specialized in the production of racing components), and operates following an Engineer-To-Order strategy in a one-of-a-kind-production context.

Initially, the SLA technology is compared with SLS [6], and due to several reasons, SLA has been selected as the most appropriate choice. First of all, the company considered the liquid material (raw material for SLA) easier to manage (than the powder required for SLS). Secondly, the durability of the products (longer for SLS) was not required, since the prototypes are used no longer than one month. These requirements have been changed in the last years, and so the company needs to re-evaluate the available technologies. The company's choices are limited to SLA and SLS technologies, since other AM variants produce products whose technical characteristics wouldn't match with those of the company and its customers. Thus, the company is happy with limiting its range of selection to these two AM variants.

According to the guideline described before, the company context is first considered for a preliminary analysis. After the positive qualitative results, the proper technologies for the specific requirements are identified and then an economic analysis of the selected technologies (and printers) is performed.

Having already discussed with R&D department and wind tunnel managers in order to analyze the main product features as well as the company's specialty, the company is understood to be operating in a one of a kind production sector, where each product is realized upon specific customers' requirements and needs. Considering the quantitative drivers introduced above, (at least) two of them are considered relevant for AM evaluation:

- For the majority of the products and prototypes realized, the buy-to-fly ratio is very high (exploiting conventional casting and molding technologies) according to the hollow structure required,
- And considering the uniqueness of the products, the *mold cost intensity* is also very high, in accordance with the allocation of the mold cost to only one product manufactured.

Considering these two drivers, and in response to the high levels of product complexity and customization, as well as the low volume productions, the company context immediately appears to be highly suitable for AM application. Once the evaluation of the preliminary feasibility study of AM techniques is performed for the products, the next step i.e. the technical assessment is started, through which it becomes possible to identify which technologies are able to satisfy company's requirements. Taking into account products' dimensions, surface finish, mechanical properties, and the required production volume (data collected through interviews with R&D manager), the technical database is consulted to exhaust all the available options: not surprisingly, the output provides 15 printers using SLA and SLS technologies for polymer materials. These technologies ensure an appropriate level of product porosity, which is one of the main requirements for the company (even though SLA reaches better performance levels related to this parameter). The technical database provides: 6 printers out of 15 exploit SLA technology (differing only in the chamber's dimensions), while the remaining 9 printers make use of SLS technology for manufacturing parts.

According to the proposed guideline and using the collected data, an economic evaluation is then performed to compute the total production cost for all 15 printers. In the remainder of the paper the data for two analyses are discussed: one related to the SLA technology (the iPro800 printer which is the actual one adopted by the company), in order to validate the model, and one related to the SLS technology, in order to evaluate an alternative scenario (considering the most advanced printer coming from previous step, that is the Spro140 HD by 3D Systems).

In the first analysis in which the company's 3D printing cost structure (given by the interviewed personnel) is compared with the value computed by the proposed model, an initial model validation is obtained: the output approximates the actual cost given by the company with high accuracy (>95 %). So, in a preliminary way, it is assumed that the model adequately represents the behavior of the real system for the project objectives. Then the model is modified in a way to estimate the SLS printing process cost structure (according to the 3 cost elements described earlier). As a result, an evaluation of the performances in the as-is and to-be scenarios is obtainable. The comparison between SLS and SLA model outputs, highlights lower overall cost for SLS, with a global saving of more than €300,000 per year (about 25 % reduction). In Fig. 2, a comparison of the cost structures for as-is and to-be scenarios is illustrated.

- Material Cost is lower for SLS, considering that higher waste rate of this technology is balanced out with cost per kg of raw materials, which is roughly half compared with SLA.
- Machine Cost is higher for SLA, and constituted the majority of the gap between the overall costs of the two technologies. This is due to the stacking parameter: SLA does not permit to stack up different products on different layers, while SLS (that exploits

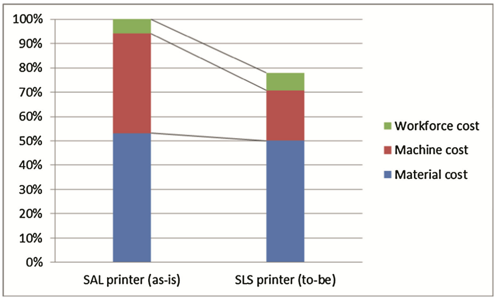

Fig. 2. Economic analysis of as-is and to-be scenarios

powder material) ensures to fully saturate the printing chamber with different layers of products. For this reason SLA technology requires more printers to fulfill the annual demand of products than SLS does. In particular, SLA requires 6 printers while SLS needs only 2.
- Work Cost is similar for the two technologies. SLS requires more time for finishing operations, while SLA requires longer time for the setup activities.

Considering that the evolution of SLA and SLS technologies has enhanced precision and resolution of these technologies onto very high (and almost similar) levels, the decision concerning which of them to implement is closely related to the total manufacturing process cost. Therefore, taking into account the economic assessment provided, and the strategic alternative about the technical performance of the two technologies, the company is now evaluating the possibility to (gradually) change its technology and substitute the old SLA machine with a new SLS machine.

6 Conclusion

There are two points about AM that draws a lot of attention among concerning researchers in the field. First, the rather young age of AM compared with the traditional and conventional technologies and second, the ongoing process towards full adoption of AM as a viable manufacturing system in the industrial world. However, it must be noted that due to the incomplete maturity and ongoing research, many of AM's aspects including, but not limited, to process measurement and standardization, finish surface quality, throughput rate, raw material selection, still lack enough competence to replace conventional technologies and become a widely accepted manufacturing system. In order to define a more holistic approach to AM, implementation of more case studies and accurate tests deem necessary to provide guidelines which help to identify the threshold value for the abovementioned four drivers to immediately discriminate which products should be subjected to a technical and economic evaluation, and which should be excluded from further analysis.

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Defining the Research Agenda for 3D Printing-Enabled Re-distributed Manufacturing

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Abstract. Advanced manufacturing technologies are changing how and where goods are produced, with established organisational practices and value chains being disrupted by the adoption of these technologies. The 3DP-RDM network has been created to explore the changes caused by such technologies, focusing on the emergence of 3D printing and the effects it is having on the re-distribution of manufacturing. This paper reports on the first activities of this network, describing the process used in a multi-disciplinary scoping workshop and the selection criteria for the feasibility study competition, and how these help to achieve the network achieve its objective of defining the research agenda for 3D printing-enabled re-distributed manufacturing.

Keywords: 3D printing · Additive manufacturing · Re-distributed manufacturing · Research agenda

1 Introduction

Advanced manufacturing technologies are changing how and where goods are being produced. One of these technologies, 3D printing (3DP, also known as additive manufacturing), offers the prospect for on-demand, mass personalisation, localised, flexible and more sustainable production. The ability to manufacture goods only when needed, closer to the point of consumption and in response to consumer needs has enormous ramifications for established organisational practices and value chains.

While advances are being made to the technical capabilities of 3DP, the impact of adopting these technologies remains highly uncertain. The 3DP-RDM network has been created in an effort to better understand their implications and how 3DP could enable re-distributed manufacturing (RDM). The objectives of this network are to develop an improved understanding of the research challenges that lie at the intersection of 3DP and RDM, and to define the agenda for future research in this area.

This paper reports on the first activities of the 3DP-RDM network. It documents the process that was used at the first scoping workshop in January 2015 to identify potential feasibility studies. Due to space constraints, sample outputs from the workshop are included in this paper with links to the full data provided. This paper also provides an overview of the process and selection criteria used in the feasibility study

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competition that followed. In reporting on this overall process we show how the initial steps have been made to define the 3DP-RDM research agenda.

2 3D Printing and Re-distributed Manufacturing

3D printing describes a range of additive manufacturing processes that have recently begun to be applied in direct manufacturing. In the UK, their societal and economic importance has been identified in a number of recent reports, with the TSB defining it as one of the UK's 22 priority process technologies [1], and the Government Office for Science expecting 3DP to have "*a profound impact on the way manufacturers make almost any product*" [2]. As the latter report commented, additive manufacturing "*will become an essential 'tool' allowing designs to be optimised to reduce waste; products to be made as light as possible; inventories of spare parts to be reduced; greater flexibility in the location of manufacturing; products to be personalised to consumers; consumers to make some of their own products; and products to be made with new graded composition and bespoke properties*" [8]. The report recommended that greater efforts should be made to understand key technologies such as 3DP in order to guide policy.

Re-distributed manufacturing has been defined by the Engineering and Physical Sciences Research Council (EPSRC) as: "*Technologies, systems and strategies that change the economics and organisation of manufacturing, particularly with regard to location*" [3]. The increased maturity and applicability for manufacturing of 3D printing (3DP) technologies [4, 5] and their resulting diffusion is one factor that may accelerate the re-distribution of some manufacturing activities [1, 6, 7]. "*Companies are re-imagining supply chains: a world of networked printers where logistics may be more about delivering digital design files – from one continent to printer farms in another – than about containers, ships and cargo planes*" [8]. The resulting vision of 3DP wider adoption is that: "*The factories of the future will be more varied, and more distributed than those of today* […] *The production landscape will include capital intensive super factories producing complex products; reconfigurable units integrated with the fluid requirements of their supply chain partners; and local, mobile and domestic production sites for some products. Urban sites will become common as factories reduce their environmental impacts. The factory of the future may be at the bedside, in the home, in the field, in the office and on the battlefield*" [2].

There is a growing realisation of the ways in which 3DP could lead to RDM. However, the impact of 3DP on RDM and vice versa will depend on a variety of interconnected aspects that go beyond the technical performance issues. These include:

1. Economics: the economics of 3D printing, including assessment of the cost advantages and disadvantages;
2. IP: the protection of intellectual property and value appropriation, particularly the protection of copyrights and design rights;
3. Materials: attributes such as quality, durability and recyclability;
4. Skills: the education and development of a 3DP-skilled labour market;
5. Standards: manufacturing standardisation.

A number of recent policy reports have acknowledged the connections between the issues of 3DP and RDM [1, 6, 9]. Despite these connections being acknowledged, the implications and their feasibility remain largely unexplored. The knowledge in the technical, economic and social issues and the dependencies between them that could support industry, policymakers and funding agencies is still fragmented and siloed within specific academic disciplines.

2.1 3DP-RDM Network[1]

The 3DP-RDM network was created due to the growing significance of these manufacturing trends. It was granted funding by the EPSRC/ESRC under its “Re-distributed manufacturing Networks” theme in November 2014 and its activities began in January 2015. The core research issue of the network is to understand the connections between the diffusion of 3DP technologies and RDM (as shown in Fig. 1).

Specifically, the network seeks to understand:

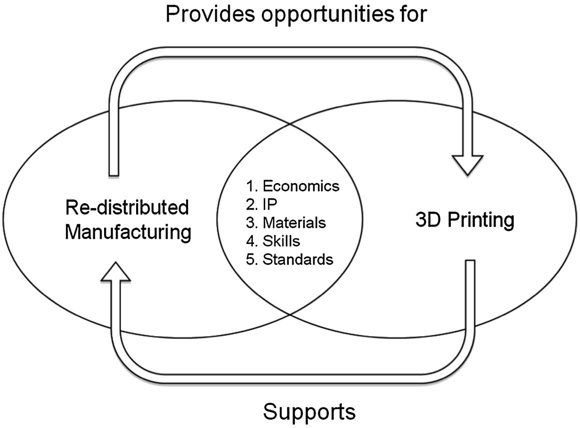

Fig. 1. The conceptual logic for the 3DP-RDM network

1. The features of 3DP technologies that help enable re-distributed manufacturing;
2. How re-distributed manufacturing may accelerate the diffusion of 3DP technologies and vice versa;
3. Sector specific and generic aspects of 3DP enabled re-distributed manufacturing.

These research objectives will be achieved by convening a multi-disciplinary research and multi-industry user community that provides the required breadth and depth of research capabilities to define and disseminate the research agenda for RDM focused around the emergence of 3DP. Specifically, the network involves active

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[1] The authors of this paper are the Network Coordinator and Principle Investigator of the 3DP-RDM network respectively.

engagement of this community through scoping workshops and the identification and delivery of six targeted feasibility studies.

In fulfilling our objectives we will develop an improved understanding of the interaction between 3DP and RDM, providing an essential input to the research council's wider goal of defining the research agenda for RDM.

3 3DP-RDM Scoping Workshop

As a first step in establishing the research agenda in 3DP-RDM, a scoping workshop was organised on 30th January 2015 at the Institute for Manufacturing in Cambridge, UK. The workshop involved 37 participants from academia and industry. Its objectives were to identify potential feasibility studies and to facilitate networking because participants were from a wide range of disciplines. To achieve these aims the workshop was organised into the three processes described in the following sections.

3.1 The Identification of 3DP-RDM Research Topics[2]

On arrival at the workshop, participants were assigned to tables to create multi-disciplinary groups of 5-6 people. For the first discussion activity seven groups were created and given the task of answering the question: "*What are the research issues at the intersection of 3D printing and re-distributed manufacturing?*" They were given pens, Post-it notes and the template shown in Fig. 2 to structure the discussion. Towards the end of their discussions, the groups were instructed to identify the top five research topics that they thought needed to be investigated.

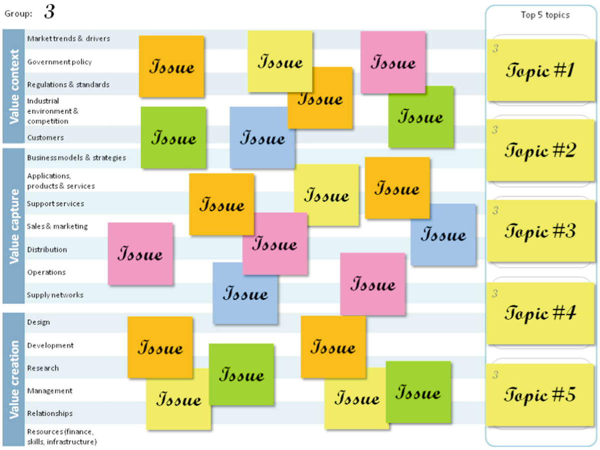

Fig. 2. Template used to facilitate small group discussion and identify potential research topics

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[2] Full results can be found here: https://capturingthevalue.wordpress.com/2015/02/05/3dp-rdm-scoping-workshop-discussion-activity-1-outputs/.

3.2 The Prioritisation of 3DP-RDM Research Topics

Following the small group discussion, representatives from each group described their top five research topics to the whole group, with the Post-it notes detailing these placed onto a larger 'landscape' map that resembled the template and which everyone could see. Where possible, similar topics were clustered together on the map in real-time. With seven groups, this resulted in the placement of 35 Post-its.

Once these Post-its were all placed on the landscape map, each participant was invited to vote for those topics they thought should be investigated through feasibility studies during this first year of the network. Each participant was given five dot stickers to place on the topics on the landscape map. The only rule they were given was that they could not place more than one vote for any one research topic. Table 1 provides a list of the top ranked research topics that was generated from this process.

Table 1. Prioritised research topics

Research topic	Votes
Standards + compatibility + regulation + certification //avoidance + convergence?	12
How will value be created and captured in the 3DP-RDM economy?	12
To research gap between hardware (very advanced) and design methods and tools: there is no CAD conceptually suitable for AD	11
Reconfiguring supply chain: consumers becoming prosumers, ownership?	11
Software requirements and infrastructure in redistributed environment. How is it accessed?	11
Liability and IPR: traceability, certification	8
Material supply chain – how structured and delivered?	8
"Facebook problem" who owns/shares design in re-distributed 3DP hubs?	8

3.3 The Development of Selected Research Topics to Identify Potential 3DP-RDM Feasibility Studies[3]

Following the outputs of the prioritisation process, participants were invited to join in groups of 4–5 people to explore one of the prioritised topics. This resulted in the creation of the eight groups listed in Table 2.

The eight groups were provided with a second template as shown in Fig. 3. Through following the steps in this template, members of the group learned about each others' research expertise and interests, before exploring what research could be conducted within the chosen topic. After generating some ideas about possible research needs and research questions, groups then chose three to explore in greater depth, considering how these could be addressed though feasibility studies. A final step was to decide which of these three feasibility studies was most important.

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[3] Full results can be found here: https://capturingthevalue.wordpress.com/2015/02/13/3dp-rdm-scoping-workshop-discussion-activity-2-outputs/.

Table 2. The eight groups formed for the second discussion activity

Group(s)	Research topic
1	Material supply chain
2	Standards + Compatibility + Regulation + Certification
3	Reconfiguring supply chain: will consumers become prosumers?
4	Software and conceptual infrastructure
5, 6	How will value be created and captured in 3DP-RDM economy?
7	Who owns/shares designs in 3DP-RDM hubs?
8	Business models

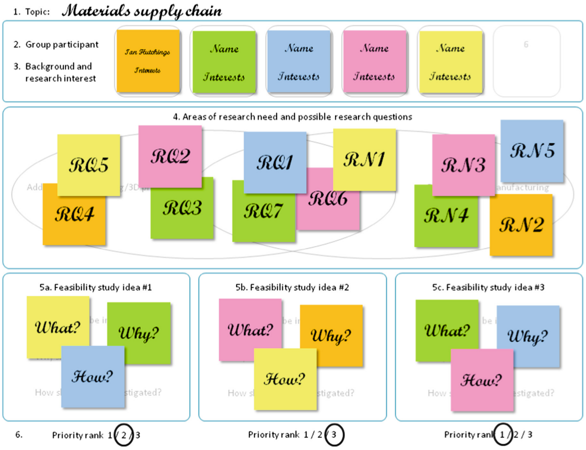

Fig. 3. Template used to discuss selected research topic and identify potential feasibility studies

The results of this second discussion activity provided the network with insights into the types of research questions and needs within the topic, and possible ways for researching the topic through feasibility studies. Example data is provided in Table 3.

Table 3. Summary of outputs from group 1 that explored the material supply chain

Areas of possible research	Feasibility study #1
• Dual sourcing of materials essential for robust process/business model • Security of supply • Effect of significant increase in demand on existing raw material supply chain • Exploration of new, cheaper sources of feedstock (currently very restricted) • Localised, small-scale production of feedstock • Local recycling of materials 'in-process' as feedstock for 3DP	• What should be investigated? Analyse existing feedstock supply chain: who, where, how, why? • Why should it be investigated? To inform: policy, investment. To identify: weaknesses, security issues, opportunity • How should it be investigated? Create example situations and interview stakeholders: 3DP user, material suppliers, end product OEM, regulators, manufacturing process experts

4 Feasibility Study Competition

An open call for feasibility study funding was announced at the scoping workshop as well as through the network blog and EPSRC website. The call invited proposals for feasibility studies investigating 3DP-RDM. A total of 34 proposals were received in response to this call. Following an initial screening process and indicative marking by a three person review panel, a shortlist of 9 proposals was created. This shortlist was then scored using the ten opportunity and feasibility criteria in Table 4. This scoring system was developed based on guidance from on the use of anchoring statements to drive consistency [10], the criteria used by EPSRC to select projects, with additional criteria specific to the nature of the 3DP-RDM feasibility study. In addition, due to some conflicts of interest that were identified during the indicative marking stage, the panel

Table 4. Selection criteria for feasibility studies

	0	3	6	9	12
Strategic importance	No link to explicitly identified issue		Some linkages but some supposition		Clear linkage to issue identified by policy documents
Future potential/impact	Unclear/absent potential impact		Some evidence of impact, but needs strengthening		Clear potential impact, and articulation of how this might be delivered
Synergy opportunities	Isolated research, no obvious linkages		Some potential synergy, but requires elaboration		Very clear engagement/complementarity with other projects
Learning potential	Weak/not discussed		Some, but benefit to network not clear		Clear learning for team and network
Timing and relevance	Low importance for being conducted now		Moderate importance for being conducted now		High importance for being conducted now
Quality	Vague, incomplete plan		Core elements of plan but some gaps		Complete plan: Clear aim, method, outputs
Applicant's domain expertise	Not relevant and/or not demonstrated		Some relevance but may need partner		Highly relevant and demonstrated
Alignment with applicant's existing research	No connection		Some alignment but extends beyond core area		Builds directly upon established high quality research
Resources	No appropriate researchers; justification unclear		Resources appropriate but not clear if available		Appropriate, named researcher available on start-date and for duration of project
Management	No detail on management		Basic management plan but some gaps		Clear management process and responsibilities

was increased to four reviewers to ensure that all applications were scored by at least three reviewers.

Following this review process four studies were selected for funding:

- *Investigating the Impact of CAD Data Transfer Standards for 3DP-RDM*
- *OPTIMOS PRIME: Organising Production Technology Into MOst Responsive States – 3D PRInt Machine Enabled Networks*
- *The enabling role of 3DP in redistributed manufacturing: A total cost model*
- *Redistributing Material Supply Chains for 3D printing.*

5 Conclusions

The interaction between 3D printing and the re-distribution of manufacturing is a complex one and has been identified as requiring further investigation. The four studies being funded by the 3DP-RDM network cover economic modelling, production systems, materials, supply chains, software and standards. Their selection ensures a balanced portfolio of projects and establishes a platform on which the 3DP-RDM research agenda can grow.

This paper has provided a detailed description of the process for generating and selecting feasibility studies in an emerging field of enquiry. It has demonstrated how the use of structured templates at a scoping workshop enables multiple disciplines to collaborate and synthesise their ideas. Customising these templates allows this process to be replicated in other academic domains in order to generate new research ideas, concepts and projects.

Acknowledgements. Thanks go to all those that participated in the scoping workshop and submitted feasibility study proposals. Special thanks go to Jo Griffiths for supporting the workshop organisation and to Mélanie Despeisse for helping analyse the workshop outputs.

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Operations Management in Engineer-to-Order Manufacturing

A Mockup Stochastic Program to Study the Impact of Design Uncertainty on ETO Shipbuilding Planning

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Abstract. A major driver of planning complexity in dynamically changing ETO shipbuilding is design uncertainty far into the design planning and production processes. This leads to uncertainty in task and project completion time, and complex dependencies and correlations driven by the uncertainty in multiple task parameters. The problem is difficult to be solved exactly, and decision-making is largely based on experience and gut feeling, with subsequent behavioral challenges. We build a mockup stochastic program to draw attention to- and analyze the complexity of formulating and solving the engineering design planning problem. We demonstrate how design uncertainty is affecting the planning complexity and solutions.

Keywords: ETO · Project planning · Stochastic programming

1 Problem Description and Relevant Literature

A major driver of planning complexity in customized dynamically changing ship-building projects is design uncertainty through the engineering design- and far into the production processes. This is leading to continuous adjustments in planning, procurement and execution [1], and defines the uncertainty to be dealt with on a daily basis. Design uncertainty generates uncertainty in the technical information and completion time for a chain of connected tasks, and negative/positive correlations. One design alternative potentially excludes other alternatives (e.g. weight &space restrictions), and may lead to negative correlations between the uncertain activities. Uncertain activities competing for the same resources are other sources of negative correlations. For more on project correlations see [7]. In summary, we deal with a *planning problem with two-level uncertainty,* where stochastic task completion times are conditioned by uncertain design, and correlations driven by the uncertainty in multiple task parameters. Minimal use of resources and reliable adherence to tight schedules is challenging here. Creating flexibility by solving the true planning complexity is obviously difficult. Behavioural and organizational issues are other reasons for lack of flexibility in plans. Investments in flexibility normally have costs early and potential income late, and hence often undervalued by the decision makers. Randomness is also often lost between departments (e.g. between sales and engineering), resulting in 'reduced' randomness and reduced

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value of flexibility. Many solutions ignore, as such, important characteristics of the true planning problem, and lack the necessary flexibility [8]. As practitioners increasingly recognize the shortcomings, model-based decision aids are often replaced by judgmental processes [8] that automatically open up for behavioral challenges. Judgmental decision processes are suggested to work – in an ad hoc manner though – in project organizations built on trust and experience [8]. Dealing with the described complexity judgmentally is, however, not less complex; e.g. understanding how activities are correlated with each other is important for prioritization of the project tasks, but often biased by the limitations in working memory when dealing with complex issues simultaneously, natural risk aversion, invisible and illusory correlations, etc. We believe hence the decision processes to benefit from an intensified analytical approach, as models are logical to the givens. Stochastic programming explicitly models the value of future decisions that are made after the uncertainty is revealed (i.e. future choice on design alternatives), and might be a good approach despite complexity. Although buffer management is common to hedge against uncertainty, stochastic solutions are not "something plus the original solution". This is rather intuitive if we consider cases like adapting from an originally planned 'offshore cable-layer system' to a 'firefighter system' far into the production processes.

Hence, the motivation to build a **mockup stochastic program** to *draw attention to- and analyze the complexity of formulating and solving ETO planning problems with complex uncertainty patterns*, and to *investigate what we can learn about the impact of design uncertainty on planning by analyzing small model instances.*

The remaining of this section discusses chosen literature, with focus on uncertain-ty and correlations in project management and scheduling. The applied stochastic modeling approach is described in Sect. 2. The mockup design-engineering planning test case is implemented in Sect. 3, and concluded in Sect. 4.

Decision-making trends in project management and advances in scheduling techniques are presented in [6]; emphasizing the need for analytical approaches and risk handling competences to rapidly adapt changes. Best practice and shortcomings in different research streams on robust planning and decision-making in engineering construction projects are discussed in [8]. Scheduling methods like the critical path method algorithm CPM [5], balancing time and cost while resource-oriented, and the rather similar PERT, with the main difference on stochastic activity durations, have been in focus from the late fifties. PERT, and other simulation approaches provide a picture on project risk and simulate the effects of options for decision (before decision). These facilitate better planning, but still lack decisions. Most decision makers still choose the decisions that fit the most likely outcome, and overlook the potentially high costs of adapting to a different scenario. Attempts to overcome these shortcomings exist by adding decisions within the simulation model: e.g. the decision of increasing resources if we are late relative to the plan. Future decisions, such as the decision on a design alternative, are however not explicitly taken into account, as this cannot be done within a simulation model. The authors in [2] emphasize that even finding a way to formulate the general stochastic dynamic scheduling problem seems tedious, and that the problem remains unsolved.

The difficulties in modeling and solving large mixed integer stochastic problems also motivates academics to discuss whether uncertainty should be ignored in the planning, or when in the planning process should uncertainty be included and how. The authors in [3] provide an early discussion on the use of deterministic solutions in stochastic setting. By a mixed integer stochastic commodity flow example, the authors show that deterministically chosen edges are a good start in some cases, for the first stage stochastic integer (mixed-integer) problem, with a simple linear stochastic model to set capacities for the second stage. The planning case of this paper can be seen as a related scheduling problem, and it may be tempting to look at the 'deterministic skeleton' approach. We deal however with a two-level uncertainty pattern, where we anticipate deterministically chosen sequences not to deliver good solutions for different design alternatives.

The literature on correlations in project schedules is limited, mainly due to the analytical models' limitations in handling complex uncertainty and dependency patterns. Numerical stochastic programming approaches show to offer the ability to handle complicated distributions [3, 9]. The authors in [10] formulate a product portfolio problem with bimodal distributions and complex dependency patterns, and show that hedging is mainly driven by the two possible design states (preferred/not preferred by the market), and not very sensitive to the specific values of the correlations or the marginal demand distributions of a particular design. It also shows high value in pairing items that are negatively correlated and at the same time substitutable. These findings apply to the case problem on a conceptual level, in that both of them treat a two-level stochastics problem with complex dependencies. The authors in [4] model a stochastic network design problem, and suggest that by consolidating two negatively correlated demand flows, an effective use of capacities can be achieved. In cases with strong positive correlation between high-probability high-demands, the authors suggest schedules that accommodate the most probable scenarios with most demands being high at the same time. Network flexibility has low value in this positive correlation case, and resources are suggested to be used on planned outsourcing. These findings provide interesting insights, and show that correlations matter; a conclusion also supported by [11], claiming by the use of a simulation model that correlations may be more important than the distribution representing the task duration uncertainty.

2 The Applied Stochastic Modelling Approach

The problem to be modeled is a complex and unsolved two-level uncertainty planning problem. To better understand the challenges, we divide the modelling process into two separated steps. This paper models the higher level uncertainty – *the stochastic design-*, while keeping the design-dependent task durations deterministic. The aim is to say something useful on how design uncertainty is affecting the planning complexity and solutions. In a second step, not provided in this paper, the full two-level uncertainty will be modeled, with stochastic activity durations constrained by the higher level design uncertainty, and correlations between the stochastic activities.

Unfortunately, the full formulation of the stochastic model is out of the scope of this paper. Instead, we describe the applied modelling approach. We use the so-called *compact formulation of a stochastic program*, where all variables are directly indexed on the nodes of the scenario tree—as opposed to the scenario-based formulation, where variables are indexed by time and scenario and the tree structure is enforced using the so-called *nonanticipativity constraints*.

In each node *n* of the scenario tree, we define the following binary variables for each activity *a*:

x_(n,a)	has activity *a* started at the start of node *n*?
y_(n,a)	has activity *a* finished at the end of node *n*?
z_(n,a)	has activity *a* been finished by the start of node *n*?
u_(n,a)	is activity *a* running during node *n*?
v_(n,a)	has activity *a* been stopped at start of node *n*?

In addition, we have continuous variables tracking resource usage at each node. From a conceptual point of view, it is important to realize that the only 'real' decision variables are *x_(n,a)* and *u_(n,a)*; the rest are auxiliary variables whose values are completely determined by others.

With these variables, we can implement the following functionality from the original problem description:

- Activity dependencies of type *{and}* (wait for all the specified activities) and *{or}* (wait for at least one activity).
- Stochastic dependencies: like above, but the dependency sets can differ between the scenario-tree nodes. This implements the stochastic design changes.
- An ongoing activity can be stopped at any time.
- Undo-activities: if activities *A* and *B* represent two different designs for the same element and we start work on *A*, we can require the use of a special activity that undoes *A*, before we can start working on *B*. Moreover, the duration of the undo-activity depends on the time spend on *A*.
- Resource usage per activity and period, to model access to labour, space, and equipment.
- Piece-wise linear resource-usage costs, to model higher costs for extra resources.

3 Test Case and Model Implementation

3.1 The Mockup Engineering-Design Problem

The mockup engineering-design planning problem is illustrated by Fig. 1. Real tasks are depicted by ellipses, indicator tasks with *and*-dependency by diamonds, *or*-dependency by rectangles, and the stochastic dependency by a combination of the two.

Assume a major outfitting structure with two possible design states *A* and *B*, composed by two tasks piping *P* and electro *D*; *(PA, DA)* and *(PB, DB)* respectively. These can be built in one stage and in two-stages, where the first stage decisions *P1* and *D1* can be used for both designs *A* and *B*. The "wrong" design decision implies 'undo' activities after the design uncertainty is revealed, to remove the tasks from the 3D model and from the physical unit if the task is released in production. The duration and costs of this undo-activity depend on the time spent on the "wrong" design.

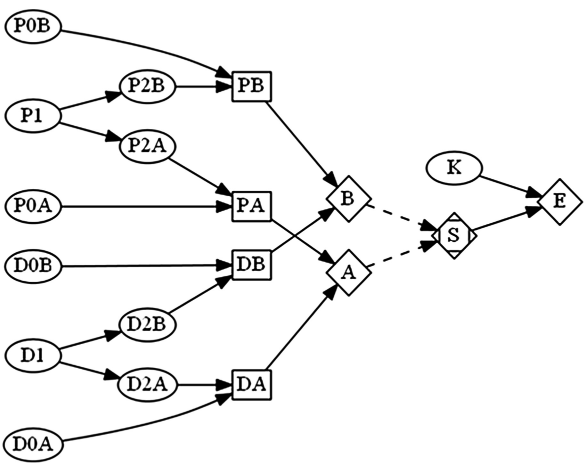

Fig. 1. Mockup engineering-design planning problem. Real tasks are depicted by ellipses, indicator tasks with *and*-dependency by diamonds, *or*-dependency by rectangles, and the stochastic dependency by a combination of the two.

3.2 Test Cases

The following test cases are implemented and analysed. **Case 1** is the deterministic static case, where we know ahead of time the preferred design alternative to be *A* (or we assume we know) and we fix all decisions by the start. **Case 2** is a deterministic dynamic case, where we plan for design *A* but the world turns to be *B*, and we 'update' the plan during the planning horizon by fixing the deterministic solution for the deterministic scenario. **Case 3** is the stochastic dynamic case, with uncertainty in design alternatives *A* and *B*. The order of decisions is not fixed here, but depends on previous decisions and the realization of the random design.

The model has been written in the GNU MathProg modeling language and the test instances were solved using Fico(trademark) Xpress Optimizer v. 26.

Important **model parameters** applied in the analysis are as follows. In each leaf of the scenario tree the probability of design *A* is 90 % and 10 % the alternative *B*. That is, the total probability of the first scenario is $0.9^4 = 0.6561$. The scenario tree - with information on the preferred alternative revealed at different nodes - is given by Fig. 2. Design alternative *A* is preferred with probability *0.6561* in the scenario finishing in

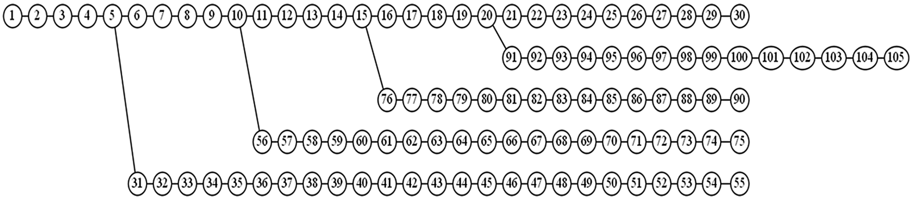

Fig. 2. The scenario tree

node 30. In the other scenarios, information on the preferred design alternative *B* arrives at different nodes (the scenario finishing in node 55, with *prob = 0.1*; scenario finishing in node75 with *prob = 0.09*; scenario finishing in node 90, with *prob = 0.081*; and scenario finishing in node 105 with *prob = 0.0729*).

We consider a 'lookahead' planning horizon (usually 6–8 week of 5 days; days defined as periods in the model). Each activity uses *1* unit of 'labour' per period. The resource-usage costs are piece-wise linear, with *1.0* for the first two units used, *1.5* for the third and *2.0* for the fourth unit; reflecting the scarcity of engineering capacity. All activities related to design *B* use one extra resource, with capacity of *1*. In other words, none of these activities can be performed in parallel. This resource is free. There is a penalty cost associated with each late finish, equaling *0.5/period* from period 16; *1.0* from period 21; *2.0* from period 26 and *4.0* from period 31. Activities have the following deterministic duration: P_0A *(10)*, P_1*(7)*, P_0B*(8)*, P_2A*(4)*, P_2B*(2)*, *PA(0)*, *PB (0)*, D_0A*(8)*, *D1(3)*, D_0B*(10)*, D_2A*(6)*, D_2B*(8)*, *K(10)*. Recall that for this paper we modeled a stochastic design/deterministic task duration situation.

3.3 Test Results

The optimal objective function value of the static deterministic **Case 1** provides a lower bound of *29.000* on the total costs. This solution will, on average, be lower than the actual costs disregard the scheduling strategy applied [2]; i.e. Case 1 is an optimistic situation. **Case 2**, the dynamic variant of Case 1, analyses the adaptation patterns and costs from design *A* to *B*. The total costs are *39.0712*; an **increase of 35 %** from Case 1. That is, decision makers believe to get the total cost of *29.000*, but in reality will end up 35 % higher; a potentially severe error. Obviously, an update like this is necessary to adapt new customer requirements. Recall also that the total cost is calculated by the use of engineering resources; a limited and critical resource for project completion time. In the model we allow for extra capacity for additional costs (e.g. overtime, flexible capacity), but this is not always the case. A substantial error in the planned capacity may lead to increase in completion time, a highly unwanted situation.

But if we don't know the preferred design alternative at the time of planning (and don't assume we know), what can we do before we learn which alternative is preferred? The solution structure of the stochastic dynamic **Case 3** shows a **flexible hedging route**, prepared to adapt both design alternatives, for a total cost of *36.008;* i.e. decision makers can do **8 % better** than if they adopt the deterministic reactive Case 2. This is *the value of flexibility*, i.e. the monetary value of the ability to make a decision later in time. The structure of the stochastic solution differs from the deterministic one in that the order of decisions is not fixed but depends on previous decisions and the realization of the random design variable. The solution prepares to adapt both design alternatives, by *first* scheduling tasks that can be used in both design alternatives, and *secondly* hedging by overlapping sequencing of both design specific tasks (where possible). This indicates that even when the probability of design *B* is low (10 % in each leaf of the scenario tree), hedging by preparing for both alternatives has value. In a deterministic setting hedging solutions are not wanted, as we know from the start that one of the 'investments' will be discarded. The IQ of hindsight is high. After the fact one of the deterministic solutions *A* or *B* will turn out to be best. Ahead of planning we don't know, though, which one will happen. And flexibility created by a proactive strategy allows for reduced adaptation costs.

Aside from showing the potential error of ignoring design uncertainty, the deterministic case provides an interesting finding, in that it *prefers the two-stage design solution to the one-stage solution*. Recall that both designs *A* and *B* can be constructed in one- or two-stages. Note that this specific behavior of the deterministic model is not driven by "flexibility" (as in a deterministic model all decisions are fixed and there is no flexibility), but to reduce the costs by more efficient allocation of the overlapping activities. A practical interpretation of this is *concurrent engineering* enabled by decomposing tasks into subtasks/modules that can be performed in different sequences. Concurrent engineering with overlapping activities that do not always follow the logic of sequential orders is highlighted by [1, 8] as one important way to reduce completion times within the case context.

4 Conclusion

In this paper we formulated a stochastic dynamic model (*a proactive strategy*) to study the impact of design uncertainty on planning complexity and solutions, and demonstrated the value of flexibility. We show that good planning solutions for uncertain design are not a deterministic plan plus some slack on the top. Good solutions are *flexible hedging strategies*, where 'hedging' relates to being prepared for alternative design solutions, and 'flexible' refers to multi-step design solutions with the first step being part of both design alternatives. Although such flexible multi-step designs have extra development costs, the solutions enable adaptation to alternatives with least costs. This implies *high value in early identifying design alternatives and activities that have most impact on the project completion time*, and that often carries the most uncertainty and may require hedging plans in early phases.

We also demonstrate that the *value of deterministic reactive strategies increases by concurrent engineering* enabled through multi-step/modularized design. I.e. multi-step design solutions have value also when an deterministic schedules are 'updated' according to new design requirements during the project execution. Concretely, we suggest that completion time is reduced by concurrent engineering enabled through module-based design; a finding that supports industrial state-of-practice.

Summarizing the paper, "*Understanding why we need stochastic programs, being able to formulate them and finding out what it makes such solutions good, can help us to find good solutions without actually solving the stochastic programs.*" [3]. This paper is hence more than an attempt to formulate a complex and unsolved stochastic dynamic scheduling problem. It provides a case of applying small model instances to show the impact of design uncertainty on planning solutions. The insights derived potentially improve the judgmental abilities in planning dynamic and uncertain projects. In practices many companies need a planning guideline to understand where and when to develop flexibility and buffers.

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Challenges of Heavy Load Logistics in Global Maritime Supply Chains

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Abstract. Global trade is steadily increasing and among the vast amount of traded goods are not only standardized cargo but also a selection of large and bulky heavy loads. Heavy loads often require special attention when it comes to identifying suitable shipping and loading means within logistic processes. In this paper the challenges of heavy load logistics are identified and discussed. Whereas the main goal of the paper is to highlight the challenges and problems in this domain, a possible solution approach within the Design for X framework is introduced briefly.

Keywords: Heavy loads · Logistics · Supply chains · Design for X (DfX) · DfT · DfL

1 Introduction

In the growing world economy, the supply chains of many companies are strained to ship the needed goods and cargo across vast distances in a timely and safe manner. Maritime commerce, the shipment of goods using maritime vessels, is a steady growing, and important part of German economy, as it generates significant economic benefits to ports and their host's cities. The traded goods are not only standardized cargo, which can be shipped with the help of container vessels, but also a selection of large and bulky heavy loads. This research paper aims to highlight the issues of heavy load transportation in maritime shipping.

In the next section, the different transportation modes of global supply chains are introduced with a special focus on non-standardized cargo (heavy loads). Following this theoretical foundation, the existing challenges and problems of heavy loads when it comes to logistics processes, especially maritime logistic processes, are discussed. After the challenges are pointed out, a possible solution approach within the DfX framework is presented in section three, before the paper is summarized in section four where a brief conclusion and an outlook on further research is given.

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2 State of the Art

In this section, first the different transportation types of cargo transport are elaborated. Following, the focus is set on maritime logistics (shipping) processes including an introduction to the currently available ship types. Finally, non-standardized cargo, also known as heavy loads or heavy lifts, is presented in more detail. Heavy loads are in the focus of this paper as they represent very specific challenges which have yet to be overcome by global supply chain practitioners.

Cargo transport can be divided into three main modes of transportation: air, sea and land transport (see Fig. 1). This publication concentrates on the maritime mode of non-standard sized cargo transport. In the contrary to other cargo types, bulk (e.g., grain, bauxite ore) and general cargo (e.g., TEU containers), the vessels for heavy loads are mostly not standardized and the shipment of oversize goods is costly and time consuming. Through a thorough examination of the shipment of exemplary non-standard sized goods, in this case wind turbines and cranes, this paper will attempt to provide an overview of challenges and possible approaches to overcoming the issues of heavy load maritime transport.

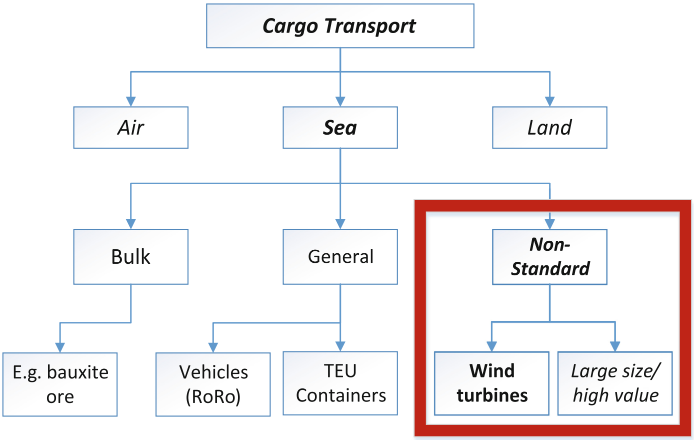

Fig. 1. Transportation types

The following subsection will provide a brief overview of the cargo transport over sea, the general vessels, and introduce in detail the issues of oversized cargo in maritime shipping.

2.1 Modes of Transportation in Maritime Shipping

As of today, the design of maritime vessels has been oriented into accommodating the craft to the to be transported product (e.g., cars, containers, iron ore, oil). It is best reflected in the various (standard) types of vessels in the shipbuilding industry (see Fig. 2), e.g. in dry cargo ships, which are comprised i.a. of tramps, cargo liners, container vessels and ro-ro (roll on/roll off) ships [1]. Among the types of cargo transported via dry cargo ships are general cargo, bulk cargo, vehicles and special heavy cargo. Regarding the size of ships, another factor influences the build with the capability to ‘fit’ through certain passages like the Panama Canal, hence ‘Panamax’/‘New Panamax’ class vessels.

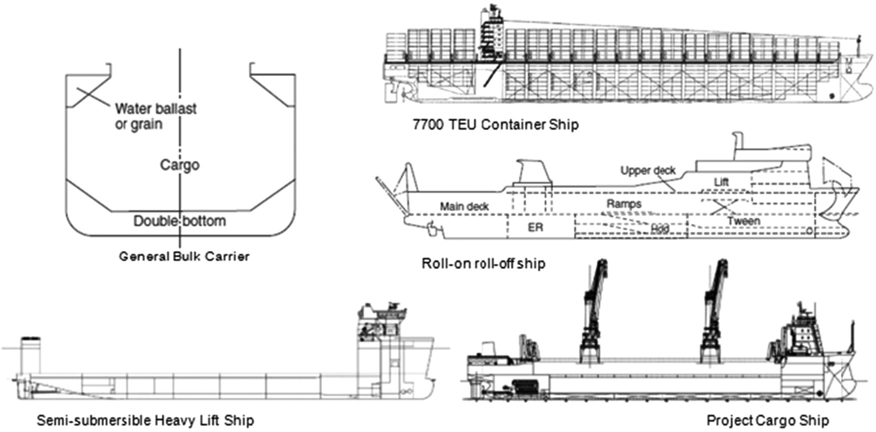

Fig. 2. Ship types (based on [1, 16])

General cargo is a vital component of the maritime commerce, generating significant economic benefits to ports and their host cities. The transport of general cargo has been dominated through the trend towards containerization since its inception in 1966 [2]. The ‘break-bulk’ freight, individual parcels or pieces, is being containerized in the dimensions of a Twenty-foot Equivalent Unit (TEU), generally referred to as standard container [3]. This trend led to a steady and substantial increase in the container vessels size in recent years, with largest ships operated by Maersk, which can carry a reported 13,500 TEU. Ro-ro ships, especially designed for the transport of vehicles, are usually fitted with various ramps for loading through the shell doors of the ship. Cargo is carried in vehicles and trailers or in unitized form loaded by fork-load and other trucks [1, 4].

Another important type of freight are the wide ranging **bulk commodities**, including i.a. coal, grain, bauxite ore, and shipments of products such as packaged steel and timber. A general arrangement of a typical bulk carrier shows a clear deck with machinery aft, and large hatches with steel covers, designed to facilitate rapid loading and discharge of the cargo [1, 4].

Additionally to bulk and standard cargo, there is also the **non-standard sized cargo**, e.g. wind turbine components. Non-standard sized cargo has distinct properties, often a relatively large size, high value, and sensitivity, that doesn’t allow for standard methods of transportation.

In this publication the focus is placed upon the non-standard sized cargo as such didn’t receive as much attention with regard to transportability compared to the others yet. In the following subsection, this will be illustrated in greater detail.

2.2 Non-standard Sized Cargo

Non-standard sized cargo, often described as Heavy loads, is nowadays a rapid growing part of cargo shipping. Heavy loads include goods like wind turbine parts, tunneling equipment, plants, heavy cranes, project cargo etc. These type of goods distinguish themselves with very special characteristics regarding the weight, sensibility and geometry, and are often very high-value products. As heavy loads have very big dimensions, and are transported either in parts or whole (depending on customer requirements), the properties of the load, including the distribution of the cargo mass, it's center of gravity, inertia, the transverse moments, the torsion, the vibration, the stability of the carrier, and the cargo geometry itself, are very important while shipping heavy loads, and have to be addressed in early stages of the shipping process [5]. The following points summarize information crucial to the physical challenges associated with the transport of heavy loads [6–9]:

- Environmental criteria (e.g. motion response during environmental events)
- Proper transport vessel due to mass and dimensions
- Stability during transport and during on-loading/off-loading
- Extreme transport force
- Cargo footprint
- Sensitivity for damage
- Cribbing and fastening arrangements (lashing, chains, slings, hooks etc.)
- Transport and Insurance costs

These factors directly relate to the transport and insurance costs. Not only the shipper, but also the designer of the heavy load cargo, has to be aware of these factors to ensure proper and safe transport. As already mentioned, heavy loads include, e.g., wind turbines or cranes. For years the vessels of choice for the shipment of wind turbines and cranes have been project cargo, and semi-submersible heavy load ships. Other vessels, used for the transport of heavy loads, are dock ships, module and crane carriers, geared project cargo ships and lo-lo (load on/load off) ships. Companies like, e.g., ZPMC (Shanghai Zhenhua Heavy Industries) adapt older bulk carriers into non-submersible heavy load ships lacking any superstructures in the main loading area and equipped with sideway funnels, both useful characteristics in the shipment of heavy loads [10].

3 Design for X as a Possible Solution Approach

The above listed issues of heavy load transport are met with several approaches: The first approach is to adapt and customize the vessels to meet the needs of heavy load transportation. We have seen this approach in the adapted open deck carriers of ZPMC, where the vessels are modified into non-submersible heavy load ships. This is not only costly but also time intensive, as the redesign and development of special vessels presents a major investment on the shipper.

Another approach to the presented issues could lie in the redesign, or inclusion of design recommendations into the design of heavy load products. The Design for X (DfX) methodology, and its extensions, i.a. Design for Logistics (DfL) and Design for Transportability (DfT) supply this publication with a framework for the above-mentioned design recommendations.

DfX, or “Design for Excellence”, describes design guidelines in many different areas of product development. Each design guideline addresses a specific design issue, caused by or affecting a specific characteristic of a product. Therefore the ‘X’ can stand for e.g., Manufacturability/Manufacturing (DfM), Assembly (DfA), Reliability, Logistics, or Transportability. DfX guidelines have proven to effectively reduce costs, time-to-market, number of assembly operations and product assembly time. The application of DfX requires manufacturing engineers and designers to work together rather than individually [11].

3.1 Design for X with Supply Chain/Logistics Focus

DfX also includes Design for Logistics (DfL). DfL aims to improve capabilities in the supply chain management to control logistic processes, and the overall customer service levels, as well as, to cut operational costs. Some of its other goals can be summarized in increasing logistics efficiency, and gaining/or sustaining competitive advantage. The DfL approach tries to reach these goals by improving the transportability and usability of the **to-be-designed** product. Products should be designed in a way, to provide sustained logistics support capabilities for its planned product life cycle [12, 13]. This can be reflected in, e.g., modularization to realize the product in parts [14].

A practical example of integration of DfL in industry is to add certain restrictions into the CAD design system or database of the designer, which would feature the logistic requirements. It is essential to connect the early design and manufacturing with the later logistic processes, as the engineers and designers are often not aware of or do not focus on necessary logistic requirements. As in DfX, it’s important to connect the expertise of inter-disciplinary experts, like engineers and logistics professionals [12].

An important extension of DfL is “Design for Transportability” (DfT). According to Dowlatshahi, **transportation costs** represent the single most important aspect of the logistics costs, and as such DfT is able to realize economies of scale and thus reduce prices and costs. Next to costs reduction, one of the main goals of DfT is a product design which allows for safe handling and transportation, free from hazards and dangers to the personnel involved. This includes **reliable** and **timely transit time** (speed of delivery) in the transport of the goods. Dowlatshahi lists a number of design characteristics that affect transportability to an extent [12]:

- Physical properties (width, height, length, center of gravity, etc.)
- Dynamic limitations (acceleration, vibration, deflection, leaking, etc.)
- Environmental limitations (temperature, pressure, humidity, etc.)
- Hazardous effects (radiation, explosives, electrostatic, personnel safety, etc.)

To reach these goals, logistic considerations such as the type of goods, size and length of shipment and mode of transportation, should be known to the designer in the early design stages (see Fig. 3), as well as to develop a standard in which the products have a compatible size with the given transport facilities. If the design guidelines can satisfy these requirements, it would be possible to reduce the transportation costs, thus improving the competitive advantage of the producing firm [12].

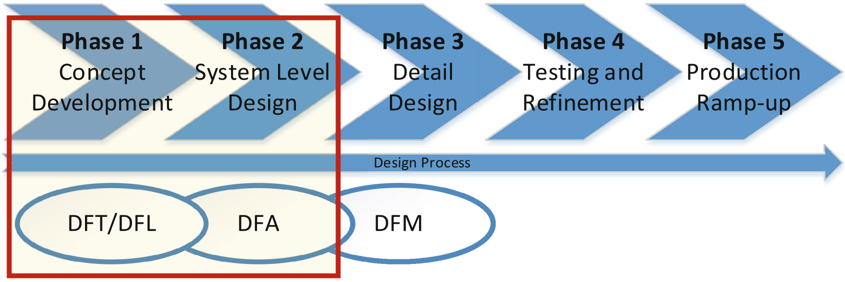

Fig. 3. Sequential DfX with DfT/DfL timing [14]

As seen in Fig. 3, the extension of DfX considerations into DfL and DfT does not exclude the need for DfM or DFA. Whereas the DfL and DfT guidelines concern the overall supply chain (logistics and transportation), the DfA and DfM relate to the company and the process levels, and thus require more detailed information. DfL and DfT are relevant from the concept development stage, as the proposed product architecture can reveal how the transportability of the product will be affected [14].

3.2 Discussion

While outlining the framework for the DfL/DfT design guidelines for improved shipment of heavy loads, there are three points, which have always to be considered [14]: DfL and/or DfT cannot be performed without **knowledge** of the products shipping **process**; it must be performed with a specific **objective** in mind (e.g. reducing costs); a measure of transportability must be defined (e.g. transportation time). With these points in mind, the following Table 1 can be seen as a starting point to DfL and DfT in maritime transport for designers of heavy load products. It provides an overview of issues the designer has to take into consideration [15].

Table 1. Issues before and after the shipment of heavy loads

Before transport (loading)	After transport (unloading)
• Departure port conditions • Vessel properties • Assembly state of the cargo • Load safety during loading • Suitable loading equipment and skilled staff	• Destination port conditions • Vessel properties • Assembly state of the cargo • Load safety during unloading • Suitable loading equipment and skilled staff

It has to be noted that this discussion is rather high level. In order to practically apply this or similar approaches in practice, a more detailed and thorough investigation, including physical design elements has to be considered.

4 Conclusion and Outlook

Shipping of heavy loads is increasing steadily, however, it bears many challenges, e.g., regarding the loading and unloading but also the choice of the right equipment. As heavy loads are mostly handled as individual, unique loads, the logistics cost and effort is rather high. To this point this is dealt with by specialized brokers who are able to book a suitable vessel and ensure the appropriate loading equipment is available. However, often the solution is not optimized and inefficient. In some cases, like e.g., wind energy platforms/blades, customized vessels specifically designed for a certain task exist. It has to be noted, that this exception is not in the focus of this paper as it presents a different set of challenges and they are still not the norm. In this paper the authors investigating existing challenges in this area to provide the reader a better understanding and a basis for the development of possible solution approaches.

In this paper, even though the focus was on providing a better understanding of the challenges and problems at hand when it comes to heavy load logistics, DfX methods were suggested as one possible way of tackling the identified issues.

Proper use, extension and adaption of DfL and DfT guidelines in early design stages seems to offer potential for a more integrated management of heavy load logistics. The DfL and DfT guidelines may not only optimize the product design to enhance the ‘shippability’; the amount of transport equipment, often specialized, may be reduced, and the safety of the load may be increased at the same time, thus reducing the transport and insurance costs.

As DfL and DfT support the overall logistics and transportability capabilities of the product design, further expansion of the DfX guidelines, regarding the special aspects of maritime shipping, have to be recommended for further research. This ‘*Design for Shipping*’ (DfS) could include the DfL and DfT aspects, while taking closer examination of the special issues of maritime shipping and heavy loads handling at the docks. The authors are currently working on developing a DfS set of guidelines to support the appropriate consideration of the logistics challenges in early product development phases including a mathematical model in order to generalize the findings. The results will be published in an appropriate archival journal within the next year.

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Managing Buyer-Supplier Relationships in the Maritime Engineer-to-Order Industry

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Abstract. Norway's shipyards have combined with a large network of maritime suppliers to become world-leading builders of offshore vessels for the oil and gas industry. This study analyzes a Norwegian shipyard and two of its suppliers in order to explore how such relationships are and should be managed. The paper presents an exploratory case study that mainly used qualitative data. The findings indicate that, by following the principles of the inter-organizational theories, the companies will reduce risks and create incentives for better performance. Implementing a real-time information sharing system between the buyer and supplier would improve both operational and managerial performance. The study also suggests that increasing value creation by leveraging the capabilities of the supply network and early involvement of suppliers will have the potential to increase this. Based on the discussion in this study, a performance measurement system for buyer-supplier relationships was developed.

Keywords: SCM · Inter-organizational management · Buyer-supplier relationship · Contracts · Performance measurement

1 Introduction

Norway's shipyards are considered to be world-leading builders of specialized vessels for the oil and gas industry. The shipbuilding process is project-based with an engineer-to-order (ETO) production type. Most projects have a unique technical solution, in which different work-packages are outsourced to other suppliers that perform the actual work [1]. Shipbuilding has similarities with construction, in that the shipyard serves as a construction site where all materials and labor are directed for assembly. The work is done sequentially and executed by different actors. This creates large dependencies between the different tasks and the suppliers; therefore, efficiency – and thus success in shipbuilding – relies on coordination and management of the various actors and activities. This paper addresses the relationships between a Norwegian shipyard and two of its suppliers. The main deliveries from these suppliers are services such as surface treatment and interior work. The supply chain of services is different from other supply chains as many decisions are made locally, and the variation and uncertainties in output are higher because of human involvement [2]. The four roles of supply chain management

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(SCM) in construction were defined by [3], and the present study focuses on the first of these roles, which is the interface between the supply chain and the construction site. The idea behind this role is reducing the cost and duration of site activities and ensuring dependable material and labor flows to the site to avoid disruptions. The purpose of the present study is to identify how buyer-supplier relationships in an ETO and construction environments are and should be managed. Part of this involves determining how companies can leverage the competences and capabilities of each of the actors in the chain to improve efficiency of the shipbuilding process and create an environment that encourages innovation and improvements. We have also tried to identify how the performance of such relationships can be measured and improved. This paper is a part of the SMART-prod research project conducted by one of the Norwegian shipyards and Møreforsking Molde AS.

2 Literature

The literature presents several areas related to buyer-supplier relationships, including SCM, inter-organizational (IO) topics, co-creation of value, contracts, and the measurement of performance in buyer-supplier relationships. One of the most significant paradigm shifts of modern business management is that individual businesses no longer compete as solely autonomous entities, but as supply chains [4]. Within IO topics, principal-agent theory, transaction cost theory, resource dependence theory, and the resource-based view have been used to highlight the different mechanisms that affect business relationships. Principal-agent theory identifies certain risk factors, based on human and organizational assumptions and how the possible negative effects such as adverse selection and moral hazard can be reduced [5]. Transaction cost theory aims to find the governance form that keeps the transaction cost at the lowest possible level [6]. Resource dependence theory proposes that organizations participate in exchange relationships to procure resources, as very few organizations are self-sufficient with regard to strategic and critical resources, and therefore seek to reduce uncertainty and manage their dependence on other companies [7]. The resource-based view looks at how one company's superior resources can create a competitive advantage [8].

It is not only dyadic relationship that is important, but also the context in which the dyad takes place. A company must relate its activities to those of other firms in order to enhance its performance. Combining and recombining the resources within the supply network creates and develops new dimensions of resources [9]. These are dynamic capabilities, which are defined as "the firm's ability to integrate, build and reconfigure internal and external competences to address rapidly changing environments" [10].

Several authors, especially within the IO field, have discussed value creation in buyer-supplier relationships, and IO theories are central to achieving this. Borys and Jemison saw value creation as a joint effort in which value is created in the interaction when one firm's competitive advantage is improved [11]. Dyer and Singh focused on value that can only be created through the joint idiosyncratic contributions of the specific alliance partners [12]. Ghosh and John considered value creation to be the increasing of revenue through positioning (what the company chooses to produce and deliver to the customer) and the company's resources, while reducing cost through an effective governance form [13]. Companies undertake value creation initiatives in order to achieve value creation. While Ghosh and John saw such initiatives as "in-house" activities that buyers want their suppliers to perform in order to achieve value creation at the relationship level [13], Borys and Jemison, as well as Hammervoll, argued that value creation initiatives are learning and development within the relationship [11, 14].

Contracts are also an essential element of a buyer-supplier relationship. The development of appropriate contracts is a key to creating an environment for innovations and continuous improvements. The contracts can be categorized as either discrete or relational. In discrete relationships, the organization's focus is on individual gains from the transaction, while in relational exchange the focus is on mutual benefits from a relationship on longer terms [15]. When it comes to duration, a short-term contract can have a negative impact on the supplier's motivation to invest in competence development. However, a long-term contract does not necessarily ensure an environment for continuous improvements and can dampen the innovation potential with the supplier as the supplier is somewhat protected from competition for the contracted duration [15]. Fixed price and payments for time spent and material used both have positive and negative sides. The latter will motivate the supplier to focus mostly on the contracted activities, and not on finding innovative solutions to improve efficiency. In fixed price contracts, the supplier is in a self-motivating situation to improve contract execution efficiency and focus on continuous improvements [15].

In order to track performance and be able to improve in IO relationships, the performance must be measured. As relationships of this kind are cooperative and flexible, measures of both qualitative and quantitative should be included [15]. Appropriate supply chain measurements should be selected and assessed to ensure that outcomes and strategy are aligned and fit the industrial application [16]. To develop such a measurement system for buyer-supplier relationships, the balanced scorecard (BSC) is used [17]. The BSC, which was originally based on a company's vision and strategy, measures the four following dimensions: financial, customer, internal business processes, and learning and growth. Brewer and Speh suggested linking this to SCM by changing the dimensions into financial benefits, customer benefits, SCM goals, and SCM improvements [18]. Important metrics for evaluating partnerships are the level and degree of information sharing, buyer-supplier cost saving initiatives, mutual cooperation leading to improved quality, the entity and stage at which the supplier is involved, and the extent of mutual assistance in problem solving efforts [19].

3 Research Methodology

This paper presents an exploratory case study of a Norwegian shipyard and two of its suppliers. The scarcity of previous research in this field in the Norwegian maritime industry created the need for an exploratory study. The purpose was to gain a better understanding of how IO relationships are managed in this industry and compare it to the literature within IO management. Based on an initial literature review, an interview guide was developed and interviews conducted. A second round of literature review and a final interview guide was then developed and further interviews conducted. Ten semi-structured interviews were carried out, six at the focal firm and two at each of the suppliers. To secure a reliable and valid research, several interviews were held with employees in different disciplines at both the shipyard and at the suppliers.

4 Analysis

The variation of output in service supply chains is higher than other supply chains due to the human involvement factor. Much of the work carried out in the shipyard is done manually, and leads to variation in the time spent performing the tasks. The flow of information is found to be one of the most important elements in the supply chain of services. The degree of uncertainty involved means that it is also necessary to have high levels of collaboration and transparency to improve operational performance and reduce disruptions in the chain [2]. It is vital to reduce the time to outfit and disruptions and make improvements in operations.

Adverse selection arises ahead of the time at which the suppliers are chosen. If the shipyard decided to switch suppliers, it will find itself in a situation with asymmetrical information and will not know whether the new supplier has the same capabilities as the old one. Moral hazard is linked to ongoing relationships, and the question is whether the supplier will actually deliver the effort that was agreed upon. The shipyard controls the quality of all the work done by the suppliers before an area or a task is approved. By paying a fixed price per square meter, the shipyard is able to reduce the risk as it will gain the supplier to have the work approved the first time.

These two types of relationships are regarded as hybrid governance forms [6]. This mode works well when the need for cooperative adaptations is vital for an efficient operation and there is a strong need for administrative control. Investments that are made to improve the relationship (for example, specific assets) are among the attributes of buyer-supplier relationships. Investments can reduce transaction costs, but the actors are vulnerable to a locked-in situation. Another attribute is high frequency and long duration. The suppliers work at the shipyard almost every day. Due to general practice, minor problems and delays are usually handled by the workers and the foremen and are not enforced by the contract. Another attribute is uncertainty about the conditions that will prevail. Because of the complexity of the ship, it is both difficult and inefficient to plan for every contingency. Errors in plans or the engineering will occur during the building process. To secure smooth operations in spite of these occurrences, a price is paid for work outside of the scope, which creates flexibility. The main attribute that raises transaction cost is the connectedness and dependencies between tasks and activities and between the different suppliers.

4.1 Network and Value Creation

Some examples of combining and recombining of resources were found in the study, such as the cooperation between the shipyard and the supplier of surface treatments and their paint supplier. The paint supplier uses the ships to test new types of paint, whereas the supplier performs this work and receives training from its supplier. This can be seen as a reconfiguration of resources, which is one of the clusters of dynamic capabilities.

Leveraging a capability involves replicating a process or system from one business unit to another or extending a resource into a new domain. The interviews revealed that the interior supplier uses a Microsoft Excel-based system to continuously track its current progress in each task it performs on a day-to-day basis. The supplier only uses this system to track its own performance and the information is only shared through the weekly planning meetings. By allowing the shipyard's planning department access to the system, the shipyard would be able to track the achievement of each task in real time. This would enable it to make better plans and operate more efficiently by avoiding delays, executing early starts and making more effective use of resources.

The third cluster of dynamic capabilities is learning, which allows tasks to be performed more efficiently as an outcome of experimentation. Through their work, the supplier's workers gain knowledge of the shipbuilding process. Without a system that captures the performing experiences, knowledge will be lost. Only a few of the suppliers participate in the project evaluation, which can lead to vital knowledge being lost.

Creative integration is the fourth cluster of dynamic capabilities. This concerns the ability to integrate the assets and resources of the firms, which results in a new resource configuration [10]. The shipyard may integrate more of the resources of its interior supplier, which is part of a multinational cooperation that is able to source many effective and high-quality solutions. However, the supplier rarely has the opportunity to discuss this due to a strong focus on the current project. Earlier involvement of the suppliers will make discussions of future improvements possible.

4.2 Contracts

The shipyard has framework agreements with both of the suppliers. These contracts last for three years at a time and stipulate all prices for the different types of work.

In terms of maintenance and service, it is suggested that the relationships should be relational rather than discrete, as the need for cooperation is high during contract execution [15]. The relationships studied here should be regarded as relational, as problems that occur in the project are usually solved without referring to the contract. There is a high degree of flexibility and the main focus from both parties is to get the work done and to deliver on time. The respondents claim that the complexity means that close cooperation between the parties and flexibility is essential. For additional work that is not planned for in the scope, the contract includes an hourly price to safeguard the suppliers against this risk.

With a three-year contract, the suppliers are involved in at least nine projects, which provides incentives to invest in competence development and new technologies to improve. As they have an outcome-based contract where prices are fixed, any improvements will reduce their cost per square meter. A long-term contract has the potential to reduce continuous improvements and dampen innovation due to protection from competition, which means that buyers must be safeguarded against this contingency [15]. The use of a fixed price per square meter is one way to dampen this effect, as it is in the supplier's own interest to improve, given that reducing their relative costs per square meter will increase their profit.

One of the respondents at the supplier mentioned that risks are improperly distributed in some areas and provide a specific example. The shipyard has an accommodation unit for the workers to stay in when working at the shipyard. The suppliers pay a fixed price to rent this unit. However, they do not guarantee places for all the workers, meaning that the suppliers might need alternative arrangements. Because the suppliers do not know whether they will need these alternatives, or to what extent and at what price, they must include a risk premium. This results in a higher price to the buyer and shows the importance of having a correct risk apportionment between the buyer and supplier, and of continuously reviewing these risks to improve the conditions for the relationship.

4.3 Performance Measurement

The literature review revealed the adaptation of BSC to SCM. To measure performance in buyer-supplier relationships, this has further been adapted (Table 1).

Table 1. Balanced scorecard adapted to business relationships.

Original	SCM	Business relationships
Financial dimension	Financial benefits	Financial benefits
Customer dimension	Customer benefits	Customer benefits
Internal business processes	SCM goals	Relationship goals
Learning and growth	SCM improvements	Relationship improvements

The level and degree of information sharing was mentioned as an important partnership evaluation criterion. The interviews revealed several challenges, including the delays caused by high interdependence between activities about which the suppliers are not informed. Measuring the number of times a delay occurs where information about it was not shared beforehand will highlight the importance of information sharing and can help identify where the delays originate.

Another partnership metric is mutual cooperation leading to improved quality. Delays are mainly caused by low quality of the steel. This problem needs to be solved in cooperation, as it is the shipyard that should control the steel. An example for the performance metric here is to measure the number of times finished work must be redone.

A further criterion is the entity and stage at which the supplier is involved. In particular, the interior supplier says it should be included at an earlier point in the presales phase in order to discuss solutions it can provide. This measurement could lead to improvements in terms of delivery of the work, products, and other solutions from the suppliers.

Buyer-supplier cost saving initiatives can be measured within the financial benefits in the BSC. A suitable measure is the number of hours paid to suppliers that are not caused by change-orders from the customer, but by delays or rework.

Finally, a measure is needed for customer benefits in the BSC. The ship-owner, which is the customer, continuously controls the work done through the project and approves and signs off areas that are ready. The ship-owner often finds something that must be repaired later and must therefore control an area several times. An example of a measurement for customer benefit could be whether the customer can sign off on the room the first time they control it. Figure 1 shows the specific BSC developed for measuring the performance of these two buyer-supplier relationships.

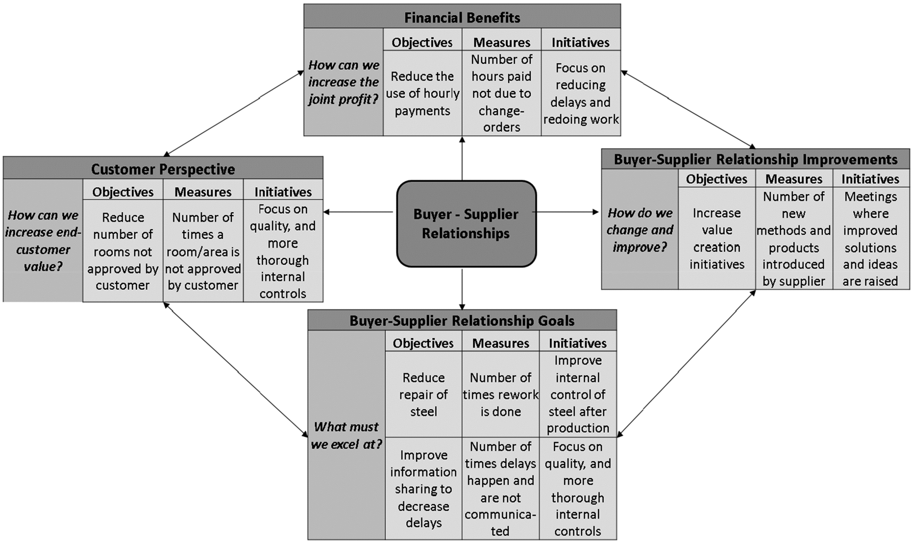

Fig. 1. Balanced scorecard for buyer-supplier relationships.

5 Conclusion

This study has explored the relationship between a Norwegian shipyard and two of its suppliers. The analysis showed that having all three actors share the same goals, as well as having control mechanisms and a fixed price contract, have mitigated many hazards and negative consequences related to buyer-supplier relationships. These features have also reduced transaction costs through investing in the relationship, and having relationships with a high transaction frequency and a long duration. Problems related to uncertainty in these kinds of relationship have been solved through having a fixed price for planned work, and an hourly price for additional unplanned or extra work. By doing this they will remain flexible, which is important to remain competitive in ETO production. The features discussed here are all important when managing any buyer-supplier relationship in an ETO environment. Some issues were found to be less optimal. One problematic issue was found in relation to communication and information sharing. Having shared access to the information systems the suppliers currently use could be one way to minimize the loss of important information. In addition, a clearer chain of information should be developed, and a higher focus on the importance of information sharing should be communicated widely. Information sharing and systems for achieving these points should have a high focus in the management of buyer-supplier relationships.

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Backsourcing and Knowledge Re-integration: A Case Study

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Abstract. Recently, the interest in the phenomenon of backsourcing has increased, which has been inspired by awareness of the real costs of global outsourcing and the importance of keeping manufacturing in-house or in geographical proximity. However, backsourcing research is still in its infancy. In particular, this strategy requires a successful knowledge re-integration process when organizations employ backsourcing as their new sourcing strategy, which is addressed in this paper. To expand the understanding of backsourcing, a literature review of this phenomenon is given, and based on findings from a case company in the Norwegian shipbuilding industry, we present critical success factors for knowledge re-integration when bringing manufacturing back in-house.

Keywords: Backsourcing · Global outsourcing · Knowledge re-integration

1 Introduction

Few logistic trends have caught as much attention from academics and practitioners as has outsourcing [1]. Today, there are indications that the complexity of outsourcing strategies will increase over time [2, 3], making insight of sources of competitive advantages and core competencies more important than ever. The growing amount of literature within SCM and outsourcing, stress that a number of global relationships and outsourcing contracts have failed to deliver on the promises they set out to achieve [4, 5]. Such experiences have made businesses reconsider their strategies, and instead started to recall value creation processes back in-house, which previously have been outsourced to third-party companies. The early academic literature within the field of backsourcing, claims that backsourcing can be motivated by changes in the environment, redefinition of the characteristics of the outsourced activities or dissatisfaction of the initial assessment that had led to outsourcing [2, 5, 6]. However, backsourcing may introduce difficulties to organizations when they make the decision to bring value creation processes back in-house that previously have been outsourced. The client and the vendor organization might have developed contradictory or incompatible routines, codes and cultures, which may hamper the process of the reintegrated activity [7]. The success of re-integrating an outsourced process will to a large extent depend on how

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well the organization manages to capture and understand what types of knowledge that needs to be re-integrated. The organization will have to take charge of their competences again, or develop new capabilities [8]. At the same time, organizations also have to make sure that the appropriate type of knowledge fits in the new structure. Consequently, backsourcing represents a significant challenge in terms of re-transferring and re-integrating knowledge, value chain activities and skills. Therefore, it is essential for the organization to (re)build a required structure and acquire or maintain employees with the right type of knowledge base. However, there is a conspicuous absence of studies on backsourcing in the literature [2]. Specifically, we need to understand the drivers of this strategy, and identify the challenges that come with this global-local shift, and furthermore, the risk of losing vital knowledge, especially in relation to core competences. These issues are addressed in this paper.

The rest of the paper is organized as follows: First, we present theory related to sourcing strategies, concluding with the need to studies of backsorucing, where the knowledge dimension is highlighted. We briefly address the methodology used in this study, and present the case company and the findings. Finally, we present the discussion, conclusions and contribution of this paper.

2 Literature Review

2.1 From Global Sourcing to Backsourcing

Global outsourcing, also referred to as offshoring, can be defined as the relocation of some organizational activities such as information technology, finance, human resources, back office etc. to a subsidiary or independent providers across national borders [9], which is different from an outsourcing strategy. In global outsourcing/offshoring strategies, the relocation of activities can be organized both within and outside the boundaries of the organization, encompassing both a captive model (offshoring to a new e.g. factory which is owned by the organization), and offshore outsourcing (offshoring to an independent third party) [7, 10]. Nowadays, global outsourcing of central supply chain activities as manufacturing is the norm. By adopting this strategy, and specializing on limited activities, outsourcing companies have to some degree been able to improve cost efficiency, and enhancing their core competence activities [11–13]. However, the actual benefits of outsourcing have been increasingly challenged, which have led businesses to embrace alternative methods of activity relocation. The different relocation processes which have emerged from the evolution of existing global value chain strategies, are referred to by relatively new terms such as; reshoring, backshoring, inshoring, nearshoring, re-insourcing and backsourcing. This includes relocation of value creating activities to a neighboring country or a recall of these activities back to their home country, as well as reincorporated into their focal firm where the latter is perceived as the latest phenomenon [2, 9, 14–16].

In this study, we make a distinction between the novel terms reshoring, backshoring and backsourcing since they seem to converge in different studies. Reshoring, also referred to as backshoring, is generally defined as moving manufacturing back to the country of its mother organization while others describes it as a location decision only, as opposed to decision regarding location and ownership [15]. Reshoring/backshoring is concerned with where manufacturing activities are to be performed, independent of who is performing the manufacturing activities in question. The new phenomenon called backsourcing, on the other hand, denotes a recall of activities back in-house that previously have been (globally) outsourced [7], with the goal of rebuilding internal capabilities [2, 5], and distinguishes itself from reshoring/backshoring by being depended of the ownership structures. The definition of [5] implies that the decision to backsource is made after considerations whether to extend, renew, renegotiate an existing contract, re-tend with another vendor, or bring back the operation in-house in order to rebuild own competences and capabilities regarding the specific process, which is the definition we support in our study.

While the scale of this relocation activity, especially the backsourcing phenomenon, still is modest, a large number of businesses aspire to have strategic IT and business process activities performed locally [5, 7, 17]. Comparable drawbacks have been debated in general, and it has frequently been claimed that outsourcing might have gone too far.

2.2 Sourcing Strategies and Knowledge

Knowledge is as a complex phenomenon with several different dimensions, and is regarded as the critical resource of organizations and economies [18]. According to Polanyi [19] knowledge is a process which extends itself through a wide dimension where at one extreme, knowledge is almost completely structured and explicit and therefore also available for others than the active knowers originating it. At the other end of the dimension however, knowledge is almost exclusively tacit, that is half-conscious and unconscious knowledge embedded in human cognition and action. Furthermore, the latter dimension of knowledge is characterized as being highly personal, abstract and difficult to communicate by verbal articulation, Moreover, the main source of tacit knowledge creation is a result of experiences performed by the individual(s). However, all organizations and supply chains contain a mixture of these dimensions, and their relative importance may differ. What is important in an outsourcing context is how external institutions interact with the internal organizational structures and activities to generate the right type of knowledge [18]. Local embedded knowledge is the collective form of tacit knowledge, which is based on shared perceptions and understanding of a context specific situation, which according to [18] facilitates effective communication so it can be maintained. However, embeddedness is often lost when crossing borders, as organizations encounter different cultural and institutional settings [18].

Given that a lot of outsourcing occurs across national borders, organizations are dealing with some sort of “knowledge exchange”. Backsourcing involves re-integration of knowledge, which is complex and hard to concretize. Hence, the success of this strategy will be depended on the ability to understand what types of knowledge needed to be re-integrated. Consequently, the organization has to activate or develop new capabilities [8]. Moreover, the re-integrated knowledge also has to fit within the new structure, since it probably will not return to the same situation. Acquiring or maintaining employees that possess the right type of knowledge base is therefore of significant importance when re-transferring knowledge [2]. Strategizing effective methods to transfer knowledge between people from different organizations, within different supply chains, all of which are carrying different knowledge platforms is not an easy task to manage [20]. With global value chains and global outsourcing strategies, this might even be more challenging since the tacit dimension of knowledge is not only related to the human dimension, it is also geographically and culture sensitive which makes it context specific [18].

2.3 Research Problems

While there is a huge amount of literature dealing with global outsourcing, there is a conspicuous absence of studies on backsourcing [2, 17]. Furthermore, previous studies are primarily focusing on cost considerations and secondly on location decisions [21, 22], rather than with the challenges that comes with this global-local shift and the risk of losing vital knowledge especially in relation to core competences. This study aims at filling these gaps in the literature firstly by studying the backsourcing decision process in order to understand the motivation behind this strategy. Secondly, we focus on the process of re-integrating knowledge. Finally, we wish to shed some light on other potential advantages experienced by pursuing a backsourcing strategy.

3 Methodology

The above research issues calls for a deeper analysis of the phenomena, making a case study design appropriate. According to Yin [23], the case study design is especially relevant the more the research question seeks to explain ‘how’ and ‘why’ some social phenomena works, and is particularly important for explorative studies aiming at developing theory [24]. Few studies have studied the phenomenon of backsourcing, and an explorative case design is therefore chosen.

According to Yin [23], the rationale of selecting a single case study, is that it represents the critical, unique, representative, revelatory and/or a longitudinal case. The case company in this study is one of the first members in its industry to implement this sourcing strategy, and have received considerable attention associated with this. Therefore, this case represents a unique opportunity to analyze the recent phenomenon of backsourcing decisions and implementation in-depth. The main data collection was performed through in-depth, semi-structured interviews of key personnel in the company. In addition, a study of published documents regarding the outsourcing decision in the case company has been carried out.

4 The Case Company

The case company in this study is one of the largest Norwegian-owned shipbuilding organizations and is part of the unique Norwegian maritime cluster, located at the Northwest coast of Norway [25]. The cluster has demonstrated its ability to innovate and grow, by continuously developing new business areas and expand its knowledge base. It is claimed that the close interaction between the different companies, which members whom are sharing knowledge is the main strength of the cluster, where the tacit dimension of knowledge is a critical factor [25]. However, even if local embedded knowledge is regarded as key to long-term cluster success and survival, we still see a greater tendency towards a local-global shift. Already during the 1990's, global sourcing of vessel construction was attracting more attention, where considerations such as cost efficiency had a strong focus, leading some cluster members to embark on an outsourcing strategy where the constructions of hulls was moved to Eastern European countries. Several companies pursued a strategy involving increased global sourcing, which had a direct impact on traditional production principles with regard to the actual construction of hulls. From being module based, to building the complete hull before equipping the vessels. The upstream side of the cluster supply chains was no longer limited to a local area, but rather to a global one. The implication of this new strategy was that these organizations had outsourced what they once regarded as parts of their core activities, such as the design and construction of complete vessels. This later expanded to also include other activities of the ship constructing process, like engineering. The decision to outsource these former core business activities were mainly based on cost considerations, as a way for the organization to maintain a competitive edge and concentrate on other core activities. Hence, the focus in the industry shifted from production towards their building capabilities in developing new technological solutions and knowledge of more efficient maritime operations. The case company in this study also embarked on an outsourcing strategy in the late 1990s, by offshoring steel production and welding work to external parties in Poland.

5 Findings

5.1 The Backsourcing Decision

The backsourcing decision in the case company was not a result of a deliberate strategic process, but rather a result of an incidental event. In 2004, the company was competing for a contract on six small vessels, where the customer required delivery only after 10 months, which was impossible to accommodate within the existing setup. In order to meet the customer's requirements, it was decided to modularize and construct the hull at their own slipway, which they reopened for this contract, as it had been closed since the late 1990s. This event took place about the same time as the Eastern European countries entered the EU, which opened up for free access and flow of labour, something that resulted in lower labour costs then before which gave them an advantage without using a third part company. Furthermore, as a result from this experience, being able to adapt to the constantly changed environment and to compete with low-cost countries, the company chose to learn from other industries such as the furniture- and automobile industry, where automation was the norm. By developing their methodology and their equipment so that they could handle larger and heavier modules than before, the company implemented a technology focused strategy and invested heavily in automation and robotics at all levels in their business.

5.2 Re-integration of Previous Outsourced Knowledge Activities

Even if this case company's backsourcing journey started as a coincidence, they now have a clear and deliberate strategy towards backsourcing even more capabilities.

During the backsourcing process, the case company had re-evaluated their core competence to also include steel construction as source of their most important competitive advantages. In fact, the company's technology focus by using robotics in production was a contributing factor for steel production to be considered as a part of the core business again. Further, it also revealed that domestic labor costs became less relevant through automation, since the company thereby managed to achieve reducing their working hours. Additionally, to be able to change their sourcing strategy they saw the need to keep their tacit knowledge within their own organization. The company stresses that the backsourcing operation would not have been achievable without any in-house competence. Furthermore, the time aspect was also claimed to be crucial. The longer time that has passed since the outsourcing decision, the higher the probability to lose manufacturing knowledge is. Hence, the most important staff that worked on building modules and had hull-expertise was still a part of the organization.

Moreover, the modularization process was found to be a significant competitive advantage for the company. Building the models separately, increased flexibility and reduced capacity problems, which led to increased efficiency. The process also became useful in relation to prevent suppliers to grow into competitors, since the complex product design (modulation) was an effective way to protect important knowledge.

However, they also saw the need to develop new capabilities since they had a desire to backsource while they still had access to their employee's knowledge. They re-evaluated the importance of engineering and considered it as a part of their core value, as a skill they needed to have control of. Further, in order to be able to backsource without increasing the total costs in a long-term perspective and at the same time be able to compete with low-cost countries, they need to continue to invest in automation and therefore renew their knowledge platform. Consequently, in addition to their existing knowledge dimensions, they also were in need of a more technological competence/skill set. In order to satisfy this acknowledgment, the company has implemented a deliberate HR-strategy in relation to these new requirements. By hiring people with the right type of automation know-how and then strategically encourage knowledge sharing within the organization through learning by doing or experience-based collective action between different disciplines within the different departments, the company have achieved to motivate their workers to adopt the new technical changes through better knowledge flow processes.

6 Discussion and Conclusions

The main finding in this study is that the presence of in-house organizational knowledge platform has been a vital criterion for backsourcing success in the case company. When embarking a backsourcing strategy, it seems to be of significant importance that specific know-how and tacit knowledge representing or being close to an organization's core competence, is kept within the organizations own boundaries. Aspects of a still existing knowledge base enabled a renewal of the knowledge platform by combining robotics- and automation skills with steel- and welding competence within this company. Furthermore, the stakeholders interviewed also acknowledged the need for shipbuilding knowledge as one of the main drivers to backsourcing.

One important success factor in the backsourcing process has been the time aspect. The less time the organization has had a particular activity outsourced, the easier it was to backsource, since the chances for important knowledge to still exist seems to be greater. Furthermore, the fact that the organization had remained relatively similar as it was before the outsourcing decision, facilitated the re-integration of knowledge through backsourcing. Even if the organization might have new structures and/or new leadership, it usually takes a long time to change culture aspects of an organization, which is of great importance when one is trying to manage and/or locate knowledge transfer processes. Moreover, the case company was operating in a knowledge intensive industry, where a strong dimension of tacit knowledge within the cluster have been built up over generations and was embedded in the industrial context [25, 26], which created an awareness of not letting traditional shipbuilding competence erode. This may have been a contributing factor to keeping the knowledge within the organization. Through the backsourcing strategy supported by modularization and robotics, the company achieved more flexibility and at the same time enhanced their ability to retain production and embedded tacit knowledge in Norway, while still achieving operational advantages.

Although the method limitation involving a single case study, we conclude that organizations should consider their manufacturing decisions from a wider perspective than simply make or buy decisions, giving more weight to supply chain issues as well as strategic factors concerning retaining and renewal of organizational knowledge platforms. Future studies should examine the knowledge re-integration process in more detail, and include several companies.

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Game Theory and Purchasing Management: An Empirical Study of Auctioning in the Automotive Sector

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Abstract. The purchasing function is assuming an increasingly relevant role within companies in the last decades, taking over the main responsibility for the costs of goods purchased as well as for supplier management. Its relevancy is due to the fact that purchasing can contribute to develop competitive advantages by aligning its strategy to the business strategy. Purchasing strategy is usually deployed per (purchasing) category and operationally executed in the so called tactical purchasing process. One key step is the negotiation/bidding where there is a lack of empirical research regarding the application of game theory. This paper contributes by discussing how game theory can be systematically utilised for designing negotiations (i.e. games) and getting more efficient results –by presenting an empirical study on automotive sector company, specifically on a bidding process for constructing a new production facility in Mexico.

Keywords: Purchasing strategy · Category management · Negotiations · Game theory · Auction · Automotive · Construction

1 Introduction

In the past few years purchasing (PU) has become a strategic business function due to the increased importance of supply chain management. Furthermore the PU function has the main responsibility for the costs of goods purchased (e.g. materials, products or services), as well as for supplier management [1, 2]. The purchasing capabilities (i.e. among others to foster close working relationships with a limited number of suppliers) can allow the companies to create sustainable competitive advantage by enabling to build and leverage beneficial inter-organizational relationships [3, 4].

It often appears that PU can contribute not only to the net income, but also to revenues. Since most companies spend more than half of their sales turnover on purchased parts and services, efficient and constructive relationships with suppliers are key to the company's short-term financial results and long-term competitive position. Additionally, PU policies can significantly improve sales margins through realizing substantial cost savings [5].

Strategic PU is defined as "the process of planning, implementing, evaluating, and controlling strategic and operating PU decisions for directing all activities of the PU

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function toward opportunities consistent with the firm's capabilities to achieve its long-term goals" [6]. PU objectives are based upon the company's objectives and could be related to e.g. cost reduction, reduction of supplier base or improving product quality. The PU objectives are later deployed into PU strategies and operative policies, in order to contribute to business success [5]. Therefore, one key element is to make sure the alignment of business and PU strategy, which are later deployed into categories [7]. As the results from both PU and supply management might have a direct impact on financial results of the company [8, 9], PU (operations) strategy must be designed to match and thereby support the business strategy [7, 10–12]. Moreover, different PU strategies are needed for different types of purchased items [7, 13].

Therefore, the research question is: how can–within Purchasing Management- the negotiation framework design profit from game theory in order to achieve more efficient results and therefore increase the firm's competitiveness?

This paper will firstly present a brief literature review and research methodology. The later part of the paper will introduce the case study and main contributions.

2 Literature Review

Category Management. Category Management (CM) is defined as "a process that involves managing product categories as business units and customizing them on a store-by-store basis to satisfy customer needs" [7]. CM shifted the traditional focus from brand management approach to a category management approach [14] and it was also adapted to categorize purchased items [4]. A category is defined as "a group of products which can be substituted for one another by a consumer" [5], as e.g. cereals or bakery. CM can be used as the basic unit of strategic analysis, which measures the competitive improvement on PU management [5, 16].

In order to define the strategies for each category, it's recommended to have systematic classifications [15]. One common approach used for it was developed by Kraljic [7] -so called "Kraljic's purchasing portfolio matrix"-. This matrix has become the standard in the field of purchasing portfolio models [17, 18].

Kraljic Purchasing Portfolio. The objective of (Kraljic's) purchasing portfolio matrix is to categorize every purchase into one out of four quadrants, according to their profit impact and supply risk [5, 7, 18, 19]: routine commodity, bottleneck, leverage and strategic. Each of these quadrants requires a differentiated purchasing strategy [5], i.e. a firm's supply strategy depends on the two classifying factors mentioned above.

One of the main critics to the Kraljic matrix is that it does not provide comprehensive strategies for all quadrants, as well as that only proposes options based on power/dependence for items in the strategic quadrant [19]. Although some authors expanded the original matrix and filled in strategies for other quadrants [20–22], there have been concerns that even one strategy per quadrant is not sufficient [19]. Other authors addressed some gaps related to developing the Bottleneck, Non-Critical and Leverage quadrants [19]. Gelderman and van Weele [23] have made valuable contributions by surveying a large number of cases regarding which strategies should be used for each Kraljic's quadrant, as well as by providing a more comprehensive version of Kraljic's initial matrix.

Caniels and Gelderman [19] have demonstrated that there can be a number of strategies for each quadrant, each of which serves a different purpose – to stay put or to move quadrants. It leads to another critic of the original Kraljic matrix – its simplicity regarding complex strategic decisions by basing them on 2 axes alone [23].

The Purchasing Process. The above defined (PU) CM is the basis for the strategic PU management and is operationally deployed as a sequence of tasks which are outlined on the (so called) tactical process [5]. This tactical (PU) process has been defined by Van Weele [5] as the sum of PU specification determination, selection of the best supplier and the preparation and conduction of any negotiation with the supplier in order to establish and sign legal contract. The key issue of effective PU decision-making is to guide the efforts of the various organizational parties involved so that an optimal result is achieved for the organization [5].

The selection of a supplier starts with a market research and a list of potential suppliers for a needed item [5, 18]. The next task is to reduce this list to a manageable short list considering suppliers' expertise, past performance, product designs, and quality, among others [18]. In order to select the best supplier, there are two ways: competitive bidding and negotiation. [5, 18] Competitive bidding means situation where a buyer asks for bids from different suppliers, creating a level playing field. One supplier will be selected with whom the delivery of the product will be negotiated [5].

Game Theory Contribution to PU Management. Dixit and Skeath [23] define a (strategic) game as "interactions between mutually aware players and decisions for action situations where each player can choose without concern for reaction or response from others". Moreover game theory (GT) can be explained as a compilation of analytical tools designed to help us understanding the phenomena that we observe when decision-makers interact [24]. The games can be classified depending on three dimensions [24]: (1) Noncooperative and Cooperative Games, (2) Strategic Games and Extensive Games and (3) Perfect and Imperfect Information.

Within GT, Nash equilibrium can be defined as a "list of strategies such that no player can get a better situation by switching to other available strategy, while all other players adhere to the strategies specified for them in the list" [23, 25].

One standard way of applying GT within PU processes is to allow qualified suppliers to bid in auctions [26]. A wide variety of companies applies auctions to the regular negotiations in order to keep best supply-market pricing [26].

In order to conduct a proper auction, each supplier has to be qualified and approved as a suitable provider in case of winning the awarding. Once a proper supply base has been defined, the auction gives the chance to the buyer to conduct the awarding in a fast way to achieve the optimum prices [27]. There are different kinds of auctions: in a forward auction the bidders are buyers and the auction manager is a seller. In a reverse auction the suppliers are who do the bidding and the auction manager is a buyer. A further categorisation depends on if it is ascending or descending, and if the bid is made by the auction manager or bidders (English, Dutch or Japanese) [27].

Even when it is known that reverse auctions in fact “work” to save organizations time and money in their purchasing negotiation, there is few literature in the academics regarding to the specific “whys” and “hows” of this success [28]. As Tassabehji [29] had observed “the study of e-auctions is still in the early stages and there remains a dearth of substantial empirical research and much more to uncover”. Mithas et al. [30] discussed that there has indeed been lack of academic research in the area of reverse auctions. The limited availability of data and the proprietary in nature of them [31] could be reason for the limited research in the use of reverse auctions in the B2B (business to business). Additionally, since only few purchasing professionals have actually used reverse auctions, the empirical research is complicate [32]. The studies that have been conducted have largely been either simply descriptive or prescriptive in nature [33]. Thus, studies that provide more details on the actual workings or reverse auctions will be of great interest to both practitioners and academicians in field of purchasing management.

3 Research Methodology

The research is based on a literature review and a case study following the constructive research (CR) methodology. CR is an approach that aims to produce solutions to explicit problems and is closely related to the concept of innovative constructivism [34]. This approach develops an innovative solution, which is theoretically grounded, to a relevant practical problem. An essential component of CR is the generation of new learning and knowledge in the process of constructing the solution [35]. The case study as such is exploratory in nature. Two of the main researchers have been actively involved in the project transition of the case company. Thus, facets of action research (AR) have also been deployed. In AR both researchers and practitioners are actively engaged in solving a client-initiated project dealing with a certain business problem [36–38]. The company selected for the case faced the challenge of increasing the competition in a given negotiation, which counted for being the second highest invest of the company ever. The company wanted an innovative approach for assuring a highly performing negotiation, providing the company the highest possible competition to its awarding process –an interesting case for academics in order to develop, structure and test new knowledge.

The studied case implied the design, construction and execution of a GT based awarding process for the construction of a new industrial facility in Mexico for the client company (Spanish company in the automotive sector). The main data collection and observation period lasted for 4 months during end of 2014 and beginning 2015: it consisted of meetings, semi-structured interviews and company internal documentation, as well as direct participation in the case. The researchers attended several preparatory meetings with the CEO, Purchasing Manager, Chief Engineer with the Project Manager of the new production site in Mexico. The first phase of the case research included meetings and interviews that focused on understanding the challenges for the company within the global footprint of the automotive industry and the strategic reasons for implementing a new facility in Mexico, as well the factory role within the company’s network. The second phase coped with the game design: it started with joint workshops of researchers and practitioners to develop standard technical project definition which will be the standard base for the later awarding process. Additionally researchers together with Purchasing Manager and Chief Engineer developed a common understanding of the general awarding process and expected outcome from the design and execution. The final outcome of this second phase was the detailed design of the "game" (i.e. awarding process), which included the identification of players, set the rules of the game –especially regarding know/unknown information and awarding decisions- and the operative plan for executing the game. The third (and last) phase included the real supplier market research, which had two main qualification waves, and the final execution of the designed game, i.e. awarding process.

4 Case Research

The case company is a Spanish Tier-1 and Tier-2 automotive company which supplies to important OEM companies (e.g. PSA Group, Mercedes-Benz, Volvo, etc.) and Tier-1 corporations (e.g. Robert Bosch, TRW, Continental, etc.) and is specialized in metal forging for safety parts. The case company is increasing its global footprint by opening a new facility in Mexico, which is aimed to satisfy regional demand from already established OEM and Tier-1 customer in Mexico and USA. The researchers were involved for supporting the company in the design and execution of the negotiation for constructing the new factory facility in Mexico during 2015. The construction of the new facility was clustered within the category "Facility Construction".

The whole negotiation design and execution followed a construct which assured a systematic approach:

(1) In order to have a first proper negotiation design, the initial step was to assess the purchasing strategy for the category and to analyse the profit impact and supply risk by utilizing Kraljic's purchasing portfolio matrix. Semi-structured interviews with the management team as well as group discussion were carried out. Specifically for the positioning of items (the measurement), i.e. for the process of reviewing the positions in the matrix and a process of reflection on the consequences, the consensus method as described by Gelderman and van Weele [10] was utilized. The managed category (i.e. construction of the new facility) was the second highest invest ever for the company and the supply risk was defined as low. Therefore the category was position in the "Leverage" quadrant (Fig. 1):

(2) Taking into account the quadrant and the possible strategies [19–23], the researchers and case company agreed that the suitable strategy should be "Exploit buying power". Individual semi-structured interviews were carried out, mixed with group discussions.

(3) The initial negotiation design demanded that the highest number of suppliers should take part in the negotiation process. In order to make bidding comparable, a standard technical specification (including drawings, technical requirements, etc.) was developed by an independent architect – what created the basis for making all bids comparable. After contacting 16 companies from Spain, Mexico and USA, 9 companies sent an initial project offer. A first filter was executed by

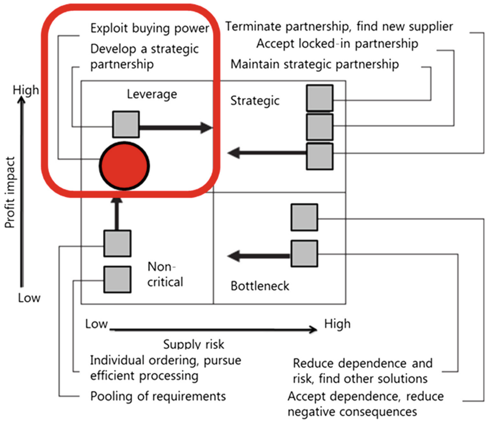

Fig. 1. Purchasing strategies for all portfolio quadrants, based on Kraljic's matrix [7, 20–22]

the company utilizing a priorisation matrix developed by the researchers (including criteria as: cost, offer quality, technical discussions, financial statements, etc.).

From these 9 companies, only 4 companies were selected and invited to participate in the (final) negotiation/awarding process (i.e. game).

(4) The negotiation (i.e. game) design defined the following game rules components, specifically: (a) Non-cooperative game, only one supplier will be awarded; (b) the whole process will have imperfect information; (c) two-phase game: the first one will be a (no electronically managed but manually) reverse Japanese auction. The best supplier in the first phase will be the first supplier starting the second phase (and subsequently). The second phase has been designed as an extensive game, where the supplier is offered the awarding under certain conditions and should either accept or reject it. If these conditions are accepted, the supplier is awarded, if not the subsequent supplier has the same chance to win the awarding.

The 4 suppliers were contacted for confirming their participation in the final awarding (on 2015, March 11th) and for being available the day before in order to explain the game rules extensively. Finally one out of these 4 suppliers did not accept the invitation for participating in the final awarding. The final negotiation started with 3 suppliers playing a reverse Japanese auction, which lasted for 4 h and had 20 bidding rounds. After the first phase, 2 suppliers were selected for the second phase of extensive game. The supplier with the lowest bid in the first phase had the first chance to meet the case company and received a binding proposal for winning the award. In fact, the first supplier accepted the conditions and the process finished. Interestingly, the supplier qualified third in the first phase (Japanese reverse auction) gave an (economically) improved offer to its bid in the auction, but the case company did not accept it since it was out of the game rules.

(5) The awarded supplier was immediately offered a legally binding contract, which was signed by the supplier and the case company, finishing the awarding process.

The economical result of the awarding process showed a cost reduction of 24% (the saving counted for approx. 20% of the yearly EBIT of the case company) comparing the construction cost agreed in the contract vs. lowest bid provided among the 9 suppliers which sent project offers in the initial phase.

5 Contribution

This case research shows that GT could help PU practitioners to conduct more efficient negotiations, by increasing competition among suppliers. Specifically, this research showed that a proper game design is a crucial element for the latter execution, especially for giving players clear information regarding the game rules. Additionally our case illustrates how business strategy is deployed into PU strategy by means of CM. The presented CM tools are the later basis for a proper awarding process, i.e. negotiation process is fully aligned to the company's strategy, directly contributing to its competitiveness. We call for further empirical research of GT applied to PU management, enriching the understanding of GT influence in real life games. Additionally more research in the CM and its deployment in negotiation techniques could provide interesting insights for the PU strategy field.

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A New Value Stream Mapping Approach for Engineer-to-Order Production Systems

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Abstract. Companies seeking to implement lean practices in engineer-to-order environments experience major difficulties due to a high degree of non-standard products and non-repetitive processes. Current lean methods need to be further developed to be more efficiently applied in manufacturing environments with high variety and complexity. This paper presents a new approach for value stream mapping adapted to engineer-to-order production systems. The approach combines the classic value stream mapping approach with recent works dealing with lean methods in high mix and complex production systems. Also, it proposes a stronger focus on the choice of location of the customer order decoupling point compared to previous research.

Keywords: Lean manufacturing · High-mix/low-volume manufacturing · Customer order decoupling point

1 Introduction

Engineer-to-order (ETO) manufacturing environments are typically characterized by high levels of product and process variation, high product complexity and deep product structures, and low production volumes. Each new order involves product design and development based upon customer specifications. Moreover, design, delivery speed and flexibility are typical order winners and the customer order decoupling point is typically positioned at the very start of production [1].

It is well known that companies that seek to implement lean practices in production environments that involve a high degree of non-standard products and non-repetitive processes, experience major difficulties. Current lean methods therefore need to be further developed before they can be efficiently applied in manufacturing environments with high variety and complexity [2, 3]. Despite the growing trend towards increased customization and personalization that imply enhanced variety and complexity in manufacturing, research on the implementation of lean approaches in ETO settings is scarce [e.g. 3, 4]. In this paper focus is on value stream mapping (VSM), a simple and well-known approach to achieve lean flow. The method is developed for analysis and improvement in discontinuous flow line manufacturing environments [5], and is most

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suited for linear product routings and standard products. VSM has three main drawbacks for ETO manufacturing:

- The method does not address the challenges of identifying and mapping value streams in manufacturing environments where the product structure are complex and routings are intertwined.
- Only basic guidelines and techniques for developing lean flow for standard products are included. Techniques that are more sophisticated [4, 6] are needed before the method is applicable for customized manufacturing.
- The Customer Order Decoupling Point (CODP) is merely considered as a frame condition for future state design, and how to position the decoupling point is not sufficiently addressed. Positioning the decoupling point is crucial for the performance of engineer-to-order manufacturing and should include an assessment of both engineering and manufacturing lead times.

The purpose of this paper is to create a new value stream mapping approach for the design of flow oriented ETO production systems. The new method integrates the classic VSM method with recent techniques and methods for creating lean flow in high variety and complex manufacturing environments.

2 Methodological Approach

A review of relevant literature in the lean manufacturing field was carried out with focus on the design of lean production control systems in ETO environments. Several relevant studies were identified and used as a starting point in the development of the approach with a particular emphasis on Duggan's mixed model approach [4] and the improved VSM for complex manufacturing [7]. The identified procedures and processes were reviewed and relevant aspects were selected. Several drafts of the approach have been iteratively discussed and tested during a two-year period in a case company. Since the main focus of this paper is to present the proposed approach, its application in the case company is dealt with only to a limited extent; a simplified version of the current state map that was developed in the case company is included in the paper.

The case company is an ETO manufacturing company of heavy and complex ship equipment. It was critical to get access to in depth and detailed insights of their operations as well as to quantitative data. Moreover, the involvement of company representatives in discussions during the development process has been important.

3 Review of Literature

The literature review identified a set of relevant previous works that suggest adjusted lean approaches for various types of high mix low volume manufacturing settings, Table 1. These methods are briefly described in the text below. Common for several works is that they are based upon the classic VSM approach [5].

Table 1. Summary of the literature review

Approach	Manufacturing setting	Type of method	Focus
Mixed model value streams [4]	High variety or mix of products or product variations	Step-by-step process and questions	VSM, future state mapping
Improved VSM [7]	Products with non-linear value streams	7 step procedure, iterative process	VSM, critical path, temporized BOM
Value network mapping [8]	Products with dissimilar routings that share common resources	6 stepwise approach	Current state mapping
VSM [9]	MTO products, job shop environment	Guidelines, options, data requirements	Current state and future state mapping
VSM [10]	High mix, low volume manufacturing, job shop	5 step methodology, 10 questions	Future state mapping
VSM [11]	Batch-of-one environments	9 step procedure	Value stream monitoring
Pacemaker, bottleneck, CODP [12]	MTO and MTS	3 steps/guidelines	Future state VSM

In brief, several relevant works are identified that deal with MTO and high mix/low volume environments although there are few studies dealing explicitly with specific ETO settings. VSM constitutes a core framework in several studies. There are variations regarding their focus on current state and future state mapping. Several studies present adapted guidelines and stepwise methods. However, few address the choice of CODP location, which is natural as lean implies positioning the CODP as far upstream as is possible in the relevant value stream without interfering with resources shared with other value streams.

4 The Suggested Approach

The proposed approach for value stream mapping in engineering to order manufacturing is based upon the classic VSM approach [5] and is extended by the other existing studies that have adapted methods for ETO and similar manufacturing situations. The approach is divided into two main parts; the first part (step 1–4) aims at mapping the current state of the value stream while the second part (step 5–11) concentrates on designing its future state. It comprises major steps that may be carried out in a sequential order. However, depending on the complexity of ETO production system, it may be necessary to carry out each step in several iterations as well as to go back and forth between steps.

4.1 Step 1: Select Product Family

This is a critical and challenging task in ETO due to the high complexity of products and irregular process routings. In high-variety/low-volume manufacturing, multiple products with different demand rates and different operations are produced in the same value streams [13]. The product family is essential for defining an appropriate overall scope of the value stream. A product quantity analysis visualizes the product mix in a chart sorting products in order of decreasing production quantity or selling revenue; high volume or high revenue value streams are prioritized [7, 10]. Process routings are mapped to group products according to process commonality in the plant, with focus on downstream processes [4]. A product-process matrix is drawn to make groups of products with the same processing steps; at least 80 % process commonality is required [4, 7]. A work content matrix is drawn to analyze total operator time variation; less than 30 % process time variation is required [4]. Products are combined, sorted and revised in several iterations until a suitable family for the value stream is selected.

4.2 Step 2: Identify Critical Value Stream

The main critical value stream is a key component branch of a product, typically the processing sequence responsible for the total frame of production time of that product [7]. The bill-of-material (BOM) is mapped for typical products and the lead time is analyzed for each branch. Components on the critical path are identified [11]. A temporized BOM is drawn to graphically visualize the maximum length of lead time needed in the global value stream of supply and production [7]. Shared resources on the critical path are also identified with a distinction between internal and external sharing i.e. when machines are used for different components of the same product, and machines are used by different product families [7].

4.3 Step 3: Identify Customer Order Decoupling Point

The inventory locations are analyzed to identify the CODP position of the critical value stream. In an ETO situation, the CODP is typically located upstream in the production process [1]. The CODP is also related to shared resources and bottlenecks [12]. In ETO, the order-based engineering lead time and the order-based production lead time are parts of the delivery time and need to be addressed in the CODP analysis. The CODP is positioned upstream when a key branch of the product includes new elements that are engineered to order.

4.4 Step 4: Map Critical Value Stream

The current-state-map is drawn based upon the VSM modelling framework with standard icons and metrics [5]. A high level value stream map is needed since demand rates, process routings, and work content may vary for different products in the value stream [4]. Shared machines, bottlenecks and insertion points where secondary branches merge with the critical value stream are defined [7]. Bottleneck resources that cannot be eliminated are managed to ensure balanced flow [5]. An example of a current state map that represents a simplified map of a critical value stream of the case company is shown in Fig. 1.

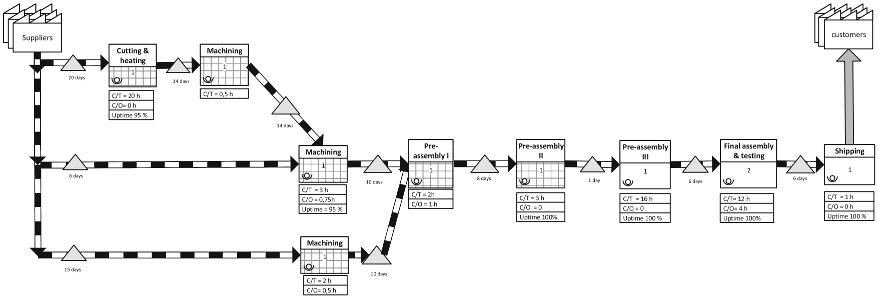

Fig. 1. Example of a current state map of a critical value stream

4.5 Step 5: Calculate Average Takt Time

Takt time is defined as the customer demand rate or rhythm [4]. Since a pure takt time control principle is not considered to be appropriate in high-variety, low-volume manufacturing [6], an average takt time is more appropriate for ETO production [13]. The average takt time for the critical value stream that allows for variations is calculated. In order to deal with demand changes, various takt modes are defined based on demand and resources [4].

4.6 Step 6: Create Continuous Flow Wherever Possible

To create continuous flow, all the resources needed to perform consecutive activities on the family are dedicated in a set of adjacent cells or lines. The level of process completeness per cell depends on distances between machines, imbalance in cycle times, use of shared resources, and differences in operator skills [4, 14]. Where one-piece flow is not possible, activities are connected into FIFO lanes [4]. FIFO lanes are created between all cells downstream of the CODP. FIFO lanes can be used to create flow between cells/ resources that are dedicated to the family, but a single FIFO lane will create flow disruptions if used alone to connect resources that are shared between different product families [4].

4.7 Step 7: Define the Customer Order Decoupling Point

A feasible CODP is selected that is the most efficient in terms of combined requirements for customization and short delivery lead-times for the value stream. Since the delivery lead time includes the order-based engineering and production lead time, the CODP is positioned upstream when a key branch of the product includes elements that are designed and/or engineered to order. ETO products typically consist of standard components, modules, and sub-assemblies that do not require engineering lead time, elements where the design can be easily modified and some elements that need an extensive engineering lead time. A range of possible inventory points in the sequence of activities at each key component branch are possible CODPs that can separate the order driven flow from the speculation or pull driven flow, but only a few of them can be regarded as feasible CODPs. Feasible CODPs typically have a natural breaking point that correspond to inventory points with the same production lead time in all key branches of the value stream, and allows engineering modifications to be finished before any production activities start [15]. Other factors to take into consideration are demand volatility and volume [1]. A CODP is chosen that minimizes delivery lead time for a given level of customization.

4.8 Step 8: Create Pull Where Continuous Flow Cannot Be Extended

Critical points in the value stream, where continuous flow ends and pull must begin, are identified. Pull through supermarkets are often required to buffer between cells with resources that are shared between product families, cells that are located far away from each other and cells with resources that are too unreliable to couple direct in a continuous flow [5]. Many parts, modules and subassemblies in a customized product are standard and can be handled through pure supermarket pull system [16]. Various parts are classified into runners, repeaters, and strangers; runners and some repeaters are typical candidates for a pure pull system [17]. Pure pull is not applicable for custom parts or for strangers, while pull mechanism such as sequential FIFO, generic Kanban, Conwip, and Polca may be used for such parts [18].

4.9 Step 9: Define the Pacemaker

The production process that will receive a schedule and set the pace for the entire value stream is defined. The pacemaker process must have equipment dedicated to the product family and is usually in the form of a cell where continuous one-piece flow exist [4]. The pacemaker sets the pace upstream by withdrawing parts through pull systems and downstream by regulating the release of work to maintain FIFO processing flow to the customer. A resource that is shared with other product families cannot easily be a pacemaker because the flow often is too disruptive to follow a takt. In ETO, the position of the pacemaker depends on the position of the CODP because the schedule or work instruction for customized products needs to be sent to the first cell after the CODP [12, 16]. High-variety/low-volume value streams tend to have an imbalance in capacity between different cells. An obvious bottleneck resource will determine maximum throughput and can be a pacemaker candidate [19].

4.10 Step 10: Level the Production Mix

The production of different products is distributed evenly over time. The time intervals that every regular product in the family will be able to run through are specified (Every Product Every Interval). A small interval as possible is defined in order to produce the right mix of each part number to satisfy customer demand, and not create excess inventory that is wasteful [5]. Obtaining short intervals mean levelling the mix of products that will run through the pacemaker. For high mixes of product variants, all products are not ordered in every time period. In high mix value streams a level pattern based on product sub-families (Every Family Every Interval) is created [20]. Sub-families are further segmented into runners and strangers. Each runner sub-family represent a fixed time period in the interval. Stranger families are grouped to form one or more periods in the pattern.

4.11 Step 11: Level the Production Volume

The production load on the pacemaker process is divided into small consistent amount of production [5]. In high-mix/low-volume manufacturing, the product work content will vary and risks slowing down the pacemaker. If the bottleneck process is different from the pacemaker, capacity constraints at the bottleneck must be taken into consideration in the pacemaker schedule [12]. Orders are thus broken down into equal time increments of work (pitch) based on the bottleneck capacity [16]. In high mix environments the pitch increment is defined to include variations within the family [4]. In order to level the work volume, products are built in a fixed sequence starting from low to high cycle time, products are built ahead in a FIFO lane, products are stored in supermarkets, or labor is added for products that exceed takt time [4, 16].

5 Conclusion

The literature on ETO adjusted lean methods is scarce and companies meet major challenges when implementing lean in non-repetitive production. We have used the VSM method as the overall structure, and have developed a more comprehensive method that can be used in ETO environments. We have reviewed recent literature on how to create a lean future state in high mix low volume manufacturing. For each step of the original VSM method, we address the specific challenges related to high mix - low volume environment, and propose extensions and adaptions to the original method in order to overcome these challenges. The CODP is important, and we have extended the original method with two extra steps to identify the current CODP and determine the future CODP. The method combines various lean methods available in literature that are adapted to non-repetitive manufacturing settings. In contrast to these methods, it highlights the position of the CODP in the current state and future state maps. Further research is needed to refine and validate the method in real life settings. Therefore, further work is planned to utilize the general method to create continuous flow in the case company.

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Detecting Early Warning Signs of Delays in Shipbuilding Projects

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Abstract. Ship design and construction involves numerous activities that have to be effectively performed, coordinated and integrated. Various elements can influence the effectiveness of the process due to projects' large number of stakeholders and the high level of uncertainty. One of the most challenging issues is the delay in product delivery. However, the elements which might result to delay do not develop overnight and there might be early warning signals addressing that the delay, is likely to happen. This paper discusses that by following an early warning procedure, it will be possible to identify possible early warning signs of potential problems which might cause delay. These signs can provide an aid for the project team to take actions before the problem reaches its full impact, thus delaying the project delivery.

Keywords: Early warning signs · Ship building projects · Delays · Proactive project management

1 Introduction

Despite the application of project management tools and techniques in projects worldwide, still a large number of projects fail to meet their objectives. There is a consensus among authors that the growing technology, global economy and the nature of information technology is bringing more complexity to projects and their environments. The increase of complexity is partly the cause of projects going wrong and difficulty in bringing them to successful completions (Williams 2002). Shipbuilding is an interesting industry in which highly complex products with tight delivery times are produced mainly in project organization forms (Koivunen 2007). It is a complex process that involves numerous related activities, such as design, tendering, contracting, engineering, procurement, production, commissioning, delivery, and guarantee service (Andritsos and Perez-Prat 2000). In the recent years, the ship design and construction community has become increasingly aware of the significance of the operational and managerial side of such activities if they are to be effectively performed, coordinated and integrated (Semini et al. 2014). The large number of stakeholders involved within the process and the complexity of the product creates a potential for delay in shipbuilding projects.

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Based on studies on the history of failed or troubled projects, it is obvious that projects do not result in problems overnight. Usually, they proceed from “green,” to “yellow,” to “red,” and during this process early warning signs can indicate if a project is on its way to failing or if urgent changes are needed (Kerzner 2011). With hindsight, project managers are often able to point out the most likely factors leading to project failure. One approach towards prevention of project failure or deviation from the main goal is to detect possible signs of project problems in early stages of projects. These signs are referred to in the literature as Early Warning (EW) signs.

Clearly, the higher the risk of upcoming events, the more crucial it is to be able to predict and take actions in order to decrease the threat of failure. There is a need for more careful planning, close monitoring, and strict control of large, high-risk projects (Couillard 1995). Identification of EW signs and relating them to the appropriate project problems and their causes can contribute positively to the prevention of undesired consequences (Nikander and Eloranta 2001).

This paper addresses the possible delay factors within shipbuilding projects in general and the possible EW signs of the elements which might cause delay within these types of projects. It also suggests that applying an EW procedure within shipbuilding projects can contribute to prevention or lessening the impact of the delay factors on the project delivery time.

2 Shipbuilding Projects

The main ship design and construction activities are often categorized into two categories including acquisition/information processes and production processes (Andritsos and Perez-Prat 2000; Gale 2003). Acquisition/information processes are the non-physical activities performed prior to production, such as planning, design and acquisition. They generate an enormous amount of information which needs to flow seamlessly across units, departments and companies. Production processes carry out the physical transformation of materials, components, and equipment. In Semini et al. (2014), we illustrate how the different activities in the ship design and construction process may be organized in different ways depending on the degree of customer involvement. Figure 1 shows the typical approach the Norwegian shipbuilding industry uses to build highly customized ships, where most activities are carried out based on a specific customer’s requirements and expectations.

Usually, the different activities are not performed by a single company, but a network of geographically dispersed parties with different roles and interactions. Even a single activity, such as engineering, can be split among several parties. The degree to which each party is involved in the various activities differs from project to project, and so does the level of integration and coordination between them. This is a characteristic of ship design and construction.

The parties with the most significant roles in carrying out the ship design and construction activities include the ship designer, shipyard, ship owner, main equipment suppliers and the classification society. Each of these parties has tasks and responsibilities in one or several of the activities presented in the previous section. The level of

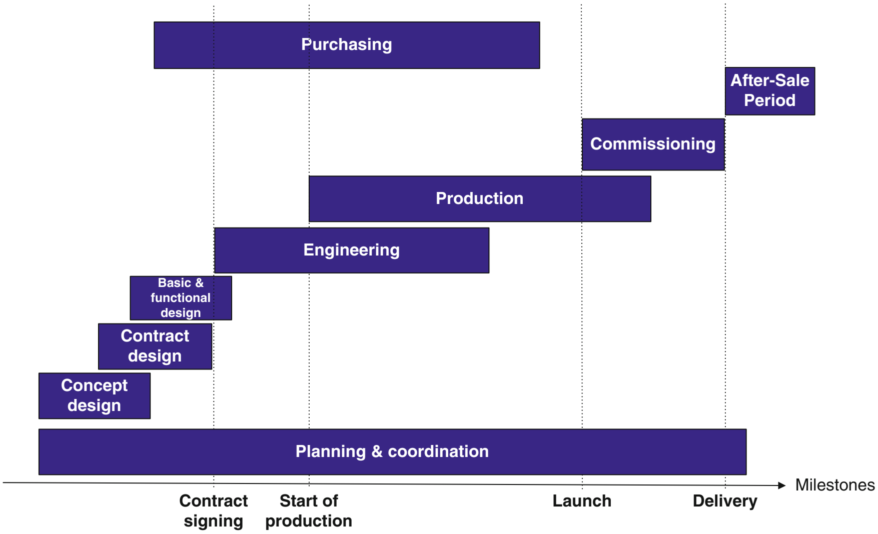

Fig. 1. The main activities in the design and construction of a customized ship (Semini et al. 2014)

integration between them varies from project to project. Sometimes, several parties belong to the same company or group, but they are often independent.

The next section deals with the uncertainties involved with different stages in the project which might result to delays and extra costs in shipyard projects.

3 Delay Factors in Shipbuilding Projects

The occurrence of delays is a major problem that impacts the performance of a company and its supply chain in Engineering to Order (ETO) projects in general (Mello 2015). Long delays and reworks are common in the large engineering projects since these types of projects require several refinements during the implementation stage that increase lead times and costs (Caron and Fiore 1995). The delay might occur in different stages within the project life cycle due to various reasons. The causes of project delay also varies considerably in different projects due to the existence of diversifies types of uncertainties (Elfving 2003; Gosling et al. 2012). Uncertainty is an important factor which has been recognized as one of the major factors leading to delays in complex projects (Mello 2015).

Although all the project stages are interrelated and delay in one stay will eventually result in delay in the subsequent stages as well, however according to Mello (2015), one of the most important milestones within a shipbuilding project is when the vessel is scheduled to enter into operation. At this point, the ship owner puts pressure on both the ship designer and the shipyard to deliver the vessel as soon as possible in order to avoid penalties from the oil and gas company. Since companies are most likely not able to effectively coordinate the project, problems arise causing rework and delays which increase the lead time. Mello (2015) in his work mentions a number of factors which contribute to delay within the project. These factors are seen as uncertainty elements which if identified and managed timely enough and acted upon accordingly might result in avoiding the delay. The uncertainty elements also referred here as delay factors and the specific stage where it belongs to are mentioned in Table 1.

Table 1. Uncertainty elements within the project lifecycle (Based on Mello (2015))

Uncertainty elements	Relevant stage
Product changes after the production process starts	Manufacturing and assembly
Delay in delivering the detailed engineering drawings	Engineering
Occurrence of unpredictable events	Whole life cycle
High number of quality problems	Engineering, manufacturing
Self-over-evaluation of partners on their skills	Concept design, engineering
Delay to deliver equipment	Procurement
Poor quality of design alternatives	Concept design
Poor risk management	Project planning and detailed design
Inadequacy of supplier competence	Procurement

4 The Concept of Early Warning (EW) in Projects

The general idea of EW is a broad concept. It applies to almost any area where it is important to obtain indications as early as possible of some development that in the future will become clearer, usually of a negative nature. The concept of EW in a management context was first discussed by Ansoff in 1975 and was later supported by Nikander (2002) in his doctoral dissertation. Ansoff stated that strategic surprises do not appear out of the blue, it is possible to predict their occurrence by the aid of signs which are called weak signals. A weak signal was defined by him as "…imprecise early indications about impending impactful events…all that is known is that some threats and opportunities will undoubtedly arise, but their shape and nature and source are not yet known" (Ansoff 1984).

In Nikander's words (2002), "an EW is an observation, a signal, a message or some other item that is or can be seen as an expression, an indication, a proof, or a sign of the existence of some future or incipient positive or negative issue. It is a signal, omen, or indication of future developments". In his study he devises a preliminary model illustrating the character of EW observations (See Fig. 2).

This model sees project events as a time-bound consecutive stream of events. At a given moment, information about this stream can be obtained (e.g. EWs of potential future project problems). This information is processed and responses are required in order to influence the flow of the project. A crucial factor in choosing a response appears to be, according to Ansoff (1984), time available for responses before the potential problem significantly impacts the project.

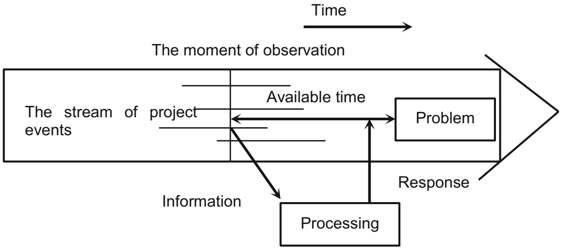

Fig. 2. Preliminary model illustrating the character of the phenomenon of EW (Nikander 2002)

The authors believe that in case EW signals are identified in the front-end stage of a project, the available time will be rather long enough for project managers to take the right actions in the subsequent stages of project. Identification of EW signs related to technical issues, can aid the responsible persons to make better decisions on risk management and production of key variables in the execution phase. Of course the challenge lies in the possibility of detecting the EW signs and their level of reliability.

5 Identifying EW Signs of Delay

According to Nikander (2002), two stages of assessing the future are included in EW utilization. First the severity, likelihood of materialization and time available of the potential problems should be analyzed, based on the view point of the evaluator, and second the decision maker should examine the impact of the planned responses on the project, and the reactions, and responses of the various project parties and/or outsiders in the situation at hand.

Although it is not a proven fact that identification of EW signals is a guarantee against project failure, there are a number of resources which consider paying attention to these signals and attempting to respond to them as a contribution to project success (Haji-kazemi 2015). Figure 3 presents the main steps which should be followed in order to identify and act upon EW signs in projects. The authors believe that although different projects face different types of problems which can have different EW signs, the procedure for identifying and acting upon them is common.

It should also be noted that there are different approaches for identifying EW signs in projects. Examples are performance measurement, risk analysis, stakeholder analysis, Earned Value Management (EVM), etc. (Haji-kazemi 2015). According to Emblemsvåg (2014), EVM is one of the practical approaches within shipbuilding projects which acts as an aid for reducing delays. However, it is said to have some shortcomings when it comes to the engineering phase of the project.

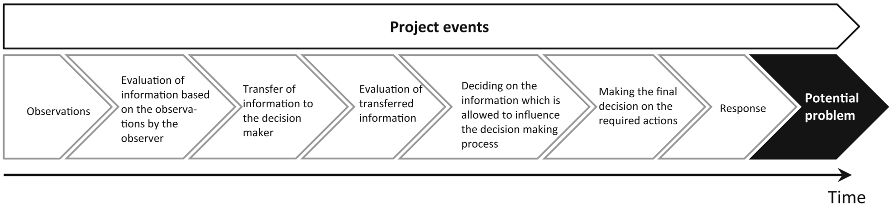

Fig. 3. The EW procedure (Haji-kazemi 2015)

As mentioned earlier, project problems do not appear overnight and therefor it is usually possible to point out a number of the most likely factors contributing to project problems and also identify a number of signs addressing the ensuing problem. The procedure can be carried out in each and every stage of the project life cycle. In other words, it is a dynamic process which should be applied to consciously monitor the possible EW signs addressing a future problem. Hereby we will focus on one of the elements mentioned in Table 1 as an example of a delay factor and analyze the possibilities for sensing the EW signs of its occurrence before it impacts the project. The example is based on the results of a case study done by Mello (2015) on a real ongoing shipbuilding projects located in Norway.

The demand for critical changes in the manufacturing phase can most probably be predicted in the design and engineering phase of the project. The product technical specifications in the design/engineering phase are usually involved with high level of uncertainty and changes are often required at later stages to cope with unforeseen challenges. They may also be required in order to adapt to changes in market requirements, regulations, and technology that occur during the project period.

It is crucial at this stage that the engineering and design departments in all the three main actors involved in the project (e.g. suppliers, shipyard and ship designer) have clear interfaces in order to be able to transparently communicate and transfer the information regarding a warning sign that a future development is about to happen in the manufacturing phase. For example quality problems regarding detailed engineering drawings and sketches or the number of unapproved engineering drawings can be EW signs that critical changes which lead to delay are likely to happen. The unclear interface among the engineering departments can be EW signs of later problems which if not identified and acted upon can lead to extensive delays. Development of indicators which aid project managers to foresee potential problems causing delays in later stages of the project life cycle is crucial in order to attempt for lessening the impact of these problems. One approach is to design key performance indicators which can act as a source of data for detecting possible EW signs of potential future problems (Fig. 4).

It is important to mention that concurrent engineering is becoming ever more common within the shipbuilding industry, where different project stages run simultaneously, rather than consecutively thus creating overlaps in different stages. This will create challenges regarding the time available for acting upon identified EW signs of potential problems causing delays within the project, and the concurrency also means more things are happing at the same time making assessing the situation more complex. The authors believe that although the time available will be more limited comparing to

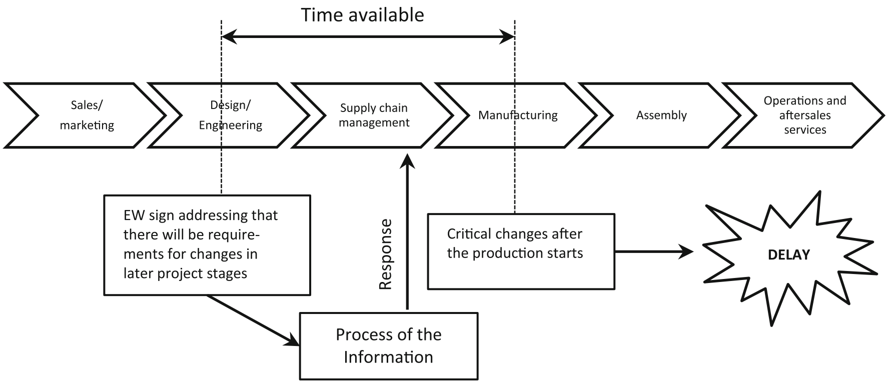

Fig. 4. Identification of EW signs within shipbuilding projects

non-concurrent approaches, it is still possible to identify EW signs of potential future problems. How-ever this requires efficient application of EW identification tools and urgent responses to the signals.

6 Conclusions

On-time delivery is one of the most important requirements in shipbuilding projects (Koivunen 2007). However there are various factors which cause delays (delay factors) in these types of projects. An attempt for overcoming these problems is to detect possible signs of delays in earlier stages of the project. These signs are referred to in the literature as EW signs. This study endeavors to indicate that in order to identify and act on these signs, it is crucial that an EW procedure is applied within the project. In addition, it tends to address that by following this procedure it will possible for project managers to foresee potential delay factors within shipbuilding projects. As a result, the delay can be prevented by acting upon these signs before the problem reaches its full impact thus leading to delay in project delivery time.

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Engineer-to-Order Enabling Process: An Empirical Analysis

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Abstract. Increasing competition and fast innovation take up new challenges for engineer-to-order (ETO) companies to address special requests from customers without losing efficiency. The optimization of the trade-off between customization and operational efficiency is a core competence for ETO manufacturers. Most advanced companies are reacting by introducing an ETO Enabling Process, which is the process of transforming special requests alongside the ETO value chain into know-how to be subsequently reused with a gain in productivity. This paper, therefore, presents relevant best practices implemented within a research project with three ETO companies while adapting the ETO Enabling Process to their specific organizational settings.

Keywords: Engineer-to-order (ETO) · ETO enabling process · Best practices

1 Introduction

Globalization, margin shrink, increased competition, delivery-time pressure and turbulent technological advances [1, 2] are central issues relating to the current Engineer-to-Order (ETO) environments. As a consequence, it is essential for executives to deal with such challenges in order to achieve profitable businesses. Scholars and experienced professionals put efforts to address how to react to such transformations in the competitive environment. Interestingly, they have identified a viable approach in reorganizing processes aiming at increasing operational efficiency. In this context, the introduction of product configurators is likely to optimize the trade-off between productivity and customization [3]. Along the same lines, it visualizes final product for the customer in the bidding phase and facilitates the process of quickly generating detailed drawings. Overall, this brings the possibility of efficiently programming the manufacturing machines and in turn, increases the level of automation [4].

The companies that employed the configurator in their processes, consider the 'configured' products as 'standard' products which have been produced in Make-to-Order (MTO) settings [5], despite the remarkable variety of products they are able to deliver. Although configurators have been widely examined in the past studies, recoveries in efficiencies out of the MTO process have been largely neglected. A recent study by Schönsleben [6] indicates that advanced ETO companies are able to implement an ETO Enabling Process that is an ad hoc process to collect and retrieve knowledge. Nonetheless, this knowledge is not entirely standardized but is sufficiently

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structured to be quickly retrieved. In the next sections, we introduce the ETO Enabling Process concept and we illustrate how market leaders have adopted such process out of the boundaries of the MTO process.

2 The ETO Enabling Process

2.1 Redefinition of Standard and Non-standard

The Solution Space (SS) is a statement of all the possible permutations of design parameters that are predefined and offered to prospective customers [7]. Value creation within a finite SS is a distinctive element of ETO companies and discriminates them from conventional craft customization [8, 9]. In fact, setting the appropriate SS directly affects the customer's perception of the utility of the customized product and determines the efficiency of downstream processes in the fulfillment system [10]. Advanced ETO producers are capable of representing their SS within a configurator aiming for a more efficient way of retrieval of solutions.

However, it is less likely for ETO companies to satisfy all the customers' requests just by a technical configurator and it often happens that solutions require additional manual engineering processes before being produced [11]. Schönsleben [6] claims that this kind of ETO companies have two classes of products. One is the "standard" products that can be engineered through the utilization of a configurator, and another is the "non-standard" products that call for manual processing since they have not been represented in the configurator. Also, he underlines that the "standard" solutions are developed in the context of an MTO process while "non-standards" are managed within an ETO process [12].

2.2 ETO Enabling Process

ETO Enabling Process "means that queries from the ongoing ETO business process are answered through a form of know-how transfer. If additional know-how is gained during implementation, it is fed back to the enabling process in the form of lessons learnt" [6]. Therefore, the ETO Enabling Process can be considered as a model for describing the way that the SS is dynamically widened in the advanced ETO companies. The ETO Enabling Process on the one hand, generates the necessary information supporting the creation of new "non-standard" solutions; on the other hand, it generates a feedback to the ETO process under the form of lesson learnt.

Each "non-standard" solution conveys, indeed, new information (the feedback of the ETO Enabling Process) that has to be adequately stored for an effective and efficient expansion of the SS. The Fig. 1 shows a typical ETO business process in ETO companies (DTO stands for design-to-order which is used as a synonym of ETO). The sales phase, including quoting, is followed by the receipt of the customer's order, followed in turn by design, production and delivery [13]. We can notice that at different stages, specific requests are generated by the ETO process that must be elaborated by a parallel

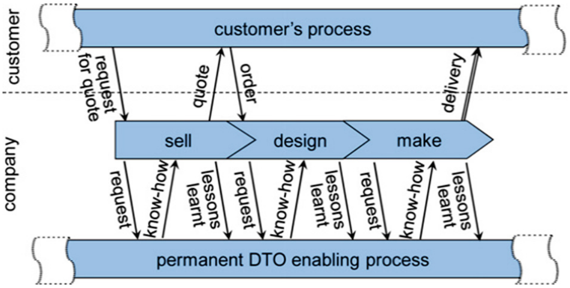

Fig. 1. The ETO enabling process [6].

ETO Enabling Process, which in turn delivers know-how, represented by immediate solutions to the requests and permanent lessons learnt.

3 Best Practices for an Effective ETO Enabling Process

During the two years research project, in cooperation with three main industrial partners from the Swiss ETO manufacturing industries (see Table 1), various methods and tools have been developed aiming for a fast and efficient ETO process. Most notably, new reference models have been conceived and best practices have been identified. In what follows we describe the case study companies taking part in the project and we continue with the different structures of the ETO Enabling Process. Finally, a concluding table is provided to summarize the striking findings.

Table 1. Case study companies: generalizability of the results

Company	A	B	C
Industry	Industrial steam turbines	Elevators	Concrete mixing and mineral processing plants
Product	Extremely diverse, ad hoc technologies for different customer	Slightly Diverse, high degree of commonality among product families	Very Diverse, different core technologies
Market (units/year)	Less than 50	More than 1000	300–500
Supporting IT systems	Sales configurator	Design configurator	Design configurator

The best practices that are presented in this paper are aligned with the use of configurator. Depending on the need of the company, the configurator can be used in different phases of the solution delivery: if it is utilized in the design phase, it will be a technical configurator; otherwise if it is used only as a support for the bidding phase, it will be a sales configurator [14].

3.1 Company A

Company A is a large multinational enterprise, which operates in the power generation sector. The division collaborating in the research project is offering power steam turbines units. The business unit counts approximately 120 engineers placed in three different European countries. The unit, appointed to realize order specific engineering, accounts only for a small percentage (less than 5 %) of the total turnover of the company, but is on rapid expansion.

More than the 70 % of the total lead time to deliver a product is due to the engineering purposes. The high diversity in terms of technology and functionalities leads to more than 5000 man-hours of engineering on average to complete a project. In fact, an engineering project is divided into subtasks that each of them refers to a specific component for the product.

Being the business unit at a low maturity stage, the utilization of the configurator is limited only to the sales phase. For what concerns the technical configuration, Company A has employed a “configuration matrix”, collecting the rule of association between a few modules they have already developed. Therefore, the ETO Enabling Process for this kind of company is mainly settled to the quick retrieval of product-related information. This is achieved both through the creation of ad hoc repositories and through the introduction of search functions fulfilled to navigate through the company’s SS. In the following the company’s tailored solutions have been introduced accordingly.

Naming Convention. Naming convention provides a common language protocol for the product. The naming convention allows to rapidly gather relevant engineering related information like the position in the work breakdown structure (WBS), the type, the material and/or any other special attributes. Naming Convention plays a vital role in the Company A’s ETO Enabling Process because when new requests are coming to the engineering stage, the process of retrieval is therefore, facilitated with substantial savings in time and cost.

Order Execution Configurator. This tool is utilized to acquire more information about product subassemblies and components. This information might be both technical (past drawings) and process related (list of suppliers or internal manufacturers). By filling in a small set of parameters it is, therefore, possible to find a component which is the most similar to the special request entered in the ETO process. Thus, this tool yields considerable benefits in compressing the time needed to develop customer-specific solutions.

Documentation Sharing Platform. It is a platform for the storage and sharing of documentations between the company and its suppliers/customers. One advantage is related to the storage and retrieval of old documentations. For instance, if the post-sales services are delivered many years after the delivery of the order, it provides an effective process to retrieve documents instead of having these documents stored in scattered email archives. A second advantage is the greater visibility over the documentation exchange process.

3.2 Company B

Company B is among the worldwide leaders in design, engineering, manufacturing and maintaining of freight and special elevators. The research project was conducted with the division offering high-rise elevators. The investigated business unit has more than 200 employees and acts in two different locations, in Europe and in the Asia-Pacific Area, with the 75 % of the total of the realized projects. The investigated division is appointed to realize order specific engineering for customers' specifications and offering support to the sales manager. This division is attached to the technical direction of the group. A remarkable point is that the level of knowledge in the two locations is significantly different. The reason is that despite several years of trainings and group works, most of the advanced technologies and know-how are kept by the European site. In terms of standardization, its level appears markedly high, with a considerable amount of projects designed and realized entirely within the technical configurator. The configurator has showed a great level of flexibility through the adoption of parametric product families. It is made possible by the high volume of specifications sold per year, which allows to identify communalities in the requests of customers and in turn to include new requests into the configurator.

Company B is at a mature stage, additionally its products can be considered of lower complexity compared with the two other companies. For this reason this company owes an especial configurator which is, at the same time, a sales and a technical configurator. Therefore, the ETO process at Company B is extremely advanced and a large portion of the company's product variance can be managed within an MTO process. Nonetheless, when non-standard boundary is extremely far from the company's SS, engineers are obliged to intervene with manual calculations and drawings. The following methods and tools have been applied to structure the ETO Enabling Process at Company B.

AE-PLM Process. Application Engineering (AE) is the office at Company B responsible for the execution of non-standard orders and it is the owner of the ETO Enabling Process as the source of know-how for non-standard requests. Product Line Management (PLM), owners of the product lines, also contributes to the ETO Enabling Process as it retains the modification rights in the configurator. AE and PLM are periodically (6 months) called to collaborate and modify the configurator so that it continuously incorporates previously developed non-standard solutions. In order to optimize this process, Company B decided to formalize it. This process can be considered as a part of the ETO Enabling Process.

Frequently Asked Request Tool. The FAR (Frequently Asked Requests) tool purpose is to support Application Engineers in the identification of incoming frequent tasks. Frequent tasks are often related to the same violation in the configuration parameters (each of the configuration parameters is laying in a certain range). Therefore, by identifying frequent tasks, we obtain a rule for the modification to be applied to the configurator. The FAR Tool is used at a very early stages of the AE-PLM Process. This is an extremely advanced setting of the ETO Enabling Process, because it drives the automation to the processes related to the less standardized part of its SS.

SE-AE Process. Sales Engineering (SE) is responsible for the MTO process at Company B. When they are not able to deal with the requests within the configurator, they ask for the assistance of AE. SE gives engineering tasks as inputs to AE and receives, as outputs, solutions to non-standard related issues. In this process, it also automatically transfers the list of all the parameter range violation (list of deviations). In the past, SE had to manually fill in the information related to the engineering tasks, this brought to incompleteness or low quality of input data for AE. Applying automation in the process of creation of engineering tasks increases efficiency of the ETO Enabling Process.

3.3 Company C

Company C is a manufacturer of asphalt mixing, concrete mixing and mineral processing plant. A tailored business unit is appointed to manage the concrete mixing plants. This includes a division taking care of operations (production), planning and engineering, a dedicated commercial unit for sales and a key account manager. It is worth mentioning that the design is taking place in three different engineering locations.

Even if the knowledge base is already widely developed, Company C's ETO Enabling Process has not already been fully developed. The extreme engineering complexity has prevented the company from reaching the same degrees of standardization as observed at Company B. Nonetheless, the company is introducing new tools and processes, aiming at reducing the amount of redundancy in operations thanks to the accumulation and use of past knowledge and experience.

Task Manager. In order to avoid inefficient recycles in the ETO process the company has designed a Task Management System. Whenever an issue emerges at each stage, a solution to the request must be immediately provided by the technical office. Nonetheless, at Company C, despite the fact that the reaction to the emergent requests is effective and efficient, the reoccurrence of the same request is a waste of resources. For example, if an error in production happened because of a mistake in the drawings and these are not permanently modified, there is the possibility that the same error will take place again. The Task Manager is also, a supporting tool for successful execution of the ETO Enabling Process. The Task Manager enables the possibility for the company to turn project-specific requests into knowledge (e.g. fixed drawings) used to avoid wasteful recycles.

Sharing Platform. The three main engineering locations are able to engineer the whole product mix offered by the company, even if they serve different markets. It is likely to happen that the two locations respond to similar requests from the customers. Subsequently, a low degree of knowledge sharing brings significant wastes in the time spent in engineering phase since it is likely that the same issues are solved twice. In order to avoid the inefficiencies deriving from low communications, the company has decided to develop a Sharing Platform in its business intranet. Hence, engineers at each location can rapidly apprised of the configurations developed in the other locations. The platform is also a communication tool, but it primarily is a knowledge repository where special requests are transformed into valuable knowledge for the whole company. This sharing platform is an interesting example because, it transforms requests into knowledge not only to transfer them, but also to reuse them in the future projects.

3.4 Summary

On the one hand, some of the aforementioned best practices (AE-PLM Process, Documentation Sharing Platform, SE-AE Process and the Task Manager) support fluent information flow between different actors. In addition, they stimulate the standardization of the information exchange that eventually make it less dependent on the key actors. On the other hand, other best practices such as the Order Execution Configurator, the FAR Tool and the Sharing Platform, are information repository tools that create reusable knowledge. Moreover, this knowledge creation leads to shrink the non-standard solution space and in turn, offers more degrees of customization (Table 2).

Table 2. Best practices summary

	Enabling process	Description
Company A	Naming convention	A new naming convention has been developed in order to create a reference language within the company for the identification of products, sub-assemblies and components
	Order execution configurator	Dynamic Design Containers have been established. Design Containers function as maps for the retrieval of the relevant historical information related to the product parts
	Documentation sharing platform	A documentation sharing platform has been implemented. The objective of this platform is to create a single point of contact between the company and its customers/suppliers and to have a unique repository for relevant documentation (no dispersion in several mail boxes)
Company B	AE-PLM process	The interface between AE (Application Engineering) process and PLM (Product Line Management) process has been defined. A detailed definition of this interface was necessary to guarantee a rapid and accurate execution of new releases of the product configurator
	FAR tool	An FAR (Frequently Asked Request) tool has been developed in Visual Basic in order to extrapolate relevant statistics related to the requests in order to identify the most common ones
	SE-AE process	The exchange of relevant information between the Sales Engineering and Application Engineering offices has been automatized. In particular, the system has been modified to feed in automatically necessary information during the phase of generation of new engineering requests
Company C	Task manager	A task management system has been designed in order to guarantee a permanent solution of the engineering related issues
	Sharing platform	A repository for sharing new engineering solutions between different engineering locations has been designed

4 Conclusions

The challenge for ETO companies is still the tradeoff between customization and operational efficiency. In order to counterbalance the tradeoff, we present results in terms of best practices to achieve efficiency in the ETO process, which have been explored in the research project with three industrial partners. As a know-how transferring process, it represents for companies a long-term key strategy that aims to reduce the degrees of uncertainty in ETO environment. Thus, through the adoption of the right tools, the companies aimed to extend the predefined solution space by integrating order specific solutions, making them reusable for future projects, and eventually increasing standardization. Additionally, those practices turn out to reduce the degrees of uncertainty and complexity in an ETO environment that is by definition, subject of constant changes.

Each company involved in the project has focused their efforts on the solutions that better fit their products, markets and organizational structures. Company A had to bring to light hidden processes and knowledge that were embedded to the individuals and are spread in the dispersed repositories. The ETO process of company B is taking place in different countries. Consequently, the main improvements of Company B were in light of standardizing the communications and sharing processes. For company C, whose engineering business function is spanning in three different locations, the focus was on facilitating the communication process between the locations, establishing a framework to standardize the outputs, and to share the locally discovered solutions.

Depending on the degrees of similarity with the three project companies that have successfully implemented the practices, other ETO companies are likely to duplicate the practiced tools to achieve higher performances in terms of uncertainty and complexity reduction. This study opens up new avenues for exploring a proper taxonomy of the ETO environment in order to effectively bring companies' characteristics and the best practices together.

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Remanufacturing as a Sustainable Strategy in Shipbuilding Industry

A Case Study on Norwegian Shipyards

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Abstract. Shipbuilding industry in Norway, mainly operating in the Engineer-to-order environment, is one of the most innovative in the world in terms of technology and production methods. In this paper we investigate the applicability of the concept of remanufacturing in the shipbuilding industry. The research takes a case study approach to study the topic and also presents an overview of the existing literature on remanufacturing and its benefits for businesses and environment. A five stage framework is proposed for integrating the concept of remanufacturing into the strategic decision making process in shipbuilding companies. This framework would streamline the decision making process of shipbuilding companies entering the vessel remanufacturing business.

Keywords: Remanufacturing · Shipbuilding · Sustainability · Engineer-to-order · Strategy

1 Introduction

Environmental friendliness and sustainability initiatives have become a prime focus in all industries including shipbuilding. The industry, an example of a typical ETO environment has witnessed a number of strategic changes to incorporate these initiatives, such as life-cycle focused ship building, cleaner production methods, less polluting fuel and so on (Dugnas and Oterhals 2008; Kumar et al. 2011). This is primarily due to the specific characteristics of ETO environment, which is known for its high complexity involved in its project based activities, multiple partners involved in the project execution phase and the need for good coordination due to project specific demands (Gosling and Naim 2009). Despite a growing concern about being green in shipbuilding, investing in such solutions has been considered to be less profitable from the strategic viewpoint of a company. Further, most such endeavours aimed at being green are driven by the need to comply with environmental regulations. (Gehin et al. 2008).

However, end-of-life strategies such as the concept of remanufacturing have given us real life examples of being both profit making and environmental friendly.

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The remanufacturing concept, for example, have been well studied and applied in various industries (Ijomah et al. 2004; King et al. 2006). Nevertheless, the concept is yet to be widely accepted and adopted in the shipbuilding industry. This paper proposes that remanufacturing is a sustainable and viable business strategy for the shipbuilding industry.

2 Literature Review

2.1 Remanufacturing

Remanufacturing is ‘the process of returning a used product to at least OEM original performance specification from the customers’ perspective and giving the resultant product a warranty that is at least equal to that of a newly manufactured equivalent’ (Ijomah 2002). The first known application of the remanufacturing process was from the ship industry in the year 1861, where a steam frigate was transformed into an ironclad ship (Ilgin and Gupta 2012).

As seen in Fig. 1, Remanufacturing is different from recycling as the latter involves the collection, extraction and processing of component materials into the same product or a useful degraded material (Ijomah et al. 2004). Further, remanufacturing is more environment friendly, as it minimizes the use of virgin material, energy and has lesser material processing (Sharma et al. 2010).

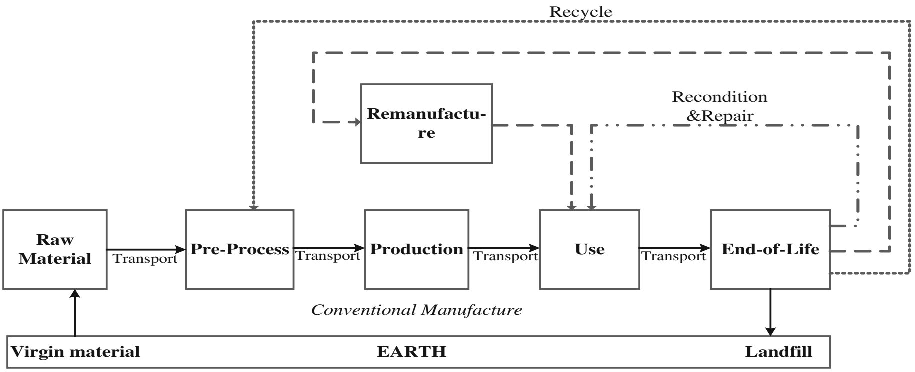

Fig. 1. Remanufacture concept and significance (Adapted from Ijomah et al. (2007))

Integrating the concept of remanufacturing in the business strategy is further more important as it facilitates the product designs suitable of remanufacturing and also reverse logistics needed for the remanufacturing activity. Further, remanufacturing does not hamper innovation as remanufactured products can incorporate innovative solutions in it (Gehin et al. 2008). These factors make it suitable for the shipbuilding industry.

Remanufacturing is already in practice in a number of industries such as the automotive and aerospace industries (Gray and Charter 2007). Further, in contrast to other secondary market or used products, remanufactured products are characterized by better reliability and quality, because the remanufacturing process involves the complete disassembly of all the components in the product and restoration and replacement where needed (King et al. 2006).

In order to streamline the analysis of this research, the authors selected a decision making framework proposed by Subramoniam et al. (2009). As illustrated in Fig. 2, this paper focusses on the last three stages of the framework, i.e decision making factors, strategic thinking process and the decision framework for applying the remanufacturing philosophy into the shipbuilding company's decision making process.

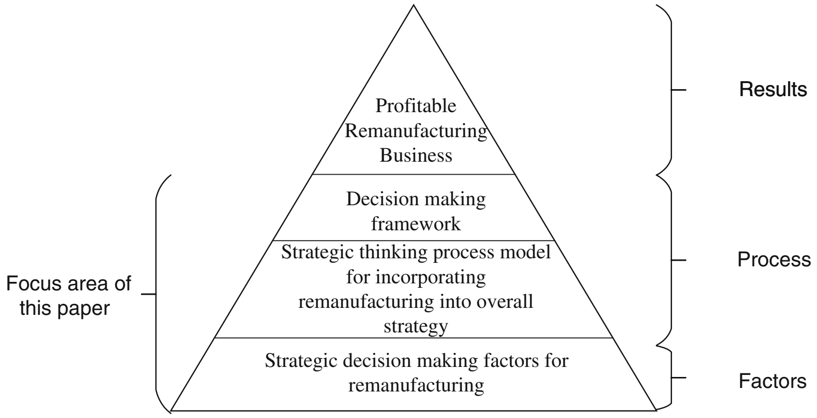

Fig. 2. Remanufacturing decision making framework and focus area of the paper (Adapted from Subramoniam et al. (2009))

Sustainability in Strategy. In order to identify the theoretical linkage between sustainable practices and strategy, we selected the natural resource based view (NRBV) proposed by Hart (1995). The NRBV view is relevant for any company that operates in close interaction with the environment, as in the case of the shipbuilding industry. Hart (1995) argues that in the long run, business strategy will be *'constrained by the ecosystems'* and companies' capabilities to tackle the environmental challenges would determine its competitive advantage.

The NRBV would remain relevant only if the strategists in companies and organisational theorists make efforts to understand the potential of environmentally oriented resources and capabilities in creating competitive advantage for the companies. In order to aid this, he presents the NRBV with three interconnected strategies, one of which is the *product stewardship strategy* (Hart 1995).

The concept of product stewardship attempts to reduce the life cycle environmental costs of the products by either redesigning the existing products to reduce liability or by developing new products with lower life cycle cost (Hart 1995). The concept of remanufacturing was found to have close alignment with product stewardship strategy, thus further strengthening this paper's argument that remanufacturing is a viable sustainable strategy.

3 Research Methodology

A case study method was preferred because of two reasons, firstly, the research focussed on the ‘how’ and ‘why’ areas of the topic. And secondly, the investigators had little control over the events and the focus in strategies is always on the con-temporary activities in the company (Yin 2009). The article draws on information collected from three different sources, namely interviews, formal discussions and literature review. The literature review for this research was supported by an in-depth pre-study covering 35 research articles pertaining to the topic.

For the interviews, semi-structured style was preferred as it provides more flexibility to both the interviewer and interviewee. It helps both the parties develop ideas and questions more widely on the issues raised in the research (Denscombe 2014). The interview process is summarized in the Table 1 below.

Table 1. Interview process overview

Type of Interview	Respondent position in the organization	Number of formal interviews	Number of Informal interviews
Case Company A			
Face to face	Deputy Managing Director	1	2
Face to face	Manager Planning Department	1	1
Face to face	Senior Business Analyst	1	2
Case Company B			
Face to Face	CEO	1	–
Telephonic	Sales Director	1	1

3.1 Research Questions

This research aimed at studying the applicability of the concept of remanufacturing in Norwegian shipbuilding industry and how the concept can be incorporated in the strategic decision making process of the industry.

3.2 Case Companies

The case companies selected for the research were two Norwegian shipbuilding companies who have been in the shipbuilding business for nearly 100 years. The following paragraphs provide an overview of the case companies.

Case Company A. Being the largest among the two case companies both in terms of resources and scale of business, the responses from this case company was not just restricted to the shipyard alone, but the mother group of the company of which the shipyard was a major business division. The strategy for the shipyard was driven by the main strategy of the group.

Case Company B. Operating at a much smaller scale and specialized in a different portfolio of vessels, case company B had a different approach to strategic thinking. They had more short term strategies and are one of the very few shipyards in Norway that still carry out both ship repair and new ship building activities simultaneously in their yards (Table 2).

Table 2. Case companies overview

Case Company	Company A	Company B
Size (employees)	800–1000	200–300
Customer base	Worldwide	Mostly European clients
Major competencies	Design and customized offshore vessels	Alternate fuel powered and hybrid vessels
Business areas	New building, designs	New building and repairs
Project portfolio	Offshore	Ferries and cargo

4 Findings and Discussion

The literature review carried out as part of this research work revealed that the sustainability focus in strategies of the shipbuilding companies has been mostly driven by profit motives. Further, as identified by Hart (1995), the most practical step is improved production methods and better control over the companies' activities.

The major findings from the interviews summarized in Table 3 also points towards a similar observation. The deductions and findings in Table 3 are categorized into 3 sustainability issues in the industry and the way forward. As mentioned in the Table, most respondents opined that an innovative and environmentally friendly production concept is the way forward. The interview also revealed the need for a framework to successfully implement such a concept. These findings further strengthen the view of the paper that remanufacturing is a potential sustainable strategy in the shipbuilding industry and is yet to be studied in detail in the industry.

The framework illustrated in Fig. 3 was developed through a series of iterative steps, where the findings in the literature were correlated with the findings from the interviews. This was then cross checked with the interview respondents for improvement until a desired result was obtained.

The proposed framework is divided into five different stages. The first stage begins with the receipt of a new ship order from the client, followed by overall strategy stage, resource capability stage, environmental regulations and finally organizational factors. Each stage consists of a set of decision boxes and subsequent action stages.

The description for each decision stage in the framework is as following:

(1) Is remanufacturing a financially viable approach? (2) Is the existing design of the core designed to be remanufactured? (3) Are any alternate solutions available? (4) Is it compatible with the current business strategy of the firm? (5) Can the business strategy be modified? (6) Does the changed business strategy align with the stated

Table 3. Major Findings and deductions from the case study

Respondent	Themes			
	Sustainability in practice			
	Economic	Environmental	Work	Way forward
Case Company A				
Deputy Director	Increased return on equity focus	UN Global compact, cleaner production	Labour welfare, social security, organisational training	Revisiting operational condition, increased efficiency, flexibility
Senior Business Analyst	Cost reduction, judicious material usage	Waste reduction, waste water treatment	–	Improved production methods and designs
Manager Planning Department	Cost reduction, increased vessel efficiency	Lean production, last planner system, enclosed painting, sand blasting facilities	Training, Personal protection	Lean, waste reduction, cleaner and innovative production concepts
Case Company B				
CEO	Joint ventures, innovative business models,	LNG fuelled vessels, hybrid fuels, waste reduction,	Training, abide by the labour laws, employee participation	Environmental financing, favourable government policies, innovative production concepts
Sales Director	–	LNG fuelled vessels, hybrid fuels, waste reduction	–	Better decision making frameworks, improved production practices

mission and vision of the firm? (7) Does the company have necessary resources to execute the project? (8) Can the missing resources be acquired at an affordable rate? (9) Will the remanufactured product comply with existing and future environmental regulations and standards? (10) Will it comply with the existing standards and regulations? (11) Can improvements be made to the product to ensure compliance? (12) Has the company established local facilities and communication channels to in order to coordinate the activities with the stakeholders? (13) Is the company working in a business environment that supports and promotes remanufacturing?

The shipbuilding company can analyze a newly placed order based on the framework and then decide if the vessel should be remanufactured or not. Such a calculated approach would help the company take a multi-dimensional approach factoring different elements affecting the success of the vessel being remanufactured. The framework also proposes to document the lessons learnt from each such projects for further reference and assessment.

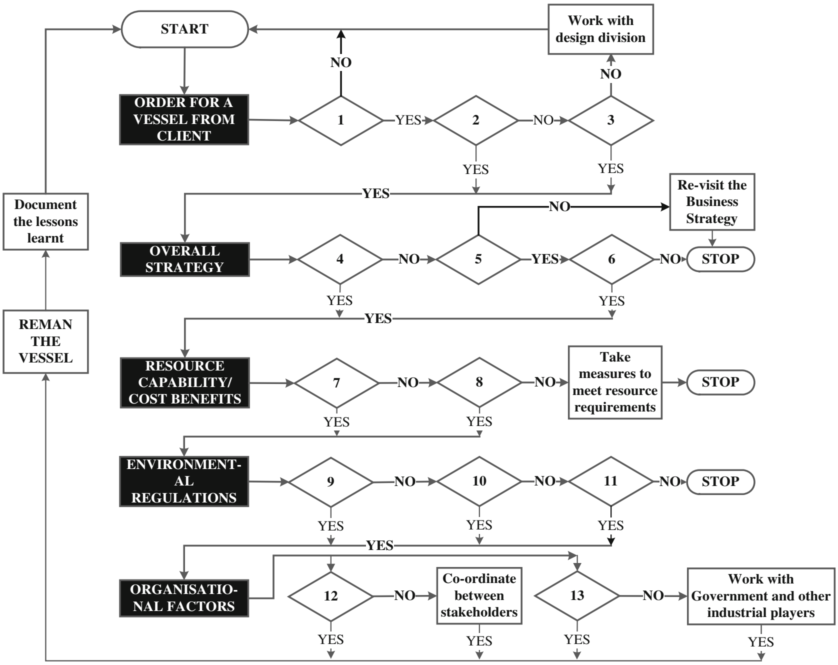

Fig. 3. Framework for integrating remanufacturing into the strategic thinking process (Based on the framework tool in (Dowlatshahi 2005))

5 Conclusion

The paper studied and analysed the potential of remanufacturing as a sustainable strategy in the shipbuilding industry. An in-depth pre-study was conducted as part of the research. The 35 journal articles reviewed as part of it revealed that even though remanufacturing is a widely studied topic in the automotive and electrical component industries, the scientific literature on remanufacturing in the shipbuilding industry was still lacking depth. It was in this premise that this research work was initiated. The responses from both the case companies also aligned with this view. Subsequently, the authors further studied and analysed the concept and developed a five stage framework that would aid the shipyard in integrating the remanufacturing concept into its strategic decision making process. These strategic decisions with a thorough consideration of carefully selected factors will help the shipyards to successfully launch remanufactured vessels. As explained in the benefits of remanufactured products, these vessels would have the same operability as a new vessel but at a lower cost and lesser environmental footprint. Further, the 13 decision boxes in the framework strive to incorporate the different project specific needs existing in an ETO environment of the shipbuilding companies.

The authors believe that the proposed framework can be adapted to meet the needs of other industries too. However, it should be noted that the framework is not a strategy in itself, but a decision tool for shipbuilding companies' that enter the vessel remanufacturing business. Further research will involve testing the framework in a real industrial setting and also documenting the environmental performance of remanufactured vessels.

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From First Planner to Last Planner

Applying a Capability Model to Measure the Maturity of the Planning Process in ETO

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Abstract. Engineered-to-order (ETO) networks are dynamic and hard to define, and their planning and control functionalities are commonly affected by the actions of suppliers and customers. Frequently, projects experience delays, budget overruns, and quality defects. Consequently, there is a need for project management that synchronizes engineering and production processes throughout the network.

The aim of this study is to develop a project planning maturity model (MMPP) in order to improve project performance in ETO manufacturing networks. Moreover, a multiple case study approach is used to test the applicability of the developed maturity model. The results of the case studies from three ETO case companies show that there is (1) no or low degree of standardization of the planning processes, and (2) there is little or no integration between engineering and production planning processes.

Keywords: Maturity model · Project planning · Project management · Engineered-to-order (ETO)

1 Introduction

Planning is the process of thinking about and organizing the activities required to achieve a desired goal by creating and maintaining a plan. In managing and controlling projects, planning is an important factor that can contribute to both success and failure of meeting the projects objectives. As early as 1988, Pinto and Slevin [1] listed a number of factors that contribute to project success during the execution phase, such as *defined project goal, effective communication, commitment from senior management and project planning and monitoring*. In 2002, Cook-Davies [2] complemented this list by adding *scheme for performance measurement and report* (e.g. Earned value) as a success factor to project success. Measuring how well the process of planning is performed can be a difficult task due to its complexity and interdependence with other processes.

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The term project maturity is used as measurement of an organization's ability to execute projects [3]. As shown by Project Management Institute (PMI) many maturity models exist (PMI, 2015). Many of these models are rather limited in scope and focus on the categorization of the actual behavior of the organization. Our research objective is to create a deeper understanding of the maturity of the project planning process by presenting a maturity model that can map the maturity of the project planning process within ETO networks. ETO networks are dynamic and hard to define, and their planning and control functionalities are frequently affected by the actions of suppliers and customers which typically may result in excessive inventories, long lead times low customer satisfaction and poor resource allocation [4]. Many projects experience delays, budget overruns, and quality defects [5]. Design changes are inevitable and make it difficult to coordinate projects with multiple subjects and actors [6, 7]. Excellent and successful ETO projects require rapid reaction capability for adaptation [8]. Consequently, there is a need for project management that synchronizes engineering and production planning in the value chain. Despite the significant challenges associated with this, little research has been done in this area [4], and more specifically little has been done related to integration of project management (activity-based) and production planning and control (material based) as a way of responding effectively to design changes.

ETO products are highly customized and contain a variety of components. Main products have complex structures where some components are highly customized (as a management system and advanced technological equipment), while others are standardized (as some steel components) [9]. This high complexity means that companies need to coordinate the engineering, procurement, manufacturing, assembly and installation in supply chains efficiently. Ordinary ERP systems are not well suited to handle the myriad of product specifications and parameters in an ETO supply chain and support to manage design changes are extremely limited [10]. There is a great need for planning methods that can assist the chaotic production in complex ETO environment [8].

This paper therefore aims at highlighting the challenges of an ETO project based production, and argues that an integrated and well-structured planning process can enhance project and ultimately overall business performance. This is done by applying known theories within lean construction and project management as well as performance measurement literature.

2 Theoretical Discussion

2.1 Project Management and Earned Value Management

In managing and controlling projects, planning is an important factor that can contribute to both success and failure of meeting the projects objectives. As early as in 1988, Pinto and Slevin [1] listed a number of factors that contribute to project success during the execution phase, such as *defined project goal, effective communication, commitment from senior management and project planning and monitoring*. In 2002 Cook-Davies [2] complemented this list by adding *scheme for performance measurement and report* (e.g. Earned value) as a success factor to project success.

Measuring how well the process of planning is performed can be a difficult task due to its complexity and interdependence with other processes.

Earned value management (EVM) is a technique to measure project progress by comparing the baseline of the project with reported physical results, the resources consumed and the remaining hours to the completion per activity [11]. A good performance metrics used by EVM is the Cost Performance Index (CPI). CPI calculates and predicts costs at completion of the project within a finite range of values after only 15–20 % completion of the project [12].

2.2 Lean Construction, Last Planner System and Lean Project Planning

Lean construction applies production-based ideas from lean thinking to project delivery within construction industry [13]. In such projects, lean changes the way projects are managed during the building process. Lean Construction is based on lean production philosophies that thrive to maximize value and minimize waste expressed in specific project management techniques [14]. Ever since the 90s, lean construction community has recognized the need for a change in the way traditional project management plan and measure activities in a project. One of the best examples is the invention of Last Planner System (LPS) by Ballard [15, 16]. The role of LPS is to increase planning reliability by decreasing workflow variability, through recognizing and removing activity constraints, identifying root causes for non-completion of plans and monitoring its improvements by means of Percentage Plan Complete (PPC).

Kalsaas [17] and Emblemsvåg [18] point out that LPS is not able to handle advanced engineering design work and needs a better instrument to measure physical progress for such activities. By introducing Lean Project Planning (LPP) Emblembsvåg attempts to combine elements of LPS and EVM [18]. LPP is based on Lean thinking and applies the Plan Do Check Act (PDCA) cycle, a basic problem-solving approach, which in LPP context involves making problems visible, finding proper solutions, checking the result and acting on deviations [18].

2.3 Maturity Models

The planning process as well as organization as such, evolve over time and have to pass several stages of development or maturity. Ever since the late 70s, different types of models have been used to map and measure this path of development.

Nowadays, maturity models are widely used and a systematic mapping study undertaken by Wendler [19] showed that alone in 2009 and 2010, 62 academic articles on maturity models were published. The focus of these publications is still software engineering and as up-today there are few maturity models on planning.

A maturity model consists of a sequence of maturity levels for a class of objects. It represents an anticipated, desired or typical evolution path of these objects shaped as discrete stages. This definition by Becker et al. [20] severs as a starting point for the conceptual design of our maturity model on project planning where we combine elements of LPS and LPP to design a project planning process that will reduce the challenges observed within ETO manufacturing organizations in regards to planning.

3 Method

This study is based on a case study and as there is little previous research in this field, this topic calls for qualitative research approach [21].

The choice of method is closely related to the type of research question [22]. The purpose of this study is to explore and describe the applicability of performance measurement tools (maturity model) in order to map the engineering and production planning processes in ETO networks. The elements of the maturity model are drawn from theories of project management, lean planning as well as performance measurement literature and selected in cooperation with planning and project management personnel from the case industry. Studies undertaken by Bitici et al. [23] showed that maturity models with certain characteristics, promote organizational learning as well as enabling efficient and effective assessment of the performance management practice of the organization.

The empirical basis for this study has been based on three case studies representing three ETO manufacturing companies in the maritime industry in Norway. These aforementioned companies deliver highly complex and special heavy lifting as well as pressure tank equipment for the offshore industry. The main business activities of the said case companies are designing, manufacturing and testing and commissioning and engages 500 h of engineering, 500 h dedicated to procurement, fabrication and production, as well as up to 2000 h of assembly and testing. Lead times can vary from nine to 12 months. Each solution is highly customized and designed to meet individual customer requirements.

This Norwegian industry experiences increased global competition and cost pressure. Many Norwegian manufacturing companies are therefore moving some or all of their operations to low-cost countries. Changes in customer requirements are frequent throughout the entire project execution phase which requires detailed and real time planning with proper change order management systems in place. Effective planning and control is a key to success for companies in such project, low volume environment.

The main data collection was undertaken through semi-structured, focused interviews and observations as well as discussion and site visits over a one and a half year period in close cooperation with key personnel.

4 Results

The following part presents the findings of our study. Our case industry can be characterized by: (1) ETO manufacturing environment, (2) Project based production, (3) Expressed need for improved planning process (few resources dedicated to planning, little competence), (4) Plans are too difficult to update (plans are drawn at an early stage but not updated, and lose therefore validity and value), (5) planning is done at a high managerial level without including the person that are executing the activities. Further our case industry has (6) outsourced production which leads to phased based project management and, (7) many changes from customers lead to a need of flexible and dynamic planning.

In order to structure and improve the process of planning a maturity model for project planning (MMPP) was designed (Table 1). The elements of the maturity model are drawn from elements of LPS and LPP and selected in cooperation with planning and project management personnel from the case industry resulting in six parameters for evaluation as presented in Table 2. The planning process is enhanced by lean project planning and evolves over time, starting with poor planning at the first planner level moving to second and third and finally evolving to the final – *the last planner* –

Table 1. Maturity model for project planning (MMPP)

Parameters/Process	First planner/Ad hoc	Second Planner/Standardized.	Third Planner/Defined	Last Planner/Optimized
Level of flexibility	The plan is created at the beginning of the project. No updates at later stages	Random updates of high level activities only	Pre-set updating dates at all level of activities	Updates as often as required – all level of activities
Level of integration	No common plan for all project disciplines. Some disciplines have their own plan	Some project disciplines are taking other proj. disciplines into consideration when making the plans	Some project disciplines are taking other proj. disciplines into consideration when making the plans. No common plan exists	One integrated plan for all project disciplines
Making the plan	The plan is created at the high management level	Each discipline makes own plans	Some project disciplines are involved in creating a common plan. No commitment from participants	All project disciplines participate and commit to one common project plan
Project planning meetings	Random plan meetings no formal agenda	Regular plan meetings with no formal agenda nor obligatory participation	Regular plan meetings with formal agenda, obligatory participation with no formal reporting	Regular plan meetings with formal agenda, obligatory participation for all project disciplines with formal reporting
Project performance measurement (EVM)	No or random reporting	Reporting at project top management level	Reporting from some project disciplines on a standardized report	All project disciplines report on a standardized report. (Integrated EVM)
Physical progress measurement (PPC)	No physical progress reporting	Physical progress reporting at project management level	Physical progress reporting from some project disciplines on a standardized report	Physical progress reporting from all project disciplines on a standardized report. (Integrated PPC)

Table 2. Six parameters of the maturity model for project planning (MMPP)

1. **Level of flexibility** - This parameter defines how flexible the plan is, expressed in how often and at what level the activities within the project plan are updated.
2. **Level of integration** - This parameter defines how integrated the plans are - are all disciplines (e.g. design and engineering, steel work and piping) integrated in one common plan?
3. **Level of autonomous planning -** This parameter defines the way the plan is made – Is it a typical top-down approach or do all disciplines engage and commit to one common plan?
4. **Project plan meetings -** This process defines the existence and regularity of dedicated project plan meetings. Do all disciplines have to attend?
5. **Project performance measurement (EVM) -**The fifth parameter defines how project performance is measured? Ultimately we are looking for Earned Value management reports from all disciplines.
6. **Physical progress measurement (PPC) -** Finally the last parameter defines the level of usage of physical progress measurement (PPC).

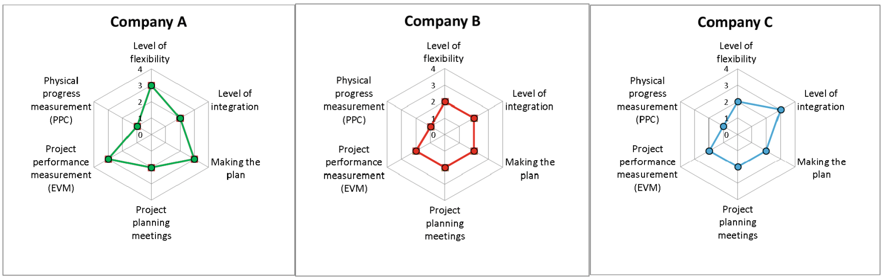

Fig. 1. First AS-IS measurement of the planning process

level of maturity. After designing the MMPP a first As-Is measurement was undertaken. The results are presented in Fig. 1 and briefly explained in following conclusion.

5 Conclusion

In order to structure and improve the process of planning, a maturity model for project planning (MMPP) was designed. The elements of the maturity model are drawn from elements of LPS and LPP and selected in cooperation with planning and project management personnel from the case industry resulting in six parameters for evaluation. A first As-Is measurement of the planning process within three ETO companies operating in the Norwegian offshore supply industry was presented. We see especially low maturity in regards to the integration of all project disciplines and physical progress measurement. Meetings and information exchange processes (updating the plan) are not standardized. This confirms our observations of an ETO industry characterized by informal planning and information exchange. Maturity in any organizational process evolves over time. In alignment with performance measurement literature we believe that by mapping and visualizing the steps to maturity organizations can succeed more easily with implementing a well-functioning and standardized planning process.

6 Future Research

Wendler [19] points out that most of the contributions within MMs look at the design process of models or the applicability of existing models to other areas but that too few contributions within MMs focus on validation and implementation of models. The conceptual maturity model presented in this paper will be further developed and validated and maintained in collaboration with the Norwegian offshore supplier industry.

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Implementing Lean in Engineer-to-Order Industry: A Case Study

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Abstract. There is generally agreed that lean pull production principles like Kanban, ConWIP or takt time are successful tools within repetitive production where with one-piece flow, where each job produces exactly what the next job needs, when it is needed and with no inventory in between the stations. To our knowledge, very little research is done on implementation of these concepts within Engineer-to-Order (ETO) environment. This paper presents a case study on implementing the three principles within a Norwegian company that builds complex and highly customized vessels for the offshore industry.

Keywords: Lean · CONWIP · Takt time · Kanban · Engineer-to-order

1 Introduction

Norwegian shipbuilding industry is a typical engineer-to-order (ETO) manufacturing environment where customers are involved in the building process from the concept design phase, follows it through the detail engineering as well as the production and the testing phases. The scope of such involvement is to maintain the possibility of changing features of the vessels while under construction and that result in one-of-a-kind product at the end of the each project. Most of the vessels build through an ETO approach start as a conceptual frame for a future possible service, but during the building project things frequently change and the final product can look quite different from the starting idea. This means that the design/engineering/production phases in an ETO must be flexible and adaptable to this dynamic system within which changes occur all the time [1].

Lean production is seen by many as a manufacturing philosophy applicable to mass production or other repetitive manufacturing industries [2], with high volume production environments that demand mass consumption [3]. Looking at these characteristics, it seems like an ETO environment would not fit for lean ideas. However, Vard, a Norwegian shipbuilder, adopted and implemented some lean tools in the process of building highly customized vessels. Vard initiated a set of improvement

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projects in different departments involving lean principles and the lean tools implemented by the group were: Plan-Do-Check-Act (PDCA); Last Planner [4]; Kanban, Takt time and Constant Work in Progress (ConWIP). This article presents the preliminary results of the project dedicated to implementing Kanban, Takt time and ConWIP at the assembly line in the hull factory.

In the following, we present a short literature review on ETO and lean followed by research methodology. Then we present the case company, the results of the implementation process and the discussion.

2 Literature Review

In this section, relevant theories for this study are presented. First, we address the peculiarities of ETO industry that challenge each phase of a project, frequently seen in isolation from each other. This approach increases the lead time of the total project and makes overall improvements quite difficult to achieve [5]. We also present some important features of the lean thinking concept as well as some of its principles and tools that were implemented at the case company. The literature part ends with the presentation of the lean shipbuilding concept.

2.1 Engineer-to-Order Features

ETO is a manufacturing strategy where the design, engineering and production activities do not start until after the order is confirmed by the customer [3]. The main characteristics of ETO manufacturing are low-volumes, high degree of customization and project-based environment [6]. Manufacturing process in an ETO are typically non-repetitive yet labor intensive, demanding quite often highly skilled labor force [3]. In an ETO project the customer is involved in the decision process from the concept design phase, and has the possibility to decide most of the product features while the project is ongoing. Consequently, planning and controlling activities in an ETO project must cope with a dynamic system, product complexity and information uncertainty [7]. A dynamic system is defined as a system in which changes occur all the time [8]. The complexity of the product is given by (1) the structure of the goods flow; (2) the number and the composite of the parts that are needed to the final product; (3) the number of the ongoing projects that each department is involved in. Uncertainty of an ETO project is mainly defined by the amount of information necessary to perform a task compared with the information already available in the project organization. There are three uncertainty factors specific to ETO manufacturing: (1) The uncertainty of the product specifications where change occur all the time especially in the beginning of the project, (2) Mix and volume of the future demand (the firm do not know when the customer will place a new order and that affect the forecast of people and materials). (3) Process uncertainty where parts of the product are not known and are difficult to estimate in terms of machines, materials amount of resources [7].

The ETO features described here apply to the shipbuilding case in this study.

2.2 Lean Production

Lean can be defined as a philosophy of management that "*consists of an ideal to be pursued, principles to be followed in that pursuit and methods to be used to apply the principles*" (p. 86) [2]. Delivering exactly what the customer wants, with no waste is the main ideal for the lean way of thinking. One guiding principle when pursuing the lean ideal is only to do work when the customer requests it. In order to apply lean principles in different circumstances there are tools and methods developed over the years [2]. Among the tools and methods applied for achieving a continuous flow of work, we find Kanban, Takt time and ConWIP, which are the subject of this paper. These are all pull concepts that enable to limit the work in progress (WIP) along the production line [9] in order to achieve a continuous flow of production [10]. There is an ongoing debate whether these concepts can be implemented within the ETO environment. Stevenson et al. [11] argue that Kanban is not appropriate for non-repetitive production, but argue that other types of card like ConWIP could be possible in some cases. In a recent paperm Park and Lee [12] developed an algorithm for applying ConWIP within non-repetitive production processes. A brief description of these concepts is presented in the following.

Kanban is a card based system used in production to signalize the need for refill of materials at a work station [10]. It is a pull type system for managing and ensuring the flow and production of materials as requested by the immediate customer [10]. Moreover, the system is used to signal completion of a job.

Takt time is inspired from a German word for rhythm or meter and defines the rate of customer demand. According to [10], Takt time together with continuous flow are methods used mainly in repetitive operations.

Constant Work In Progress was first introduced by [11] who defines it as a generalized form for Kanban based on the same cards signaling principle. However, ConWIP is used for managing an entire production line while Kanban signals production of a specific part. In the ConWIP approach, cards that are used to signal the start/completion of a job are not numbered as opposed to Kanban, where cards have numbers and are attached to a specific part. ConWIP cards are assigned to the production line, and then part numbers are assigned to each card at the beginning of the specific line. The numbers must match with the cards by referencing a backlog list, and no parts are allowed to enter the line without a card. When the job on a specific part is completed at the last station, the card is transferred to the first workstation and a new part is loaded on the line [11].

2.3 Lean Shipbuilding

Lean shipbuilding as a concept was first described by Liker and Lamb in [13] where the two authors present and recommend application of lean principles and methods in shipbuilding. Figure 1 illustrates a transformation of the Toyota house (principles and methods supporting the lean ideal) to a vessel perspective.

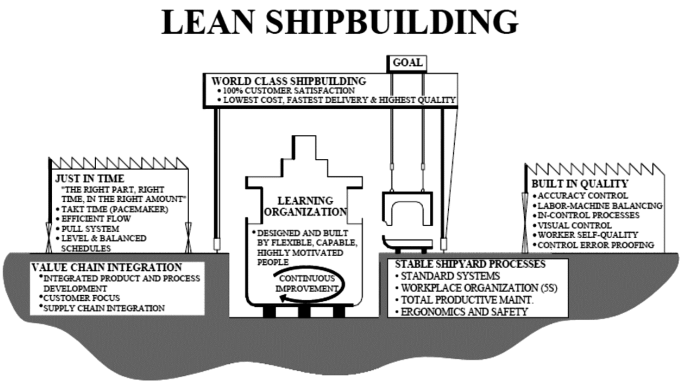

Fig. 1. Lean shipbuilding concepts [13]

Lean principles like for example built-in-quality are presented in the figure together with methods which support the process of achieving it. In the following, we present the research methodology approached for this study.

Previous research is conflicting regarding the applicability of these lean principles in an ETO manufacturing environment. The present study aims at contributing to this debate by providing a case study from the shipbuilding industry in Norway, where these lean principles have been implemented. The methodology, the case company and experiences from the implementation process will be presented in the following.

3 Research Methodology

This article is a result of action research (AR) based approach to the process of implementing lean concepts at the assembly line at hull factory. Two of the authors were directly involved within the process from the proposal/analysis phase and all the way through the testing and operative phases. All authors have both academic and practitioner perspectives from the Norwegian shipbuilding industry.

The concept of action research was formulated by Kurt Lewin in the late 40's with the scope of finding a method to help the practitioners.AR is defined as a process of mutual learning between researchers and practitioners where the researchers get the possibility to experience different situations with their own specific circumstances [14]. The AR seems to be the most appropriate methodology for ETO complex projects that are difficult to comprehend from outside. Through AR, the researcher can understand the settings and participate to the process of finding a right solution while the case company can improve their working processes. AR can be categorized as a knowledge construction process able to generate scientific knowledge. From such perspective, this research contributes to filling the gap on case examples of lean concepts adapted and implemented within ETO. From the case company perspective, this research will contribute to the development of a planning process that integrates design and engineering activities.

4 Case Company: Vard Group AS

Vard is a global designer and shipbuilder of offshore and specialized vessels used in the offshore oil and gas explorations as well as in production and oil service industries. Headquartered in Aalesund, Norway, the company owns in total 10 shipyards located in Norway, Romania, Brazil and Vietnam. For most of the shipyards within the group, the building process is similar the one described in Fig. 2. The shipbuilding process starts with customer negotiations where the basic features of the vessel are designed. Subsequent to contract signing, the design, detail engineering and procurement work start almost concurrently. Soon after the basic features of the vessel are designed and materials are procured, the production phase starts at the hull yard (or hull department of some yards), where the body of the vessel (hull) is built together with some pre-outfitting activities. For most of the shipyards within the group, the hull must be towed from the hull yard to the outfitting yard where outfitting activities are completed together with the commissioning (testing of the whole vessel) phase. The vessel can be delivered only after the completion of the commissioning phase.

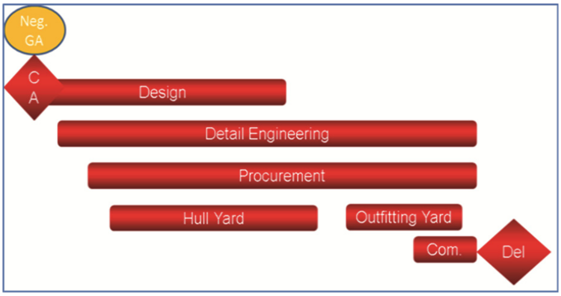

Fig. 2. Shipbuilding process

4.1 Implementing Lean Concepts

The hull building process starts by cutting and welding steel plates into different shapes and sizes, which are then assembled in a unit. Units are then assembled to blocks, each vessel being made of five to seven blocks, depending on the size and complexity of the vessel. The focus of this paper is on the units' assembly hall where Kanban, Takt time and ConWIP concepts were implemented since the end of 2013.

The number, size and shape of the units differs from vessel to vessel depending on the type and size of the vessel as well as equipment to be installed, making standardization impossible. At the assembly hall, small units get weld together and processed to form bigger units, which are then sent to another hall to join the block they belong to. There are several production lines within the assembly hall, and the shipyard management decided to start the implementation process at one of these lines [15].

4.2 Before the Implementation Process

Before starting the implementing process, activities at the assembly line were lacking a clear planning process and a good overview over the lead time of each unit on the line. Some units were on hold, waiting on the line for alterations or technical information. The number of units on the working line was variable, depending on availability of information and workforce. Afore implementation of the lean principles the hall was filled up with as many units as possible. The high density of units and the high probability of alterations during the building process caused problems for the flow of units through the assembly process. Poor flow resulted in long and unpredictable lead times of units' assembly.

4.3 After the Implementation

In order to reduce the lead times and to increase throughput and predictability of lead times, a limited number of moving production platforms were installed. Here, workers allocated to that job from a dedicated pool of skilled workforce, assembled the units following an established takt. Since the number of assembly platforms was limited and had a dedicated workforce pool, this implementation phase could be seen as ConWIP system with a first-in-first-out (FIFO) sequence. The production platforms have a limited size, which resulted in a selection of units to be assembled on those assembly lines. Units which had unforeseen changes during the assembly process and which would disturb the flow on the line, were postponed and executed later on the designated areas. These delayed units had to follow the whole process in order to be removed to a designated area. The combination of ConWIP, a FIFO sequence, a stable workforce, and grouping of units influenced positively the throughput and the predictability of the lead times. Introducing Takt time for each assembly stage improved predictability of lead times further.

The Kanban concept was implemented with the scope of improving the control over the number of WIP units on the assembly line. Some of the rules used for this board (Fig. 2) were: (1) All the units for the assembly hall were shown on the board for better visual planning. (2) Each unit had one Kanban card. (3) Only coordinators or foremen moved the card/units on the board, (4) The most urgent units were on top of the board. (5) Use a color code for delayed units or the one missing materials.

Takt time was introduced by gathering units in a given number of wagons that move at a fix interval through the assembly line during the production process.

The preliminary results of implementing takt time, ConWIP and Kanban, at the assembly line were showing a better flow of materials and a better planning for the assembly line. The average lead time for the units was reduced from about 1.9 to 0.5 on the takt time lines. Some of the supporting principles in implementing takt lines were: (1) ConWIP limits the number of wagons and, as a consequence, the number of units on the line. (2) As a result of takt time implementation, the adoption of a strategy of a dedicated pool of skilled workers on the line was possible which in turn improved the planning and scheduling processes. (3) Planning was made based on the actual situation at the line showing the workload and capacity for the next period. (4) Each line has an own coordinator that manages eventual issues on his/her line and has a better overview of the situation on the line. However, the implementation process for these lean concepts is put on hold due to limited effect of the investment. It is an open question if just proper planning can give the same effect as the takt conveyor system (Figs. 3 and 4).

Fig. 3. Kanban board (with Vard permission)

Fig. 4. Takt time (with Vard permission)

5 Conclusion

This case study presented here shows that the pull production concepts, Takt time, ConWIP and Kanban can be applied to some aspects of ETO manufacturing environments. The preliminary results shown by Vard confirm the possibility of achieving a continuous flow for the hull units' production, where the processes performed to each fabricated part are repetitive even though the parts are customized. By analyzing each process and identifying the processes that are repeated from one product to the next, the possibility of implementing pull concepts within ETO projects can be further demonstrated.

However, there are limited application of these concepts within ETO manufacturing, and more research into this subject will prove the feasibility of implementing lean concepts in such dynamic environments.

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Understanding Key Engineering Changes for Materials Management in ETO Environment

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Abstract. Researchers have recognized engineering changes affecting operations as a major obstacle to the delivery of the product in ETO environment. However, there is little academic literature addressing sources of engineering changes that affect materials management throughout the order fulfillment process in an ETO environment. The key research question addressed in this paper is how the substantive sources of engineering changes impact materials in ETO environment can be identified and categorized. Due to the nature of different supply chain configurations different engineering change situations exists within and across these companies.

Keywords: Engineering changes · Engineer-to-order · Case studies · Materials management

1 Introduction

Companies that operate in ETO strategy build unique products designed to customer specifications. Products are complex with long lead times and the customer is heavily involved throughout the entire design and manufacturing process (Gosling and Naim 2009). In these companies, engineering changes are way of life due to high probability of design and production changes (Tavčar and Duhovnik 2005). Moreover, because materials account for 50–60 percent of total project costs, its effective management provides an opportunity to increase cost competitiveness, market share and profitability (Wänström and Jonsson 2006). Materials management includes all activities and processes which aim to address material choice, lot sizes (for purchased or produced materials or parts), delivery location (to inventory, to shop floor, or directly to customer location) and time (to purchase or initiate production) (Wänström and Jonsson 2006). Within the context of an ETO company, materials management usually involves strategy, planning and control of materials and information influencing the flow of materials. If the engineering changes (EC) are not recorded and monitored, then it would be hard to determine who bears the responsibility of the additional cost and it may act as a critical factor affecting the materials management while impacting the profitability for ETO manufacturers. Despite of their significant impact on the ETO manufacturing environment, it is actually not too surprising to see the lack of research done in ECs within the context of materials management under engineering change

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situations in ETO environment. In this paper we present an overall understating of the key engineering changes that affect the materials management ETO environment. The aim is to provide a categorization framework to understand the developments that have emerged in the literature as well highlight its applicability in the industry.

2 Literature Review

Material planning in ETO production environment has historically been challenging (Hendry and Kingsman 1989; Hicks et al. 2007; Jin and Thomson 2003). Following the industrial revolution and the increasing sophistication of industrial equipment and product complexity increased with the high cost implications. One can imagine the material planning challenge faced when the first commercial aero plane was built or the challenge of building a subsea compression station for a field development project operated by a multinational corporation.

2.1 Engineering Change Management

Engineering change is concerned with changes/alterations in a product and the engineering change management is the process which describes and controls the change process (Kocar and Akgunduz 2010).

1. *Definition engineering change:* We used (Jarratt et al. 2011) comprehensive definition, “An engineering change is an alteration made to parts, drawings or software that have already been released during the product design process. The change can be any size or type; the change can involve any number of people and take any length of time”.
2. *Classification of engineering changes:* The ECs were classified in accordance with their impact on the company, on time; and based on urgency (Jarratt et al. 2011). Huang and Mak (1999) developed an EC taxonomy based on the following categories: routine, expedite, emergency, high risk and mandatory.

2.2 Engineering Changes and Its Impact on Materials Management

In ETO companies due to the degree of complexity, innovation and variability of the product, an ECM system should consider the degree of unpredictability, and also have capability to manage a good cooperation with external suppliers and customers approvals etc. (Tavčar and Duhovnik 2005). As in the other companies the change in ETO companies can range from a small change in single component to major ones, which might have a knock-on effect on the entire product (Jarratt et al. 2011). Hence, effective, reliable, and robust ECM system is required to manage exceptional cases.

Factors effecting Engineering change: Based on the literature review and analysis, six categories of challenges have been identified within the ECM. However, two of the challenges (e, f) will not be emphasized as it is mainly considered as organizational issue, with no ECM related solution.

a. **Unidentified change propagation:** Possessing the capabilities to identify change propagation has been recognized as an important and critical skill in the ECM process (Giffin et al. 2009) change propagation stems from components being coupled with each other, either directly or indirectly (Eckert et al. 2004). Complex products often experiences more change propagation than other products, due to more couplings (Cheng and Carrillo 2012). Other major problem that ECM need's to take into account is the engineering bills of materials (EBOM) needs to be transformed to manufacturing bills of material (MBOM), but MBOM transformation has to be done in such a way that it fit the particularities of each manufacturing sites. Also the ECM system should be having flexibility to interact with the BOM conversion module as its one of the most important challenge that needs to be addressed.
b. **Knowledge management:** For new product development, knowledge management is considered to be critical (Lee and Lee 2005; Lee et al. 2006). Changes are more likely to propagate due to the innovation factor. This is due to low degree of knowledge and information (Jarratt et al. 2011). The ECM system today does not possess the capabilities to easily capture and manage knowledge that is generated from collaboration and the decision making process (Lee et al. 2006). Hence, the knowledgebase available to decision makers is significantly reduced, and decisions will rely more heavily on personal experience.
c. **Distributed environment:** As stated, the ECM process is a rather complex process, involving different disciplines both internally (e.g. production-supply), externally (e.g. design collaboration between multiple companies) (Terwiesch and Loch 1999). Companies tend to work in a decentralized manner, even within the internal departments (Koçoğlu et al. 2011). This is mainly addressed towards management group/staff. The review and approval process in ETO environment is difficult and time-consuming, even for technical staff. Thus, the management might have difficulties comprehending complicated parametrical and graphical information correctly, something that could lead to misinterpretations and errors, further delaying the EC process capacity.
d. **Capacity and congestion:** The problem of capacity and congestion has been defined as a general problem in this project. Although it might have an impact on the actual ECR lead time, as discussed by Terwiesch and Loch (1999), it appears more as a project structure issue than an ECM issue. Terwiesch and Loch (1999) argues that one of the reasons for long ECR lead time is due to the limited capacity of an individual engineer. In the Case "The climate control system in automobile development" written by Terwiesch and Loch (1999) about 50 % of this capacity was consumed by the current development project. The second general problem, also identified by Terwiesch and Loch (1999) was setups and batching. Batching is an old and familiar principle in management research, and its advantages in the presence of fixed setup costs or setup delays are unquestionable. However, batching also has its downsides; one of them stemming from the time a task has to wait for its cohorts in the same batch, to proceed. Applying this to ECM, results in ECs not being implemented directly on occurrence, but rather batched with other changes, lengthening the EC lead time, and possibly causing congestion problems as discussed above.

2.3 Current Strategies and Methods to Cope with for Materials Management Under Engineering Change Situations

Strategies have been proposed in literature to meet these needs or manage these challenges. It is more common in ETO to find companies using order-based management for unique components/materials demand and the reorder point for more standardized components. Indeed, this leads to the need to have a differentiated strategy similar to that proposed by Semini et al. (2014). Moreover, many manufacturing companies often have more than one material planning method. This was highlighted by Jonsson and Mattsson (2003) in a study of companies in the food manufacturing and chemicals, mechanical engineering (which made up almost half of the companies sampled). The findings are summarized in the table which follows (Table 1).

Table 1. Proposed solutions to material planning challenges under engineering changes (from literature)

Author (year)	Proposed solutions to characteristics/challenges
(Harhalakis and Yang 1988)	• An integration of MRP with CPM where the schedules are determined by the CPM and the MRP module computes the firmed dates for each activity after interacting with inventory records and open/planned order records [Limitation: the integration in now 'organic', and many tasks must still be carried out in a parallel system and the data fed into the MRP system]
(Silver et al. 1998)	• Include an experienced materials management person in the early phase (concept and feasibility) • Closer collaboration between engineering and materials • Develop mechanisms for handling design changes • Have backup supplier for every commodity to guarantee supply • Reduce the need for expediting by developing 'responsible' suppliers/vendors • Implement warehouse material control and feedback mechanism such tagging
(Jonsson and Mattsson 2003)	• Both MRP and order-based planning are used in complex customer production environments. However, order based planning is most suited for both MTO and ETO type production environments
(Stevenson* et al. 2005)	• Workload control is the most appropriate PPC approach for MTO companies
(Song et al. 2006)	• Manage (find optimum) raw material release times to minimize the work-in-progress holding cost, product earliness cost, and product tardiness cost
(Wänström and Jonsson 2006)	• Date effective; Blocking change; Serial number; Firm planned orders; Use-up technique • Use a self-correcting (which will not place replenishment orders when there are no customer orders or backlogs to be fulfilled) re-order point system

3 Categorization of Engineering Changes

Wänström and Jonsson (2006) categorized the characteristics as engineering change, demand, material supply, manufacturing, and product. *Engineering change* (EC) characteristics comprise attributes such as urgency grade, dependency of engineering changes or the degree of interconnectedness of the change requests and activities and information quality. *Demand* characteristics include demand volume, demand lumpiness for either products or component items, uncertainty, demand time distribution for planning purposes, type of demand, P/D ratio, customer service elements and ramp -up level. Product characteristics comprise BOM complexity indicated by the depth and width of the BOM structure (Song et al. 2006; Hicks et al. 2007), product/item value,

Table 2. Categorization of engineering change situations affecting materials management from literature in an ETO environment

Categories	Complicating factors	References
Products attribute characteristics	Deep and complex product structure complexity of design and engineering Uncertainty (and changes) of product specification High degree of customer specification (customization and variants) Critical parts dictated by project production 'critical path'	(Gelders 1991; Jonsson and Mattsson 2003, 2008; Jin and Thomson 2003; Krishnamurthy and Suri 2009)
Manufacturing process characteristics	High product mix and low volume process characteristics Dynamic nature necessitates frequent replanning and 'nervousness' Complications of concurrent activities complexity of process routings complication of multi-project planning Engineering activities takes a large part of the order- to-delivery process Functional or job-shop type of flow configuration	(Barrett and LaForge 1991; Yeung et al. 1998; Hicks et al. 2007; Jin and Thomson 2003)
Market demand characteristics	Uncertain time and quantity of customer order High service level requirements Need for quick response to seize market opportunities Uncertainty of due date setting and cost estimation Few large customer orders per year	(Bertrand and Muntslag 1993; Hendry and Kingsman 1989; Abd Rahman Abdul and Mohd Shariff Nabi 2003)
Supply characteristics	Risk of supplier competition Complication of supplier relationship (number, capacity reservations, contracts) Difficulty in knowing the actual material consumption during production period	(Jonsson and Mattsson 2003; Tyagi et al. 2013)
Engineering change (EC) characteristics	Customer involvement in the product specification close to the time the product is near completed Panic towards the end of the project	(Silver et al. 1998; Wänström and Jonsson 2006; Jarratt et al. 2011)

customer specific items and degree of benefit. *Manufacturing process* characteristics comprise shop floor layout, throughput time, batch size, inventory recording, material addresses, volume flexibility, product mix flexibility, delivery flexibility, use of new tools for engineering change and manufacturing scrap. *Supplier* characteristics comprise supplier service elements (such as agreements on delivery precision and who bears the cost of supplier scrap), material supply scrap in the company of interest, lot size (whether to calculate or use any order cost optimization technique, or the preference of full trucks or pallets to minimize transport costs) and the type of procurement ordering (are purchase orders sent once per day or when there is a customer order). The findings are summarized in Table 2.

4 Conclusion

The capability of managing ECs efficiently is thus a major advantage due to ECs potentially big impacts. Thus, it does not come as a surprise that this study reveals that efficient materials management under engineering change situation. The literature re-view on engineering change identified four core problems, change propagation, knowledge management, collaboration, and decision makers. Furthermore, by using these four problems as a basis, we developed a conceptual framework, which may ease and be used for developing engineering change management systems to effectively handle and allocate materials. The framework is an attempt to response to the inadequate attention to materials management under engineering change in both research and industry, and is believed to assist in bringing more attention to the current materials management issues in the industry.

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Designing a Performance Measurement System for Materials Management Under Engineering Change Situations in ETO Environment

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Abstract. In this study we aim to understand how performance indicators should be designed and implemented across various phases and levels in materials management in the order fulfilment process under engineering changes. The paper address questions such as how can such systems help managers to handle and manage materials management under engineering change situations? How do we convince potential users and obtain their support when starting to develop such a system? How can we aggregate performance indicators? How do we present results? Then using the literature review and the results of the empirical study from a Norwegian company operating in ETO product delivery strategy, we develop a framework.

Keywords: Engineer-to-order · Engineering change · Performance measurement · Case studies

1 Introduction

Materials management has always been one of the most important and critical processes within production planning and control at companies with ETO supply chains (Persona et al. 2004). Managing the material flow in an effective and efficient way facilitates achieving success as it provides availability of materials with the right type, in the right quantities and at the right time to different phases of the supply chain. In a situation that material-planning activity does not perform well, supply chain faces problems such as work stoppages, delays of end product, losing responsiveness and hence loosing valuable customer satisfaction.

Having a supply chain with large number of suppliers creates even greater need for an effective and efficient management of material flow, as it is required to take into account deliveries of numerous components from different suppliers. Moreover, there are many challenges in ETO production environment that affect performance of material planning; e.g. engineering changes (Wänström and Jonsson 2006) and uncertainty of product specification, mix and volume (Bertrand and Muntslag 1993). In addition material and production requirements vary from project to project which makes planning and control more difficult (Stevenson* et al. 2005). Therefore, it is vital for ETO companies to control and monitor the performance of materials management under engineering change situation precisely. Measurement and assessment of performance are prerequisites for improvement (Armstrong and Baron 2005; Otley 1999;

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Douwe et al. 1996; Parthiban and Goh 2011). The processes of measuring and improving the performance are gathered in an area called performance management which provides an iterative process between these two steps (Parthiban and Goh 2011). The main concern of performance management is mostly what to measure and developing performance measures for different activities and individuals (de Leeuw and van den Berg 2011; Gunasekaran and Kobu 2007).

Even though a lot of literature on topic of performance measurement and performance measurement systems for supply chain exists, (Kaplan and Norton 2001; Theeranuphattana and Tang 2007; Otley 1999; Lin and Shen 2007) there is little information regarding performance measurement specifically in management of materials under engineering change situations in an ETO environment. The main result of this paper is to design a performance measurement system for materials management under engineering change situations in ETO environment.

2 Literature Review

2.1 Materials Management in ETO Environment

ETO environment are characterized mostly by large and complex products, which are designed and produced by customers' requirements (Hicks and Pongcharoen 2006; Bertrand and Muntslag 1993; Gelders 1991). Products in this type of supply chain are required in low quantities and sometimes in medium volumes, but generally they contain a diversity of components in a complex combination (Hicks and Braiden 2000). Each component should be assigned to specific operation in the production (Jiao et al. 2007).

Overall task of material planning process is to ensure material availability at the right stage of production and at the right time. To do so material planning uses bill of materials, inventory data, and data from master production schedule in order to determine time-phased plans for all components and raw materials required for production (Vollmann et al. 2005). For conventional material planning accurate lead times and safety stocks are the most critical characteristics to determine the performance of this process (Jonsson and Mattsson 2008).

Material planning process includes broad set of tasks and activities like planning required materials, supplier selection, purchasing, inventory management and forecasting. Therefore, this process is not only simple computer calculations but also it includes effective communication mechanisms, education activities and training programs (Bell and Stukhart 1986). The material planning process starts when the order is received, materials specifications and materials coding systems are established and bill of materials is created (Bell and Stukhart 1986). In order to link bill of materials with process structure, each component in the bill of materials should be assigned to specific operations in the production (Jiao et al. 2007).

2.2 Performance Management

In ETO environments the biggest investments are put into materials, it would be very costly for a company with ETO supply chain to have an ineffective material flow.

It is critical to manage the performance of material planning activity and material flow throughout the supply chain. As products have deep and complex structures which lead to a wide range of assembly processes, it is necessary to consider performance associated with end products and assembly as well as performance relating to components (Hicks and Braiden 2000). Effective performance of material planning activity in the supply chain supports the overall production by providing materials in a complete, timely and reliable manner. Material planning performance depends to a great extent on the environment it is executed in (Jonsson and Mattsson 2003) proved that user environment (software support available in the enterprise, quality of planning information, the function of planning activities in organizational design, education and knowledge of planner) have important impact on planning performance (Fig. 1).

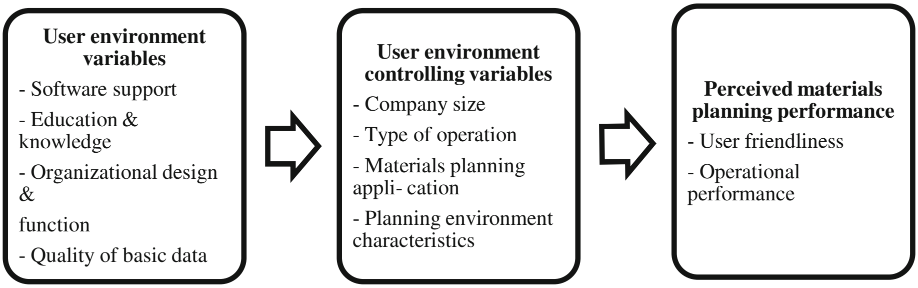

Fig. 1. Material planning user environment based on (Jonsson and Mattsson 2008)

2.3 Research Methodology

A case study method was preferred because of two reasons, firstly the research focussed on the 'how' and 'why' areas of the topic. Secondly, the investigators had little control over the events and the focus in interface between engineering and production on the contemporary activities in the company. The article draws on information collected from interviews, formal discussions and literature review, which be- long to the six sources of evidences for a case study (Yin 2009).

A literature review on the topic aimed at providing a brief yet comprehensive understanding of the existing academic research in the area was carried out. For the interviews semi-structured style was preferred as it provides more flexibility to both the interviewer and interviewee develop ideas and questions more widely on the issues raised in the research more widely (Denscombe 2014). The interview process is summarized in the table below (Table 1).

Table 1. Interview process overview

Type of interview	Respondent position in the organization	Number of formal interviews	Number of informal interviews
Case Company			
Face to Face	Engineering manager	1	-
Face to Face	Manager Planning Department	3	2

(*Continued*)

Table 1. (*Continued*)

Type of interview	Respondent position in the organization	Number of formal interviews	Number of informal interviews
Face to Face	Senior Engineer (s)	4	2
Face to Face	Purchasing Manager	2	-
Face to Face	Sales Manager	1	1

3 Findings and Discussion

Requirements for engineering changes come both from customers/suppliers (external), but also from design/engineering (internally). And as planning phase situated before design stage-managing such changes become problematic for the company. The time for re-planning the required material to fulfil changes influences the total lead-time of the project. Engineering changes encompass a lot of paper work, which is time consuming to proceed. Material planning should be quite flexible in order to deal effectively with order changes in each project. Hence we design a performance management system based on the indicators below, the ISO14031 guidelines and on studies from (Andersen and Fagerhaug 2002).

The lack of a performance measurement system in the company led to the design and develop a performance measurement system with a strong focus on material planning that would consider the indicators in Table 3, which focused on how to measure the performance of material planning and what type of measures should be taken into the system. Secondly, since the engineering changes are an unavoidable characteristic of case company, it is critical for material management to be flexible with regards to engineering changes and to be able to quickly respond to these changes. The indicators will be further developed, based on multiple case studies.

Table 2. Current KPI at the Case Company

Department	KPI	"Formula"/What is measured
Sales and development	Project implementation	Sale price - materials - work (hours * hourly charge) Measures margin calculation to the actual margin after the project is completed. "Full Results": <1 % deviation Positive deviation: 1 % < x < 10 % > 10 % Negative deviation: 1 % < x < 10 % > 10 %
Sales and development	Sales of projects/acceptance rate	(1) Value of offers versus value of contracts actually signed over a 12 - and 24-month changing average (Krone Value) (2) Contracts/number of offers (Aggregate Percentage)
Technical	Number of thrusters in production	
Technical	Number of thrusters delivered	
Technical	Number of errors detected	Grouping by type of error - (1) During production, (2) After delivery

Table 3. Performance indicators for materials management under engineering change: adapted from (Sjøbakk and Bakås 2014)

Performance indicator	Measure
BOM complexity	BOM is complex with many levels, and items can appear at more than one level. Thus, an EC will also affect many neighbouring and parent items. Actual time used for BOM change/Calculated time used for BOM
Engineering change costs	Σ Cost of engineering change orders Sales/Total cost of labour for all engineering changes made during the last period.
Engineering capacity (Flexibility, People)	Σ Calculated time used for engineering/Σ Available time for engineering calculated for the next period (e.g. a month)
Proportion of customer-specific products	All products are customer-specific and are assembled from modules. These modules are produced from both standard and special items.
Engineering change urgency grade	Three EC urgency grades: special orders (for customizing products), quality ECs (carried out quickly) and regular ECs to reduce cost (planned in advance).
Engineering change dependency	Most EC orders include items that are dependent on other EC orders; there is thus usually a high degree of EC dependency
Engineering change information quality	Information quality is sufficient but the materials planners sometimes lack appropriate or correct information. The materials planners do not receive the EC information until the phase-out date is confirmed, which can be too late.
Incoming delivery precision (Delivery precision)	Number of incoming deliveries received on time/Total number of incoming deliveries
Incoming delivery quality (Quality)	Number of incoming deliveries containing defective parts/Total number of incoming deliveries
Percentage rework (Quality)	Rework hours/Total production hours

Currently the case company does not have a specific performance measurement system. The set of key performance indicators developed for reporting are presented in Table 2.

This way of measuring will help to assess the performance of material planning during the order fulfillment process by means of tracking and monitoring the current state of each project. If any deviations from the plan occur it will be shown by measurement and further actions can be taken to fix the gaps for future projects. For this purpose a standard set of performance measures can be set in order to evaluate projects performance with the same indicators. This will give possibility to internal benchmark and further improvements. However, at the same time a problem may arise, as success criteria can be different from project to project. Standard set of measure does not address these differences.

The indicators are designed based on characteristics of the case company considering its unique and non-repetitive situation; they can be generally applied to other

ETO/project- based production with similar characteristics. Therefore, it is recommended to take them into account when implementing performance measurement system for material planning in the case company as well as in other companies with similar ETO supply chain. Performance measures may require adjustments to serve the actual needs of a project performance tracking and evaluation. It can be time consuming for manager to measure every time new values for each project. For managers it is more suitable to assess performance of material planning activity from an operational point of view as this helps to measure and monitor day-to-day project operations. Moreover non-financial measures are preferred at operational level to give clear picture of current state of performance of production operations. Properly chosen operational measures can help to identify weak areas of production activities on which improvement initiatives should focus. Nevertheless, the operational measures do not provide shareholders with an overall picture of company's performance (e.g. return on investments) that is so important for shareholders (Fig. 2).

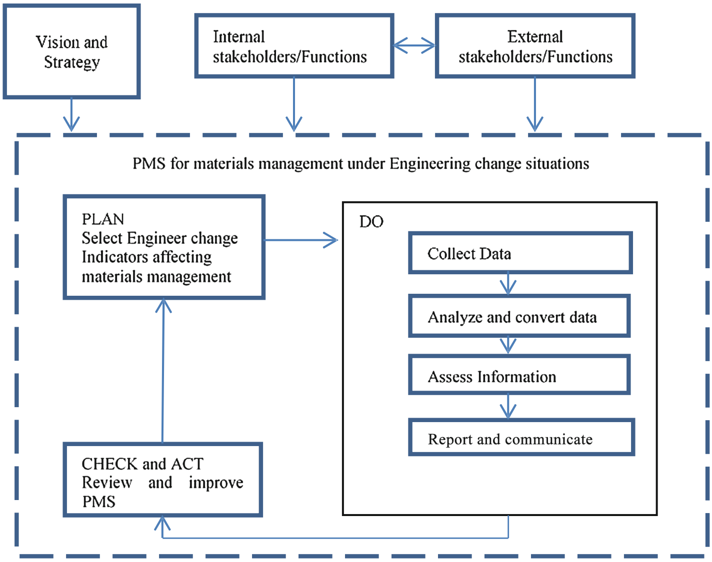

Fig. 2. Designing a performance measurement system

4 Conclusion

The study revealed the necessity to develop an integrated performance measurement system for managing engineering changes affecting materials management. The measures found in this study could help managers to address challenges incurred due to engineering changes, which affect different operations, more specifically materials. Having received little attention in academic literature, this topic is an area with much potential for further research. The researchers therefore call for more studies describing the design process itself, and the actual resulting performance indicators that should be tailored to materials management-specific and engineering change situations.

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Lean Production

A Quantitative Comparison of Bottleneck Detection Methods in Manufacturing Systems with Particular Consideration for Shifting Bottlenecks

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Abstract. There are numerous different bottleneck detection methods both in academia and in industry. However, most do not take the shifting of bottlenecks into account. This paper compares a number of methods, namely methods based on cycle times and utilizations, waiting times and queue lengths, the arrow method, the turning point method, the active period method, and the bottleneck walk. All methods are tested against two different manufacturing systems, a pseudo static system consisting of a static system that changes once halfway through the production run and is designed to have shifting bottlenecks, and a dynamic system that includes variations for a multitude of different processes.

Keywords: Bottleneck detection · Shifting bottlenecks · Theory of constraints · Capacity improvement

1 Introduction

Bottlenecks are processes that limit the overall system capacity of manufacturing processes. Hence, as part of our never-ending quest to produce more with less, there is frequently the need to improve system throughput. For this, it is necessary to improve the bottleneck, since improving the speed of a non-bottleneck will have no influence on the system capacity. This gives rise to the need to find the bottlenecks.

1.1 Bottleneck Definition with Respect to Shifting Bottlenecks

The need to find the bottleneck is complicated by the dynamics of real-life systems. In real systems, processes are not static but may change. There are numerous definitions of bottlenecks in literature. Reference [1] describes a bottleneck as processes that limits output. Reference [2] defines the bottleneck as the process whose isolated production rate has the highest sensitivity of the system's performance compared to all other processes. References [3, 4] defines the bottleneck as the stage in a system that has the

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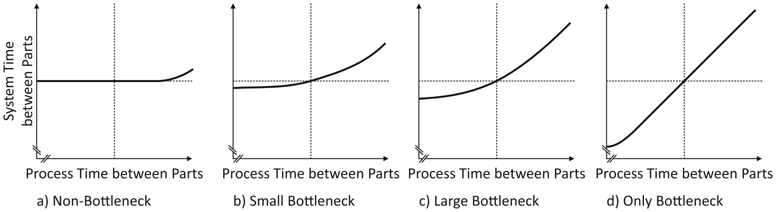
largest effect on slowing down or stopping the entire system. We expand these definitions to include both multiple bottlenecks and a measure of influence on the system:

Bottlenecks are processes that influence the throughput of the entire system. The larger the influence, the more significant is the bottleneck.

1.2 Degree of Influence of the Bottlenecks on the Entire System

Since more than one process is likely to be a bottleneck using the definition above, it is of interest to compare the relevance of the bottlenecks. The larger the bottleneck, the larger its influence on the system throughput. While this sensitivity is difficult to obtain analytically, it can be obtained experimentally by comparing the system behavior for different cycle times. In our simulations we change the speed of the process and observe the change in the speed of the entire system. The gradient of this relation in percent represents the degree of influence of the process on the entire system. Four examples are shown in Fig. 1 with the time between parts for the process on the x-axis and the time between parts for the system on the y-axis. The horizontal and vertical dashed lines indicate the point under observation for which the gradient was measured.



a) Non-Bottleneck b) Small Bottleneck c) Large Bottleneck d) Only Bottleneck

Fig. 1. Gradient between process time between parts and system time between parts

If a process is no bottleneck at all, the gradient is 0 % as shown in (a). The other extreme is having only a single bottleneck as shown in (d). In both cases major increases or decreases of the process speed will eventually change the gradient. Graph (b) and (c) in Fig. 1 show intermediate stages. Hence the degree of influence of a process onto the system can be between 0 % and 100 %.

2 Reference Systems Used for Comparison

2.1 Pseudo-Dynamic System

The first system for comparing the bottleneck detection methods is a pseudo-dynamic system. This system is composed of two static systems, (a) and (b) as shown in Fig. 2 with unlimited demand and supply. The three processes are separated by FIFO with a capacity of 3. Process P3 always has the same cycle time of 90 s. However, process P1 and P2 change between system (a) and (b). During the first half of the observed period, the entire system behaves like static system (a). During the second half of the observed period, the system behaves like static system (b). For each subsystem, the bottleneck is determined easily, being P1 and P2 in the subsystems (a) and (b) respectively. Hence, by constructing such a pseudo-dynamic system, *we have forced a bottleneck shift from process P1 to process P2*. P3 is never the bottleneck. Hence the degree of influence of the processes on the entire system (as per 1.2 above) should be 50 % for P1 and P2. The simulation results of the pseudo-dynamic system are shown in Table 1 below.

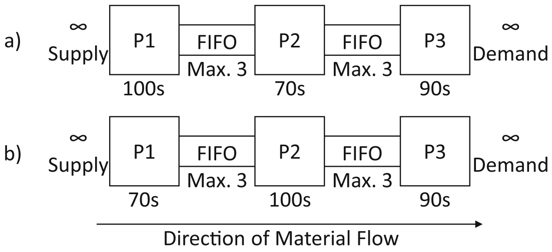


Fig. 2. Pseudo-dynamic manufacturing system

Table 1. Results of the pseudo-dynamic manufacturing system

Process	First half			Second half			Average		
	Utilization	Blocked	Starved	Utilization	Blocked	Starved	Utilization	Blocked	Starved
P1	100 %	0 %	0 %	70 %	30 %	0 %	85 %	15 %	0 %
P2	70 %	0 %	30 %	100 %	0 %	0 %	85 %	0 %	15 %
P3	90 %	0 %	10 %	90 %	0 %	10 %	90 %	0 %	10 %
Queue	First half			Second half			Average		
	Average inventory	Average inventory (%)	Average waiting time (s)	Average inventory	Average inventory (%)	Average waiting time (s)	Average inventory	Average inventory (%)	Average waiting time (s)
P1 to P2	0	0 %	0	3	100 %	300	1.5	50 %	150
P2 to P3	0	0 %	0	0	0 %	0	0	0 %	0

2.2 Dynamic System

The dynamic system is a more complex system, shown in Fig. 3 below. It has four processes, separated by FIFO's of capacity 3, and also with unlimited demand and supply. The cycle times of the processes are exponentially distributed with means of 90s, 95s, 100s, and 90s for the processes P1, P2, P3, and P4 respectively.

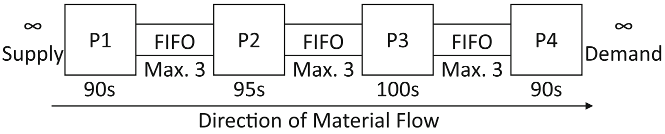


Fig. 3. Dynamic manufacturing system

The overall performance results are shown in Table 2, based on the average of 100 simulations with 10,000,000 s each and including the 95 % confidence interval. To determine the degree of influence this system has been simulated both for the original cycle times and for each process being 1 s faster and slower. The results of these simulations are shown in Fig. 4, Please note that the lines are not straight but have a minor convex shape. The process P3 h the slowest cycle time of 100 s had the largest gradient of 47.2 %, making it the largest bottleneck. The second slowest process P2 followed closely behind with a gradient of 40.3 %. The fastest processes P4 and P1 had the smallest gradient with 23.7 % and 21.7 % each.

Table 2. Results of the dynamic manufacturing system

Process	Utilization	Blocked	Starved
P1	71.03 ± 0.051 %	28.97 ± 0.051 %	0.00 ± 0.000 %
P2	74.97 ± 0.048 %	18.36 ± 0.055 %	6.68 ± 0.032 %
P3	78.89 ± 0.051 %	7.43 ± 0.035 %	13.68 ± 0.050 %
Queue	**Average inventory**	**Average inventory (%)**	**Average waiting time (s)**
P1 to P2	2.08 ± 0.002	69.44 ± 0.001 %	264.00 ± 0.310
P2 to P3	1.63 ± 0,003	54.17 ± 0.001 %	205.94 ± 0.362
P3 to P4	0.96 ± 0.002	32.10 ± 0.001 %	122.06 ± 0.255

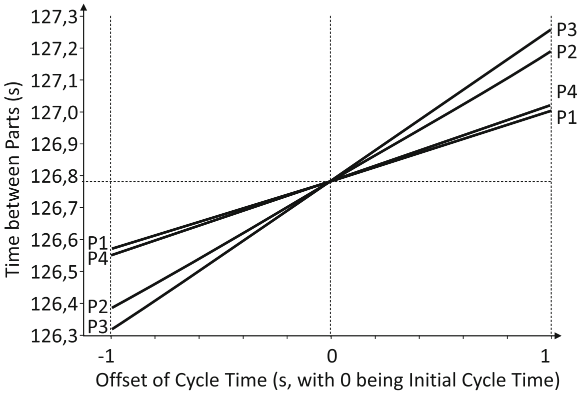


Fig. 4. Graphic representation of the gradients for all four processes of the dynamic system

3 Analyzed Bottleneck Detection Methods

3.1 Methods Based on Cycle Times or Utilizations

One of the most common approaches in industry is to determine the bottleneck based on the largest average cycle time or the utilization. Variations of these methods are described for example, in [5]. This approach fails for the pseudo-dynamic system, erroneously determining P3 as the bottleneck. For the dynamic system, P3 has the longest average cycle time and the largest utilization of 78.89 %. Therefore, the method correctly considers this process to be the main bottleneck. However, the significant influence of P2 and the smaller influences of P1 and P4 are completely ignored. Hence, utilization give a very incomplete picture of the situation.

3.2 Methods Based on Waiting Times or Queue Lengths

There are a number of different methods described in literature that determine the bottleneck based on the inventories between the processes. These use for example total waiting time [5], average waiting time [6], length of the queue [7], or combinations thereof [8]. For the pseudo-dynamic system, the first FIFO has an average inventory level of 50 %. The second FIFO is always empty. The bottleneck should be at the process with the largest drop in waiting time or queue length. As such, we have two drops of equal magnitude from 100 % to 50 % around P1 and from 50 % to 0 % around P2, giving an "unclear result." In the dynamic system, the largest drop would be from 32.10 % to 0 % around P4. The second largest drop would be from 100 % to 69.44 % around P1. Hence, this approach would incorrectly consider P4 to be the bottleneck.

3.3 The Arrow Method Based on Starving and Blocking

The arrow method presented by [2] is based on the frequencies of processes being starved and blocked. "*If the frequency of manufacturing blockage of machine* m_i *is larger than the frequency of manufacturing starvation of machine* m_{i+1}*, the bottleneck is downstream of machine* m_i*. If the frequency of the manufacturing starvation of machine* m_i *is larger than the frequency of the manufacturing blockage of* m_{i-1}*, the bottleneck is upstream of machine* m_i*.*"

In the pseudo-dynamic system, process P1 is not blocked at all in the first observed half, but blocked 30s out of 100s for the second half, giving an average blocked probability of 15 %. Similarly, P2 has a starving probability of also 15 %. P3 has to wait for parts 10s out of 100s no matter what, and is hence 10 % starved. Adding the arrows as shown in Fig. 5 clearly identifies P3 as a non-bottleneck, but fails to offer a direction between P1 and P2. The results of the dynamic system are shown in Fig. 6. The method clearly identifies the primary bottleneck P3. However, the arrow method considers P1, P2, and P4 to be non-bottlenecks.

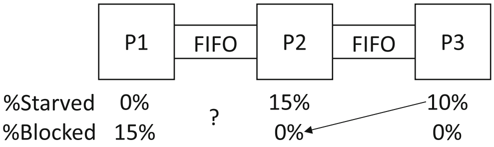


Fig. 5. Arrow method for the pseudo-static system

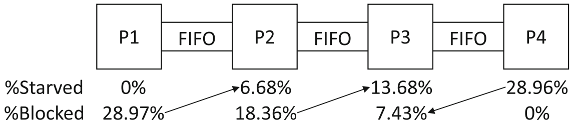


Fig. 6. Arrow Method for the Dynamic System

3.4 The Turning Point Method

The turning point method developed by [9] is also based on blockages and starvation similar to the Arrow method, although the calculation is more complex. In short, the bottleneck is the process where the difference between blocking and starving turns from positive to negative AND the sum of both blocked and starved must be lower than the two adjacent processes. The method can detect more than one bottleneck and even includes a ranking of multiple bottlenecks. The turning point method fails for the pseudo-static system. According to the turning point method, there is no bottleneck in the pseudo-static system. While in the dynamic system the turning point correctly identifies P3 as the main bottleneck it misses all other bottlenecks in the dynamic system.

3.5 The Active Period Method

The active period method was developed by [10, 11]. In this method, a process is considered active whenever the process is not waiting for parts or material. At any given time, the process with the longest active period is the momentary bottleneck. Overlap between the longest active periods are times of shifting bottlenecks. Periods with no overlaps are sole bottlenecks. The total bottleneck probability is the likelihood of a process being a sole or a shifting bottleneck. Regarding the pseudo-dynamic system, the active period correctly identifies the bottleneck likelihood of 50 % for P1 and P2 each, whereas P3 is never the bottleneck. The bottleneck probabilities for the dynamic system including a 95 % confidence interval were 24.1 ± 3.7 % for P1; 36.1 ± 4.8 % for P2; 49.8 ± 2.9 % for P3, and 24.3 ± 3.2 % for P4. These results match almost perfectly with the experimental results from 2.2 as shown in Fig. 7.

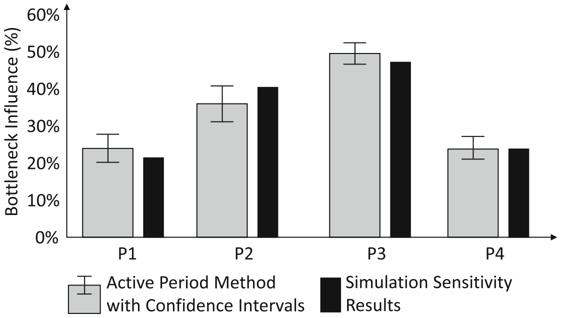


Fig. 7. Active period method results for the dynamic system

3.6 The Bottleneck Walk

The bottleneck walk [12] uses observations of processes being starved and blocked and inventory levels to determine the direction of the bottleneck. The method is particularly suited for use on the shop floor, as no mathematical calculations or detailed measurements are required. For the pseudo-dynamic system, the bottleneck walk correctly determines both P1 and P2 are bottlenecks with an influence of about 5 0 %. In the dynamic system, the bottleneck probabilities and their 95 % confidence interval were 28.7 ± 2.9 % for P1, 31.4 ± 2.2 % for P2, 40.8 ± 1.7 % for P3 and 29.7 ± 1.9 % for P4. While these results are not as good as the active period method, they still come very close to the true sensitivity as shown in Fig. 8.

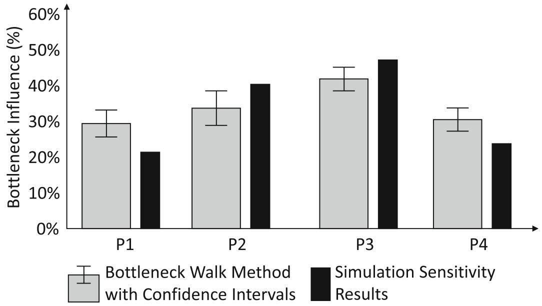


Fig. 8. Bottleneck walk results for the dynamic system

Table 3. Results Overview

Examined System		Pseudo-Dynamic System			Dynamic System				Mean Squared Error
	Process	P1	P2	P3	P1	P2	P3	P4	
Baseline Simulation Results	Bottleneck	Prim.	Prim.	No BN	Sec.	Sec.	Prim.	Sec.	n/a
	Gradient	50,0%	50,0%	0,0%	21,7%	40,3%	47,2%	23,7%	
Max Cycle Time/Utilization	Bottleneck	No BN	No BN	Prim.	No BN	No BN	Prim.	No BN	29,21%
	Gradient	0,0%	0,0%	100,0%	0,0%	0,0%	100,0%	0,0%	
Waiting Time or Queue Length	Bottleneck	Unknown	Unknown	No BN	No BN	No BN	No BN	Prim.	20,29%
	Gradient	Unknown	Unknown	0,0%	0,0%	0,0%	0,0%	100,0%	
Arrow Method	Bottleneck	Unknown	Unknown	No BN	No BN	No BN	Prim.	No BN	10,89%
	Gradient	Unknown	Unknown	0,0%	0,0%	0,0%	100,0%	0,0%	
Turning Point Method	Bottleneck	No BN	No BN	No BN	No BN	No BN	Prim.	No BN	14,92%
	Gradient	0,0%	0,0%	0,0%	0,0%	0,0%	100,0%	0,0%	
Active Period Method	Bottleneck	Prim.	Prim.	No BN	Sec.	Sec.	Prim.	Sec.	0,04%
	Gradient	50,0%	50,0%	0,0%	24,1%	36,1%	49,8%	24,3%	
Bottleneck Walk	Bottleneck	Prim.	Prim.	No BN	Sec.	Sec.	Prim.	Sec.	0,29%
	Gradient	50,0%	50,0%	0,0%	28,7%	31,4%	40,8%	29,7%	

4 Summary of Results and Conclusion

Overall, the accuracy of these bottleneck detection methods varies widely. Table 3 shows the overview of the results for all examined methods and systems. Fields in gray represent an incorrectly identified process. The last column shows the mean squared error of the bottleneck likelihoods.

With the dynamic system, all but the waiting time or queue length were able to determine the primary bottleneck correctly. However, only the active period method and the bottleneck walk were able to quantify the secondary bottlenecks. Regarding the pseudo-dynamic system, the shifting of the bottlenecks makes the detection more difficult. Only the active period method and the bottleneck walk were able to identify the bottlenecks correctly, although the arrow method and the waiting time/queue length method were undecided between the two bottlenecks. Only the active period method and the bottleneck walk were able to measure the bottleneck likelihood. The active period method were also the methods recommended by [13].

Overall, to detect shifting bottlenecks, it is imperative to **first detect the momentary bottleneck before calculating averages of the overall effect on the system**. Any method using averages before detecting the bottlenecks is likely to fall short for shifting bottlenecks. Of the presented methods, the active period method is particularly well suited for data-rich environments like simulations, whereas the bottleneck walk is best suited for a shop-floor-based observation.

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Guidelines for the Selection of FIFO Lanes and Supermarkets for Kanban-Based Pull Systems – When to Use a FIFO and When to Use a Supermarket

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Abstract. Modern lean production systems most often use a pull-based production control, usually implemented as kanban or CONWIP. The material flow in pull systems is managed using both FIFO lanes and supermarkets as inventories, which are well described in academic literature. However, there is so far little guidance as for when to use a supermarket and when to use a FIFO lane. This paper aims to provide an exhaustive list of considerations regarding the selection of a supermarket or FIFO lane between processes. While the detailed decisions depend on the particularities of the system, a number of general recommendations and considerations can be made. To the best knowledge of the authors, no such effort has been undertaken before, and we believe that this summary of considerations is long overdue and of immense value for the practitioner.

Keywords: Pull · FIFO · Supermarket · Kanban · Value stream design · Material flow · Information flow

1 Introduction

One key to a lean manufacturing system is to control production through a pull system. The most well-known approach to create a pull system is through the use of kanban in a loop with supermarkets and FIFO lanes. This system was developed at Toyota in Japan after World War II [1] and was first presented in English by [2]. Before we proceed, we will briefly explain the function of FIFO lanes and supermarkets. For details we refer to the vast body of literature on kanban, FIFO lanes, and supermarkets, as for example [3]. Please note that kanban systems are ill equipped to handle high-variety production, in which case a CONWIP system may be more suitable.

1.1 FIFO Lanes

FIFO stands for “First in – First Out.” The first part that goes in the inventory is also the first part that goes out. There is a limit to the maximum number of parts in a FIFO lane. A full FIFO eventually stops the preceding process, whereas an empty FIFO naturally

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stops the succeeding process. The example system shown in Fig. 1 shows four processes connected through three FIFO lines. Please note that we will use the widely accepted value stream mapping nomenclature to describe value streams throughout this paper [4].

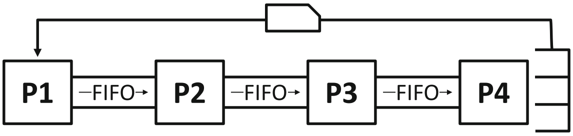

Fig. 1. Example of a four process kanban system with FIFO lanes and supermarkets using standard value stream mapping nomenclature

Only the first process P1 needs to receive separate information about the production plan – here in the form of a kanban – whereas all other processes simply process the next part in the FIFO lane. FIFO lanes also work very well with any type of product mix or lot size. However, it requires an identical material flow for all parts and thus is usually ill-suited for job shops; hence this paper focuses on flow shop type of production.

1.2 Supermarkets

Supermarkets can be seen as a number of FIFO lanes in parallel, one for each part type produced in the system. Hence the material flow is very similar to FIFO lanes, except that the flow is split by part type. However, the information flow is more complex in supermarkets. Whenever a part is removed from the supermarket, the information about the removed part has to travel back to the beginning of the loop to initiate the replenishment of this particular part type. This information is usually called kanban. The example of Fig. 1 shows one kanban loop with four processes. Operating the supermarket is slightly more complex than a simple FIFO lane, as the material flow and the information flow splits. Additionally, a supermarket usually takes more time to set up and implement compared to a FIFO lane. Finally, the number of kanban has to be determined and updated regularly, and the system has to be checked for lost kanban.

1.3 Problem Statement: Options Between FIFO Lanes and Supermarkets

A manufacturing system with multiple processes has different options for kanban system implementations. Figure 2 shows the kanban loop options for a manufacturing system with three processes. In option (a), a single kanban loop covers all three processes. Option (b) and (c) use two kanban loops to implement a pull system for the three processes. Finally, option (d) establishes a separate kanban loop for each process. The question this paper aims to address is: **Which of these options is superior to the others for a specific production system?** I would like to emphasize that all four options, (a) to (d), are usually completely valid pull systems. In general, the relation between number of possible system options p and the number of separate processes n is $p = 2^{n-1}$. Between every sequential pair of processes there is the option to use either a FIFO lane as part of a bigger loop or to split it into two loops using a supermarket. The question is: **When**

should a supermarket be used, and when a FIFO lane? Within this paper we assume that all materials are stored within a FIFO lane or a supermarket as part of a kanban based pull system.

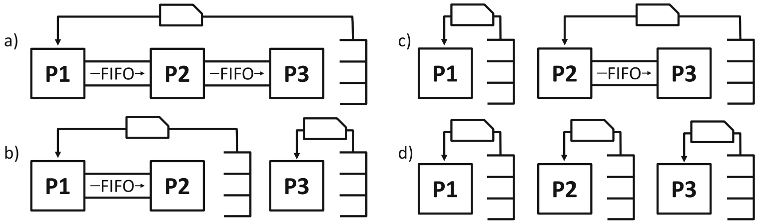

Fig. 2. Four options for a three-process system with FIFO lanes and supermarkets

2 On the Placement of FIFO Lanes and Supermarkets

2.1 Use FIFO Whenever There Is No Particular Reason to Use a Supermarket

Generally speaking, FIFO lanes have significantly less management overhead compared to supermarkets. Hence, the first guideline is to use a FIFO whenever there are no particular circumstances that would advise the use of a supermarket. This will also marginally improve the delivery performance for the same inventory, although the difference is not very large [5].

2.2 Consider a Supermarkets for Production Lot Size Differences

Some processes in the production system may have a different lot size from others. Assume you have a kanban loop with two processes and one FIFO lane in between as shown in Fig. 3. Depending on the lot sizes of the two processes P1 and P2, the system may come to a gridlock due to a lot size mismatch. Below is a complete list of possible situations with respect to lot size and their effect on the use of a FIFO lane.

a. If the processes have equal lot sizes, then no supermarket is needed.
b. If the process with the smaller lot size can accept any lot size equal to or larger than the other process, then there is no supermarket needed as long as the larger lot size is applied to the entire loop. For example, if the lot size of P1 is 100 parts, and the lot size of P2 is anything larger than 30 parts, then no supermarket is needed between the processes
c. If the process with the smaller lot size requires an exact lot size, then no supermarket is needed if and only if the larger lot size is an even multiple of the smaller lot size. For example, if the lot size of P1 is 100 parts, and the lot size of P2 is 50 parts, then no supermarket is needed between the processes since P2 can simply do two lots of exactly 50 parts each. Otherwise a supermarket is needed to decouple the processes and re-arrange the lot sizes for the different product types.

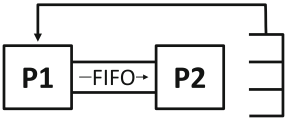

Fig. 3. Kanban loop with two processes and one FIFO lane.

Hence, with different lot sizes there may be a situation where a supermarket is required for the system to function. Of course, in practical experience the lot size is rarely fixed, and the lot sizes of the system can be almost always adjusted to avoid the need for a supermarket as outlined in situation (c) above.

2.3 Consider a Supermarket Before Creating Product Variants

Another instance where a supermarket may be superior compared to a FIFO lane is during the creation of variants. Using again the example of Fig. 3, let's assume that the first process P1 has one variant only. During the second process, ten different variants are created based on the single product created by P1. Using a FIFO lane before creating variants has a number of disadvantages. The first and less important reason is that the information regarding the variant has to be included on the kanban card already on process P1. Yet, process P1 does not need this information. Hence, there is an unneeded information transport. Additionally, since P1 does not need this information, there is a possibility that this information is considered unimportant by P1, resulting in a higher likelihood of the information being lost.

The second and more significant reason is that the replenishment time becomes longer and the system more sluggish, since a kanban has to pass through all processes in the longer loop, which takes more time. All these problems can be avoided through the use of a supermarket. P1 would produce only generic electronics for the clock, while P2 would assemble it in the color on the highest-priority kanban card waiting for production.

2.4 Consider a Supermarket After the Final Process and Before the Customer

It is common practice in kanban systems to have a supermarket before your customer. It is theoretically possible to include the customer in the loop as shown in option (b) in Fig. 4. However, this requires close interaction and cooperation with the customer. While it is possible, it requires additional effort and care to make sure all kanban cards eventually return to the producer for replenishment. Much more common and usually much easier to implement is to have a supermarket before the customer as shown in option (a) below. Since the kanban never leaves the producer's sphere of influence, it is much easier for the producer to create a smooth pull production.

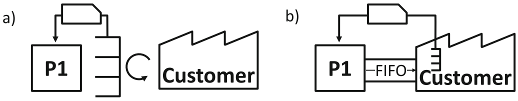

Fig. 4. Kanban loop excluding and including the customer

2.5 Consider a Supermarket for Merging Material Flows

A supermarket may also be highly beneficial for merging material streams. Assume there are two processes, P1 and P2 that jointly feed a third process, P3. If the material flow between P1/P2 and P3 uses FIFO lanes, a number of different problems may result, regardless whether there are two FIFO lanes as shown in (a) or one FIFO lane as shown in (b) in Fig. 5. This is also regardless whether process P3 merges the two parts from P1 and P2 through assembly or merely processes them individually, although in the reasoning we need to distinguish these cases.

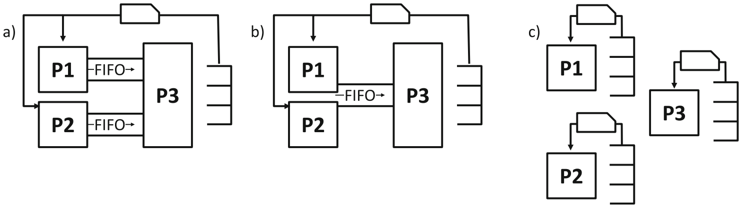

Fig. 5. Merging material flows

If P3 assembles products and requires parts from both P1 and P2 to work, the kanban has to reach both processes. While an electronic kanban can easily be sent to two processes, this is more difficult for physical kanban like paper or boxes. These kanban also somehow have to merge again in P3, resulting in two kanban per unit in the supermarket. Overall, it will make production control more demanding and will create additional potential for errors. Furthermore, if there are variants, the parts coming from P1 and P2 have to match the desired product. If for any reason the product sequence in either P1 or P2 becomes out of order, P3 may come to a gridlock if the two provided parts do not match. This gridlock then has to be resolved manually.

If P3 does not assemble products but merely processes one of the products, the kanban card would go to either P1 or P2. Hence additional decision making is needed to decide which process the kanban card goes to. If the processes P1 and P2 would differ the situation would become even more complex. Additionally, at P3 in example (a), another decision is needed regarding which FIFO lane to process first. This is less of a problem in (b), although production lot sizes and sequences from P1 and P2 become out of order. Hence merging material flows may benefit from the use of additional supermarkets.

2.6 Consider a Supermarket for Dividing Material Flows

Similar to merging material flows, dividing material flows may also benefit from supermarkets. A FIFO lane as shown in (a) or (b) in Fig. 6 will require additional decision making to determine if the produced part goes to P2 or P3 in both situation (a) and (b). Furthermore, especially in case (b), there may be the possibility that either process P2 or P3 has to wait since the foremost part in the FIFO is intended for the other process. While overall this is less complicated than a merging material flow, depending on the circumstances a supermarket may also be beneficial for dividing material flows.

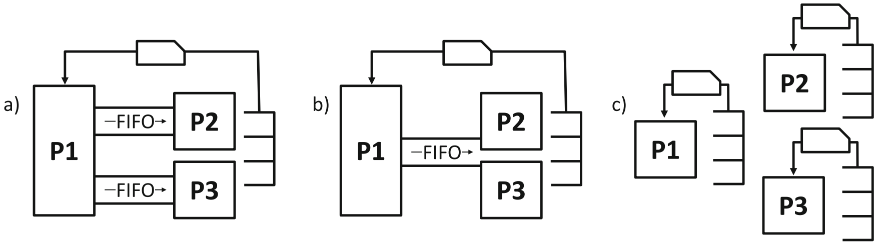

Fig. 6. Dividing material flows

Splitting material flows in most discrete manufacturing represent a process P1 that alternatingly provides for process P2 and P3. However, in the rare situations where process P1 actually disassembles one product into two subcomponents, there is a similar problem with the splitting of kanban as described with the merging material flows. In any case, any division in material flow may be a candidate for closer consideration for a supermarket.

2.7 Consider a Supermarket for Very Different Speeds or Times

Yet another instance where a supermarket may be beneficial is for time differences in production. Such time differences may come from significantly different cycle times, changeover times, or shift patterns. The problem is small if the time difference is small, but may become larger depending on the time difference. Assume again in Fig. 3 that P1 and P2 have very different speeds or working times. Standard practice is to decouple these processes with buffer stock.

Such buffer inventory could, for a pull system, consist of either a FIFO lane or a supermarket, with similar inventory levels. However, if the system lacks robustness and is sensitive to changing customer demands, a FIFO lane may have a disadvantage due to the time delay. The production sequence of the faster process would be defined long beforehand. While this poses no problem in theory, in practice production systems are rarely static. Within the duration of a shift, priorities can change and material can become available or (more likely) missing due to delivery delays, quality problems, or other mishaps. In any case the ideal production sequence for subsequent processes may change while the parts are in the inventory. A supermarket allows for an easier access of the highest-priority materials compared to a FIFO lane. Therefore, the longer the time differences and therefore the buffer inventory reach, the higher the benefit of a supermarket instead of a FIFO lane.

2.8 Consider a Supermarket for Large Distances Between Processes

The above example of long delays between creating the production pattern in the preceding process and using the pattern in the succeeding process also applies for transport delays. Taking an extreme example, a shipment of goods from Shanghai to San Francisco can easily take two weeks or more, not even including delays by customs or through unloading. While in this example it is already nearly impossible to maintain FIFO physically, even a data-based FIFO where each part is delivered in the sequence it was loaded is difficult. However, more significant is again the time delay. As described above, circumstances and priorities may change significantly while the goods are in shipping. This change of circumstances would then require a break in the FIFO sequence. This would be much easier with a supermarket on one or even both sides. While ideally maintaining a product-specific FIFO sequence, the receiving side can prioritize the production much easier with a supermarket than using a FIFO lane. Therefore, it may be beneficial to split a larger loop into two parts by adding a supermarket if the physical or time-wise distance between processes becomes too large. This is definitely true for different continents, but also applies to different locations within one continent or country, and may sometimes even be sensible for different locations within one plant.

2.9 Consider a Supermarket for High Demands on Agility

Long replenishment times in one kanban loop can be shortened by splitting it up into two separate loops. Hence, adding more loops may make the production system more agile and responsive to changes in demand. Ideally, these changes can come from the customer side, but in less-than-perfect systems they may also arise due to problems elsewhere including material availability, machine troubles, or availability of skilled labor. In any case, it may be necessary to change the production plan to match the new circumstances. If there is only one long kanban loop, any change in the production plan has to go through the entire value stream before resulting in a finished product at the end. Smaller loops will be able to react much quicker. Hence, having multiple loops will allow each loop to become more agile and to react faster to changes. If the changes stem only from the customer side, a small loop at the end will suffice. However, if the changes are also caused by other factors along the value stream, splitting the entire value stream into multiple loops by adding supermarkets may help.

2.10 Consider a Supermarket for Changes in Responsibility

All of the above considerations for using a supermarket were based on logical reasons related to time and quantity in order to get the maximum effect with a minimal effort. This last reason, however, is different. It is not based on logical conclusions of cause and effect, but rather on the intricate behavior of the human mind. Ideally, if there are problems, the goal of the people involved should be to resolve the problem as fast as possible and resume operations. Practically, depending on the company culture, the people may be more concerned with finding the responsible party than with solving the problem (colloquially known as the *blame game*). There is often disagreement on whom to blame, and, naturally speaking, each person involved considers her- or himself innocent and sees the problem with someone else. Far too many companies extend a greater effort on this blame game than on fixing the problem. While a mere supermarket cannot eliminate this problem, it can reduce its spread as a sort of separator of responsibilities. The supplying party should keep the material stocked, and the demanding party should not exceed certain limits on fluctuation. Hence a supermarket at the boundaries of changes in responsibility may be able to contain the overhead friction of problems within one area of responsibilities.

3 Conclusion

While generally speaking a FIFO lane is much easier to manage and hence preferable in the often-hectic environment of the modern shop floor, there are a number of reasons when it may be beneficial to split a larger kanban-based pull loop into smaller loops through the adding of a supermarket. All of the reasons can also be managed through a FIFO lane. However, this may require additional efforts and non-standard procedures as, for example, breaking the FIFO sequence of parts. Besides the additional manual effort, a possible break in the FIFO sequence can lead to higher fluctuations in throughput times and production delays for some products and hence missed deadlines. Furthermore, this can also result in aging of products and possibly higher inventories and scrap rates. Depending on the circumstances, a supermarket may be the better tool for inventory management in many of the above cases. Of course, a vast number of additional circumstances will also influence this decision on the shop floor. However, the above paper will help and guide the practitioner in designing a value stream by listing the possible considerations for a supermarket in contrast to the standard solution of a FIFO lane. This will eliminate waste and create a smoother, more productive manufacturing system.

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Negative Side Effects of Lean Management Implementations – A Causal Analysis

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Abstract. The side negative effects of Lean Management implementations are well known among practitioners. Recently they became a subject of systematic research. This paper presents conclusions from a causal analysis of the unlikely results, which were identified along case studies. The research was conducted in the machine building industries in EU. The insights from interviews and expert-panels were systemized by cause-and-effect models, thus suggesting the root causes of the negative effects. The synthetized results are considered herein as an input for constructing a method for multi-perspective assessment, to enable better planning and control of the Lean Management implementations.

Keywords: Lean management · Side negative effects · Management control

1 Introduction

The Lean Management was attracting a lot of interest among researchers, companies and consultancies in recent decades. Although the scientific and professional literature is principally positive about its use and effects, it is well known among practitioners that Lean Management often brings side negative effects. Recently this issue became a subject of systematic research [1]. It was confirmed by a sound empirical evidence that in many cases the losses from Lean Management implementation, which usually come with a delay, may exceed the gains. This exhibits an important practice gap and raises a question about causes of such a phenomena. It seems impossible that simple reasons, like mistakes or incompetence, can explain its frequency and scale.

This paper investigates the root causes of side negative effects that often follow Lean Management implementations. The researched phenomena is surprising and no explanations are given by practice or by literature. Hence it was assumed to respect the rules of empirical phenomenology to protect robust outcomes from the investigation. The research was conducted in machine building industries along a series of case studies. The paper presents conclusions from analysis of insights from interviews and expert-panels, which were systemized by cause-and-effect models. This way the major root cause of negative side effects could be identified, which is argued to be the reductionist assessment of planned effects and risks. The conclusions are later considered as inputs for guidelines for multi-perspective and holistic assessment, to enable improved planning and control of the Lean Management implementations.

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2 Literature Review

A bold volume of Lean Management literature exposes advantages of this approach [2, 3] and links improved plant performance to its implementation [4–9]. Some papers even suggest that "… the research question of primary interest in the literature is no longer whether lean can benefit performance …" [10]. The recently provided empirical evidence neglects this unilaterally positive outlook [1]. The published results suggest that almost half of the researched Lean Management implementations finally outcome in a negative balance of effects [1]. The typically reported negative side effects are as follows: (i) Fall-outs, i.e. late or cancelled deliveries, mainly due to internal problems in supply chains; (ii) Quality problems/issues; (iii) Increased stock/buffers; (iv) Customer dissatisfaction, or even damaged reputation; (v) Reduced sales; (vi) Misuse and loss of competence, e.g. by misusing experts outside of their professional qualifications, fluctuation of core employees; (v) Increased costs: due to the above effects, or even exceeded budgets of Lean projects/initiatives, hence no return from investment into them. As yet there are no accessible papers that directly investigate the causes of negative side effects of Lean Management implementations. The dichotomy of reported results from Lean Management implementation cannot be resolved on the basis of literature knowledge. This exhibits evident practice and methodological gap. Potentially publications on managerial control and accounting, particularly those focusing on measurement of improvements (in terms of performance), could provide some valuable inspirations. These are reviewed later on.

A number of papers examine how the management control activities foster or impede implementations of Lean Management [5, 6, 10–16]. A major attention is given to the following practices: the extent of dedicated teamwork, focused performance reporting, implementation or regular audits, allocation of responsibilities, use of financial and non-financial incentives. It is argued within this stream of literature, that some management control practices have a limited fostering impact, if any at all like the financial awards or top-driven management audits. Many authors suggest to use few non-financial performance indicators, rooted in the company strategy, clear and understandable to easy motivate people, linked to processes but not to humans. Visualizations and periodic comparisons of actual effects against targets are proposed to follow up and facilitate improvements. Guiding and motivating people, who are involved in Lean Management implementations, to add more value and to avoid waste, is typically focused on. Some authors suggest creation of accounting or controlling system for value streams, addressing costs of product development, sales, production and supplies [15]. Evidently such high level methodological recommendations are not helpful when tackling the discussed problem. The published findings and proposals do not explain, nor protect against the reported side effects. Notably, the literature bypasses the issue of potential side effects of Lean Management implementations, that can come out after some time or manifest themselves in other areas of company activities. This leads to a conclusion that holistic assessment of the effects is possibly missing. It must be also pointed out, that although the link of expected Lean Management effects to company strategic objectives and overall performance is often mentioned, it is never a subject of systematic and detailed considerations.

Very few papers attempt to investigate how Lean Management implementations may be affected by some contextual factors. The following have been researched: company age [5], plant size [5] and unionization [5, 9, 10]. The presented evidence suggests that large plants are more likely to implement the Lean practices, while the two last factors have minor importance. Other contextual factors are not addressed.

The management control literature has long focused how to coordinate company activities and motivate employees to implement the strategic objectives [17]. Possibly the overall methodologies of management control and accounting could provide some value with regard to the issue. Among them strategic control methods (e.g. Balanced Scorecard [18]) or managerial accounting methods (e.g. Activity Based Costing [19], Process Costing [20], Flexible Margin Costing [21], Resource Consumption Accounting [22], Throughput Accounting [23]) seem to be potentially useful. However, none of them can be straightly applied to explain the causes of discussed effects.

The above review exposes that existing literature knowledge does not explain the discussed phenomena nor directly applies for its diagnosing. It even does not provide indications of its hypothetical reasons. Hence a prior causal analysis is indispensable.

3 Research Methodology

As it was argued in the preceding section, the existing literature does not provide useful insights for explaining in a robust way why the phenomenon of side effects of Lean Management implementations is so frequent and has significant negative impacts. This comment applies in particular with regard to development of hypothetical causes. The picture of problem domain is not clear, as no direct explanations to the issue are given by practice or by literature. Therefore it would be rational, to assure valid outcomes of the research, to respect the rules of empirical phenomenology, i.e. to directly investigate the reality of phenomenon by a kind of field investigation.

The research presumed a number of case studies. These were conducted in the machine building industries. Companies from the EU, sizing from 200 to 1000 employees, were approached. Altogether sixteen case studies were performed. The staff of various departments, with regard to the scope of particular implementations (i.e. also considering the side effects), participated in the case studies, namely from departments of: production, purchasing, sales and product development. Senior and executive management associates were usually involved as the experts into the research.

At the beginning, to get an initial understanding of the phenomenon, a series of Lean Management implementations was investigated. By interviewing managers and collecting relevant data. Considering the main objectives of the investigation, the conclusions from empirical data were systemized by cause-and-effect models, which addressed the twofold manifestation of the phenomenon. The first layer of causes and effects reflects the straight matter of the projects. The conditioning factors, like those contextual or related to the management control and organization, i.e. including the hypothetic root causes, compose the second layer. The items from both layers are also linked by causal relations. To validate and extend the initial results second iteration of the field research was performed, by expert-panels. All experts were fully equipped with compiled results of first iteration research, very detailed. They were expected to validate the identified roots causes and to assess them. Their weight and correlation could be eventually expressed in terms of frequency, importance of the side negative effects, and amplification power for causal relation. For the beginning subjective assessments of experts were considered as a sound mean for explanation and weighting the impact of previously identified root causes. The conclusions about root causes could be later used as inputs for developing guidelines for practice oriented countermeasures, which eventually protect against the unlikely effects of Lean Management implementations. The drafted overall plan of research is presented above in Table 1.

Table 1. Plan of research

Phase	Scope	Methods/tools
Initial	Problem conceptualization	Analysis of literature
Empirical phenomenology	Case studies – initial phase	Semi-structured interviewing
Causal analysis	Case studies – root-cause analysis of side effects	Cause-effects modelling Expert panels (2nd iteration) Root-cause modelling
Conceptual development of countermeasures	Guidelines for multi-perspective assessment	Theoretical synthesis of root-causes

4 Research Findings and Conclusions

All performed case studies were luckily supported by a full access to the available data related to Lean Management implementations, however due to the non-disclosure agreements all the quantitative data had to be transformed into synthetic information.

It has appeared that without any exception, projects were used as the vehicle for driving Lean Management implementations, which were expected to be planned and controllable, using the measures of financial outcomes. The approach was considered itself like a kind of technology leading to some specific types of outcomes, namely:

- Slimmed waste in different departments, along exact processes or within functions
- Reengineered products to minimize costs of goods sold
- Reduced fixed costs or minimized other expenditures by outsourcing
- Improved performance/competitiveness by investment in technology or automation
- Ensured cash flows due to increased sales by high or steady order entries

The above is in opposition to the Japanese approach to Lean Management, which is considered as an open philosophy, focusing on elimination of waste in value streams and emphasizing non-financial measures to facilitate and control improvements.

The primary findings from semi-structured interviewing were mapped to the form of cause-and-effect diagrams. Separate diagrams were prepared for all investigated implementations and the two mentioned layers. This way a precise and sound picture of all researched cases could be obtained. An example diagram is presented in Fig. 1.

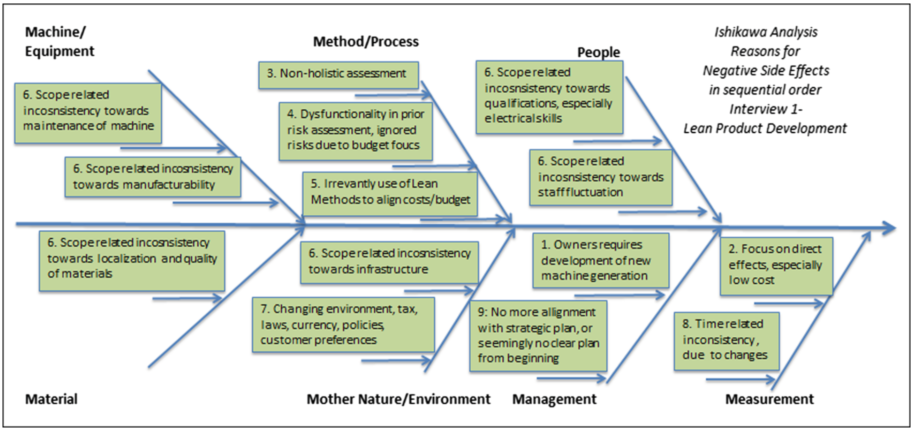

Fig. 1. An example cause-and-effect diagram (root causes layer)

Later on the causes and effects have been systematized, reflected and compiled, to enable identification of root causes of the observed side negative effects. The faults or dysfunctionalities of Lean Management were not considered as a potential source of root causes, as it was presumed that the management control system should not allow using any inappropriate method. The following root causes have been identified:

1. Irrelevant use of the Lean Management, i.e. applying it for purposes (capacities, processes etc.), that should not be targeted by this approach or its method.
2. Incompetent use of the Lean Management, i.e. from the methodical point of view.
   (a) Misapplication of methods;
   (b) Misapplication or no use of cross-X teamwork (X: functions, departments etc.);
3. Dysfunctionalities of management control, like:
   (a) Dysfunctionalities of assessment of effects:
      (i) Time-related inconsistency of planned effects, i.e. omitting later effects;
      (ii) Scope-related inconsistency of planned effects, i.e. bypassing effects in other areas (departments, etc.) or those experienced by other stakeholders;
      (iii) Focus on direct, i.e. first momentum effects;
      (iv) Non-holistic assessment, i.e. ignoring significant interdependencies, trade-offs or discrepancies of effects, which can be only identified when a whole (company, supply chain etc.) is assessed considering its complexities;
      (v) Difficulties to account or relate performance and financial measures;
      (vi) Changing conditioning factors (e.g. environmental factors, baselines etc.);
   (b) Dysfunctionalities of prior assessment of risks;
   (c) Missing link to company strategic objectives.
4. Contextual factors, like:
   (a) HRM practices (e.g.: assessment, incentives, responsibilities, promotion);
   (b) Corporate governance, in relation to the ownership type, by push from the top management towards short-term effects, due to the requirements of company value management.

Along the second iteration of field research the experts verified and validated the identified roots causes. This was documented in a number of ways. One of them is by representing the precedence relations between the root causes. This view is presented below in Table 2. The numbers in columns reflect the sequential order of occurrences.

Another view could be obtained by assessment of relative importance of the root causes, i.e. taking into account their impact on level and occurrence of the negative side effects. This aspect was analyzed in several ways. Table 3 presents a simple but transparent picture, i.e. by subjective weights assigned by the experts, who have used the Likert scale (1–5). It was understood by all of them that correlations between root causes may take place, as well as some kind of overlapping.

According to the precedence view of the root causes it is evident that "all begins with the wrong setting of objectives". Sometimes it is due to the stress from the top management, sometimes by ignoring company strategic goals, sometimes due to narrow focus on direct goals, finally it may be due to non-holistic assessment of possible effects. An extended perspective can be derived by considering the impact factor of root causes. It is also evident, that from the overall point of view, the different aspects of dysfunctional effects assessment compose altogether the major determinant of side negative effects of Lean Management implementations. It can be also concluded from the findings, that when appropriate assessment of effects would be accompanied by linking them to company strategic objectives, in most cases the side negatives effects could be effectively avoided. Furthermore, in such cases mistaken initiatives, like due to stress from top-management on short term effects, would be most likely rejected.

It can be argued by concluding from the obtained research findings, that the following guidelines provide a comprehensive and sound framework for effective management control of Lean Management implementations:

1. The objectives of any Lean Management initiative should be derived from or confronted with the company strategic objectives.
2. The expected effects of Lean Management implementation should be assessed in a holistic way, i.e. by applying multiple perspectives of company or supply chains, and by considering all possible significant interdependencies, trade-offs and discrepancies of causes and effects. This should be primarily protected by:
    (a) Multi-perspective assessment of the effects by the Cross-X teams, i.e. through involvement of different stakeholders;
    (b) Qualitative controlling of effects, which should be supported by the means of qualitative modelling, in most cases probably by the cause-and-effect models.
3. Specific complexities of effects should be analyzed by dedicated modelling means, to relate some factors and to estimate trade-offs, and to elicit the possible second momentum effects. The holistic method of assessment should be equipped with a range of such means, making it ready for the most common circumstances, like e.g.: using standard Lean methods, targeting typical effects, and so on.

Table 2. Sequence of occurrence of the root causes

Root cause	Case															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Irrelevant use of Lean Management	3					5				2				4		
Misapplication of Lean Management methods	4	6		4	3							3		3		
Misapplication or no use of cross-X teamwork			3		4				3							
Time-related inconsistency of assessment	8	8	6	8	8	7	4	3	6		4		5			5
Scope-related inconsistency of assessment	6	7	5	6	5	6			5					4	5	6
Focus on direct (first momentum) effects	2	2	2	1	1	2	1	1	1		2		2	2	3	2
Non-holistic assessment	5	5	4	2	6	3	3			1		1	3	5		3
Difficult relating perform. & fin. measures																
Changing conditioning factors	7		7										4			4
Dysfunctionalities of prior risk assessment		4		3	7	4	2	2	4	3	3	2				
Missing link to company strategic objectives	9		1	9	9	8					1	4	6	1	1	1
HRM practices		3							2							
Corporate governance context	1	1		5	2	1				4			1		2	1

Table 3. Average impacts of the root causes

Root cause	Case																Av.all	Av.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
Irrelevant use of Lean Management	1					3				2					3		0.6	2.3
Misapplication of Lean Management methods	4	2		4	3							2		3			1.1	3.0
Misapplication/no use of cross-X teamwork			3		3				3								0.6	3.0
Time-related inconsistency of assessment	1	1	1	1	1	3	2	2	3		2		2			3	1.4	1.8
Scope-related inconsistency of assessment	5	1	4	1	2	3			4					3	5	2	1.9	3.5
Focus on direct (first momentum) effects	4	4	1	4	2	4	4	4	2		4		3	3	4	4	2.9	3.4
Non-holistic assessment	4	4	3	3	3	4	2			5		4	3	2		3	2.5	3.3
Difficult relating perform.&financial measures																	0.0	0.0
Changing conditioning factors	2			3			5						4			4	1.1	3.6
Dysfunctionalities of prior risk assessment		4		3	2	4	3	4	3	3	3	3					2.0	3.2
Missing link to company strategic objectives	2		2	2	2	4					2	2	3	2	2		1.4	2.3
HRM practices		3							4								0.4	3.5
Corporate governance context	2	2		3	2	2				2			5		5	4	1.7	3.0

5 Summary

This paper elicits root causes of frequent side negative effects of Lean Management implementations. The empirically gathered evidence suggests that this unwelcome phenomenon is usually driven by particular dysfunctionalities of management control. Among them reductionist assessment of effects, plays the dominant role. It primarily manifests itself by: (i) bypassing those effects that are not directly linked to the area of given initiative; (ii) strict focus on first momentum effects; (iii) omitting complex causal relations of the effects. Additionally, the missing link between Lean Management effects and company strategic objectives brings further deterioration of effects.

In response to the identified dysfunctionalities of management control, guidelines for the holistic assessment are proposed, which meet the practice gap, and not like the literature, address the discussed question in a concrete, specific and focused way.

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Lean Management Effects - An Empirical Evidence from Machine Building Industries in Europe

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Abstract. This paper investigates planned and side effects from Lean Management implementations. Case studies from machine building industries in Europe were used as an empirical base. The focus of presented research is to provide a relevant data, that could help to explain, why the side negative effects of Lean Management implementations take place. The empirical evidence presented herein with regard to the issue, is wider than in any available publication. Also the way of analyzing effects in this paper goes beyond the existing literature.

Keywords: Lean management effects · Lean management assessment

1 Introduction

Lean Production or Lean Management is often and worldwide used by companies nowadays. From successful Lean enterprises significant results can be reported, which makes Lean Management interesting for many business sectors. Toyota is often named as the benchmark, which reports 60–90 % lead time reductions, decrease of inventory levels by 10–50 %, or improvements of productivity by 5–25 % [1]. Toyota considers Lean as a philosophy, following the principle of just reducing the time line from receiving a customer order to customer delivery, by removing any waste [2].

Lean Management is fuzzy understood by Western, who modified the original intention of the original Japanese concept and tend to understand it like a top-down driven restrictive framework for short or medium term projects, typically targeting localized or punctual improvements. The responsibility for success is normally assigned to project managers who are set in charge of expected improvements. Aimed Lean effects are commonly linked to cost savings, growth targets and utilization improvements. However, the sustainability of expected gains is not surely protected. Negative side effects become visible, which typically appear in a form of additional costs, decreased quality of products or services, customer dissatisfaction and others [3]. The above mentioned misperceptions of what Lean Management is and how it should be implemented and managed, seem to corrupts sustainability and long-term success of implemented Lean Management initiatives. This paper provides an extended empirical evidence of Lean effects, including the side negative effects. It is based on a broad basis

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of case studies, which were aiming a detailed and multi-perspective evaluation of Lean Managements projects.

2 Existing Knowledge

The Japanese approach to implementation of Lean Management is often described in five steps [4]: (i) identify a change agent; (ii) find a teacher to facilitate learning; (iii) build a challenge to motivate organization; (iv) map the entire value stream of products; (v) start removing waste at a point that quickly makes an impact and continue then with the rest. The Lean Management in Western world allows various modes of implementation, caused by literature and influence of consulting, which modifies the original Japanese concept of Lean Management [6]. Instead of thinking in terms of value streams and flows, Western managers and executives often focus on short-term-savings, or functions and departments which are in charge of implementation. Managers and project leaders receive bonuses to achieve targets, while the value stream perspective is avoided due to complexities. This is in line with tradition of management control based on standard costs accounting and common focus on utilization of machinery and workers as a major performance indicator [5]. Researchers sometimes describe today interpretation of Lean Management as “considerable variation in scientific and grey literature” being either applied as “philosophy, toolbox, strategic goal or a change process”, or even considered as a multidimensional-concept compromising hybrid models, which lead to more vague Lean thinking.

Away from the Lean Management original intentions, the Lean Enterprise Model proposed by the Lean Enterprise Institute introduces a different sequence for implementations: identification of a problem, devising processes to be improved, develop people to continuously improve, allocate managers with right thinking to drive correct leadership, to finally embed the Lean thinking in the company [7]. It is questionable how to combine typical Western approaches with the ideas of Toyota and align the company in long term with Lean thinking, where typically waste in selected processes from value stream analysis is removed i.e. by applying Kanban, Just in Time, Single-Piece-Flow, Levelling, 5S, Kaizen, TPM and diverse other principles.

Many Lean Management publications focus on advantages [5] and suggest that its implementations surely lead to improved performance [8–13]. Some papers even state that “the research question of primary interest in the literature is no longer whether lean can benefit performance” [14]. Interestingly all reviewed papers report the effects of Lean Management implementations which were targeted, while eventual side effects are not considered. This exhibits at methodological failure. If one does not look at the side effects, which can be observed elsewhere, they are just not seen at all. The recent empirical evidence neglects the unilaterally positive outlook of Lean by a multi-perspective assessment confirms the existence of side negative effects [3].

The danger of side effects of Lean Management implementations is possibly manifested in spectacular ways. Volkswagen recently reported shortages of components resulting in shutdown of plants. Mercedes and other carmakers report long customer lead times in Europe and USA. BMW extended shipping costs budget for aircraft carriage for urgent deliveries [15]. Bosch established internal task forces to cope with material shortages. ZF Friedrichshafen claims that a many of their strategic suppliers face a difficulty to cope with demand. In USA million car recalls in 2013–2014, caused by faulty airbags or other quality issues were reported [16]. Unfortunately no single publication has systematically identified or quantified the root causes of above listed observations. Although the unwelcome effects were not deeply explained, from the described circumstances they seem to be rooted in some particular Lean Management implementations, like e.g. leaning the supply base.

The above exhibits both, the practice gap and the research gap, and calls for extended empirical evidence and further methodological research.

3 Methodology and Findings

The problem stated evidently requires for a sound empirical evidence. It is due to the unilateral view of Lean Management effects presented in the literature, as well as because of the potential difficulties to explain why side negative effects occur.

After the literature review, which could help to identify side negative effects of Lean Management implementations, a series of case studies was considered. All together 16 machine building companies were approached, which are listed in Table 1.

Table 1. Researched companies

Company	Workforce	Lean Topic	Interviewees
A-Case1	1000+	Product development	Chief technical officer Head of product development
B-Case2	600+	Procurement LCC	Head of procurement Senior category manage
A-Case3	1000+	Assembly tact	Head of assembly Head of outgoing goods
C-Case4	500+	Assembly LCC	Head of assembly Diverse sales managers
C-Case5	500+	Engineering relocation	Head of engineering Head of business excellence IT
A-Case6	1000+	Production LCC	Head of assembly Head of human resources
D-Case7	1000+	Machine investment	Head of production Head of quality management
B-Case8	600+	Staff exchange	Head of assembly Head of production
A-Case9	1000+	Sales KPIs	Head of sales Managing director
F-Case10	200+	Development of control units	Head of assembly Head of product development

(*Continued*)

Table 1. (*Continued*)

Company	Workforce	Lean Topic	Interviewees
A-Case11	1000+	Optimization of precision measuring for geometrical levelling	Head of production Head of product development
C-Case12	500+	Shift from control of statistical data to electrical regulation	Head of commissioning Head of product development
D-Case 13	1000+	Sale of more standard machines	Head of key account Head of assembly
E-Case14	300+	Relocation of machine Centre to LCC	Head of production Managing director
E-Case15	300+	Closing of plant, relocation to LCC	President operations Head of machining
B-Case16	600+	Build up machining in LCC	Head of machining

The case studies are grounding the research plan, which is presented in Table 2. The professionals from approached companies have been involved in semi-structured interviews and later in expert panels. Results of the two series of meetings compose the baseline of research. All interviews were centered on three key issues. Firstly, the intention to identify the field of project in devised environment. Secondly, the targeted effects as planned before the project. Thirdly, the actual effects - appearing after project. All the three issues have been based on a multi-perspective viewing of the potential side effects. This was crucial for their identification and further assessment. The applied approach is fundamentally different to published researches of that kind.

Due to confidentiality, companies and performance indicators remain unnamed or being published in a synthetic way. Using this basis, some statistical analysis of the gathered data could be provided.

Table 2. Plan of research

Phase	Scope	Methods/tools
Initial	Problem conceptualization Theory and practice of Lean Mgmt Evidence of effects in theory	Analysis of literature
Empirical	Case studies	Semi-structured interviewing Expert panels (2nd iteration)
Analysis of results	Results assessment Summary of findings	Simple statistical analysis
Synthesis of results	Conclusion	Theoretical synthesis

All investigated case studies exhibited seven common characteristics of implementations. All of them were following a common management control structure, which is illustrated below:

(I) Planning
  (1) Financial business plan
  (2) Steering committee, consisting of:
    - Minimum one executive manager
    - Controlling associates
    - Project Manager
    - Member of interfacing departments
  (3) Milestone plan for implementation
  (4) Basic risk assessment

(II) Control
  (5) Regular project meetings, including:
    - Progress of implementation
    - Financial results review, mainly cost and benefits
    - Coaching from steering committee to achieve aimed targets
  (6) Budget conformity according to annual budget plan
  (7) Verification of financial results

The case studies enabled to identify both, the planned effects of Lean Management implementations, as well as the side negative effects. All of them are listed in Table 3.

The project based setup within companies indicates that planning and control are essential for Lean Management projects. The five most common scopes of targeted effects can be categorized as follows:

- Slimmed waste in different departments, along exact processes or within functions
- Reengineered products to minimize costs of goods sold
- Reduced fixed costs or minimized other expenditures by outsourcing
- Improved performance/competitiveness by investment in technology or automation
- Ensured cash flows due to increased sales by high or steady order entries

All investigated cases targeted single elements or hybrids of the above shown scopes of effects.

The most frequent side negative effects resulting from the reviewed projects can be categorized as:

1. additional costs, i.e. unplanned costs, which in some instances even outranked the planned benefits (in nearly all projects);
2. quality issues (in more than every second project);
3. fall-outs and/or resulting penalties (in every third project);
4. higher stock or loss of competencies (in every fourth project).

The quantification of these effects is illustrated below in Fig. 1.

In order to illustrate the impact of side negative effects, i.e. in contrast to planned positive effects, a weight scale from zero to seven has been applied, where 0 is the

Table 3. Overview of targeted and side effects

Case	Field and topic	Targeted effects	Negative effects
1	Sales KPIs	Low development cost Transparent spending	Additional capex costs Quality issues Customer dissatisfaction
2	Development of control units	Saving supply cost LCC quote	Additional one-time costs Penalties, fall outs Quality issues
3	Optimization of precision measuring for geometrical levelling	Cost savings Double output Productivity increase	Additional capex costs Increased stock
4	Shift control of statistical data to electrical regulation	Saving personnel costs Saving production costs Low cost suppliers	Additional costs Customer dissatisfaction Reduced sales volume Non-acceptance by own staff
5	Sale of more standard machines	Saving production costs Utilization of plants Standardization	Additional capex costs Quality issues Missing responsibility
6	Relocation of machine centre to LCC	Saving production costs Low investment cost Growth in market	Additional costs Quality issues Non-acceptance by own staff
7	Closing of plant, relocation to LCC	Saving production cost Technological advantage Utilization	Additional one-time and capex costs
8	Build up Machining in LCC	Revenue increase Better motivation	Additional training costs Quality issues Customer dissatisfaction
9	Sales KPIs	Revenue increase Motivation	Additional costs Customer dissatisfaction Quality issues
10	Development of control units	Technological advantage Saving personnel cost	Additional capex cost Customer dissatisfaction Quality issues
11	Optimization of precision measuring for geometrical levelling	Saving personnel costs Higher quality	Quality issues Additional cost
12		Saving personnel costs	Additional one- time cost Quality issues

(*Continued*)

Table 3. (*Continued*)

Case	Field and topic	Targeted effects	Negative effects
	Shift from control of statistical data to electrical regulation		
13	Sale of more standard machines	Lower production costs Mass production benefit Utilization of plant	Customer dissatisfaction Higher stock High qualified engineers leave
14	Relocation of machine centre to LCC	Lower production costs Lower personnel costs	Quality issues Customer dissatisfaction Higher stock
15	Closing of plant, relocation to LCC	Lower production costs Lower personnel costs	Quality issues Image damage, penalties Loss of qualified staff
16	Build up machining in LCC	Lower personnel cost	Quality issues Additional capex cost

minimum rank and 7 the maximum. The findings provide a proof that negative effects exist and often outrank the planned targets. In first instance the above shown absolute quantifications of effects (Fig. 1) have been broken down to major categories of side effects, as illustrated in Table 4.

The main impact of side effects results from unplanned "extra costs" of different nature, i.e. higher than assumed project related investments or capex related costs (43 %), followed by costs of "Fall Outs", e.g. customer penalties or cancelled orders

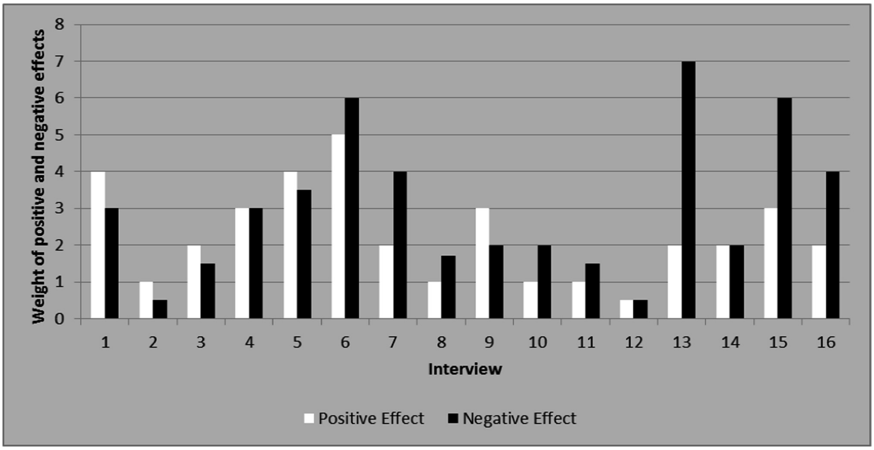

Fig. 1. Absolute quantification of lean management target and side effects

Table 4. Breakdown of side negative effects

Interview	Extra cost	Quality Issue	Fall outs	Higher stock	Competence Loss	Others	Sub-total
1	2	0,3	0,6	0	0	0,1	3
2	0,1	0,2	0,1	0	0	0,1	0,5
3	1	0	0	0,4	0	0,1	1,5
4	1	0	1,6	0	0,2	0,2	3
5	2,7	0,3	0	0	0,5	0	3,5
6	3	0	0	0	2	1	6
7	4	0	0	0	0	0	4
8	1,5	0	0	0	0	0,2	1,7
9	0,8	0,2	1	0	0	0	2
10	0,5	0,6	0,8	0	0	0,1	2
11	0,8	0,5	0	0	0	0,2	1,5
12	0,2	0,3	0	0	0	0	0,5
13	0	0	4	2	1	0	7
14	0	0,4	1	0,6	0	0	2
15	0	0,9	2,7	0	2	0,4	6
16	3,3	0,5	0	0	0	0,2	4
Total	20,9	4,2	11,8	3	5,7	2,6	48,2
% of Total	43 %	9 %	24 %	6 %	12 %	5 %	100 %

(24 %). The third highest effects can be linked to "Competence Loss" (12 %), which is described as unplanned leave of experts or specialists, carrying on unplanned costs. Fourth ranked category is "Quality Issues" (9 %), mainly appearing during project implementation or after project. Second last category is "Higher Stock" (6 %) consisting of increased stock levels, extended costs for warehousing, and additional staff for internal or external logistical efforts. The last category "Others" (5 %) summarizes other costs involved, i.e. cost of reorganization, recruitment or administration costs.

4 Summary and Further Research

The data collected along interviews shows that Lean Management implemented in the European machine building industries follows a project based approach. It exhibits a planning and control systematics, which can be considered as a deviation from the Japanese philosophical approach towards Lean. Projects aim reduced costs, reengineering, outsourcing, technology improvements or increased sales, while the intention of Lean Management should be rather to reduce the timeline between customer orders to customer payment. All cases show that side effects have a major impact and significantly reduce, or in many instances even exceed, the planned effects. The empirical data from case studies provides insights into complexity of Lean Management implementation. The critical factor for elicitation of the side negative effects of Lean Management implementations was the multi-perspective approach to their identification and assessment. Consequently it is needed to extend the research towards causal analysis of the side negative effects. Its results could then facilitate development of a method for multi-perspective and holistic assessment of Lean Management implementations.

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A Model to Evaluate Supply Chains in Disruption Events

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Abstract. Supply chain risk management is becoming increasingly necessary due to large-scale disasters. However, there is a trade-off between the long-term benefits of a supply chain and the disruption mitigation costs. Therefore, it is difficult to justify the high cost of risk countermeasures against such rare disruptions. Previous studies have discussed reducing risk in terms of mitigation and responsiveness to disruption events; however, many companies maintain low inventories and a single source supplier represented by just-in-time or lean manufacturing. Through interviews, we found that in addition to providing long-term benefits, maintaining low inventory can increase the efficiency of recovery activities. This study clarifies the effectiveness of a buffer inventory while considering risk mitigation and responsiveness by creating an evaluation model. A simulation model is used to determine the relationship between disruption time and buffer inventory.

Keywords: Supply chain · Disruption events · Supply chain risk management · Evaluation model

1 Introduction

Recently, many industries and logistic networks have experienced disruptions due to large-scale disasters, such as the Great East Japan Earthquake and the 2011 Thailand floods. The effects of such disruptions extend to companies that do not suffer direct damage and significantly affect the entire supply chain. Thus, supply chain risk management is becoming increasingly necessary (Kleindorfer and Saad 2005). However, there is a trade-off between the long-term benefits of maintaining a supply chain and the cost to mitigate disruption risks (Sheffi 2005). It is difficult to justify the high costs involved in implementing countermeasures to guard against such rare disruptions. Therefore, quantitative methods and evaluation criteria to determine the vulnerability and risk to the entire supply chain are necessary. Previous studies have discussed reducing risk in terms of mitigation and responsiveness to disruption events (Knemeyer et al. 2009; Tomlin 2006). Many companies practice just-in-time or lean manufacturing, e.g., carrying low inventories and relying on a single source supplier, even though those strategies are vulnerable to disruption risks. Through interviews, we found that in addition to providing long-term benefits, maintaining a low inventory can increase the efficiency of recovery activities.

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Previous studies have suggested that maintaining a buffer inventory can mitigate supply chain disruptions (Song and Zipkin 1996; Tomlin 2006). However, no studies have considered the negative effect of a buffer inventory on recovery activities. Therefore, this study was conducted to develop an evaluation model to clarify the conditions whereby a buffer inventory is effective to mitigate disruptions taking risk mitigation and responsiveness into consideration. We have created a mathematical supply chain model and determined the relationship between inventory and recovery activities. Finally, we considered a disruption scenario and conducted a numerical experiment.

This remainder of this paper is as follows. Section 2 explains the principal countermeasures against disruption events through a literature review and defines the relationship between recovery activities and inventory. Section 3 describes the proposed model. In Sect. 4, we present the results of our numerical experiment. Section 5 concludes the study and identifies opportunities for further research.

2 Literature Review

2.1 Supply Chain Risk Management

Studies of business continuity plans for supply chains are often divided into three groups: the probability of the occurrence of risks, direct damage to each node, and the disruption of the entire supply chain due to the effects on a single node. This study is primarily concerned with the latter. Tainton and Nakano (2014) identified behavioral patterns of manufacturing supply chains under the effects of extreme events. Figure 1 shows the disruption pattern when the supply is changed and recovery activities related to

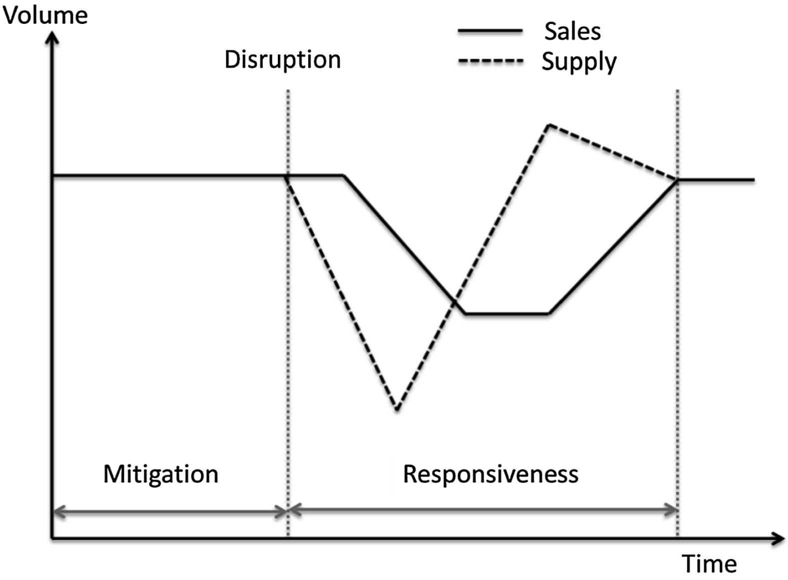

Fig. 1. Supply disruption and recovery activities

disruption events. In general, disruption risk management is classified into risk mitigation and responsiveness (Knemeyer et al. 2009; Tomlin 2006). In other words, disruption risk management consists of provisions to avoid disruption and action plans that can be implemented after a disruption. From risk mitigation perspective, previous studies have primarily suggested maintaining a buffer inventory (Song and Zipkin 1996; Tomlin 2006), diversifying suppliers (Dada et al. 2007; Tomlin and Wang 2005; Tomlin 2009), and strengthening the trust among suppliers (Krause 1997; Krause et al. 2007). Relative to responsiveness strategies, previous studies proposed using alternative or backup suppliers (Chopra et al. 2007; Tomlin 2006; Tomlin 2009) and employing management that is capable of flexibly responding to changing production plans (Tomlin 2009). Each of these strategies has advantages and disadvantages. Moreover, risk mitigation and responsiveness are related. Therefore, companies must carefully consider both aspects and manage or combine strategies depending on the situation. Note that each strategy incurs costs, which affects the long-term benefits of a supply chain.

2.2 Relationship Between Recovery Activities and Inventory

As indicated in previous studies, maintaining a buffer inventory and diversifying suppliers can mitigate damage due to disruption events (Song and Zipkin 1996; Tomlin 2006). On the other hand, many companies maintain low inventories and a single source supplier represented by just-in-time or lean manufacturing. Through interviews with a production manager, we found this strategy can provide long-term benefits, and maintaining low inventory can increase the efficiency of recovery activities. If companies maintain a buffer inventory, those that do not suffer direct damage can continue producing based on the production plan in place at the time of disruption. Therefore, where the disruption event occurs is not immediately evident, and such companies cannot comprehend why they should invest in recovery plans. On the other hand, when a disruption event occurs, if companies do not carry a buffer inventory, production stops very quickly. Consequently, companies that suffer directly immediately grasp the problem, and all companies in the supply chain can participate in recovery activities.

Figure 2 illustrates the relationship between a buffer inventory and other parameters.

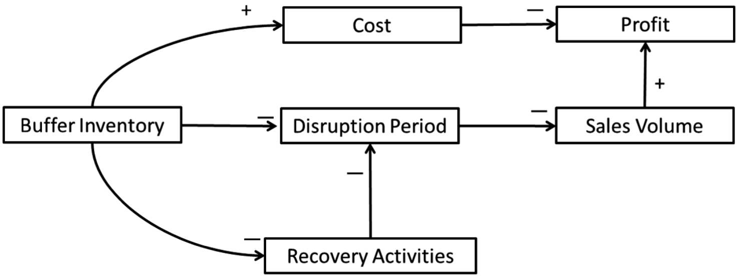

Fig. 2. Relationship between buffer inventory and other parameters

Maintaining a buffer inventory can mitigate disruption time; however, it incurs cost and can have negative effect on recovery activities.

3 Simulation Model

3.1 Definition and Formulation of Supply Chain Model

In this study, we consider a supply chain that consists of three companies. Figure 3 shows the model structure.

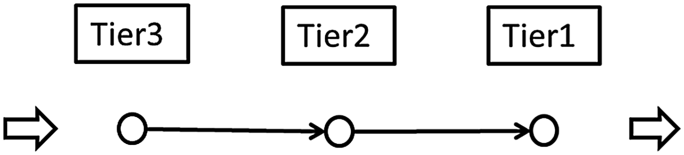

Fig. 3. Simulation model structure

For each period *t*, we define the following:
O_t^i : output inventory of supplier *i* at period *t*
I_t^i : input inventory of supplier *i* at period *t*
M_t^i : production volume of supplier *i* at period *t*
D_t^i : order volume of supplier *i* at period *t*
S_t^i : sales volume of supplier *i* at *t*

The rules of the model are as follows:

- Demand is constant through the simulation ($D_t^0 = D$).
- Each supplier orders the same amount as it has been receiving from its upper supplier (insert the equation).
- Delivery takes one period.
- Each company has the same inventory quantity before the simulation begins ($I_o^i = I$).
- The sales volume of tier 4 is the same as the orders of tier 3 ($S_t^4 = D_t^3$).

The model formulas are as follows:

$$O_t^i = O_{t-1}^i + M_t^i - S_t^i \tag{1}$$

$$I_t^i = I_{t-1}^s - M_t^i + S_t^{i+1} \tag{2}$$

$$M_t^i = \min\left\{D_{t-1}^{i-1}, I_{t-1}^i\right\} \tag{3}$$

$$S_t^i = \min\left\{D_{t-1}^{i-1}, O_t^i + M_t^i\right\} \tag{4}$$

$$M_t^4 = D_t^3 \tag{5}$$

3.2 Disruption and Recovery Model

The problem of maintaining a buffer inventory in terms of responsiveness is if companies maintain a buffer inventory, each company that does not suffer direct damage continues producing based on the production plan at the time of the disruption; thus, the problem can be difficult to identify. Consequently, it becomes difficult to justify committing resources to recovery. To model this phenomenon, we have designed a simulation model by defining the conditions of disruption, recovery, and participation in recovery activities for each tier as follows:

- A disruption event occurs at tier 3.
- Tier 3 cannot produce, sell, or order during a disruption.
- Each tier engages in recovery activities when production is halted, which helps express how an inventory buffer can affect recovery.

Here, we define the following:

R : total recovery amount
R_c : recovery constant
r_i : recovery amount of tier i at period t
Π_R : set of tiers that engage in recovery activities
t_d : disruption period.

When the following condition is satisfied, recovery activities are completed and tier 3 resumes normal production, sales, and ordering.

$$R = \sum\nolimits_{t=1}^{t_d} \sum_{i \in \Pi_R} r_i \geq R_c \tag{6}$$

The simulation model follows the flowcharts shown in Figs. 4 and 5.

4 Simulation Results

When the disruption time is calculated by numerical analysis, we set the parameters as follows: $T = 15$, $D = 100$, $R_c = 10$, and $r_i = 1$. Here, the disruption event occurred at time 2.

Figure 6 shows the disruption period of each tier and the total disruption period when the initial inventory volume changed.

The vertical axis is the stop period of each tier (left) and the total stop period (right). The horizontal axis is the initial inventory volume. In terms of mitigation, when the

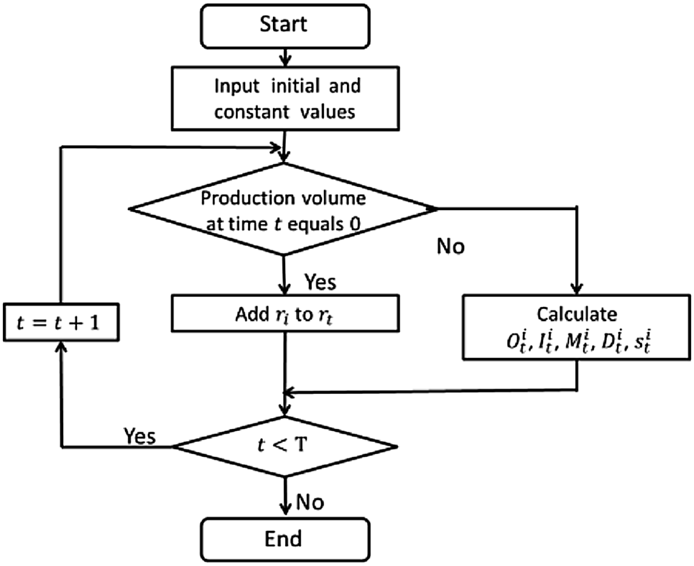

Fig. 4. Flowcharts for tiers 1 and 2

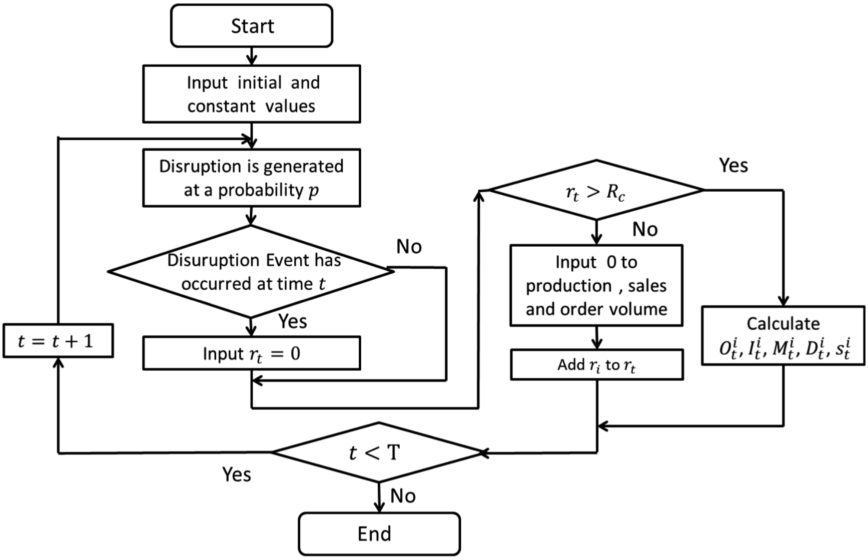

Fig. 5. Flowchart for tier 3

initial inventory volume increases, the total stop period and the stop period of each supplier tend to be reduced. However, in terms of responsiveness, we can see that the recovery time of tier 3 increases with increased initial inventory volume.

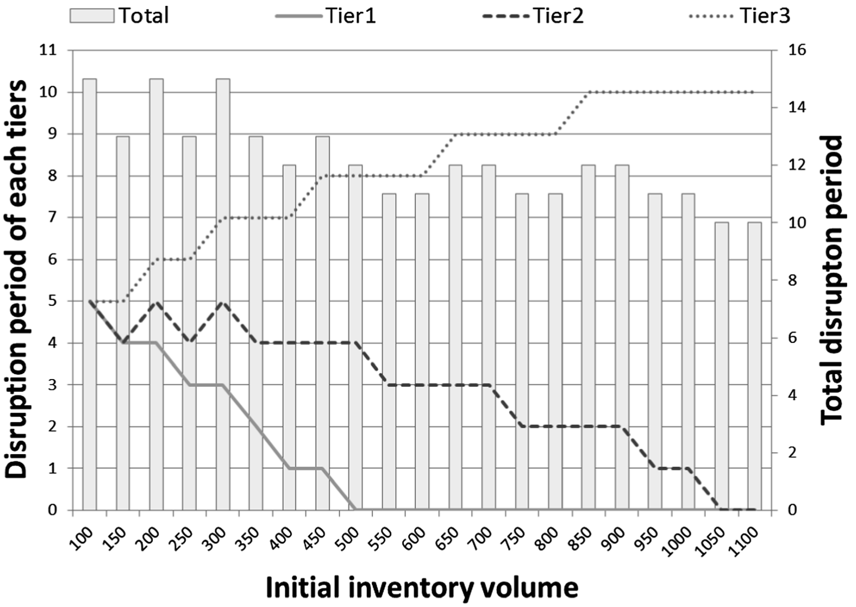

Fig. 6. Disruption period

5 Conclusion and Future Works

We have designed an evaluation model for supply chains to clarify the conditions by which a buffer inventory can affect disruption while considering risk mitigation and responsiveness. Moreover, we have conducted a numerical experiment and calculated disruption times under arbitrary conditions. Consequently, we found that maintaining a buffer inventory can reduce disruption time. On the other hand, in terms of responsiveness, the time required for tier 3 to recover increases with increased initial inventory volume. In future, in addition to extending the supply chain model to be more realistic and applying the model to real problems, we plan to determine the optimal initial buffer inventory under arbitrary recovery constant from a ratio of sales price, manufacturing cost, and inventory cost. Thus, from a review of these parameters, it will become possible to consider how companies in different industries should maintain buffer inventories.

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Towards a New Model Exploring the Effect of the Human Factor in Lean Management

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Abstract. Although lean popularity is rapidly growing, its implementation is far from problem free and companies may experience difficulties sustaining long term success. In this paper, it is argued that the human behaviour, affected by the implementation of both hard (defined as technical and analytical tools) and soft lean practices (concerning people and relations), plays a key role in achieving long-term superior performance. Through a single case research, the relationships between lean practices implementation, human behaviour and operational performance are explored. From the analysis a new construct emerged, namely "Individual characteristics". As a result, an alternative research model for further statistical testing including individual behaviour as mediating variable and individual characteristics as moderating variable has been built.

Keywords: Lean management · Human factor · Lean practices · Individual behaviour (IB) · Employees' affective attitude (EAA) · Operational performance

1 Introduction

The philosophy and practices associated with lean production have been around for many years, and have been applied in a number of settings including both discrete- and process manufacturing environments, product development and to some extent services and product-services [1]. While there are great deals of lean success stories, a number of real cases has failed in achieving superior performance by applying a lean approach. Operations management (OM) scholars discussed several causes of this lack of success, many of which are indicative of the problems that arise in the human element during a changeover to lean [2]. As demonstrated by Veech [3], there is a fundamental difference between lean organizations and conventional organizations doing lean things: companies that fail in applying lean, fail in approaching and managing the human factor. It is not enough to just apply a lean principle or tool without a simultaneous strive for lean mind [4]. What is needed is a balanced whole system view that emphasizes improved performance through a focus on the persons delivering value to customers [5]. Thus, personal focus, involvement and motivation are imperative when applying lean principles: "Focus on the people and the results will follow. Focus on the results, and you'll have the same troubles as everyone else – poor follow-up, lack of interest, no ownership of improvements, diminishing productivity" [6].

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In such a context, many studies have focused on the requirements of lean in terms of hard practices (defined as technical and analytical tools) but they paid less attention towards the human factor and the soft practices (concerning people and relations) that could support a lean journey [7, 8], and that can ensure positive results in both the long and the short term [9, 10]. It is thus essential to monitor and "engineer" human performance in the same way as the performance of the production systems is engineered to achieve a superior performance through lean management [2].

This paper aims at contributing to fill this gap by exploring the effects of both soft and hard practice implementation on the human behaviour and the effects of human behaviour on operational performance, adopting a longitudinal perspective.

The paper is organised as follows. Section 2 presents the theoretical background of the study and the research conceptual framework. In Sect. 3, the research methodology will be described and the empirical study carried out in a manufacturing company will be presented. In Sect. 4, the research findings and implications are presented. Finally, the last section closes the paper with the most relevant conclusions and future research directions.

2 Theoretical Background

2.1 Human Behaviour

The human factor is a key element for the success of lean efforts as most of the reasons for lean failure can be linked directly or indirectly to the human element. Human behaviour has been formalised in '80s by introducing the Individual Behaviour (IB) concept, defined as the attitude and actions or deeds of an individual working in an organization [11]. IB is affected by three factors, namely job satisfaction, commitment, and job stress, that represent the main components of the Employees' Affective Attitude (EAA) construct [12]. In previous research, soft practices has been shown as effective tools for the change of working climate, working methods, and working experiences [13], able to influence EAA during a lean implementation [14]. In particular, lean soft tools are argued to promote employee empowerment and group activity, which have a positive influence on job satisfaction and employees' loyalty [15]. A the same time, lean hard practices promotes resource optimization, reduction in variability of process, and defect free product leading to the improvement in performance, quality of work, and reduction in job stress [16]. Thus, the implementation of lean techniques in an organization can positively impact the three factors of EAA.

2.2 Lean Practices

A systematic literature reviews reveals that different sets of soft practices have been put forward by different researchers. However, these practices can possibly be grouped into a finite number of generic categories, common in lean implementation in different organisations. The proposed categories are [17]: (i) management leadership; (ii) management support; (iii) top management commitment; (iv) organisational culture; (v) communication; (vi) training and skill building; (vii) financial capability; and

(viii) measurement framework. Similarly, in accordance with Dennis [18], lean hard tools and techniques can be categorised into three main classes: stability and standardization, Just In Time (JIT) and Jidoka (quality). In general, the majority of empirical studies supports the overall positive direct impact of lean practices on firm's operational performance [19], without considering the key role of individual behaviour in maintaining such superior performance in the long term.

2.3 Operational Performance

When measuring the impact of lean practices, different authors have tried to connect and reflect the combined effect of these practices into one operational indicator [20], now popularly known as "leanness". It include [21]: (i) quality; (ii) speed; (iii) dependability; (iv) flexibility; and (v) cost.

The resulting research conceptual model is depicted in Fig. 1.

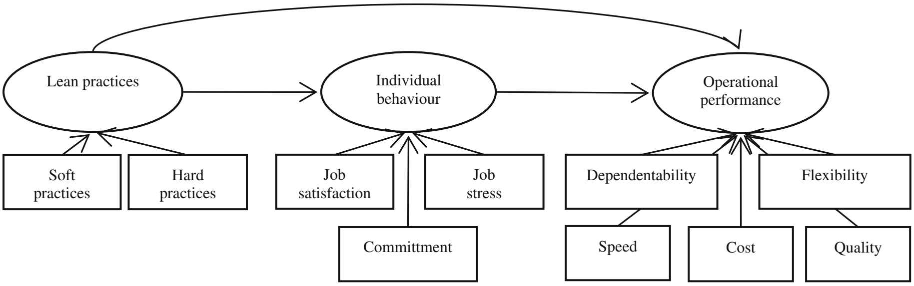

Fig. 1. The research conceptual model

3 Research Methodology

The paper is based on an exploratory case study conducted in company Alpha, a medium manufacturer of draft dispensing equipment for beer, wine, water and other soft drinks. The company, has recently expanded its production plants and has introduced a multi-year lean manufacturing project to continuously advance its production efficiency, drive out waste and increase the productivity of the whole supply chain. Based on the research conceptual model previously presented, a research protocol was designed and Alpha's management and operational employees were interviewed at two different times: before lean practice implementation and after 24 months from the beginning of lean practice implementation. A structured questionnaire consisting of four sections was adopted, to carry out the interviews.

- *General Information about the Respondent* (years of experience in Alpha, age, gender, education, main activity, type of contract, participation to lean practice implementation);

- *Employees' Affective Attitude (EAA)*, addressed to operational workers, to assess their job satisfaction, commitment, and job stress on a 5-point Likert scale;
- *Lean Practices Implementation*, addressed to company's management, measured using a Likert scale (1–5) to understand the level of adoption of soft and hard practices;
- *Operational Performance*: addressed to company's management after lean practice implementation, to assess the performance improvement achieved after the implementation of lean practices.

Based on responses from 64 operational workers and 3 managers (representing the totality of Alpha's employees) at a single lean site, the authors explored the relationship between the degree of lean implementation (soft and hard practices) and workers' EAA, as well as the EAA effects on operational performance.

4 Results and Discussion

A short description of the main results is reported in the following.

4.1 Lean Practices Implementation

As summarised in Table 1, it emerges that the company has started to implement some hard practices, but it is still in a preliminary step of its lean transformation. In particular, Alpha's efforts have been mainly focused on developing techniques and methodologies that support process flow efficiency and effectiveness. Nevertheless, lean methodologies devoted to production quality improvement deserve further significant investments.

Table 1. Hard practices implementation

	Before	After
Stability and standardization	0.00	2.17/5
Jidoka (Quality)	0.00	1.63/5
Just in time (JIT)	0.00	2.99/5

Moreover, several soft practices have been applied to ease the success of lean implementation. In particular, as shown in Table 2, project goals and values have been set (Management Leadership), adequate resources and funding have been provided (Financial Capability) to create autonomy lean organisation, as well as to establish a system to properly plan, manage and measure process performances (Management Support and Measurement Framework) and to ensure those necessary mechanisms to enable a cultural change across the whole organisation (Organisational Culture). However, internal and external communication initiatives to convey consistent information about lean and to demonstrate visible top management commitment are still lagging behind.

Table 2. Soft practices implementation

	Before	After
Management leadership	0.00	2.87/5
Management support	0.00	2.88/5
Top management commitment	0.00	1.88/5
Organizational culture	0.00	2.56/5
Communication	0.00	1.67/5
Training and skill building	0.00	2.60/5
Financial capability	0.00	3.06/5
Measurement framework	0.00	3.33/5

4.2 Individual Behaviour

The analysis of the 64 received responses that compose the total sample-whose main features are summarized in Table 3- underlines that the application of lean hard and soft practices have a positive impact on workers individual behaviour. Indeed, while both the satisfaction and the commitment increase, the level of stress remains nearly unchanged (Table 4). Moreover, the detailed analysis of the individual behaviour of each category characterising the sample suggests that:

- The higher the age and the years of experience in the company of the respondents the lower their satisfaction and commitment about lean manufacturing, whilst a direct relationship with stress emerges. Results underline the existence of a direct relationship between lean and cultural change and that lean approach encounters

Table 3. Respondents' characteristics

Gender	Male	75.00 %
	Female	25.00 %
Age	<35	13.06 %
	between 35 and 45	55.69 %
	>45	31.25 %
Years of experience in Alpha	<2	21.88 %
	between 2 and 10	29.68 %
	>10	48.44 %
Education	Primary school	35.94 %
	High school	50.00 %
	University	14.06 %
Main activity/Department	Production	55.93 %
	Logistics	15.25 %
	Other departments	28.82 %
Type of contract	Long term	81.25 %
	Short term	18.75 %
Lean experience	Yes	14.06 %
	No	85.94 %

Table 4. Individual behaviour measurement

	Before		After	
	Average	Std.dev/Average	Average	Std.dev/Average
Satisfaction	2.78/5	0.47	3.27/5	0.40
Commitment	2.93/5	0.51	3.29/5	0.37
Stress	1.72/5	0.93	1.75/5	0.93

major difficulties if implemented in organisations, where the capabilities that have been acquired over time may limit management engagement in adaptive change.

- Different types of commitments emerge considering the educational level of respondents, their age, their work experience and the type of contracts. In particular, people with a primary school educational level subject to short term contracts present the highest level of commitment in doing activities. Young people with a very short experience, are characterised by a high level of commitment in taking operational decisions, while people with an high educational level declare having a very strong commitment in creating new solutions. Such results underline how lean manufacturing ease the cooperation at any level of the organisation, eliminate the cultural barriers, and stimulate vertical and horizontal information sharing.
- Satisfaction and commitment are higher in those departments where specific lean projects have been developed. Moreover, people involved in training activities and lean projects declare a major satisfaction, commitment and brand loyalty. Conversely, those workers and employees that have not participated at any lean project appear dissatisfied and not happy about the company. This result underlines how a right internal communication could avoid internal dissatisfaction especially of those people who are not been involved in lean initiatives.

4.3 Operational Performance

Looking at operational performances achieved through the application of lean initiative, interesting results emerge in terms of quality, time and costs (Table 5).

Table 5. Operational performance measurement

	Average		Variation
Quality (Defects)	−30 %	Dependability	n.a.
Speed (Lead time)	−30 %	Flexibility	n.a.
Speed (Cycle time)	−25 %	Cost	−20 %

4.4 Research Finding and Hypotheses

Based on the results described above, a new construct emerged from the analysis, named “Individual characteristics” (Fig. 2). How these relationships occur should be further analysed:

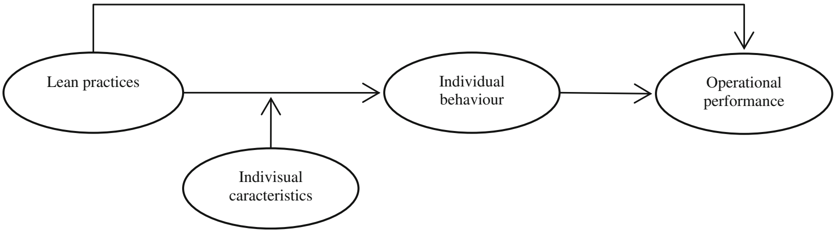

Fig. 2. New research model: individual behaviour as mediating variable and individual characteristics as moderating variable

Hypothesis 1– There is a positive relationship between lean practice implementation and individual behaviour, with the moderating effect of individual characteristics;

Hypothesis 2– There is a positive relationship between individual behaviour and operational performance.

5 Conclusion

To achieve long-term benefits of a lean approach, a focus on individuals is an essential part. Empirical evidence from this study shows that the human behaviour, affected by the implementation of both hard (defined as technical and analytical tools) and soft lean practices (concerning people and relations), plays a key role in achieving long-term superior performance. Moreover, a new construct, named "Individual behaviour" and representing individuals' characteristics, emerged. As a result, two alternative research frameworks, for further statistical hypotheses testing, have been built. The research could also be further developed by measuring the operational performance dimension through quantitative key performance indicators (i.e., OEE, throughput time, WIP, etc.) and expanding the performance construct to other types of performance, in line with a triple bottom line approach (economic, environmental and social).

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Integrated Mixed-Model Assembly Line Balancing with Unskilled Temporary Workers

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Abstract. This study extends a single-model assembly line balancing problem to an integrated mixed-model assembly line balancing problem by incorporating unskilled temporary workers, who enhance productivity. An integer program that minimizes the sum of total workstation costs and salaries of skilled permanent and unskilled temporary workers within a specific cycle time is developed. The proposed models is based on particular features of a real-world problem including simultaneous assignments of skilled permanent and unskilled temporary workers as well as precedence restrictions for the tasks.

Keywords: Integer programming · Line balancing · Mixed-model assembly line · Shojinka

1 Introduction

An assembly line is a flow-oriented production system typical of industrial sites that produce large quantities of standardized commodities, but it is also important for producers of low volume diverse or customized products. If only one product is manufactured, then all work pieces are identical and the system is called "a single model assembly line." The names of other assembly lines depend on the types of intermixed units. The different assembly line types, described by different geometric shapes, are characterized in Fig. 1. A multi-model assembly line produces a sequence of batches containing units of only one item or a group of similar items with intermediate setup operations, whereas a mixed-model assembly line produces different items in an intermixed sequence. Depending on assembly line types, single, mixed, and multi-model versions of assembly line problems should be applied and studied.

The assembly line balancing problem (ALBP) is used to search for the optimal assignment of assembly tasks to stations under precedence and additional practical constraints. Bryton (1954) introduced the idea of line balancing in his graduate thesis. The first paper on the ALBP was published in 1955. Among the family of ALBPs, the simple assembly line balancing problem (SALBP) is the best known. Assembly line balancing research has traditionally focused on the SALBP that features some restricting assumptions. However, it may offer a limited reflection of complex real-world line balancing. A comprehensive review of single-model ALBPs and related solution procedures was provided by Scholl and Becker (2006).

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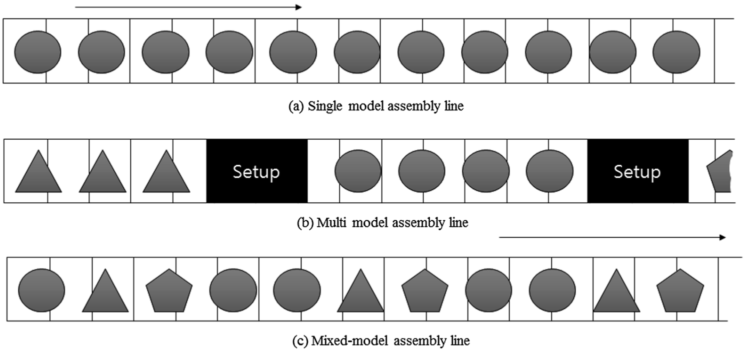

Fig. 1. Different versions of an assembly line

Over time, the needs of customers grow diverse and competition among manufacturers tremendously increases. The installation of a mixed-model assembly line is one of the best responses to this challenging situation, and this methodology has already been widely adopted by industry manufacturers who can use it to meet the diversified demands of their customers without maintaining large inventories or a string of assembly lines. The mixed-model assembly line originated with Toyota, which developed the concept of mixed-model production in the 1960s in response to problems created by line changeovers. The principle of the mixed-model assembly line is quite simple. However, designing the process and system is quite difficult. This study deals with the mixed-model ALBP.

In this paper, we present a mathematical formulation for a mixed-model ALBP with a cost-oriented objective to reduce inefficiency in a manufacturing process, which we reach by considering the employment of unskilled temporary workers. A thorough review of the latest publications did not indicate that a mathematical model has been used to solve a mixed-model ALBP that accounts for the assignment of unskilled temporary workers, which makes up a key component of this study, to obtain balances that minimize potential work overloads. Although Corominas et al. (2008) considered use of temporary workers, they did not account for integrated assembly line balancing. Their objective was to minimize the number of unskilled workers. Moon et al. (2009) studied an integrated ALBP, but they did not consider reducible task times through cooperation of permanent and temporary workers. Moon et al. (2014) is a key reference of this study and they developed an integer program that minimizes the sum of total annual workstation costs and annual salaries of skilled and unskilled workers within a predetermined cycle time. Limitation of their work is that the model can be adopted only for a single model assembly line. This study extends to an integrated mixed-model assembly line balancing problem.

The organization of this paper is as follows: In Sect. 2, a mathematical model for the integrated mixed-model assembly line balancing situation with unskilled temporary workers is introduced. In Sect. 3 computational experiment is conducted for the developed mathematical model. Section 4 provides conclusions of this research.

2 Mathematical Models

This study tries to balance a mixed-model assembly line with unskilled temporary workers. Unskilled temporary workers can only perform a subset of all tasks required to manufacture an item, so they cannot be assigned alone to any task. However, they can reduce operation times of completing tasks by cooperating with skilled permanent workers. As a result of this teamwork, the number of workstations needed for performing all tasks can be decreased. However, there is a trade-off between the salaries of unskilled temporary workers and the operation costs of workstations.

Available skill sets for each worker can differ. As a result, both tasks and workers should be optimally assigned. Salaries of workers and operation costs of workstations can be reduced under an efficiently designed workstation. The goal of line balancing is to minimize cost, and it is equivalent to minimizing the sum of the workstation costs and the salaries of skilled permanent and unskilled temporary workers. To solve the industrial problem used in this study, the following assumptions were made for the mathematical model:

(1) A skilled permanent worker cannot be assigned to more than one workstation.
(2) Skilled permanent workers should be assigned to tasks depending on the workstation task sets.
(3) Unskilled temporary workers cannot be assigned alone to any task.
(4) The operation time of tasks can be reduced by assigning an unskilled temporary worker to a task.
(5) At most, one unskilled temporary worker can be assigned to each task to reduce operation time.
(6) Operation and reducible times for production are fixed and known.
(7) Demands during the planning period are fixed and known.
(8) Precedence constraints determine the sequence in which the tasks can be processed.
(9) There is a limit on the number of workers who can occupy each workstation.

Using these assumptions, this study presents a mathematical model for an integrated mixed-model ALBP reflecting operations using unskilled temporary workers. The following notation is presented followed by a description of the objective function and constraints.

Indices:

i, j	tasks ($i, j = 1, 2, \ldots, I$)
k	product types ($k = 1, 2, \ldots, K$)
s	workstations ($s = 1, 2, \ldots, S$)
w	skilled permanent workers ($w = 1,2, \ldots, W$)

Parameters:

C	cycle time
C^u	upper limit of total operation time of each workstation
K_i	number of different products that requires task i

(*Continued*)

(*Continued*)

D_k	demand of product k
o_{ik}	operation time for task i for product k when performed by a skilled permanent worker
r_{ik}	reducible time for task i for product k when performed by a skilled permanent worker and an unskilled temporary worker together
$P_{(i,\ j\ k)}$	set of task pairs (i, j) for product k such that there is an immediate precedence relationship between them
T_w	set of available tasks that can be assigned to skilled permanent worker w
OC	operation costs of a workstation
SS_w	salary for skilled permanent worker w
SU	salary for an unskilled temporary worker
n	upper bound of the number of workers who can be assigned to a workstation
M	a sufficiently large number

The following two additional parameters are calculated with the above parameters, and Eqs. (1) and (2) are used for calculation of these added parameters.

o_i	aggregated operation time for task i under demand rates when performed by a skilled permanent worker
r_i	aggregated reducible time for task i under demand rates when performed by a skilled permanent worker and an unskilled temporary worker together

$$o_i = \frac{\sum_{k=1}^{K} D_k \cdot o_{ik}}{\sum_{k=1}^{K} D_k} \tag{1}$$

$$r_i = \frac{\sum_{k=1}^{K} D_k \cdot r_{ik}}{\sum_{k=1}^{K} D_k} \tag{2}$$

Decision Variables:

F	number of workstations to be used in the assembly line
X_{iksw}	$\begin{cases} 1, & \text{if task } i \text{ for product } k \text{ is performed by skilled permanent worker } w \text{ at workstation } s \\ 0, & \text{otherwise} \end{cases}$
Y_{sw}	$\begin{cases} 1, & \text{if skilled permanent worker } w \text{ is assigned to workstation } s \\ 0, & \text{otherwise} \end{cases}$
Z_{is}	$\begin{cases} 1, & \text{if an unskilled temporary worker is assigned to task } i \text{ at workstation } s \\ 0, & \text{otherwise} \end{cases}$
A_{is}	$\begin{cases} 1, & \text{if task } i \text{ is assigned to workstation } s \\ 0, & \text{otherwise} \end{cases}$

Objective Function and Constraints:

$$Min \quad OC \cdot F + \sum_{w=1}^{W} SS_w \left(\sum_{s=1}^{S} Y_{sw} \right) + SU \cdot \sum_{i=1}^{I} \sum_{s=1}^{S} Z_{is} \tag{3}$$

Subject to

$$\sum_{k=1}^{K}\sum_{s=1}^{S}\sum_{w=1}^{W} X_{iksw} = K_i \quad \forall i \tag{4}$$

$$\sum_{k=1}^{K}\sum_{w=1}^{W} X_{iksw} = K_i \cdot A_{is} \quad \forall i, s \tag{5}$$

$$\sum_{s=1}^{S}\sum_{w=1}^{W} X_{iksw} \le M \cdot o_{ik} \quad \forall i, k \tag{6}$$

$$\sum_{i=1, i\neq T_w}^{I}\sum_{k=1}^{K}\sum_{s=1}^{S} X_{iksw} = 0 \quad \forall w \tag{7}$$

$$\sum_{s=1}^{S}\sum_{w=1}^{W} (s \cdot X_{iksw} - s \cdot X_{jksw}) \le 0 \quad \forall (i,j,k) \in P_{(i,j,k)} \tag{8}$$

$$Z_{is} \le \sum_{k=1}^{K}\sum_{w=1}^{W} X_{iksw} \quad \forall i, s \tag{9}$$

$$\sum_{i=1}^{I}\left(\sum_{k=1}^{K}\sum_{w=1}^{W} o_i \cdot X_{iksw} - r_i \cdot Z_{is}\right) \le K \cdot C \quad \forall s \tag{10}$$

$$\sum_{i=1}^{I}\left(\sum_{w=1}^{W} o_{ik} \cdot X_{iksw} - r_{ik} \cdot Z_{is}\right) \le C^u \quad \forall k, s \tag{11}$$

$$\sum_{s=1}^{S} Y_{sw} \le 1 \quad \forall w \tag{12}$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K} X_{iksw} \le M \cdot Y_{sw} \quad \forall s, w \tag{13}$$

$$\sum_{w=1}^{W} Y_{sw} + \sum_{i=1}^{I} Z_{is} \le n \quad \forall s \tag{14}$$

$$\sum_{w=1}^{W} X_{iksw} \le 1 \quad \forall i, k, s \tag{15}$$

$$\sum_{s=1}^{S} s \cdot X_{iksw} \le F \quad \forall i, k, w \tag{16}$$

$$X_{iksw}, \quad Y_{sw}, \quad Z_{is}, \quad A_{is} \in \{0, 1\} \tag{17}$$

The objective function (3) minimizes the sum of the total workstation costs and the salaries of skilled permanent and unskilled temporary workers. Constraints (4) ensure that every task should be performed by one skilled permanent worker at one workstation. Constraints (5) indicate that the same task for different products should be assigned to the same workstation. Constraints (6) prevent inconsistency of X_{iksw} which can be greater than zero when o_{ik} is not zero. Constraints (7) prevent skilled worker w from being assigned to a workstation with a task that the worker cannot complete according to the skilled permanent worker's available task set T_w. Constraints (8) ensure that the precedence relationships between tasks are considered for product k. Constraints (9) ensure that an unskilled temporary worker can be assigned to task i only when a skilled permanent worker is also assigned to task i. Constraints (10) represent the total operation time under conditions of a demand rate of each workstation that is smaller than a specific time. Constraints (11) represent the total maximum operation time to manufacture product k at each workstation; it is smaller than the specified upper limit. Constraints (12) guarantee that a skilled permanent worker is assigned to exactly one workstation. Constraints (13) demand that a task is assigned to a skilled permanent worker at the workstation; X_{iksw} can be 1 when a skilled worker is assigned to a workstation. Constraints (14) restrict the number of total workers to one workstation to prevent overcrowding. Constraints (15) ensure that the same task for different product types is assigned to the same worker. Constraints (16) are used to decide the total number of workstations needed. Constraints (17) demonstrate the binary nature of the decision variables.

3 Computational Experiments

The mathematical model was solved with FICO Xpress-IVE version 7.3. Computational experiments were conducted with an Intel(R) Xeon(R) 3.5 GHz processor with 16 GB RAM on the Microsoft Windows Server 2008 R2 operating system. Task precedence sequence diagrams of a test problem are shown in Fig. 2. Salaries of skilled workers and their available skill sets are shown in Table 1. Demand rates of Product 1 and Product 2 are same in this problem. Reducible times for tasks of each product type are organized in Table 2. Table 3 shows the solution of the test problem. Only two

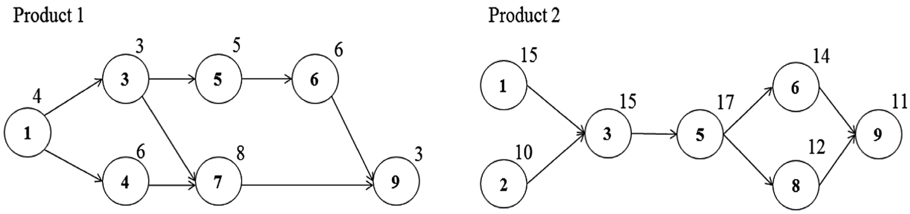

Fig. 2. Task precedence sequence diagrams for 9 tasks and 2 products

Table 1. Available sets and salaries of skilled permanent workers (9 and 14 tasks)

Tasks	Worker	Possible Tasks								Salary
9	1	3	6	8						$3,800
	2	4	5	6	9					$4,000
	3	1	5	7	9					$3,700
	4	2	3	6	7	8				$4,000
	5	1	5	8						$3,000
	6	1	2	7						$3,000

Table 2. Reducible times and salaries of unskilled temporary workers

Number of tasks	Task	Reducible time		Salaries of unskilled temporary workers
		Product 1	Product 2	
9	1	1	3	$1,500
	2	0	3	
	3	1	5	
	4	2	0	
	5	3	4	
	6	2	4	
	7	4	0	
	8	0	3	
	9	1	3	

Table 3. Solution of a test problem

Task sequence	i	k	S	o_{ik}	r_{ik}	o_i	r_i	Cumulative workstation time	w	Temporary worker
1	1	1	1	4	1	9.5	2	7.5	3	O
2		2		15	3					
3	2	2		10	3	5	3	12.5	4	
4	3	1		3	1	9	3	18.5	4	O
5		2		15	5					
6	5	1		5	3	11	3.5	26	3	O
7		2		17	4					
8	4	1	2	6	2	3	2	3	2	
9	6	1		6	2	8	3	11	2	
10		2		10	4					
11	7	1		8	4	4	4	15	6	
12	8	2		12	3	6	3	21	5	
13	9	1		3	1	7	2	28	2	
14		2		11	3					

workstations are needed if three unskilled temporary workers are employed in this problem. More experiments will be done in the future research.

4 Conclusions

Moon et al. (2009) introduced the integrated ALBP, and this study extends their idea to the mixed-model assembly line and considers simultaneous assignments of skilled and temporary workers. In the production line described herein, the skilled workers have multiple competencies and commensurate salaries; unskilled temporary workers are assigned to help them. A mathematical model was developed by integer linear program for the integrated mixed-model ALBP and the model was designed to minimize total costs, including those associated with operation of workstations and the salaries of skilled permanent and unskilled temporary workers for a specified cycle time. Due to the complexity of the problem, heuristic procedures are needed to solve the problems and it will be done in future research.

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Decoding Relationships of Success Factors for Lean Information Technology Outsourcing

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Abstract. Managing the continuous growth of modern-day IT developments and its transformation consequences in manufacturing and service organizations is arduous. It burdens organizations and supply chain management. For decades, supply chain managers have outsourced their non-specialized IT activities to third-parties. Competition compels organizations to look for ever more effective services from their suppliers. Solely outsourcing IT activities is no longer sufficient. Monitoring and optimization has become decisive. Lean, a successful philosophy to pursue continuous improvement, is extending its contributions from manufacturing and services to IT processes. This paper explores the success factors for the implementation of Lean in IT outsourcing relationships. It aids managers in designing a dashboard to optimize and monitor the implementation of Lean in IT outsourcing relationships. The causal-relationships among success factors in the context of a system, based on multiple case studies, is decoded through a causal-loop diagram and sensitivity analysis inspired by the system dynamics methodology.

Keywords: Critical success factors · Lean · Information technology outsourcing · Simulation · System dynamics

1 Introduction

Contributions of recent information technology (IT) developments influence all organizational areas and challenge contemporary supply chain management (SCM)practices [2]. Today, coordination and integration of supply chain activities strongly depend on the performance of modern contributions of IT throughout the value chain [12]. Outsourcing IT value chain activities can be a driver of flexibility, agility and leanness of supply chains [13]. For this reason, for decades, managers have made the strategic decision to delegate their non-specialized operations, including IT activities to external professional suppliers, termed IT outsourcing [10]. Among those delegated activities are IT operations, support, development and maintenance. Although the practices of IT outsourcing have been thoroughly researched over the last two decades, many IT outsourcing clients remain dissatisfied [7]. This is demonstrated by low satisfaction rates,

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a high number of backsourcing decisions, and vendor switching [19]. The main problems clients experience are degradations of service over time, lacking vendor commitment, delayed deliveries or slow implementations [7].

Solely outsourcing IT activities is no longer sufficient. Monitoring and optimization of outsourcing relationships has become decisive to succeed in the market [5]. In doing so, Lean, as a successful philosophy to pursue continuous improvement, is extending its contributions from manufacturing and services to IT processes. When speaking of Lean, we refer to Womack and Jones (2003) [20] who describe Lean as a five-step management philosophy that, in essence, allows (1) organizations to specify value, i.e., what the customer is willing to pay for, (2) to identify all value-creating activities while eliminating those that do not, (3) to align these activities to achieve flow, (4) to let customers pull the value, and (5) to achieve and sustain perfection. This process is often termed Lean transformation [4]. From an IT outsourcing perspective, the focus of Lean lies on aiming to fulfill the desire of clients by suppliers. This is realized by precisely defining the needs of clients and optimizing value-adding activities through continuous improvement, while using the least amount of resources necessary. Reported motivations to implement Lean in IT outsourcing are shortening application maintenance times, achieving higher software release frequencies, stimulating co-innovation and learning, and reducing software development costs [3].

To realize successful continuous improvement in IT outsourcing relationships through Lean, managers should first know what factors matter in this context. Through multiple case studies conducted, critical success factors (CSFs) [15] have been identified that indicate the key areas managers should focus on, to successfully implement Lean in IT outsourcing relationships [3]. However, understanding how these factors directly and indirectly influence each other, including the overall outsourcing relationship, is not straightforward. In order to address this issue, system dynamics (SD) as a methodology is deemed suitable for decoding the intricate relationships among CSFs [1]. In this paper, the causal-relationships among identified CSFs is explored by utilizing a systems thinking approach and involves the creation of a causal-loop diagram (CLD) and performing subsequent simulations. The results of so-called sensitivity analysis simulation highlight the importance and influence of several CSFs and related factors on the overall IT outsourcing relationship performance.

The remainder of this paper continues with an overview of the identified CSFs in Sect. 2. Section 3 presents a description of the research approach, followed by Sect. 4 providing an elaboration upon the contribution of SD to decode the CSFs. Section 5 presents an analysis of the system model addressing several CSFs. Section 6 then concludes this paper by pointing out the contribution and limitation of this study, and provides directions for future research.

2 Critical Success Factors

According to Rockart (1979, p. 85) [14], CSFs are "*the limited number of areas in which results, if they are satisfactory, will ensure successful competitive* *performance for the organization*". CFSs have a prominent place in Information Systems (IS) research and have been one of the earliest and most actively researched topics in the IS field [11]. For instance, it has been formerly used to analyze the implementation of IT outsourcing practices [8].

This paper explores the 16 CSFs and related factors derived from 36 interviews conducted during six case studies in different sectors by [3] for the implementation of Lean in IT outsourcing relationships (see Table 1 for an overview of the cases studied). This paper goes one step further by extending the identified success factors into a richer framework that describes their causal-interrelationships and decodes them accordingly. The 16 CSFs have been included in the CLD (see Fig. 2). In order to see the whole picture of factors influencing the success of Lean implementation and their underlying relationships, however, other factors beside the CSFs that influence the success of Lean implementation in the IT outsourcing relationship, but did not fit the criteria to carry the label 'critical' [15], have also been included in the CLD. To distinguish between critical and non-critical factors, the CSFs have been printed in **bold** whereas non-critical factors are printed in plain text.

Table 1. Overview of key characteristics of the cases studied.

Client	Industry	Supplier	Content	Size	Age
Client A	Insurance	Supplier E	Development	100	2
Client A	Insurance	Supplier F	Maintenance	50	4
Client A	Insurance	Supplier G	Development	3	1.5
Client B	Telecoms	Supplier H	Maintenance & Development	15	2.5
Client C	Government	Supplier I	Development	5	1.5
Client D	Food	Supplier J	Maintenance & Development	9	5

3 Research Method

An overview of all the consecutive research steps taken during this project, including their corresponding deliverables, is shown by means of a processdeliverable diagram (PDD) in Fig. 1. PDDs use UML and consist of two different, yet connected parts [18]. On the lefthand side, the activities conducted during this research project are modeled. The deliverables as a result of these activities, connected with dashed lines, are modeled on the right-hand side of the diagram.

For the purpose of analyzing the 16 CSFs and related factors and to uncover the relationships among them, a CLD was created with a software application named Vensim PLE[1]. The CSFs were first added in Vensim as separate variables that form the basis of the CLD (see Fig. 2). Afterwards, positive and negative

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[1] http://www.vensim.com/.

relationships among these variables were identified and added to the diagram and reviewed by experts. Subsequently, based on the CLD, sensitivity analysis simulations could be designed and run to examine policies of managers.

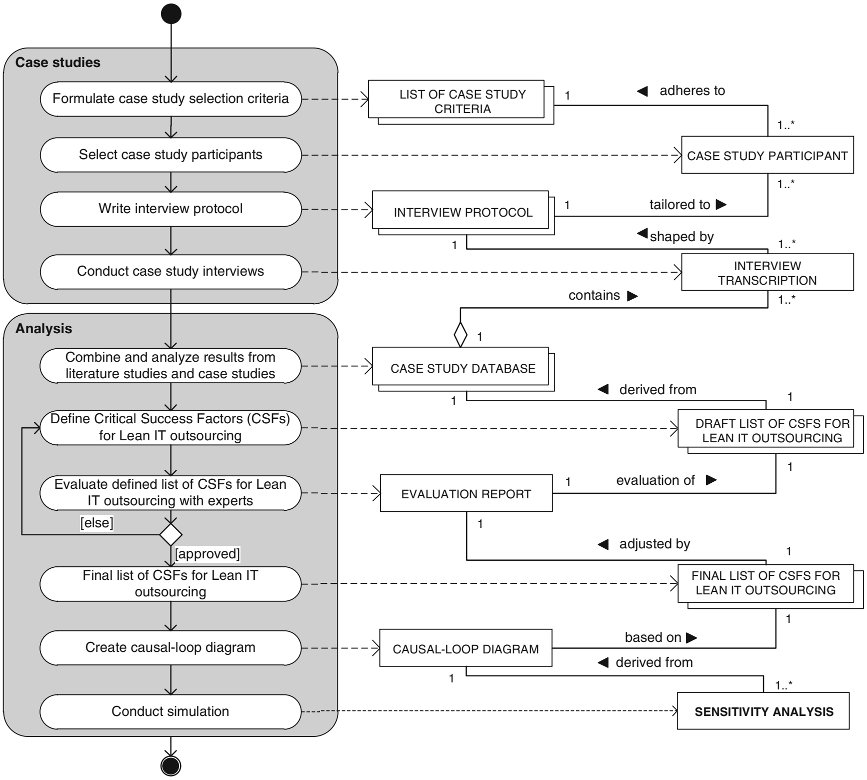

Fig. 1. Illustration of the research steps taken.

4 Contribution of System Dynamics

SD is a business process modeling methodology by making a use of systems thinking for getting a systematic perspective to complex interrelated problems with causalities [17]. This methodology was depicted by Jay Forrester at MIT in the 1960s. Systems thinking provides a problem solving approach by considering each problem as a part of an inclusive system rather than reacting to an isolated section [17]. In short, SD illustrates the causal relationships between the factors in the context of a system, i.e., direct and indirect relationships can be found by means of a CLD. Basically, interrelated causes and effects of elements in a system, representing mental models, lead to a positive or negative CLD; which aim at reinforcing or counteracting change in the system, respectively [17].

The major contribution of SD and its associate software ("Vensim") to the current study is manifold. First, SD can be used to define a thorough graphical topology of complex causal relationships among factors in Lean IT outsourcing relationships between clients and suppliers. The initial privilege of configuring the CLD of a system is the detection of direct and indirect relationships between its elements, which are difficult to recognize in a tabular form. Second, by means of the CLD, the borders of the entire problem can be distinguished. This provides a systematic perspective with defined exogenous/indigenous elements of the case studied. Third, after modeling the CLD of factors, this can assist the interested parties with understanding negative and positive feedback loops by adding polarities, and reveals the nonlinear structure of the system. The modeling position of the factors, turned into variables now, according to their supportive, contributive, and principal roles, can be classified into auxiliary, flow, and stock, respectively. Fourth, the next step is setting up a simulation model that describes the behavior of the system in a given period of time. On this basis, Fig. 2 has been developed from the case studies. The entire content of the CLD as shown in Fig. 2 is too much to discuss. Instead, it is limited to a selection of these factors. In the next section, it can be seen that four variables play a central role in the diagram, being the success of Lean implementation, trust, culture of continuous improvement, and close cooperation to identify and eliminate waste.

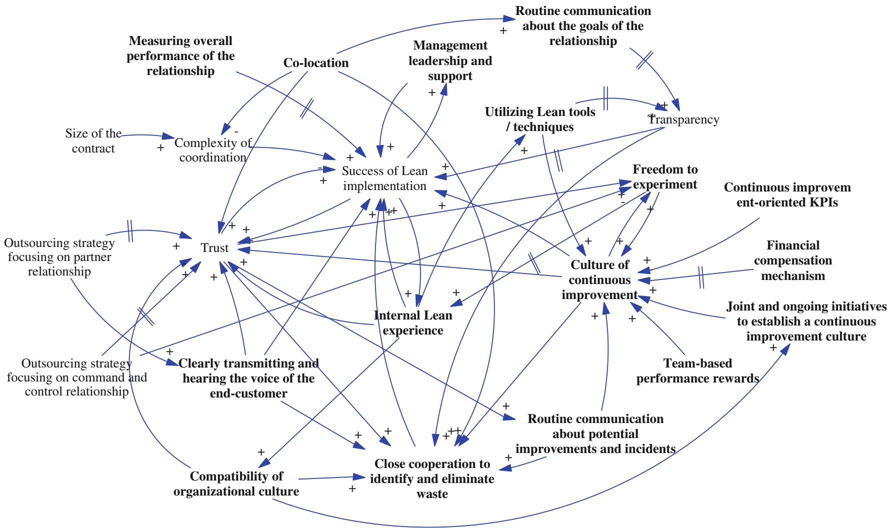

Fig. 2. Causal-loop diagram showing the causal interrelationships among the identified success factors for Lean IT Outsourcing.

5 Sensitivity Analysis

Basically, three alternative scenarios, being Base 1, Base 2 and Base 3, are assumed to experiment with the performance of the model. In order to reflect the role of time lag (delay) in the dynamic behavior of the system, for each stock (control factor) an adjustment time (AT) is devised. Among them "Lean transformation AT" is chosen to vary (see the exemplary stock and flow diagram in Fig. 3). Next, in Base 4 to check the importance of voice-of-customer (VoC), the variable "Rate of transmitting and hearing the voice of end customer" undertakes random numbers through the simulation horizon, following the normal distribution, see Table 2. These alternative scenarios result in the sensitivity analysis of the entire model.

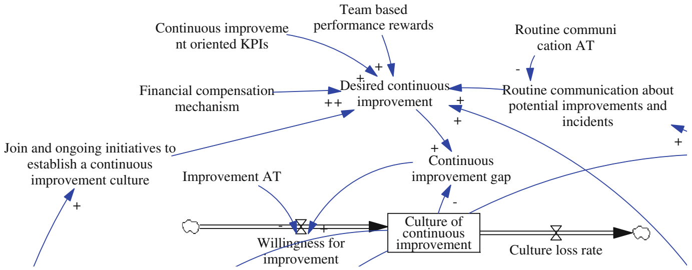

Fig. 3. Exemplary stock and flow diagram.

Table 2. Sensitivity analysis scenarios.

Variable	Scenario			
	Base 1	Base 2	Base 3	Base 4
Lean Transformation AT	1 week	10 weeks	5 weeks	5 weeks
Rate of transmitting and hearing the voice of end-customer	Constant=0.5	Constant=0.5	Constant=0.5	$\tilde{N}(\mu = 0.5, \sigma = 0.2)$

As it is seen in Base 1, Base 2 and Base 3, the role of AT in transformation is crucial. By increasing the delay in transformation, all other key factors get negatively influenced as well, as their growth curves level off (see Fig. 4). Besides, by looking at Base 4, it can be observed that oscillation in meeting the exact customer need (VoC) leads to fluctuations in related direct and indirect factors. This phenomenon is not desired neither in supply chain management [9] nor in any Lean initiative [16]. This gives rise to either unsatisfied customers or excessive lag hampering the success of operations. The responsibility of Lean managers and leadership is to avoid such disruptions as much as possible [6].

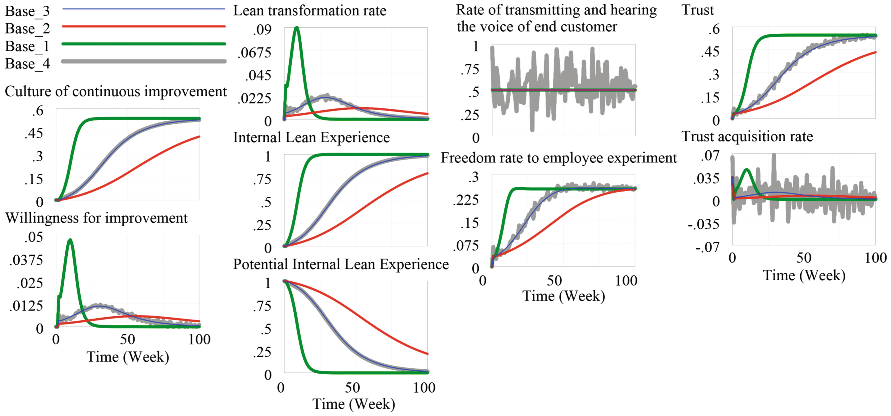

Fig. 4. Sensitivity analysis diagrams.

6 Conclusion

In this paper, the emerging management challenge of dealing with the growing demand of IT in various business sectors is discussed. As aforementioned, today, IT is the backbone of any business to facilitate collaborating, networking, providing, and delivering products/services to customers. Therefore, outsourcing these operations, while optimizing the implementation of the processes, reduces a major burden on businesses. In doing so, recently, Lean management with its prominent methods and tools are combined with IT processes for the sake of optimization. 16 CSFs have been identified in prior literature based on case study research. To show how these CSFs affect a successful and efficient implementation of Lean IT outsourcing, the SD methodology is applied to decode the complex causalities between these factors and their effect on outsourcing success. The CLD defined the associations and unfolded the complex feedback loops among the elements in the management system. Moreover, a simulation model is developed to be used for policy experiments and sensitivity analysis, of which the results were presented. It could be seen that delay in any adjustment and transformation is crucial to the duration it takes to achieve success. Furthermore, the importance of VoC is illustrated by demonstrating its fluctuations in other CSFs. In summary, this study shed light upon the comprehension of the role of CSFs in the context of a management system, and elaborated upon the monitoring and tracking capability of managers in their IT outsourcing decisions. Nonetheless, development of an authentic SD simulation model depends on several aspects, including availability of historical data, configured reference modes, and precision of mathematical equations used in the model. SD models are therefore by themselves always subject to improvement and the same holds for the model in this paper. Future research will improve and adjust the equations and expand the CLD of CSFs to incorporate more details concerning outsourcing, IT, and Lean.

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Sustainable System Design for Green Product

Introduction of Clean Energy Vehicles in Poland Under Energy Security Constraints

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Abstract. Clean Energy Vehicles (CEVs) are gradually growing in popularity worldwide due to environmental characteristics. However, they are slowly attracting attention in the world due to high prices and infrastructural constraints. Over the past century there has been a dramatic increase in usage of energy, especially in the transportation industry. The purpose of this study is to analyse the development of the CEVs market in Poland while considering economic and energy security issues. The objective of the study is to create a future scenario of automotive portfolio in 2030 that will sustain energy security. The first step is to qualitatively investigate the problem by carrying out interviews with the pundits. The second step is a quantitative analysis. This study adopts an optimization technique to uncover an optimal portfolio of the CEVs and focus on Polish market.

Keywords: Energy security · Transportation · Clean energy vehicles · Oil dependency · Gas dependency · Vehicle portfolio

1 Introduction

Along with increasing crude oil prices, a high pressure is put all over the world for the proliferation of Clean Energy Vehicles (CEVs), to reduce not only CO2 emissions, but also energy consumption in the automotive sector to provide apt energy security. The transportation sector accounts for approximately 20 % of total worldwide energy consumption [1].

Despite abundance of the choice, Poland is still lagging behind with sales of CEVs. In 2011, there were only 897 hybrid vehicles registered [2]. When it comes to ensuring energy security, the situation does not look bright too. 96.8 % of Poland's crude oil consumption and 69.4 % of Poland's natural gas consumption are being satisfied from import supplies [3]. Transport sector itself is responsible for over 60 % of crude oil consumption in Poland [4].

There have been plenty of studies carried out on the CEVs portfolio and future energy trends. The scopes of them were gathered in the Table 1. The analysis of conventional studies shows that either the studies are focused only on one type of the CEVs or do not take into account buses or trucks. Only the paper [5] incorporated energy security as well as green house gas, written in Japanese. The research

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Table 1. Conventional studies on CEVs

Research	Passenger vehicle	All types of CEV	Oil restriction	Gas restriction	Truck and bus
IEA (2012)	X	X	X		
Arimori (2012)	X	X	X		X
Choi (2010)			X		
Chua (2013)			X		
This research	X		X	X	X

incorporated data concerning bus and trucks. The paper, however, does include oil restriction, but is not taking into consideration gas restrictions.

In the case of European countries like Poland, gas is an important source of energy, also in terms of automotive usage. In line with the above, the originality of this study is, that it includes gas security restrictions due to huge LPG market in Poland and possible proliferation of CNG vehicles in the future.

The goal of this research is to forecast the share or sales of CEVs according to an optimisation model for passenger vehicles, trucks and buses, considering 8 types of vehicle engines (powertrains): GV (Gasoline Vehicle), DV (Diesel Vehicle), HEV (Hybrid Electric Vehicle), DHV (Diesel Hybrid Vehicle), CNG (Compressed Natural Gas Vehicle), FCV (Fuel Cell Vehicle), EV (Electric Vehicle), LPG (Liquefied Petroleum Gas Vehicle) till 2030, while considering energy security issues in Poland as a case. Firstly, interviews with the pundits are carried out and later optimisation model is created in order to provide a base for decisions for new governmental policies and planning for companies working in the automotive industry. Automotive portfolios considering energy security issues in 2030 are created.

Section 2 describes the automotive and energy sector in Poland. The evaluation model is explained in Sect. 3. Constraints of the model are provided with an outline of an optimisation model, governmental targets are being set and the objective function of this research is presented. The results are demonstrated in Sect. 4. In the last part, the deliverables of this research are summarized and future subjects are also identified.

2 Analysis of the Automotive and Energy Sector in Poland

2.1 Current Status of the Automotive Industry in Poland

Polish government has recently showed first signs of interest towards CEVs and is considering this area as a future investment.. However, the situation for the importation of oil and gas is undoubtedly different than it is for coal. That is why Poland should treat the introduction of CEVs as an opportunity to become more independent from fuel imports, and as a way of spurring automotive industry in Poland.

2.2 Current Status of the Energy Sector in Poland

Energy security issues are becoming another preeminent topic, especially after considering recent political developments in the Russian-Ukrainian dispute. Energy resources security is a crucial concern for a developing country. Energy security definitions have already been researched by plenty of pundits.

Energy Use in the Transportation Sector. The transport Sector is responsible for 64 % of the crude oil consumption in Poland. When it comes to the gas consumption by the sector, 37 % of total demand is consumed by industry, followed by residential use, and transportation [6]. In the time period between 1998 and 2012, demand for diesel grew by 70 %, and demand for LPG almost doubled. Currently, diesel is used in the largest quantities, followed by gasoline and LPG. Trucks are using the largest amount of diesel fuel. However, 56 % of total consumption is due to passenger vehicles [7].

Influence of Russian-Ukrainian Dispute on Energy Security. Dependency on Russian energy supplies is often cited as a threat to Central European energy security. Imports to the EU from Russia are dominated by crude oil and gas. Cuts of gas importation have happened before, e.g. in 2009 during Ukrainian-Russian gas dispute [8]. Moreover, Russia introduced a ban on imports of fruits and vegetables from Poland in 2014, depriving it of a major export market. It is estimated, that the cost of this embargo stands at 0.6 % of GDP by the end of 2014 [9]. Along with increasing crude oil prices and unstable political situation in Ukraine, the Polish citizens and government have opened their eyes, and urge securing energy safety issues.

3 Methodology

The research concerns policy, market and data study, which is why both qualitative methods and quantitative methods. The study is conducted in line with the Fig. 1.

Fig. 1. Research process

In the beginning of the study, intelligence gathering was conducted and research objective and questions were formulated: Why CEVs are not popular in Poland and what policy should be introduced to change the situation? The purpose of Qualitative Analysis is to find causes that prevent popularity of CEVs. In this part stakeholder analysis and interviews with pundits are being conducted. Qualitative findings were used and combined in quantitative analysis in order to analyse the development of the CEV market in Poland till 2030. The purpose of Quantitative Analysis is to design optimal future vehicle portfolio.

3.1 Qualitative Analysis

In order to achieve economic goals, a qualitative analysis of both the automotive and energy sector in Poland was carried out. Firstly, stakeholder analysis was carried out by using Customer Value Chain Analysis (CVCA) [10]. Later interviews with stakeholders were conducted. By using this methodology research questions were verified.

3.2 Quantitative Analysis

Qualitative analysis is computed from a systematic approach, including two parts: economical efficiency, oil and gas dependency rate. Therefore, the prior mentioned model defines economical efficiency of the vehicle portfolio while considering oil and gas dependency rates. Based on the above, the key map of a CEV portfolio optimisation model has been built, which can be seen in the Fig. 2. Three categories of vehicles are considered: passenger vehicles, buses and trucks. Moreover, 8 types of vehicles are taken into consideration based on powertrain variations (GV, DV, HEV, DHV, CNG, FCV, EV and LPG). The following model takes as input three groups of data: restriction values (gas and oil rates), vehicles characteristics (vehicle price, fuel consumption, etc.) and other preconditions (energy price, etc.). This data is input into the optimisation model and the output is the optimal solution of the volume of new vehicle registrations for every CEV. The methodology was developed at the Business Engineering LAB at KEIO SDM, Graduate School of System Design and Management, and it has not been published in an English-journal before.

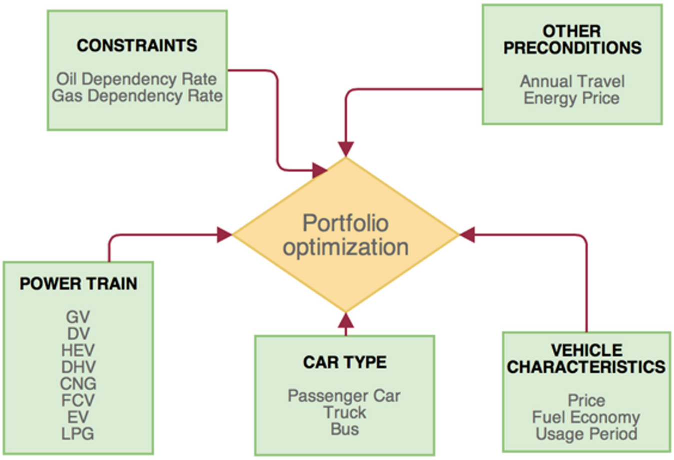

Fig. 2. Key map of a proposed CEVs portfolio optimisation model

The objective function is directly connected with the cost – economic efficiency. CEV system cost is formulated as follows (1): The right-hand side of formula expresses three costs using the volume of new vehicle registrations, which is designed as a variable. The first clause expresses fuel cost, the second clause expresses vehicles cost, and the third clause expresses infrastructure cost. The optimal solution at the time of minimizing this CEV system cost is computed as follows in Eq. (1).

$$
\begin{aligned}
& min\, f_k(x_{jk}) \\
& f_k(x_{jk}) = \sum_i \sum_j S_{jk}(x_{jk}) A_j F_{jk} E_{ik} + \sum_j x_{jk} V_{jk} + \sum_j \frac{x_{jk} T_j}{I} \\
& S_{jk}(x_{jk}) = x_{jk} + S_{jk-1} - \frac{S_{jk-1}}{U_j}
\end{aligned}
\tag{1}
$$

I : Type of energy [Gasoline, light oil, natural gas, hydrogen, electricity]
j : Vehicle type [passenger vehicle (GV), passenger vehicle (DV), passenger vehicle (HEV), passenger vehicle (DHV), passenger vehicle (CNG), passenger vehicle (FCV), passenger vehicle (EV), passenger vehicle (LPG), truck (GV), truck (DV), truck (HEV), truck (DHV), truck (CNG), truck (FCV), truck (EV), truck (LPG), bus (GV), bus (DV), bus (HEV), bus (DHV), bus (CNG), bus (FCV), bus (EV), bus (LPG)]
k : Object year [2012–2030]
f_k : k yearly CEV system cost [PLN]
x_{jk} : Volume of new vehicle registrations in k years of the vehicle type j [Unit]
S_{jk} : The number of possession in k years of the vehicle type j [Unit]
U_j : Average tenure of use of the vehicle type j [Year]
F_{jk} : Possession average real run fuel consumption in k years of the vehicle type j [MJ/km]
A_j : Annual average mileage of the vehicle type j [km]
E_{ik} : The energy price in k years of the energy i [PLN/MJ]
V_{jk} : Vehicles price in k years of the vehicle type j [PLN/stand]
T_j : Infrastructure price of the vehicle type j [PLN/Spot]
I : The ratio of the number of CEV possession to the required number of infrastructures

Gas and oil dependency rate restriction are formulised in formulas (2) and (3). The denominator of the right-hand side of a formula (2) expresses total energy expenditure, and the numerator expresses the total oil consumption, following formula (3) provides the total gas consumption.

$$D_k \geq \frac{\sum_j S_{jk}(x_{jk}) A_j (O_{jk} + F_{jk} G_{jk})}{\sum_j S_{jk}(x_{jk}) A_j F_{jk}} \tag{2}$$

$$H_k \geq \frac{\sum_j S_{jk}(x_{jk}) A_j (O_{jk} + F_{jk} M_{jk})}{\sum_j S_{jk}(x_{jk}) A_j F_{jk}} \tag{3}$$

D_k : k year oil dependency rate desired value ($D_k \in [0, 1]$)
O_{jk} : They are gasoline and a diesel amount consumption per [in k years of the vehicle type j] 1-km run [MJ/km]
G_k : Rate of the oil power, ($G_k \in [0, 1]$)
G_{jk} : k year power supply composition
H_k : k year gas dependency rate desired value ($H_k \in [0, 1]$)
O_{jk} : Amount of gas consumption per [in k years of the vehicle type j] 1-km run. [MJ/km]

Rate ($M_k \in [0, 1]$), gas dependency in electricity of the oil fire power in G_{jk}: k year power supply composition.

There have been several changes done to the model. First of all, the originality of this study is that gas security restrictions are included. Secondly, CNG vehicles are being researched instead of NGV. LPG vehicles are also included in this study and where not taken into consideration. Furthermore Energy and vehicle price is calculated based on estimations for Polish market and not global prices.

4 Results and Discussion

4.1 Stakeholders

Figure 3 presents the analysis of stakeholders and their relationship that was carried out with CVCA. Four main stakeholders were identified: consumer, car manufacturer, government and energy company. The most important stakeholder is government. It receives TAX from other stakeholders and its role is to provide subsidies and policy support.

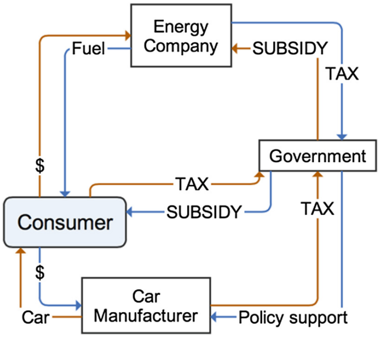

Fig. 3. CVCA analysis

4.2 Interview Results

The first interviewee is an expert from Department of Innovation and Industry from Ministry of Economy. He believes that when it comes to terms with governmental stakeholder it is the Ministry of Finance is reluctant on creating an incentive system, rejecting proposals in order to protect the yearly budget. Forgetting that those aids can bring income from other sources. The interviewee believes that change in policy is essential to change the situation. His recommendations include i.e. establishing new scrap incentive system based on the previous experience in Germany. Unless the government introduces aid for customers to buy CEVs, the number of sales will still stand at a minor level. Furthermore, new tax system is crucial to change the situation. The next stakeholders considered in this interview are automakers. Automakers aim and collaborate with local government, which is more willing to achieve aforementioned goals. Low sales means less investment from other countries and less people employed. Following, the statement on consumers was build. The pundit confirmed the fact that individuals do not wish to buy CEVs because of high prices and prefer to buy used cars, or just cheaper makes. Confusing car tax policy means that buyers postpone their decision on a purchase of a new vehicle.

Next interviewee is Sales Managing Director in Automotive Company in Poland. He stated that government and its policy discourage buyers from purchasing new cars, favoring more affordable non-efficient ones. Furthermore, European policy created an easy access to affordable used cars from Germany. Poles are not concerned with environmental issues. There is low affordability of CEVs in Poland. Consumers tend to buy cheaper, not environmental friendly cars. Polish people have very little knowledge of CEVs. There is a need to educate consumers, giving them a fresh and realistic view of CEVs. Since people travel for long distances and use cars for many years, CEVs seem like a good investment if people know that they should take into consideration life cycle cost of a vehicle and not only the initial cost. From the pundit point of view automakers expect a higher volume of vehicle sales in Poland. High demand on new vehicles, low turnover of employees and cost of employees are the factors that influence decision on establishing a new vehicle plant. Moreover, the drop in price, could give customers incentive to purchase a CEV. The Tables 2 and 3 sums up the results of interviews with stakeholders.

Table 2. Government view on CEVs problems

Government	Issues	Possible measures
Government	Protect budget	New scrap incentive system
Automakers	Low sales = low investment; poor collaboration with government	Collaboration with local government
Consumers	High price of CEVs, purchase of used cars; Confusing tax policy	Tax reduction incentives

Furthermore, Prius price analysis was conducted as shown in Table 4 and was approved by the second interviewee. The results prove that the premium consists most of the taxes applied by Polish government and not market premium of a Japanese producer. The parameter 1.0 amounts to 2 1700 00YPY.

All of the above interviews provided insight into Polish automotive sector and confirmed some of the issues that were found during the research.

Table 3. Automakers view on CEVs problems

Automakers	Issues	Possible measures
Government	Easy access to used cars from Germany Policy and rules discourage purchase of new car	CEVs subsidies
Automakers	A higher volume of sales is expected	Higher vehicle demand Proximity of factories
Consumers	Low affordability of CEVs Clients not concerned with environmental issues Consumers using non-efficient diesel engines Little knowledge on CEVs	CEVs price drop Education of clients

Table 4. Prius price analysis

Item	Value
Market price of prius in Japan	1.00
Cost of prius in Japan without TAX (8 %)	**0.95**
Transport cost	0.01
Customs – 10 %	1.06
Excise tax – 18,6 %	1.25
Tax in Poland – 23 %	1.54
Cost of prius in Poland according to calculations	1.54
Market price of prius in Poland	**1.57**
Market price of prius in USA	1.13

4.3 Experimental Results

During calculation of the optimal portfolio it became clear that both oil and gas restriction rates are not independent. Both of goals cannot be reached simultaneously if the minimisation of total system cost is taken into consideration. However, it was forecasted that gas consumption will rise anyway in years to come, and there are

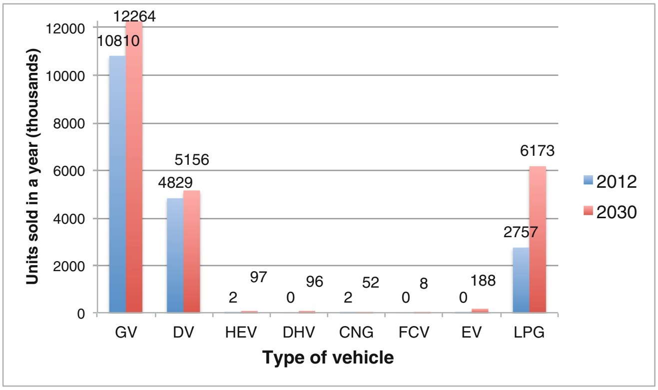

Fig. 4. Passenger vehicle portfolio in 2012 and 2030 [units]

possibilities of shale gas in Poland. Therefore it was decided that the gas spending should just be minimised. Ratio possession numbers of passenger vehicles in 2012 and 2030 are represented below in Fig. 4.

In passenger vehicles category HEVs, DHVs and EVs have attracted attention in 2030. Those were the types of vehicles, which gained the most within the time period. HEV seem to be a perfect-match solution for the Polish market, since people tend to travel long distances and EV could be popular in metropolises. In bus category there were changes recorded in sales of CEV, however bus sales are not significant.

If the gas restrictions are omitted, the transition from regular vehicles into CEV is slower and spread of them is low. Even though, the CEVs increase in total vehicle park seems insignificant, it is important to take into consideration that in 2012, 1.5 mil used vehicles were sold, but only around 300,000 new ones were sold.

5 Conclusions

Concerns surrounding energy security and climate change, along with improvements in technology have spurred an interest in clean energy vehicles. This paper has examined both the automotive and energy sector in Poland. With the present and forecasted future energy mix in Poland, CEVs are clearly much more favourable when compared with GVs and DVs. This study was designed to determine the optimal portfolio of CEVs in Poland until 2030.

One of the more significant findings to emerge from this study is that Polish society requires full portfolio of clean energy vehicles and fuel options to achieve both economic and energy security objectives. Those goals cannot be reached by introducing only one type of CEV alone. HEVs might be treated as an intermediate step before introduction of EVs, FCVs. Moreover, this research can serve as a base for future studies of governmental policies towards CEVs in Poland. The results of the study may support policy makers while making their decision on applying policy to increase vehicle sales in Poland.

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Economic and Environmental Impacts on the Portfolio of Clean Energy Vehicles in Japan

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Abstract. The introduction of clean energy vehicles (CEVs) is one of the measures expected to be employed against global warming. Because the structures of CEV parts are different from those of gasoline vehicles, the popularization of each CEV type has two different types of impacts: economic and environmental. Therefore, it is necessary to consider the optimal mix of CEVs before deciding upon a policy for the introduction of CEVs. However, most conventional studies do not consider the economic effects on industries. This paper proposes a new optimization model considering the production-induced effects as well as environmental impacts. The model is applied to estimate the impacts on the portfolio of CEVs in 2030 in Japan.

Keywords: Automotive industry · Global warming · Optimization · Production-induced effects · Sustainable design

1 Introduction

Japan accounts for approximately 4 % of global CO_2 emissions [1]. In particular, automobiles cause approximately 15 % of domestic CO_2 emissions [2], leading to increased calls for measures to reduce these emissions. One such measure under consideration is the introduction of clean energy vehicles (CEVs) such as clean diesel vehicles (CDVs), electric vehicles (EVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs). However, each type of CEV has its own strengths and weaknesses and differs in its energy source, fuel cost, CO_2 emissions, and other elements. Thus, the widespread adoption of only one type of vehicle that may be superior in just one metric is not the best solution; rather, a portfolio comprising a mix of gasoline vehicles (GVs), diesel vehicles (DVs), natural gas vehicles (NGVs), and CEVs is needed to optimize CO_2 emissions, costs, and other metrics.

Among the existing research on automobile portfolios, Ichinohe et al. [3] and Yeh et al. [4] used the MARKAL energy system model to calculate passenger vehicle portfolios that achieve the target level of CO_2 emissions in Japan and the US. In addition, Yamada et al. [5] set fuel costs and vehicle purchase costs as constraints to calculate a domestic passenger vehicle portfolio that generates the minimum possible life cycle CO_2 ($LCCO_2$). The studies of Ichinohe et al. [3], Yeh et al. [4], and Yamada et al. [5]

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differed in their models and regions but all essentially focused on the CO_2 emissions of CEVs. In contrast, in addition to CO_2 emissions, Kato et al. [6] calculated the optimal portfolios of global passenger vehicles focusing on copper resource constraints. Meanwhile, Arimori et al. [7] focused on oil consumption constraints in addition to CO_2 emissions in calculating the optimal portfolios of domestic passenger vehicles, trucks, and busses. In other words, Kato et al. [6] and Arimori et al. [7] expanded the definition of environmental properties from CO_2 emissions alone to resource and energy sustainability.

The above examples show that prior research has primarily focused on CO_2 emissions and resource and energy consumption (Fig. 1, red line). In addition, the above-mentioned studies did not consider economics, including changes in the production volumes of companies in the battery and automotive industries, the producers of CEVs. However, the composition of parts differs among the types of CEVs (e.g., GVs, DVs, NGVs, and others). Our previous research [8] focused on the differences between the components utilized in CEVs and GVs. By using the newly created Input–Output Table that added departments of CEVs in our research, production-induced effects will decline by 1.5 trillion yen from 2010 to 2030 under a sales target established by the Ministry of the Environment. In particular, the automotive and auto accessories industries in Japan account for approximately 15 % of manufacturing industry production. Therefore, any changes to the parts have great impacts for industry of Japan. However, in that study, we did not discuss environmental issues and automobile portfolios.

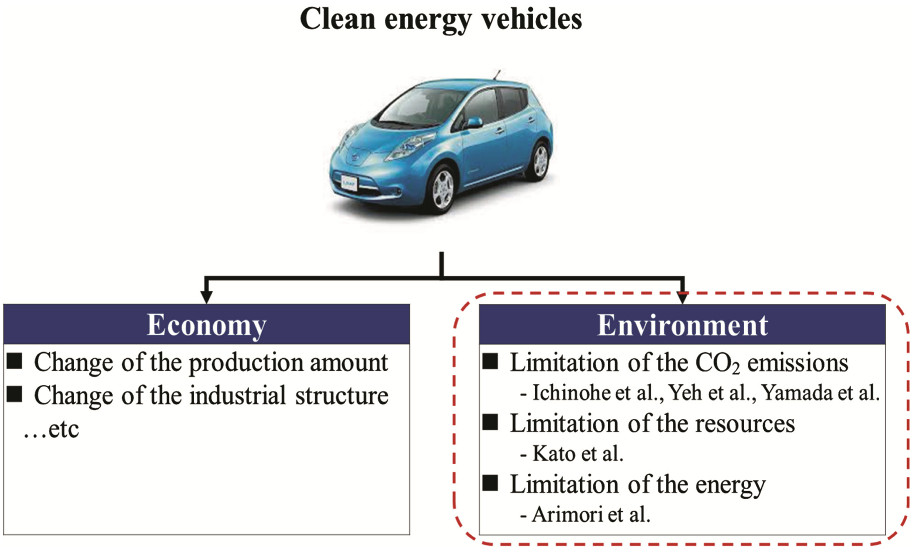

Fig. 1. Research area of portfolio optimization for clean energy vehicles (Color figure online)

Therefore, we propose a new model that optimizes portfolios by considering both the economic and environmental impacts of CEVs. The aim of this study was to determine the optimal portfolio for domestic passenger vehicles in order to assist corporate product plans for CEVs along with governmental policies for spreading CEVs. Eight types of passenger vehicles were covered in this study: GVs, DVs, CDVs, NGVs, EVs, HEVs, PHEVs, and FCVs.

In Chapter 2, we describe a newly created optimization model. In Chapter 3, we calculate an optimal portfolio in each case using the new optimization model. In Chapter 4, we summarize our research and discuss future issues.

2 Optimization Model

2.1 Framework

As noted above, in this study, we created an optimization model that considers the economics of CEVs in addition to CO_2 emissions and consumer cost. Consumer cost is defined as the sum of fuel costs incurred when driving and the vehicle purchase costs. CEV economics were evaluated using production-induced effects caused by CEV adoption. Production-induced effects indicate the total production volumes directly and indirectly required in each industry to meet the demand generated by producing a final good. In this study, this volume would be the total production volume of each industry when each model of car is consumed. In addition, this study also considered the variance in production-induced effects for each type of CEV, and the Input–Output Table ("Input–Output Table for CEVs") created by the author [8] was used as part of the optimization model because traditional Input–Output Tables are only divided into two types of vehicles: "passenger vehicles" and "other vehicles." Thus, we could not have analyzed the variance in production-induced effects for each type of CEV by using traditional Input–Output Tables. On the basis of the differences between the components utilized in each CEV, our Input–Output Table for CEVs was expanded from two types of vehicles to a total of twenty four types: passenger vehicles, trucks, and buses along with GVs, DVs, CDVs, NGVs, EVs, HEVs, PHEVs, and FCVs in each of the first three categories. Thus, by using our Input–Output Table, we could quantify the impacts of CEV adoption on production volumes and consider the economic characteristics of CEVs in the calculation of an optimal portfolio.

Figure 2 represents the optimization model built for this study. Our model can calculate the optimal mix of CEVs on an annual basis by inputting some assumptions after deciding constraints and an objective function. The production-induced effects and CO_2 emissions within the optimal solution are calculated simultaneously.

Next, we define "optimal" as it is used in this paper. We set two cases of objective functions and conducted a what-if analysis. The first case was an objective function of production-induced effects across all industries caused by the adoption of CEVs. The second case set an objective function for CO_2 emissions. We then solved this optimization problem using CO_2 emissions and consumer cost as constraints. "Optimization" in Case 1 of this study refers to a situation in which production-induced effects are the largest, even when CO_2 emissions and consumer cost constraints are met. "Optimization" in Case 2 highlights a situation in which CO_2 emissions are the smallest, even when consumer cost constraints are met.

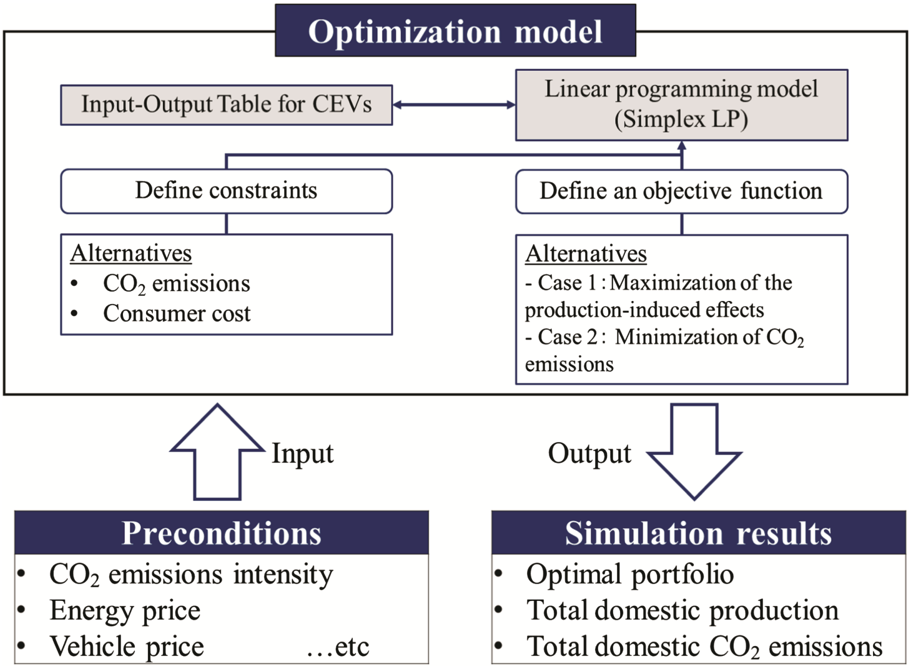

Fig. 2. Outline of CEV portfolio optimization model

In this study, to derive an optimal solution, we created an optimization model in spreadsheet form using Microsoft Excel and used the linear program (Simplex LP) in "Solver Function."

2.2 Objective Function

For Case 1, we set an objective function for the production-induced effects in Japan and formulated it as formula (1). In addition, we employed a numerical formula from a previous study [8] to calculate the production-induced effects.

The production-induced effects were calculated by multiplying the direct effects by the Leontief inverse matrix. The Leontief inverse matrix represents the "sum of direct and indirect spillovers generated in each industry by the consumption of one unit of a final good" [9]. The direct effects were defined based on three perspectives (the costs of production, fuel, and construction of the service station) for each vehicle type in a previous study [8].

$$max \quad f_k(X_{ik}) = \{I - (I - M)A\}^{-1} D_k \tag{1}$$

i: Type of passenger vehicle [GV, DV, CDV, NGV, EV, HEV, PHEV, FCV]
k: Target year
f_k: Production-induced effects in year k [yen]

X_{ik}: New sales of vehicle type i in year k [unit]
I: Identity matrix
M: Imports matrix
A: Input coefficient table
D_k: Direct effects in year k [yen]

Next, we set a Case 2 objective function for the CO_2 emissions in Japan and formulated it as follows:

$$min \quad g_k\left(X_{ik}\right) = \sum_i X_{ik} U_{ik} \tag{2}$$

g_k: CO_2 emissions in year k [kg-CO_2]
U_{ik}: CO_2 emissions of a vehicle type i in year k [kg-CO_2/unit]

2.3 Constraint Conditions

In this study, we set two constraints: consumer cost and CO_2 emissions.

Formula (3) expresses the limitation on consumer cost for any year k. Consumer cost consists of fuel costs and vehicle purchase costs. Formula (4) shows the limitation on CO_2 emissions for any year k.

$$\sum_i X_{ik^0}(P_{ik^0} + E_{ik^0}) \geq \sum_i X_{ik}(P_{ik} + E_{ik}) \tag{3}$$

$$\sum_i TS_{ik} U_{ik} \geq g_k(X_{ik}) \tag{4}$$

k^0: Base year [2010]
P_{ik}: Sales price of a vehicle type i in year k [yen/unit]
E_{ik}: Fuel costs of a vehicle type i in year k [yen/unit]
TS_{ik}: Target unit sales of vehicle type i in year k according to the Ministry of the Environment [unit]

3 Simulation Results

In this chapter, we calculate the optimal portfolio of the passenger vehicles in 2030 in each case and analyze the differences. Figure 3 shows the share of the unit sales of passenger vehicles in 2030 for each case. The left-most bar of Fig. 3 shows the target sales of the Ministry of the Environment [10] as a reference.

At first, when we maximize the production-induced effects (Case 1), HEVs and PHEVs account for approximately 90 % of all components. When we minimize CO_2

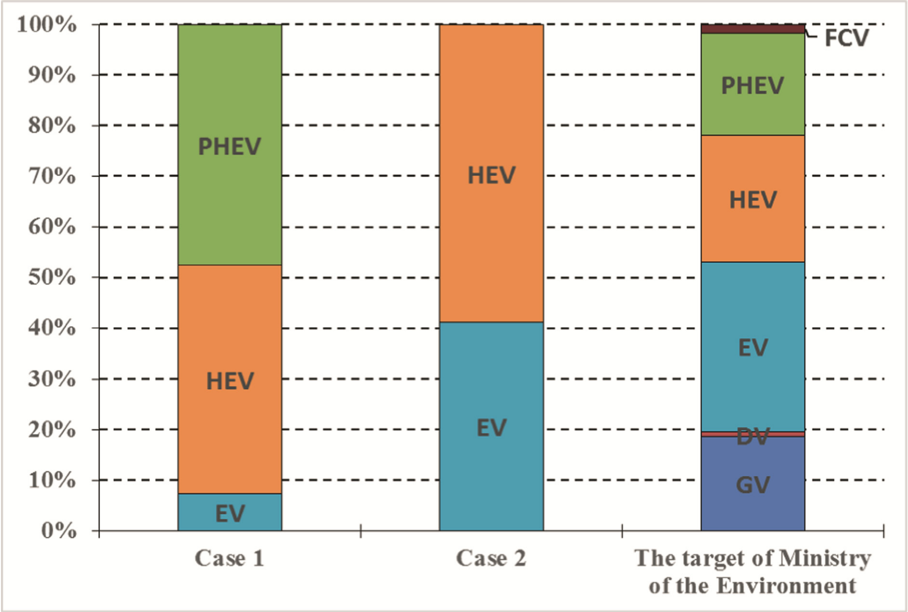

Fig. 3. Share of new sales of passenger vehicles in 2030

emissions (Case 2), HEVs play an important role, as in Case 1 (Fig. 3). Conversely, EVs account for more than 40 % of all components in Case 2.

We think that there are two reasons for the difference between the diffusion rates of EVs and PHEVs in each case. First, EVs have superior fuel consumption and lower CO_2 emissions. Therefore, the role of EVs is important when the influence on the environment is prioritized. Second, the part structure differs between EVs and PHEVs. The basic structure of a PHEV is the same as that of a GV. In addition, a battery and motor are necessary for PHEVs. Therefore, the spread of PHEVs has few negative effects on the existing auto parts industry. PHEVs also produce demand for other related industries, including the battery industry. Thus, PHEVs play an important role when we consider the influence on the economy. Although EVs have very high environmental performance, the production-induced effects of EVs are not large because some of the existing components of GVs are rendered obsolete. As a result, PHEVs are expected to become widespread in Case 1.

The above-mentioned results suggest the following conclusions. The portfolio generated with a focus on economic impacts is significantly different from that generated with a focus on the environment. These results demonstrate the importance of analyzing the portfolio of CEVs not only from an environmental perspective but also from an economic one. Also, the results indicate that the introduction of PHEVs as passenger vehicles becomes important when the influence on the economy is considered.

4 Conclusions

In this study, we built a new optimization model for composition of vehicle types that includes economic impacts (production-induced effects). We also calculated the optimal portfolio of passenger vehicles in Japan using the new model and analyzed its effectiveness.

As a result, the following conclusions were reached:

- When minimizing CO_2 emissions is prioritized without considering economic impacts, the introduction of EVs as passenger vehicles becomes important.
- In contrast, when production-induced effects in Japan are prioritized, the spread of PHEVs as passenger vehicles becomes more important. In this case, the introduction of EVs is not very important.
- The different results for the two cases are mainly attributed to the difference between the part structures of EVs and PHEVs.

This newly created optimization model that includes economic effects will aid the industry in the adoption of CEVs.

Future works will improve the model constructed in this study and help design policies to transition CEVs into widespread use.

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Cloud-Based Manufacturing

A Framework for Cloud Manufacturing Enabled Optimisation for Machining

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Abstract. Cloud Manufacturing is considered to be one of the paradigms that could revolutionize the way manufacturing has been realized in the industrial sector. Cloud Manufacturing services could be applied in most sectors of manufacturing since services can get integrated in the existing workflows. However, one of the most challenging while also most promising aspect is the reinterpretation of workflows and the creation of new workflows which could lead to more cost effective operations in the manufacturing industry. In this paper a framework for the optimization of cutting conditions in machining as part of a Cloud Manufacturing environment is presented. The aim of the framework is to provide users with an easier to use, cost efficient and well-informed solution that promotes sustainability in workshops. The main challenges, drivers and limitations in creating such an environment are discussed.

Keywords: Cloud manufacturing · Optimization · Machining · CNC

1 Introduction

Cloud Computing has established a new way of using computing resources through the web. The Cloud Manufacturing paradigm has just recently been introduced [1] and is aiming to revolutionize the way manufacturing is performed in industry. Moreover, the advances in electronics have made it possible to have wirelessly interconnected sensors and microcomputers through the internet. Lately the modern industrial environment calls for optimal manufacturing, greater energy efficiency and flexibility of production lines. In this context this paper presents a framework for the optimization of manufacturing toolpaths for milling machines, based on a Cloud Manufacturing environment. The details of the structure, the interfaces and the modules of such a framework are discussed.

The remaining of this paper is organized as follows: Sect. 2 provides the background information on the Cloud technologies and reviews the state-of-the-art in the subject. The proposed framework structure is described in in Sect. 3, while in Sect. 4 details on the proposed framework such as interface requirements are presented. Finally, Sect. 5 contains concluding remarks and future work on this framework.

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2 From Cloud Computing to Cloud Manufacturing

The way applications are structured and delivered to the clients in a Cloud Computing platform have many differences with the traditional IT approach. In Cloud Computing services can be provided through the web in a flexible scalable and on demand manner [2]. Services can be delivered in a Cloud Computing environment with three different models. Infrastructure as a Service (IaaS) provides the user access to computing resources such as computers, virtual machines storage etc. The Platform as a Service (PaaS) model provides users with computing platforms for developing their cloud application based on an IaaS framework provided and managed by the vendor. Finally Software as a Service (SaaS) is the model that customers use to gain access to applications residing on the Cloud. These applications are managed by the vendor and are made accessible to the user through thin clients or web browsers. With regards to the deployment of Cloud services this can be done in private, public or hybrid clouds, with the last being the most promising since they can combine the advantages of private and public clouds.

Similar to Cloud Computing, Cloud Manufacturing is a new paradigm for using Cloud Computing in the sector of manufacturing [1]. In addition to the usual resources used in Cloud Computing, such as networking storage and application capabilities, the Cloud Manufacturing paradigm exploits sensory networks to drive manufacturing equipment through the internet and create a cyber-physical system. In this way, a series of other services throughout the manufacturing chain can be produced.

Industry 4.0 [3] describes a framework in which modern manufacturing companies will operate using decentralized intelligence and multi-sources of information in order to create the above mentioned cyber-physical system. The main driver behind this framework comes from a series of connected devices that are connected through the Internet of Things [4].

In recent years many architectures and services have been presented in the area of Cloud Manufacturing that use the advanced capabilities of Cloud Computing to facilitate the operations in the manufacturing sector. Moreover researchers have focused on the challenges, drivers and advantages of such systems [5–8].

Wang et al. [9, 10] presented a system for process planning and operation planning and control of manufacturing equipment based on standardized Function Blocks (IEC 61499 [11]). Function blocks are event-driven logical units that calculate data and event outputs using embedded algorithms based on input data and events. This technology can be used in order to bypass the G-code generation and talk directly with the controller of CNC machines. The development of a Cyber-physical as part of a Cloud manufacturing based system was presented by [12]. Wang [13] presented a Cloud based manufacturing system for availability monitoring and process planning.

In their research, Wang and Xu [14] presented a service-oriented, interoperable Cloud Manufacturing system. A three layer Cloud Manufacturing structure was proposed that handles the Cloud Manufacturing services, the Services provider and the Cloud Manufacturing service queries. In further research [15] they discussed the sustainability aspects of Cloud Manufacturing. The way Cloud Computing could aid the manufacturing sector and create a Cloud Manufacturing environment was presented by Xu [16].

Studies have also started to focus on the development of services that operate as part of a Cloud Manufacturing environment. Anbalagan et al. [17] presented a feature recognition system that could collaborate with and adaptive process planning system and that could be based on a Cloud environment. Tapoglou et al. [18] presented a system for the calculation of optimal cutting conditions and toolpath creation that can work with a Cloud Manufacturing system.

3 Framework Structure

This work introduces a new framework for the calculation of the optimum cutting conditions and toolpaths as part of a Cloud Manufacturing based environment. The proposed framework uses a two layer optimization in order to calculate the optimum cutting parameters and tune them in an online manner. The optimization framework would be hosted in a hybrid Cloud for protecting the IP of the designs and the manufacturing knowledge while at the same time allowing access to some information to the general public. The entry point for the system is the optimization module through which the user gets access to a series of services that can be connected to the module. The architecture of the system is presented in Fig. 1.

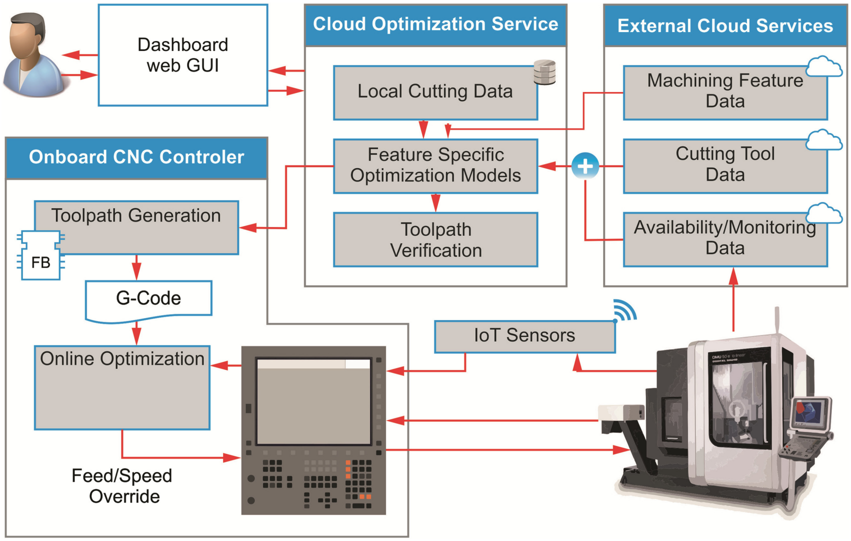

Fig. 1. The architecture of the proposed system

The first layer of the optimization is realized on the Cloud. This layer is mainly responsible for the calculation of the optimum toolpath parameters as well as feeds and speeds for machining the part's features. The data required for this operation are drawn from multiple external sources and reflect the status of the workshop, the machine tools and cutting tools. Moreover recommendations regarding the cutting tool parameters as well as user preferences are taken into account in the optimization process, to deliver an optimal result to the end user. After the optimization, the optimal parameters are verified through a toolpath verification module and then fed to the machine tool controller.

In the second layer the optimal toolpath parameters and feeds and speeds are fed into the onboard software for creating the machining code for realizing the part. During the execution of the machining code a series of embedded and external sensors give feedback information to the onboard optimization module which in turn fine-tunes the cutting parameters to adapt to the dynamic characteristics of the system. The dynamic data monitored are also sent back to the Cloud so that the information can be used for the adjustment of the cutting conditions for later use.

By using a Cloud based approach the propose architecture is able the latest information with regards to best practices taken from online sources and local centralized databases and take well informed decisions in the workshop environment.

4 Functionality and Interfaces

In this section the interfaces with the different modules that provide information to the optimization module are discussed. Moreover, the functionality of the two layers of the optimization module is presented.

4.1 Machining Feature Information

An interface protocol that describes the geometrical characteristics of the part that is going to be machined is needed. STEP protocols provide such information that are widely adopted by most CAD software. The STEP application protocol 240 [19] could serve as a good interface between the optimization module and the geometry providers. The AP240 STEP format provides the machining information details as well as the process planning details for machining the part [20]. The geometrical data regarding the parts are pulled by the optimization system through XML files. The data describing the geometrical features of the parts can be stored on the private Cloud section of the hybrid Cloud if the part is created with in-house design tools or they can be stored on the public section with the data being encrypted to preserve the IP. In the latter case the design details can be shared with users that have viewing/editing rights.

4.2 Availability/Monitoring

In order to be able to make a well-informed decision, the optimization module needs the latest information on the availability of machine tools and cutting tools. For getting access to the latest information, a universally accepted protocol such as MT Connect [21] should be used. The data collected through the availability module would allow the selection of the most appropriate tools and cutting conditions during the optimization process. Most modern CNC machines come with a MT Connect agent embedded so data regarding the status of the tools can be drawn. This protocol could also be used by additional sensors installed on CNC machines such as current measurement sensors as that could be used in the availability monitoring of legacy machines like the ones presented in [22, 23].

4.3 Cutting Tool Data

Traditionally cutting conditions are decided through tool manufacturer recommendations and operators experience. To get the manufacturers recommendations into consideration the optimization module must have connections to the tool libraries of the manufacturers. ISO 13399 [24] presented such a framework for tool data representation. Adveon [25] and NovoSphere [26] are two of the services already existing in this field that can provide the cutting condition starting values to the optimization module. Through such interfaces the normal operating windows for the cutting tools can be obtained thus allowing the optimization module to select cutting conditions ensuring increased productivity and eco-friendliness [28].

4.4 Cloud Based Optimization

In order to select the optimum conditions for machining a series of steps must be realized. The first step in the realization of the optimization is the retrieval of the process plan through the machining feature interface. Every machining feature has to have a corresponding optimization model, similar to the one presented in [18], for the calculation of the optimal cutting condition that takes into consideration the special requirements of each machining feature. The next step is the retrieval of the tools available on the machine that is selected to realize the machining process. The cutting parameter recommendations are retrieved then through the cutting tool data interface. The recommended cutting data are combined with the local cutting data stored on a private database on the cloud optimization module in order to include best practices from the tool manufacturer and the user of the system. In the optimization core, multi objective algorithms calculate the optimization problem. The objectives taken into consideration include the minimization of production cost, the minimization of energy consumption and the maximization of the throughput. The constraints that need to be taken into consideration include achieving the required tolerances, tool wear limits and respecting the machine and tools limits. After the optimization has taken place, the solution can be verified through the use of simulation software to check the validity of the proposed solution. Then the cutting parameters can be broadcasted to the machine tool. This layer of optimization does not calculate the exact toolpaths; instead it calculates the best cutting parameters for executing the machining. This way the information broadcasted to the machine are kept to a minimum. By keeping the broadcasted information to a minimum there is a smaller risk of compromising and corrupting the data.

4.5 Onboard Optimization

The second layer of the optimization is the fine tuning of the cutting conditions. After the optimal cutting conditions are fed into the machine, IEC 61499 [27] function blocks are used to create the machining code for machining a specific feature with the optimal cutting conditions. After the creation of the machining code the machining process can start. During the machining process embedded and external sensors give information regarding the machining process to the controller. Most of the signals to the controller are used by the controller for checking the status of the machine and executing the command movements. Some of these signals can also be used to diagnose the cutting process and further optimize it. In more detail sensors measuring the power needed on the main spindle and the axis drives can be combined to give information regarding the cutting power required for machining. Accelerometers fitted on the spindle could give information regarding vibrations on the spindle. The online optimization module is responsible for adapting the cutting conditions to eliminate unfavorable cutting conditions while at the same time maximizing the throughput of manufacturing and achieving the required tolerances. A multi-objective model predictive control is used to calculate the best feeds and speeds according to the sensed status of the machine. By using this layer the cutting conditions are fine-tuned according to the dynamic characteristics of the specific case.

5 Conclusions and Future Work

This paper presented a two layer framework for the optimization of cutting conditions in CNC milling machines would run as part of a Cloud Manufacturing environment. The requirements regarding the interfaces of such an environment were introduced as well as the link to existing standards. The functionality of the two layers of optimization were also discussed. Cloud based manufacturing systems are starting to get adopted in the industrial sector but some challenges need to be addressed before they are fully integrated in their workflows. Apart from the interfacing issues regarding different subsystems, the security and IP issues of Cloud based solutions need to be resolved. By using a hybrid Cloud structure and embedding knowledge in the controllers, the proposed framework presents a solution towards solving these two issues. A privately stored database is used to store the knowledge of the user of the system thus protecting the knowhow from the public. By using a two-layer architecture, the system can generate a generic optimal solution for machining a specific geometry while at the second layer the fine tuning of the cutting parameters according to the dynamic characteristics of the system can be achieved. The next steps in the development of the proposed architecture are the incorporation of the optimization modules in the framework and construction of a case study that will show the benefits of using such a system. Moreover, the inclusion of additional interfaces and services in this architecture is needed to get an all-around solution for manufacturing.

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Distributed Identical Grating Sensing System Oriented to Equipment Intelligent Sense in Cloud Manufacturing

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Abstract. The intelligent sense of equipment is a key link in cloud manufacturing. Identical fiber Bragg gratings (FBG) have a flexible multiplexing number and are unaffected by the laser's bandwidth. A distributed identical grating system oriented to cloud manufacturing equipment's intelligent sense is developed by combining wavelength tunable laser and broadband laser source in this paper. The system collects the reflect spectroscopy to calculate the center wavelength of each FBG by Gaussian fitting. Some optimization is also done to the Gaussian fitting algorithm to increase the demodulation speed in this paper. In the system, 100 reflective FBGs of only 0.1 % reflection with the interval space of 5 m are connected to a long fiber. All the central wavelengths and positions of the FBGs can be measured. The results show that the linearity of the center wavelength with temperature is up to 99.8 % in range of −10 °C to 60 °C.

Keywords: Fiber optic sensor · Intelligent sense · Cloud manufacturing

1 Introduction

Cloud Manufacturing is a new-emerging and prospective manufacturing mode which has remarkable advantages such as providing flexible service, high cooperativity and knowledge integration level [1]. The physical resource layer, which is the fundamental layer in the structure of cloud manufacturing, consists of a large number of manufacturing equipment [2]. Because of the diversity, large number of equipment and adverse working environment, the monitoring data is massive and diverse [3]. Fiber Bragg Grating (FBG) with its compactness, electromagnetic immunity and excellent multiplexing capability [4, 5] has become a research focus in optical sensing fields. FBGs are easy to form a sensor network for distributed measurement and are widely used in structural health monitoring system for huge buildings such as bridges, tunnels, dams [6]. Therefore, a distributed FBG sensing system with large capacity and high sensitivity is an effective solution to raise the performance of cloud manufacturing equipment intelligent sense.

According to different methods of multiplexing, there are mainly three kinds of distributed FBG sensing system: wavelength division multiplexing (WDM) mode [7], time division multiplexing (TDM) mode and frequency division multiplexing (FDM) mode. Because of the bandwidth limit of laser source, generally no more than 20 FBGs can be

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multiplexed on a single fiber in WDM mode [8]. FDM mode cannot achieve a long distance monitoring due to the coherence length of laser [9]. Using high reflectivity FBG, TDM mode is unable to realize a large multiplexing number of FBGs as a result of the crosstalk and shadow effect between FBGs. In the 10th references article, there are 4 FBGs of 6 % reflection multiplexed on a single fiber [10]. In the 11th references article, there are 9 FBGs of 3 % reflection multiplexed on a fiber [11]. In the 12th references article, there are 1000 identical FBGs of 0.001 % reflection multiplexed on a fiber [12]. And in the 13th references article, 20 identical FBGs of 0.01 % reflection are multiplexed on one fiber [13]. A lower reflection means a lower insertion loss and negligible crosstalk and a larger multiplexing number. Therefore, we use the low reflection FBG to increase the FBG multiplexing number. In this paper, we developed a distributed identical FBG system oriented to cloud manufacturing equipment's intelligent sense by combining the wavelength tunable laser and the broadband laser source. In experiments, 100 reflective FBGs of only 0.1 % reflection with the interval space of 5 m are connected to a long fiber. In order to insure the FBG wavelength's demodulation accuracy, we adopt the Gaussian fitting algorithm to calculate the center wavelength of each FBG according to the reflect spectrum. Gaussian fitting algorithm is complex and very time -consuming, we also do some optimization to the algorithm to improve demodulation rate.

2 Research Content and Experiment Results

2.1 System Design and Implementation

In theory, the FBG reflective spectrum is similar to Gaussian distribution. If FBG reflective spectrum is known, the center of the spectrum (also the center wavelength of FBG) can be calculated by Gaussian fitting.

The pulse modulated light with a stepping and periodic wavelength goes through the identical FBG serial array on a single fiber. Different wavelength the input light has, FBG reflects light with different power. When the input light's wavelength is closer to the center wavelength of FBG, the optical pulse reflected by FBG is stronger. On the contrary, father the wavelength between input light and the center wavelength of FBG

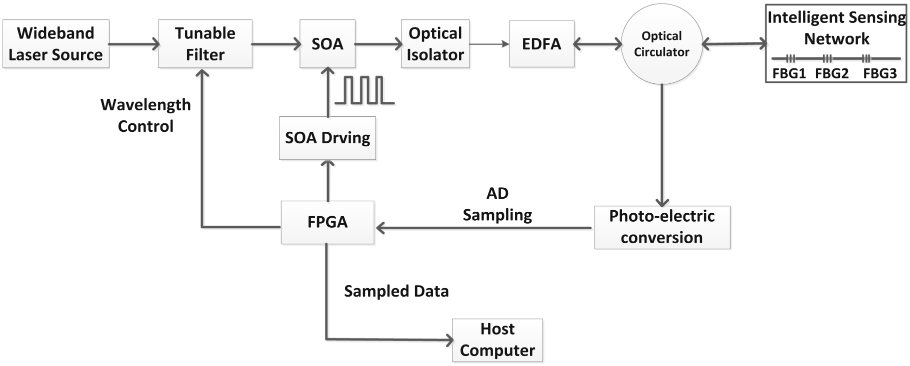

Fig. 1. Schematic configuration of the sensing system

is, the reflected light is weaker. Therefore, acquiring all the reflected pulses for each FBG over a period, we can piece together the spectral envelope of each FBG. Then, Gaussian fitting method is used to calculate the center wavelength of each FBG according to the envelope.

Figure 1 shows the specific architecture of the sensing system we design. The output of wideband laser source is light with various wavelengths. These wavelengths are screened out by a tunable filter controlled by a field programmable gate array (FPGA) processer. The FPGA processer also controls the semiconductor optical amplifier (SOA) driving circuit to produce a periodic pulse sequence to drive the SOA. The light out from the SOA module is pulsed and periodic in wavelength. In order to increase the multiplexing FBG's number, we need to increase the power of the light input. So after the isolator, we adopt an Erbium-doped optical fiber amplifier (EDFA) to amplify the light intensity. Then the light goes through the FBG array on one fiber, the optical pulses reflected by FBGs go into the photo-electric conversion module via the optical circulator. The photon-electric conversion module transforms the optical signal to electrical signal, and the electrical signal are transformed to digital signal and acquired by the FPGA processor. At last, the sampling data is uploaded to a host computer which runs a Gaussian-fitting-method based program to handle the data and then calculates the center wavelength of each FBG. As for the location of each FBG, with optical time domain reflection technology, we can easily figure out the FBG's location by time difference between optical pulses.

2.2 FBG Wavelength Demodulation

In experiments, 100 reflective FBGs of only 0.1 % reflection with the interval space of 5 m are connected to a long fiber. In theory, all the 100 FBGs have a same wavelength about 1552.5 nm at room temperature. At the time of manufacture, the long fiber with 100 identical FBGs is wrapped around a spool manually. Because of the non-uniformity of stress, 100 FBGs' center wavelengths are not the same. Figure 2 shows their differences. Therefore, the input light's wavelength is in the range of 1552.000 nm to

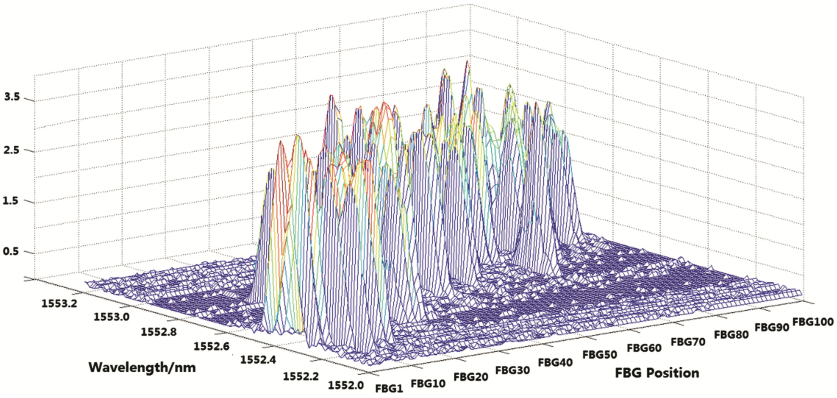

Fig. 2. 100 FBGs' spectrum distribution

1553.2 nm, the pulse width is about 10 ns, and the wavelength step is 10 pm. After restructuring all reflected spectrums, we can get the spectral envelope of each FBG like Fig. 3 shows.

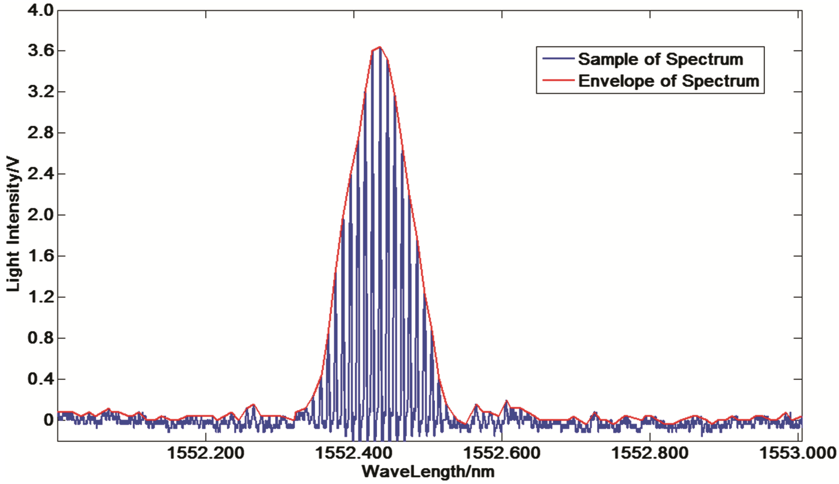

Fig. 3. Envelope of a FBG's reflect spectrum

The refection spectrum of FBG can be approximately described as the following formula:

$$I(\lambda) = I_0 \exp\left[-4\ln 2\left(\frac{\lambda - \lambda_s}{\Delta\lambda_s}\right)\right] \tag{1}$$

In formula (1), I_0 represents the power peak of the reflect spectrum; λ_s represents the wavelength when the spectrum power is I_0. $\Delta\lambda_s$ is the 3 dB bandwidth of reflect spectrum. As Fig. 4 shows, the black dots are the reflect spectrum points, and the red line is a Gaussian fitting curve line according to the black points. The spread center of the Gaussian curve now represents the center wavelength of FBG.

In the process of Gaussian fitting, we convert the non-linear Gaussian fitting methods to polynomial fitting methods which is linear and simpler. Therefore, the least square theory could be used to deduce the calculating formula for wavelength demodulation.

Firstly, some transformations should be done to the formula (1) in order to change the formula into a linear form, through which the fitting efficiency will be improved. Let:

$$\begin{aligned} y &= \ln I \\ a &= -4\ln 2/\left(\Delta\lambda_s\right)^2 \\ a &= -4\ln 2/\left(\Delta\lambda_s\right)^2 \\ c &= \ln I_0 - 4\ln 2 * \lambda_s/\left(\Delta\lambda_s\right)^2 \end{aligned} \tag{2}$$

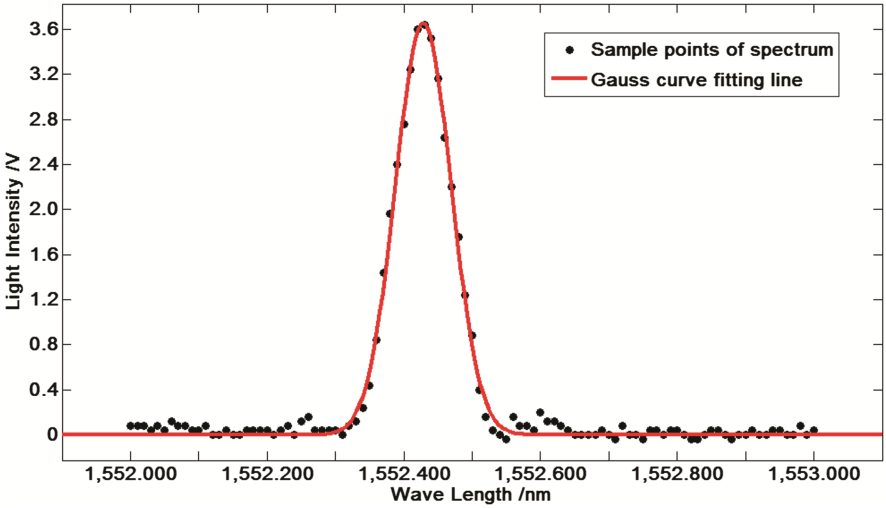

Fig. 4. Gaussian fitting of spectrum

Then the equation in formula (1) can be converted to the following:

$$\mathrm{y} = \mathrm{a}\lambda^2 + b\lambda + c \tag{3}$$

So now the least square principle will help to calculate the values of modulus a, b, c. According to the Eq. (3), the sum of squared residuals is given by:

$$\mathrm{S} = \sum\nolimits_{i=1}^{n} \left(y_i - a\lambda_i^2 - b\lambda_i - c\right)^2 \tag{4}$$

According to the least square principle, in order to achieve the minimum value of S, we take derivatives of S with respect to a, b and c and let the derivatives equal to zero as the following equation shows.

$$\begin{gathered} \sum\nolimits_{i=1}^{n} y_i = a\left(\sum\nolimits_{i=1}^{n} \lambda_i^2\right) + b\left(\sum\nolimits_{i=1}^{n} \lambda_i\right) + nc \\ \sum\nolimits_{i=1}^{n} y_i = a\left(\sum\nolimits_{i=1}^{n} \lambda_i^2\right) + b\left(\sum\nolimits_{i=1}^{n} \lambda_i\right) + nc \\ \sum\nolimits_{i=1}^{n} \lambda_i^2 y_i = a\left(\sum\nolimits_{i=1}^{n} \lambda_i^4\right) + b\left(\sum\nolimits_{i=1}^{n} \lambda_i^3\right) + c\left(\sum\nolimits_{i=1}^{n} \lambda_i^2\right) \end{gathered} \tag{5}$$

Working out the Eq. (5), the value of a, b, c will be known. Then a and b are fed into formula (6) to obtain the center wavelength value of FBG reflect spectrum that is λ_0 given by:

$$\lambda_0 = -b/\left(2a\right) \tag{6}$$

On the other side, one time wavelength demodulation of the whole sensing system with 100 FBGs costs at least 100 times Gaussian fitting process. The whole process contains many similar or same calculation procedures. We can simplify the Gaussian fitting process by working out the results of these similar calculation procedures thus making our fitting algorithm more efficient in time and improving the demodulation rate obviously. According to the derivations above, every fitting needs one logarithmic process done and a three-variable linear Eq. (5) be worked out. Given the number of sample points we need, there exists 100 time logarithmic processes, 708 times float number's addition and subtraction operations and 517 times float number multiplications. For all FBGs, the frequency sweeping range of input light are the same, in this paper the range is 1552.000 nm ~ 1553.2 nm, and the step wavelength also the same (10 pm), that means the value of λ_i in Eq. (5) for each FBG is the same. Therefore, for each FBG's fitting process, the results of $\left(\sum_{i=1}^{n} \lambda_i^4\right)$, $\left(\sum_{i=1}^{n} \lambda_i^3\right)$, $\left(\sum_{i=1}^{n} \lambda_i^2\right)$, $\left(\sum_{i=1}^{n} \lambda_i\right)$ are the same. These results above can be worked out in advance and stored in the computer's ram so that they can directly be used in the subsequent operations. After these calculation optimization, given the same sample points number 100, one time fitting process needs 100 100 time logarithmic processes and only 308 times float number's additions and subtractions and 310 times float number's multiplications, thus reducing 400 times float number's additions and subtractions and 310 times float number's multiplications.

In the experiments, we use a normal personal computer with a CPU frequency of 2.27 GHz, 4 GB memory size and a 32-bit Windows 7 operating system. A Gaussian fitting program is developed within VS2010 developing tools to execute the wavelength demodulation process. Before the optimization above, 10000 times demodulations cost nearly 0.2 s. And after the optimization, 1000 times demodulations cost only 0.025 s. The experimental results show that, the optimization methods put forward in this paper has improved the fitting efficiency obviously and raise the demodulation rate of TDM FBG distributed sensing network up to more than 10 Hz.

2.3 Temperature Monitoring Experiments

The single long fiber where 100 only 0.1 % reflection FBGs grating on with an interval of 5 m is wrapped around a spool. Then the spool is put into an incubator chamber. The temperature of the incubator chamber changes from −10 °C to 60 °C with a step of 5 °C. At each temperature point, we acquire a set of sampling data to demodulate each FBG's wavelength. Figure 5 shows the relationship between demodulated wavelengths of 1th FBG, 25th FBG, 50th FBG, 75th FBG, 100th FBG and the linear changing temperature. A good linear relationship can be seen from Fig. 5 between wavelength and temperature and the linearity degree is up to 99.8 %.

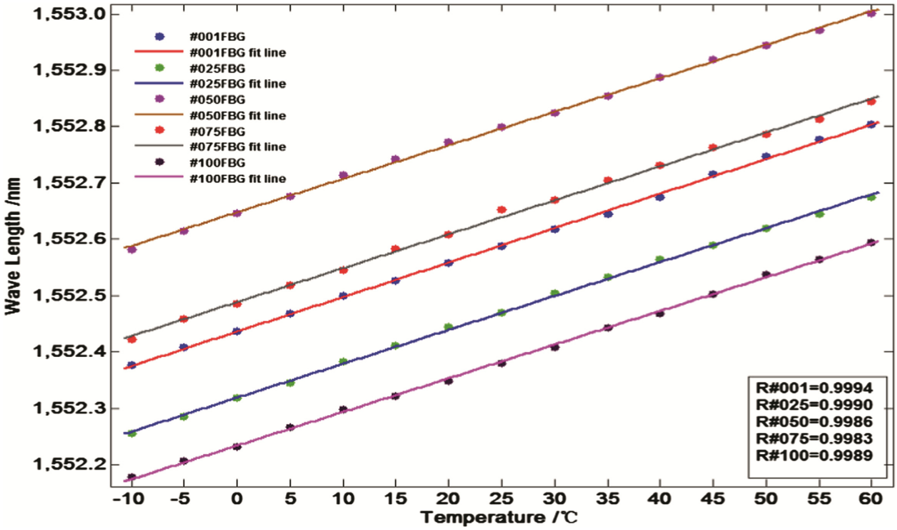

Fig. 5. Relationship between wavelength and temperature

3 Conclusion

In this paper, a distributed equipment intelligent sense system in cloud manufacturing taking use of identical FBGs is developed and implemented. In the system, 100 reflective FBGs of only 0.1 % reflection with the interval space of 5 m are connected to a long fiber. All the central wavelength and position of the FBGs can be measured simultaneously. The results shows that the linearity of the center wavelength with temperature is up to 99.8 % in range of −10 °C to 60 °C. On the other side, this paper also provides an effective optimization method to improve the demodulation rate of the system. The distributed identical grating system designed in this paper will play an active role in the equipment intelligent sense field in cloud manufacturing because of its characteristics such as high capacity and strong interference immunity.

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Resource Utilization in Cloud Manufacturing – An Energy Perspective

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Abstract. Living a "low-carbon" life has been widely recognized and is gradually adopted by the public. Such a trend becomes one of the main drivers for manufacturing innovations. Meanwhile, to meet the emerging requirements, such as providing highly customized product, building flexible and collaborative production, cloud manufacturing is proposed in recent years. A close examination of its environmental benefits is needed. In this paper, resource utilization is focused. In the architecture of cloud manufacturing, energy consumption is analyzed and re-evaluated systematically, including energy characteristics, added energy segments and required functions. Three key merits are identified, better resource integration and optimization, higher resource utility rate, and facilitated knowledge sharing mechanism. However, these improvements can be cancelled in an energy-unattended cloud manufacturing system, for example, ignorance of energy data or inadequate energy models. A framework is then designed for performing energy analysis in a cloud environment. Conclusions are given at the end.

Keywords: Energy consumption · Cloud manufacturing · Resource utilization · Framework

1 Introduction

Living a "low-carbon" life has been widely recognized and is gradually adopted by the public. People are demanding more of environmental-friendly products and processes. Such a trend becomes one of the main drivers for innovations in manufacturing. Meanwhile, intelligence for autonomous production, flexibility for highly customized products, and re-configurability for global collaboration are the representative features, imminently required by modern manufacturing [1]. This undergoing transformation is enabled by cutting-edge Information Technology (IT), such as cloud computing, and related smart technologies, such as Internet of Things (IoT) and manufacturing grid.

Cloud manufacturing, a world-widely featured manufacturing business model is proposed in recent years [2–4]. It mirrors the concept of cloud computing, and helps a manufacturing company to align its product innovation with business strategy, build smart factory networks and respond efficiently to customers' needs. Besides that, less

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environmental impact is a major expectation. Although many research works on cloud manufacturing are being conducted [5–7], only a handful of them raise a concern on environmental aspect [8].

This paper studies resource utilization with a particular focus on energy consumption. The remainder of the paper is organized as follows. Section 2 elaborates the content of cloud manufacturing. A brief literature survey is presented. Overview of energy characteristics in cloud manufacturing, as well as pros and cons is then analyzed in Sect. 3. Following that, a framework of an energy analysis service systems is suggested in Sect. 4. Further discussions and conclusions are given at the end.

2 Cloud Manufacturing

Cloud manufacturing was born in the movement from production-centric to service-oriented manufacturing paradigm. Two types of cloud adoptions in the manufacturing sector are identified, manufacturing with direct adoption of cloud computing technologies and cloud manufacturing, the manufacturing version of cloud computing. The latter one is of interest in this study, which was defined as "*a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing resources (e.g., manufacturing software tools, manufacturing equipment, and manufacturing capabilities) that can be rapidly provisioned and released with minimal management effort or service provider interaction*" [2]. It aims to provide an organization with the ability to visualize its resources, encapsulate and offer them as consumable cloud services, and manage them in a federated way.

2.1 Architecture and Deployment Modes

A upsurge of research interest in developing system architecture is observed. Adamson et al. [9] summarized existing architecture and frameworks of cloud manufacturing. Figure 1 depicts the 4-layer cloud manufacturing architecture developed based on [2]. Various manufacturing resources, of both hard and soft types, collectively form a shared resource pool. They are then presented in a virtual resource repository, such as virtualized machine tools, service capability. Human resource represents both physical and intellectual ability. These virtualized resources are encapsulated as cloud services in the global service layer. In the application layer, general and user-specific applications can be developed, covering all three stages in product lifecycle, Beginning Of Lifecycle (BOL), Middle Of Lifecycle (MOL), and End Of Lifecycle (EOL). In cloud manufacturing, BOL spans from product design to finished product assembly. MOL mainly concerns the use stage of a product, also considers necessary maintenance and service. EOL covers product recycle, component reuse, part re-manufacture, and waste management and disposal. This allows complete product lifecycle management processes to be provided as consumable cloud services.

In developing such a 4-layer cloud manufacturing system, four options of deployment modes are available, public, private, community and hybrid. Public cloud realizes the key concept of sharing the services with the general public in a multi-tenant environment. Private cloud resides within one organization and/or its subsidiaries. Community cloud is shared between several organizations of a specific community. Hybrid cloud is a composition of two or more clouds that remain distinct entities but are also bound together, offering the benefits of multiple deployment modes [10]. Please refer to [2, 11] for more comprehensive information.

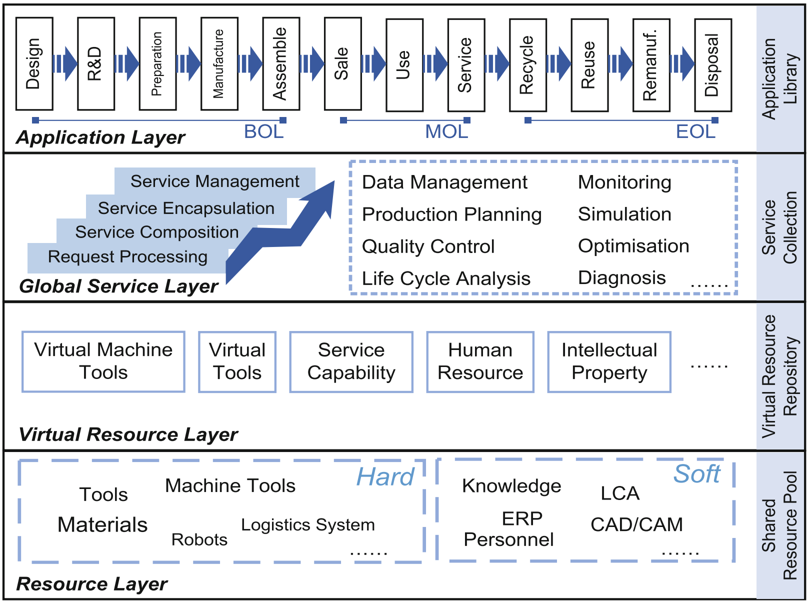

Fig. 1. Cloud manufacturing architecture

2.2 Business Benefits

A fully functional cloud manufacturing system is able to serve two key stakeholders: the enterprises that provide their resources/services, and the users that consume the available services for their own needs [10]. With the cloud approach, there is no need for every enterprise to make heavy capital investment in equipment purchase, factory maintenance, and specialized personnel. Instead, they could have instant access to the required resources, know-how or even complete solutions on a pay-as-you-go basis. Many benefits are anticipated, and three of them are highlighted here.

Resource Re-organization. Current manufacturing business model can barely be considered as a private cloud, where manufacturing resource of an organization are loosely connected and partially shared within itself. In cloud manufacturing, manufacturing resources in a much wider spectrum, whether essential or redundant, can be offered in a resource pool and dynamically organized in line with the users' requirements in regardless of their ownership.

Flexibility. Characteristics such as ubiquitous network access or rapid scalability, offer an enterprise flexibility to manage its business. Moreover, with less investment in specific equipment, production can be quickly reconfigured with different service provisions, based on feedback from the dynamically changing market. Cloud manufacturing enables the shift from capital expenses to operating expenses.

Openness. New technologies emerge every day, which potentially upgrade existing ways of production. Though these cutting-edge technologies are critical to a company's competitiveness or even its survival, most Small and Medium-size Enterprises (SMEs) cannot benefit from them. In cloud manufacturing, these technologies and core-knowledge owned by an organization can be effectively shared as a consumable service, assuring its intellectual property well-protected.

Based on the aforementioned benefits, it is believed that cloud manufacturing would re-shape manufacturing industry and accelerate its reformation. To understand its "green" performance, resource utilization is studied in an energy perspective. Here, a public cloud is assumed.

3 Energy Analysis in Cloud Manufacturing

A conventional manufacturing company relies heavily on fossil fuel-based energy resource. Its environmental impact, therefore, must be paid attention to, until renewable/green energy resources are developed to a similar scale. Energy is hierarchically analyzed and estimated in existing manufacturing companies (Fig. 2). Among different departments at the enterprise level, e.g. design, management, logistics and etc., production is focused. Its subsidiary energy consumers can be further studied at the factory level, process level and machine level. In a cloud manufacturing enterprise, however, energy utilization in these four levels is being altered.

3.1 Energy Characteristics

The overall 4-level structure of energy analysis remains applicable, while energy characteristics at some levels are renewed. First of all, the organization of an enterprise has been extended. In cloud manufacturing, enterprises are virtually formed and managed based on the shared resources pool [11]. Normally, the resources involved in a particular service request belong to various cloud service providers. The centralized energy management system can be moved to the operating cloud platform. The tighter integration between the departments requires the inclusive of comprehensive energy data, such as energy cost by logistics, or one-off cost of material supply.

At the factory level, the overhead energy consumption, supporting lighting, Heating Ventilation and Air Conditioning (HVAC) and other infrastructure, is now scattered over multiple factories, therefore, energy is consumed on a pay-as-you-go basis. Moreover, due to increasing demand of highly customized products, rigid production lines and fixed processes are retiring, instead, processes need to be dynamically organized and agilely reconfigured so as to easily adapt to the "living" supply chain.

Dividing energy consumption into elementary and meaningful segments, e.g. state-based [13] and motion-based [14] approaches, provides a basic mechanism to study energy in cloud manufacturing. Less change happens at the machine level, but machine-related energy data need to be included in the virtualization process. For example, different ways of production organization result in large difference in energy consumption, simply by taking transportation, e.g. Automatic Guided Vehicles (AGVs) or conveyers, into consideration. Eventually, energy analysis can be performed by a self-organized, self-regulated cloud energy manager that functions based on data streaming from distributed resources. When an existing production line alters or a new production line to be built, it assists in process modeling and optimization.

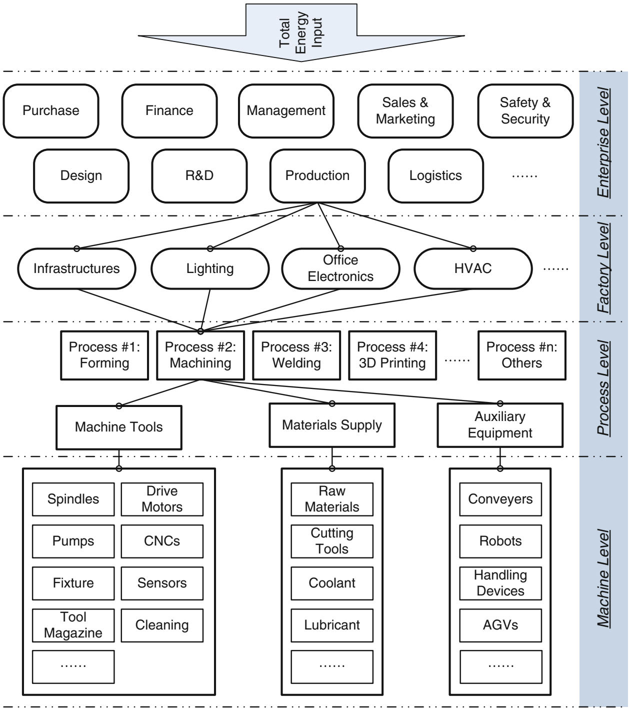

Fig. 2. Structure of energy analysis for production (modified from [12])

3.2 Pros and Cons

Energy study of cloud manufacturing reveals three key merits, that is better resource integration and optimization, higher resource utility rate, and facilitated knowledge sharing mechanism.

Resource Integration and Optimization. With a shared resource pool, cloud users are granted the access to more manufacturing resources and capabilities. This enables the optimum matching and best combination of manufacturing equipment in terms of energy usage, for instance, energy waste is minimized by excluding overqualified machines. Additionally, a better supply chain may be formed locally with several specialized SMEs to avoid unnecessary transportation within a large-size enterprise.

Resource Utility Rate. The meaning of higher resource utility rate is twofold. Firstly, companies can offer their unused or temporarily idle manufacturing equipment and/or packed with its associated personnel and know-how as cloud services. Secondly, the sharing mechanism allows more diversity of manufacturing tasks to be conducted on a machine, so that its full functions and capability can be utilized, and energy consumption data in different conditions can be obtained. SMEs that specialize in fewer manufacturing processes are more likely to develop the energy-efficient operating strategy for their resources.

Knowledge Sharing Mechanism. As a matter of fact, energy consumption behavior is often machine- and process- specific. Many models were developed using empirical or experimental methods. Yet, no single energy model can describe diverse manufacturing processes. The inherent sharing mechanism in cloud manufacturing is perhaps a solution. Cloud users who want to perform energy evaluation of a particular manufacturing process, can request relevant analysis services that utilize energy models maintained in a shared database. This saves modeling efforts and continuously improves accuracy and effectiveness of energy analysis.

Nevertheless, these improvements can be cancelled in an energy-unattended cloud manufacturing system, for example, ignorance of energy data or inadequate energy models. Such an issue may root in the fundamental objectives of developing a cloud manufacturing system. Cost is usually the main concern, which was evaluated in monetary form, in most cases. Energy as well as other environmental factors hardly carry weight in this sense. Large attention is paid merely to the high-cost resources. Though "green" requirements from the end-users are noticeable, they are not properly considered in the design stage and not reflected in the development stage [15].

Furthermore, there is an ongoing debate that whether the impact of improved energy efficiency on reducing energy use might be partially, or more than wholly, offset through "rebound" and "backfire" effects [16]. The economic factors underpinning rebound effects are straightforward: resource utilization improvements result in an effective cut in resource prices, which produces output, substitution, competitiveness and income effects that stimulate resource demands. However, the possible presence of strong rebound or even backfire does not mean that cloud manufacturing is inappropriate; rather it suggests that sharing alone are insufficient to generate environmental improvements. A coordinated system design is required.

4 EAS Framework

A framework of an Energy Analysis Service (EAS) system is developed for cloud manufacturing. The basic principle in designing this framework is to consider energy utilization as an integral part and one of the main objectives for long-term competitiveness of an enterprise. Figure 3 depicts the designed “tower” framework. The base of the tower is comprised of three levels, manufacturing resource, data streaming and processing. These are essential steps to reach the core level, energy model, data and knowledge bases. Based on the core, cloud users can utilize various publicized energy services via application interfaces, such as energy estimation and energy labeling.

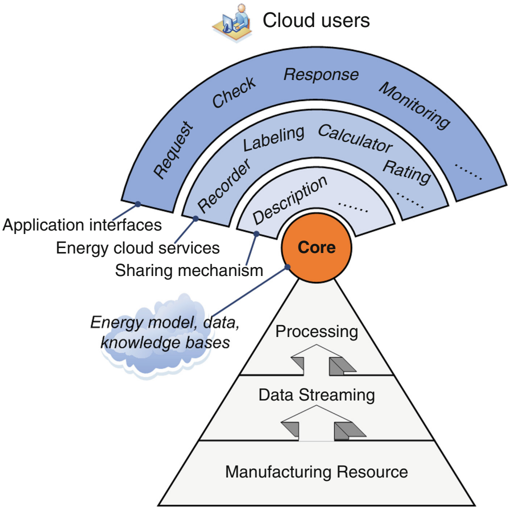

Fig. 3. Proposed EAS framework

Some key functions of energy-aware systems are also supported: (1) closed-loop data streaming (online energy monitoring, in-time feedback control), (2) energy calculation (componentized energy models, trustworthy simulation), (3) intelligent data processing (energy pattern analysis, energy supervisor and inspector, service rating), and (4) metering and billing system (pay-as-you-go style, energy traceability). Extra cost should occur at both cloud service provider’s and user’s ends, when user choose the less energy-efficient processes. This strategy evokes public “green” awareness and encourages continuous improvement of manufacturing processes.

Fig. 4. Example of cloud manufacturing platform

The developed EAS system could be integrated with a cloud manufacturing platform (Fig. 4). Energy resource utilization is envisioned as a virtual application service, and intended to support online resource description, monitoring, and data analysis.

5 Conclusions

Though the issue of energy consumption in manufacturing draws significant attention, manufacturers hold their further actions on adopting energy-related improvements, awaiting the proof of feasibility and benefits in production. Cloud manufacturing aims to reform the manufacturing industry, where companies can actively participate in a broader virtual enterprise, and cooperatively fabricate highly-customized product in a more cost-effective manner. Enabling technologies in the 4-layer cloud manufacturing architecture enhance resource integration and utilization, as well as meet the up-to-date requirements of global market.

New energy characteristics reveal the advantages introduced by cloud manufacturing, that is better resource integration and optimization, higher resource utility rate, and facilitated knowledge sharing mechanism. But these can be cancelled in an energy-unattended cloud system. The proposed EAS framework provides preliminary thoughts in developing energy-aware cloud services, which could be integrated with a functional cloud manufacturing platform. Some other critical issues exist in cloud manufacturing, such as physical equipment integration, logistics and transportation, data security and safety. Energy data should also be addressed in these processes.

It is time to change the dated view on overhead energy cost. Customer interaction in the product lifecycle imposes restrictions on energy utilization, which promotes "green" awareness, motivates the innovation in technology, and the introduction of greener products. System development and integration is planned as future works.

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A Unified Sustainable Manufacturing Capability Model for Representing Industrial Robot Systems in Cloud Manufacturing

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Abstract. Nowadays, the sustainable manufacturing capability of manufacturing devices has attracted more and more attention from academia and industry, in order to coordinate the conflicts between serious environmental impacts and economic benefits. As one kind of advanced manufacturing devices with intelligence, the industrial robot (IR) is an important driving force to make the production activities more efficient, safe and sustainable. A unified sustainable manufacturing capability model for representing IR systems in cloud manufacturing based on ontology was proposed in this paper, so as to solve the description problems in terms of the various capabilities of IR systems, and also to facilitate the factories to effectively manage the IR systems' manufacturing activities during the whole production life-cycle. The case study and its implementation show the developed ontology model is suitable for all types of IR systems, and can comprehensively reflects their sustainable manufacturing capabilities in real-time.

Keywords: Industrial robot systems · Sustainable manufacturing capability · Unified model · Ontology

1 Introduction

Cloud Manufacturing is a new service-oriented manufacturing mode that provides user with on-demand manufacturing services after organizing manufacturing resources on the Cloud Manufacturing Service Platform on Internet. The virtualization of manufacturing resources, especially the manufacturing equipment, is the foundation of Cloud Manufacturing. IR is regarded as an advanced manufacturing equipment, which integrates mechanics, electronics, cybernetic, computer, sensor, artificial intelligence and other advanced technologies and it executes the tasks by manufacturing capability. Manufacturing capability is the level at which a manufacturing company or a manufacturing equipment completes a task during a specific manufacturing process [1]. It's not only the factor which influences an enterprise to do related activities but also the preliminary judgment for users to select marketing partners. Current IR is becoming more and more

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complex and sophisticated. And an IR's manufacturing capability will vary with the occurrence of its failures and used hours. All kinds of reasons make it difficult for factories to effectively manage and maintain the manufacturing capabilities of IR systems. In addition, the sustainable manufacturing capability of an IR should be studied to solve current serious environmental problems due to the manufacturing model driven by economy. Sustainable manufacturing capability is a manufacturing equipment's ability to minimize the negative impacts on the environment and maximize the resource utilization ratio and comprehensive benefits during one or more life cycles of products [2]. But there is limited research in this area because IR is a new emerging technology industry.

In order to solve above problems, this paper is organized as follows. Section 2 introduced current researches about manufacturing capability. A unified sustainable manufacturing capability model for representing IR systems in cloud manufacturing was posed in Sect. 3. In addition, the specific ontology structure was given too. In Sect. 4, an IR individual was built to validate the theory proposed. Conclusions and future work were drawn in Sect. 5.

2 Related Work

At present, many scholars have done some researches on manufacturing capability. In 1969, Skinner firstly noted that manufacturing capability was determined by factors such as cost, quality and the relationships between the various elements [3]. From the point of view of an enterprise, Xun Xu et al. held that manufacturing capability was provided by software resources, human resources, material resources and processing resources (e.g., processing equipments, tools.) [4, 5]. Only focused on manufacturing equipments, Xu et al. built their own capability models which included weight, type of machining parts, roughness, machining accuracy and feed efficiency [6, 7].

Some scholars have studied the manufacturing abilities of IR systems. Nitzan D thought an IR achieved the functions by its actuators, sensors, computers and other auxiliary facilities [8]. Abele E studied the manufacturing precision which will be influenced by high load in the field of shaping, milling and cutting [9]. The manufacturing capability of an IR is determined by many factors such as cost, load capacity and processing interfaces [10, 11]. Kahraman et al. proposed a fuzzy multi-criteria evaluation algorithm to analyze the manufacturing capability of an IR from the perspective of technical attributes and economic attributes [12]. Khandekar et al. took seven indicators (e.g., installation location, repeatable positioning accuracy, payload, weight and speed of each joint.) into account to evaluate an IR's manufacturing capability [13]. Sen DK only think over some quantitative indicators [14]. In addition, there is an urgent need to reduce the energy consumption of an IR because of the shortage of resources and global warming [15, 16]. Brossog et al. proposed a modular model to analyze the energy consumption and dynamic behavior of an IR [17].

Current researches mainly focus on the manufacturing equipments and the manufacturing resources of enterprises. There are few studies about an IR's manufacturing capability, especially the sustainable manufacturing capability. And factories find it hard to grasp the manufacturing capabilities of IR systems with different functions and features. A unified sustainable manufacturing capability model for representing IR systems in cloud manufacturing based on ontology was proposed in this paper to solve above problems. And it's possible to dynamically improve the information of individuals in the ontology based on established mappings [6].

3 A Unified Sustainable Manufacturing Capability Model for Representing IR Systems in Cloud Manufacturing

IR is a manipulator with multiple joints or a mechanical device with multiple degrees of freedom. It automatically executes tasks by its own power and control mechanisms. It can accept human commands, and also can run according to pre-programmed procedures or the principles set by artificial intelligence techniques. In this paper, it was divided into point robots and continuous path robots according to control mechanisms. Point robots control an actuator from one point to another. They're used for spot welding, loading, unloading and handling. Continuous path robots make an actuator move at a given track. They're suitable for continuous welding and coating. On the basic of arms' movement modes, IR was classified into rectangular robots, cylindrical robots, spherical robots and joint robots.

3.1 A Unified Description Model

A unified description model of sustainable manufacturing capability for IR systems was proposed in Fig. 1. There are five procedural steps as follows.

(a) The relation between an enterprise and an IR was set. As one kind of machining tool, an IR is possessed by an enterprise. An IR has its basic information which including name, ID, manufacturer and so on while an enterprise also has information which describes its name, phone and address.

(b) Various technical parameters (e.g., payload, memory capacity, repeatability.) of an IR is an important part of this model. They were collected from websites about IR systems. A suitable IR used for a specific task is selected by the values of its technical parameters. The manufacturing capability of an IR can be figured out through appropriate evaluation algorithms [18].

(c) In order to make this model dynamic, the manufacturing process of an IR was monitored. Operation is one part while the property during manufacturing is the other part. Operation can be extended according to the functions of an IR. An IR perform an operation on a task. And the property during manufacturing will reflect not only the execution status of a task but also the sustainability of an IR. This paper mainly took energy consumption and efficiency into account to analyze the sustainability of an IR. At the basis of power consumption, the consumption of resource used for producing power and the emission of carbon and dust particles exist in the process of generating power can be figured out.

(d) Mapping the sensory data to the property during manufacturing. Observation exists as a tie between sensors and properties. An observation is observed by a sensor. The value of a property is logged at a certain interval by an observation. The execution status of a task and the sustainability of an IR can be reflected in real-time

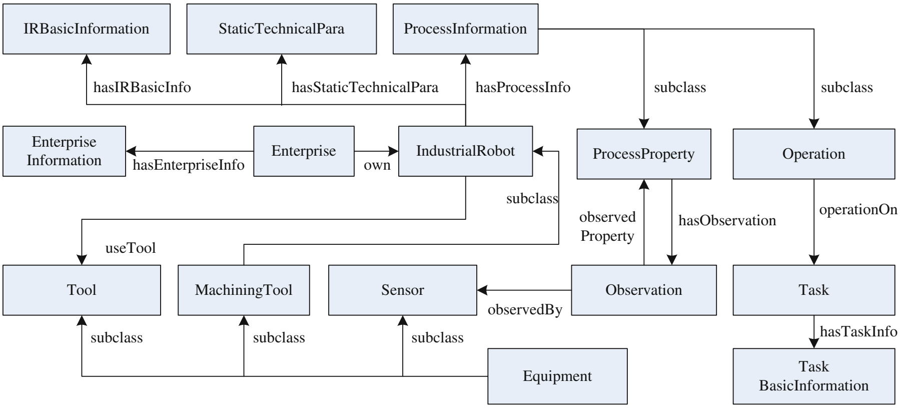

Fig. 1. A unified description model of sustainable manufacturing capability

through the mapping method. What's more, combining with the rules set in advance, it's helpful to expand and update the model.

The model proposed in Fig. 1 can be extended to meet the demands of a specific IR. In other words, it's fit for all kinds of IR systems. More relations will be detailed in next section.

3.2 Ontology Structure

An ontology model was proposed based on the unified description model. Ontology has many description languages. This paper adopted Web Ontology Language. And Protégé was used for ontology construction here.

The main concept in the ontology is "IR". It has three primary categories of information, namely:

- IRBasicInformation – describes the basic information of an IR, such as ID, name, type and manufacturer. The structure of an IR (e.g., movement mode of arm, type of power source.) was also included.
- StaticTechnicalPara – describes the manufacturing capability of an IR in terms of static attributes. ControlledAxes, MaxReach, MaxJointSpeed and Repeatability are classes which are expressed numerically while MountingPosition and ProtectionDegree are classes which are expressed qualitatively, as shown in Fig. 2.
- ProcessInformation – reflects the status of an IR and a task in the process of manufacturing. It includes direct properties, the value of which is monitored by sensors, such as speed, temperature and power. There are also some indirect properties, whose value should be calculated or be reasoned, as shown in Fig. 3. Properties, such as IRUtilizationRate, QualifiedRate, CycleTime, reflect the efficiency of an IR. And the power collected during the manufacturing illustrates the energy consumption of an IR. These properties are all factors of the sustainable manufacturing capability of an IR. Further, the state of an IR is split into five levels, namely, Off, Breakdown,

Brake_On, Brake_Off, Running. This model will show the energy consumption under different states in real-time. Then the enterprise not only know the energy consumption of an IR, but also is able to figure out a management scheme of brake to minimize the energy consumption.

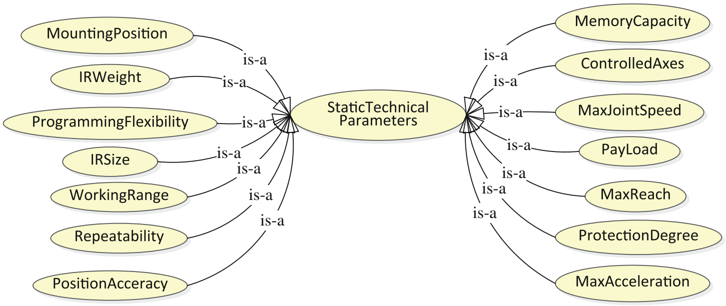

Fig. 2. Ontology of technical parameters

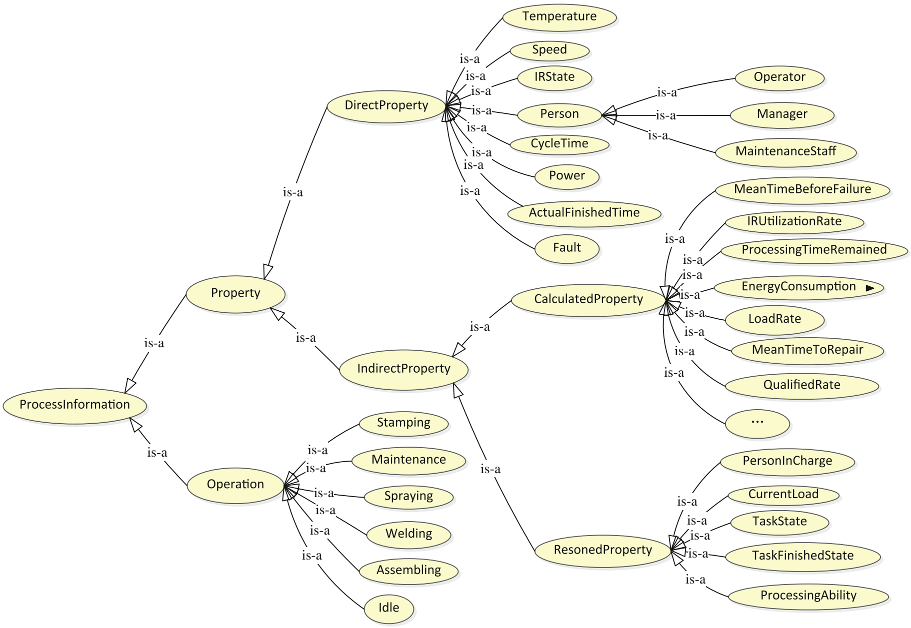

Fig. 3. Ontology of manufacturing process

4 Case Study and Implementation

The semantic link between sensory data and model elements make it possible to analyze the sustainable manufacturing capability of an IR. An IR individual KUKA-KR-16 arc HW was built to verify the theory mentioned above. It's a robot good at welding the door of a car. The query language SPARQL is used to seek the information of the model. Here is an example to query the energy consumption during the manufacturing, including at which time the observation happened, what's the value of the observation and what's the object of the observation, shown as follows. The values of other direct properties can be queried like that.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX fa:<http://www.semanticweb.org/ontologies/2015/0/
Ontology1422348210197.owl#>
SELECT DISTINCT ?operationType ?propertyType ?time ?object ?value
WHERE{
    fa: KUKA-KR-16 arc HW  fa:hasProcessInfo ?processInfo.
    ?processInfo fa:hasCurrentOperation ?operation.
    ?operation rdf:type ?operationType.
    ?operationType rdfs:subClassOf fa:Operation.
    ?processInfo fa:hasPower ?property.
    ?property rdf:type ?propertyType.
    ?propertyType rdfs:subClassOf fa:DirectProperty.
    ?property fa:hasObservation ?observation.
    ?observation fa:hasOutput ?output.
    ?output fa:isObservatedAtMoment ?time.
    ?output fa:hasObservationObject ?object.
    ?output fa:hasObservationValue  ?value.
    }
```

In addition, some inference rules were set as follows to help reasoning implied knowledge from real-time sensory data.

Rule1:Idle(?x),ProcessInformation(?y),hasIRState(?y,Brake_Off)-> hasCurrentOperation(?y, ?x)
Rule2:Idle(?x),ProcessInformation(?y),hasIRState(?y,Brake_On)-> hasCurrentOperation(?y, ?x)

These two rules means that if the current state of an IR is Brake_On or Brake_Off, the current operation of this IR is Idle.

At the basis of query results and inference outputs, it's possible to construct an analysis view composed of diagrams for each process property as depicted by Fig. 4. With these properties and relationships, the sustainable manufacturing capability of an IR is clearly shown in real-time.

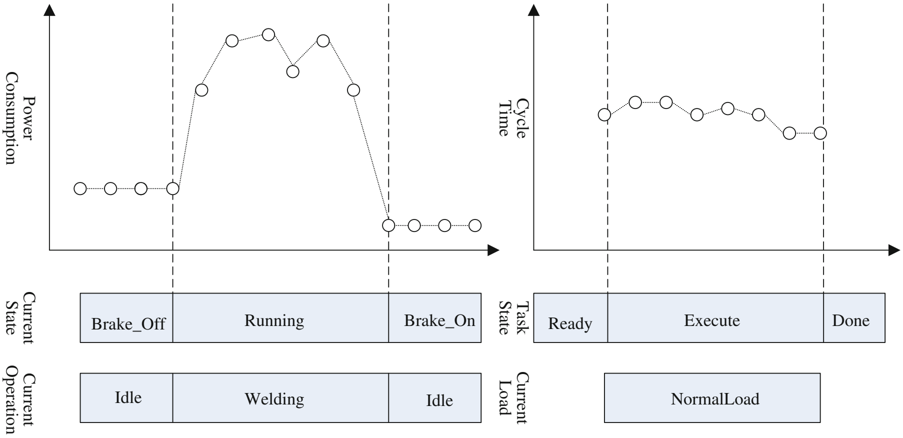

Fig. 4. Visualization of process property values

5 Conclusions and Future Work

A unified model of IR systems which can be described by ontology, is proposed to analyze the sustainable manufacturing capabilities of IR systems. It is able to solve the description problems due to the IR systems' various functions and complex structures. It is useful for factories to effectively manage the manufacturing capacities of IR systems. The proposed model still needs to be extended in future, and the evaluation algorithms should be studied to get a numerical result from the technical parameters and the manufacturing information.

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Dynamic Assessment of Sustainable Manufacturing Capability for CNC Machining Systems in Cloud Manufacturing

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Abstract. Sustainability has been attracted extensive attention in manufacturing industry for the increasing excessive resource consumption and serious environmental pollution. The assessment of sustainable manufacturing capability is a vital factor, especially in cloud manufacturing, in which the capability assessment of the manufacturing resources is the premise of selecting the optimal manufacturing services. While the CNC machining tools are the basic manufacturing resources in production process, so the dynamic assessment of their sustainable manufacturing capabilities is investigated in this paper. A set of indicators is established considering manufacturing sustainability and a new dynamic assessment model is proposed based on a modified "vertical and horizontal" method. The model is verified through a case study and it can comprehensively evaluate the capability performance of the CNC machining systems, and also effectively follow the dynamics of their production activities.

Keywords: Sustainable manufacturing capability · CNC machining systems · Dynamic assessment · "Vertical and horizontal" method

1 Introduction

Currently, cloud manufacturing becomes a new manufacturing model under the promotion of manufacturing informatization. The capabilities of manufacturing resources are presented in the form of services consumers can share together globally. Selecting the optimal manufacturing resource from the global shared resource pool becomes a vital issue under cloud manufacturing. Meanwhile, sustainability has been the focus of heated discussion in recent years. There're many definitions about sustainability. The most acceptable one is defined at 1987 World Commission on Environment and Development [1], which states, "Meeting the needs of the present without compromising the ability of future generations to meet their own needs." Generally, sustainable manufacturing is the reflection of sustainability in manufacturing. Meanwhile, manufacturing informatization makes digital design and manufacture become a way to

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improve manufacturing capability. CNC machining tools are widely used and they can solve many parts processing problems (e.g., high-precision, small batch and multi varieties production). They are the key to parts processing, which will greatly affect the processing quality, cost, time, energy, wastes, etc. So the assessment of manufacturing capability for CNC machining systems is of great significance.

2 Related Works

The concept of manufacturing capability was first proposed by Skinner in 1969 [2]. He stated that manufacturing capability is a kind of ability for enterprises to achieve manufacturing strategy and is composed of costs, quality, time and the relationship between these elements. Corbett and Claridge [3] pointed out that manufacturing capability is consist of quality, cost, delivery speed, flexibility and innovation. Reference [4] defined manufacturing capability as time, quality, cost, technology, service, corporate performance etc. when selecting virtual enterprise partners. In the field of sustainable manufacturing, some scholars have applied sustainability assessment to manufacturing decision making from economic, environmental and social aspects [5, 6].

The relative assessment methods mainly have two categories: One is the subjective method which has certain subjectivity. The other is the objective method which cannot reflect the preferences of decision makers. So far, most assessment models are static. The dynamic assessments have already made some achievements [7, 8], which have two classifications. One is a twice-weighted method which confirms the weights at different times; the other is dynamically dealing with the time series data, by which the weights are updated along with the update of data. For the former, reference [9] proposed a dynamic method based on Time Entropy to assess manufacturing capability, while it only considers subjective weights ignoring the effect of objective data.

Overall, the existing relative researches mainly have two shortages. Firstly, the researches solely focus on economic benefits without considering environmental impact and resource consumption. Secondly, most assessment methods are static which cannot reflect the capability dynamically. Therefore, this paper establishes a set of indicators system of sustainable manufacturing capability for CNC machining systems. A dynamic assessment method is proposed, which combine the advantages of subjective and objective assessment methods. Finally, “time-value coefficients” are introduced to aggregate data to obtain comprehensive capability value.

3 Assessment Model and Indicators

3.1 Assessment Model

For CNC machining systems, the indicator values are changing dynamically. Therefore, the issue of manufacturing capability assessment is a multidimensional decision making problem of three dimensions with indicators space, object space and time space. It can be supposed that there are n alternatives $s_1, s_2, \ldots, s_n$, m indicators $x_1, x_2, \ldots, x_m$ (suppose all the indicators are standardized), and N historical task orders drawn from N recent time periods in chronological order. The original data can be got as $\left\{x_{ij}(t_k)\right\}$, constituting a time series database shown in Table 1. Based on the dynamic time series data, the connotation of manufacturing capability and sustainable manufacturing, this paper mainly concern economic and environmental aspects. A dynamic assessment model is proposed as Fig. 1.

Table 1. Dynamic timing database

Alternatives	t_1	t_2	…	t_N
	$x_1, x_2, \ldots, x_m$	$x_1, x_2, \ldots, x_m$	…	$x_1, x_2, \ldots, x_m$
s_1	$x_{11}(t_1)$ $x_{12}(t_1)$ $\cdots$ $x_{1m}(t_1)$	$x_{11}(t_2)$ $x_{12}(t_2)$ $\cdots$ $x_{1m}(t_2)$	…	$x_{11}(t_N)$ $x_{12}(t_N)$ $\cdots$ $x_{1m}(t_N)$
s_2	$x_{21}(t_1)$ $x_{22}(t_1)$ $\cdots$ $x_{2m}(t_1)$	$x_{21}(t_2)$ $x_{22}(t_2)$ $\cdots$ $x_{2m}(t_2)$		$x_{21}(t_N)$ $x_{22}(t_N)$ $\cdots$ $x_{2m}(t_N)$
$\vdots$	$\vdots$ $\vdots$ $\vdots$ $\vdots$	$\vdots$ $\vdots$ $\vdots$ $\vdots$		$\vdots$ $\vdots$ $\vdots$ $\vdots$
s_n	$x_{n1}(t_1)$ $x_{n2}(t_1)$ $\cdots$ $x_{nm}(t_1)$	$x_{n1}(t_2)$ $x_{n2}(t_2)$ $\cdots$ $x_{nm}(t_2)$		$x_{n1}(t_N)$ $x_{n2}(t_N)$ $\cdots$ $x_{nm}(t_N)$

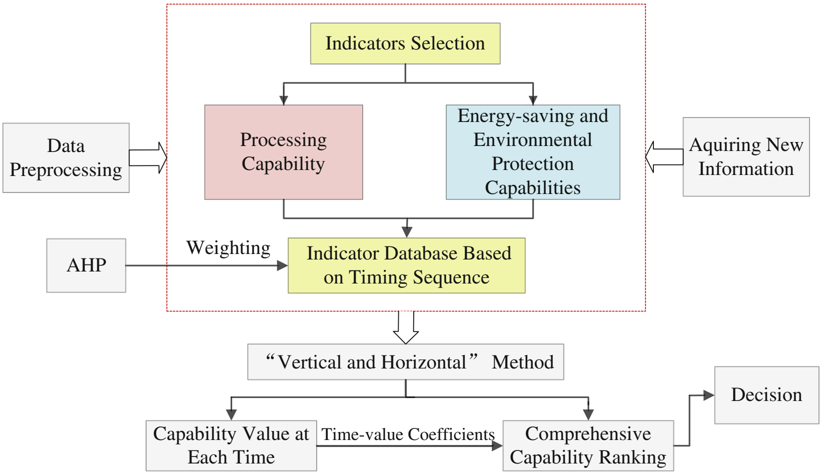

Fig. 1. Assessment model

3.2 Assessment Indicators

According to the connotation of manufacturing capability and the demands of sustainable manufacturing, besides quality, time and cost, the basic elements of manufacturing capability, resource consumption and environmental impact are also considered in this paper. Given the actual processing of machining system, the five factors can be decomposed to establish the indicator system shown in Table 2.

4 Dynamic Assessment Based on Timing Sequence

4.1 Subjective Weight Calculation Based on AHP

Analytic hierarchy process (AHP) was first put forward by Saaty as multi criteria decision tool that quantifies the qualitative analysis [10]. It is used in this paper to determine the subjective weights. The method consists of the following steps:

Table 2. Indicators for sustainable manufacturing capability assessment

Goal	Indexes	Sub-indexes
Assessment of sustainable manufacturing capability for CNC machining systems	Processing quality	Dimension machining precision
		Surface machining precision
		Shape machining precision
	Processing cost	Workers' wages
		Equipment depreciation
		Operation expenses
		Maintenance cost
		Material cost
	Processing time	Machining time
		Auxiliary time
	Resource consumption	Main material consumption
		Auxiliary materials consumption
		Energy consumption
	Environmental impact	Air pollution
		Cutting liquid pollution
		Noise
		Wastes

1. Firstly, define the problem and find the indicators related to the decision goal.
2. Establish a hierarchical structure according to the subordinate relations between the indicators: top level is the goal of the decision; intermediate levels represent criteria or sub-criteria; and the bottom level represents the alternatives, such as Table 2.
3. Construct the comparison matrices by conducting pairwise comparison between the elements of each level with respect to each element in the immediate upper level.
4. Calculate the eigenvector of each matrix to find element's relative weight and check consistency index CI and consistency ratio CR for each eigenvector. Due to the length limitation, further details can refer to reference [10].

Based on Table 2, the subjective weight vector $w' = (w'_1, w'_2, \ldots w'_m)$ can be obtained by AHP. Then the weighted timing database can be got by Eq. (1)

$$x'_{ij}(t_k) = w'_j x_{ij}(t_k), \quad i = 1, 2, \ldots, n; \quad j = 1, 2, \ldots, m \tag{1}$$

4.2 Objective Weights Calculation Based on "Vertical and Horizontal"

Based on Eq. (1) and Table 1, "vertical and horizontal" method [7] is used here for dynamic assessment. For time $t_k (k = 1, 2, \ldots, N)$, the linear function can be defined as:

$$y_i(t_k) = \sum_{j=1}^{m} w_j x'_{ij}(t_k), \quad k = 1, 2, \ldots, N; \quad i = 1, 2, \ldots, n \tag{2}$$

$y_i(t_k)$ is the assessment result of system s_i at time t_k; $w = (w_1, w_2, \ldots, w_m)^{\mathrm{T}}$ is the subjective dynamic weight vector. The principle of determining w_j is to maximize the difference between systems $s_1, s_2, \ldots, s_m$, which can be described by Eq. (3).

$$\sigma^2 = \sum_{k=1}^{N} \sum_{i=1}^{n} (y_i(t_k) - \bar{y})^2 = w^{\mathrm{T}}(\sum_{k=1}^{N} A_k^{\mathrm{T}} A_k - nN\bar{x}^{\mathrm{T}}\bar{x})w = w^{\mathrm{T}}Hw \tag{3}$$

where $H = \sum_{k=1}^{N} H_k - nN\bar{x}^{\mathrm{T}}\bar{x}$, $H_k = A_K^{\mathrm{T}} A_k (k = 1, 2, \ldots, N)$, A_k is the matrix of $x'_{ij}(t_k)$;$\bar{x} = (\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_m)$, $\bar{x}_j = \frac{1}{N}\sum_{k=1}^{N}\left(\frac{1}{n}\sum_{i=1}^{n} x'_{ij}(t_k)\right)$, $\bar{y} = \frac{1}{N}\sum_{k=1}^{N}\left(\frac{1}{n}\sum_{i=1}^{n} y_i(t_k)\right)$.

Obviously, σ^2 have no upper limit if w isn't limited. Limit $w^{\mathrm{T}}w = 1$. When w is the corresponding eigenvector of the largest eigenvalue $\lambda_{\max}(H)$, σ^2 reaches the maximum. If $w > 0$, normalize w to make it satisfy $\sum_{j=1}^{m} w_j = 1$. If $\exists j \in (1, 2, \ldots m), w_j < 0$, w can be obtained by the following nonlinear programming problem:

$$\begin{cases} \max w^{\mathrm{T}}Hw \\ s.t.\ w^{\mathrm{T}}w = 1, w > 0 \end{cases} \tag{4}$$

4.3 Obtaining Time-Value Coefficient

The system capability of different time $y_i(t_k)$ has been obtained from Eq. (2). The linear comprehensive assessment function can be defined as

$$y_i = \sum_{k=1}^{N} v_k y_i(t_k), \quad i = 1, 2, \ldots, n \tag{5}$$

v is the time weighting vector. Furthermore, time-degree factor $\lambda = \sum_{k=1}^{N} \frac{N-k}{N-1} v_k$ is introduced to characterize the preference degree to time series. The closer λ to 0, it indicates the more attention to the recent data. The closer λ to 1, it indicates the more attention to the distant data. The principle of determining v is to find a set of stable time weights which have small fluctuation. It can be described by the variance of v, which can be calculated by the following mathematical programming problem. The solution of this problem can be easily got in reference [11].

$$\begin{cases} \min(D^2(v) = \frac{1}{N}\sum_{k=1}^{N} v_k^2 - \frac{1}{N^2}) \\ s.t.\ \lambda = \sum_{k=1}^{N} \frac{N-k}{N-1} v_k, \sum_{k=1}^{N} w_k = 1, w_k \in [0, 1], \quad k = 1, 2, \ldots, N \end{cases} \tag{6}$$

5 A Case Study and Implementation

5.1 A Case Study

The case about selecting the machining system which has the optional sustainable manufacturing capability for machining a batch of shafting parts is presented. s_1, s_2, s_3 are the matched alternatives. Based on Table 1, pruning some indicators with small difference comparatively, 11 indicators are selected: quality(x_1 dimension machining precision; x_2 surface machining precision; x_3 shape machining precision), time(x_4 processing time; x_5 auxiliary time), cost(x_6 operation expenses; equipment depreciation), resource consumption(x_8 electricity), environmental impact(x_9 noise; x_{10} cuttings; x_{11} liquid wastes). The original data are shown in Table 3.

Table 3. The value of indicators

		x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}
t_1	s_1	0.05	0.05	0.05	20	10	50.8	1.0	5.02	80.2	1.23	6
	s_2	0.09	0.09	0.09	30	13	32.5	1.5	5.25	75.3	2.28	5.5
	s_3	0.06	0.06	0.05	18	10	30	0.8	5.50	82.6	1.35	6.1
t_2	s_1	0.05	0.06	0.05	21	10	51.8	1.2	5.08	82.2	1.25	5.8
	s_2	0.08	0.09	0.09	32	14	34.5	1.6	5.25	76.5	2.01	5.4
	s_3	0.05	0.06	0.06	20	11	32	1.4	5.48	85.0	1.59	6.5
t_3	s_1	0.07	0.06	0.05	21	10	52.8	1.0	5.02	82	1.85	6.2
	s_2	0.10	0.09	0.08	33	13	32.5	1.5	6.25	78	2.30	5.9
	s_3	0.06	0.07	0.07	19	12	30	1.2	5.88	83	1.50	6.5
t_4	s_1	0.08	0.07	0.05	20	10	41.8	1.2	5.02	82	1.72	5.6
	s_2	0.09	0.10	0.09	29	14	42.5	1.3	5.25	76	2.30	4.7
	s_3	0.08	0.06	0.08	19	10	32	1.1	5.88	84	1.35	5.8
t_5	s_1	0.08	0.07	0.09	25	12	58	0.8	4.84	77.9	1.19	5.8
	s_2	0.09	0.07	0.09	24	12	59	0.7	5.04	80	1.98	5.7
	s_3	0.09	0.08	0.07	25	12	60	0.8	5.84	79	1.28	5.5

Firstly, standardize the data and use AHP to calculate the weights (normalized)

$$w' = (0.089, 0.183, 0.049, 0.156, 0.104, 0.140, 0.07, 0.09, 0.055, 0.029\ 0.036)$$

Then we can get the weighted time series database $x'_{ij}(t_k)$ by using Eq. (1). The objective weight vector is calculated by Matlab based on Eq. (4)

$$w = (0.113, 0.251, 0.081, 0.242, 0.177, 0.004, 0.055, 0.029, 0.004, 0.040, 0.004)$$

So we get $y_i(t_k)$ by using Eq. (5). Let $\lambda = 0.3$ by attaching more importance to the recent data. The time weighting vector $v = (0.04, 0.12, 0.2, 0.28, 0.36)$ is obtained based on Eq. (6). The assessment results are shown in Table 4 by the expansion without affecting the ranking. From the results, we see s_1 is the optimal.

Table 4. Alternative value table

	t_1	t_2	t_3	t_4	t_5	Comprehensive value	Capability ranking
s_1	11.72	10.44	10.07	9.18	6.85	8.77	1
s_2	2.63	1.84	1.58	1.60	6.83	3.55	3
s_3	11.12	9.98	8.58	9.94	5.72	8.20	2

5.2 Results Analysis

1. The dynamic assessment method proposed considers both the references of decision makes and the impact of objective data. The weights at different time are consistent, so we can compare the capabilities of alternatives at the same time from the horizontal and get the capability trends with time from the vertical. The capabilities of three alternatives are shown in Fig. 2. We can know that s_1 is on the decline but it is optimal overall.s_2 improves much at t_5. Finding out the possible causes of the improvement can provide guidance for improving capability.
2. The proposed dynamic assessment method is based on the time series data. If the data are updated, the weights change correspondingly. So it effectively follows the dynamics of manufacturing process. The weight vector of each time can be calculated by Matlab within seconds for one time, so it has less computation.
3. From w, we can know x_2 and x_4 are the key factors of capability. More attention should be attached to them to improve the sustainable manufacturing capability.
4. The time-value factor λ can affect the comprehensive assessment value. Take λ as 0, 0.2, 0.4, 0.6, 0.8, and 1 respectively, the corresponding capabilities are shown in Fig. 3. How to adjust the time-value coefficients to forecast the capability of machining system at next time is the next research content.

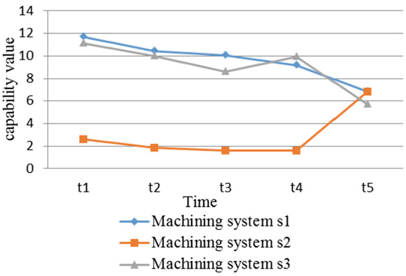

Fig. 2. Trend of capability for alternatives

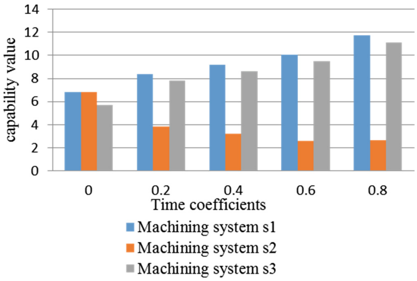

Fig. 3. The capabilities of different λ

6 Conclusion

This paper focuses on the dynamic assessment of sustainable manufacturing capability for CNC machining systems. A set of indicators system is established from quality, time, cost, resource consumption and environmental impacts. Then a dynamic assessment method based on “vertical and horizontal” method and AHP considering “time-value coefficients" is proposed to assess the capability dynamically and effectively. Its application in a case study verified its advantages and effectiveness. The dynamic assessment model is also applicable to other dynamic decision making problems, such as economic decision-making, performance assessment of systems, etc.

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Protecting Intellectual Property in a Cloud Manufacturing Environment: Requirements and Strategies

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Abstract. In today's knowledge economy, intangible knowledge assets have become the key drivers of organisational success. Protection of intellectual properties for all parties is a challenging issue in cloud manufacturing environment. This paper focuses on the protection of intellectual property in the cloud manufacturing environment. Several strategies for protecting intellectual properties are proposed in this paper. In addition, a privacy enhanced business interaction mechanism is presented. Furthermore, this paper discusses some practical technologies in the cloud context.

Keywords: Cloud manufacturing · Intellectual property protection · Security policy

1 Introduction

In recent years, cloud manufacturing has been regarded as a novel way of organising fast collaborative product development [1]. Cloud manufacturing is a service-oriented business model, whereby distributed manufacturing resources are encapsulated as consumable services over the Web [2]. This business model is anticipated to bring unique opportunities; it turns a capital investment model (of a typical manufacturing business) into a recurring expenditure model. In the ever-increasing distributed, networked and crowd-sourced cloud environment, the protection of intellectual property (IP) is a critical challenge.

World Intellectual Property Organisation (WIPO) [3] gave the definition of intellectual property as "inventions, literary and artistic work, symbols, names, images, and designs used in commerce." IP contains two categories [3]: industrial property and copyright, both of which can be represented by intangible proprietary information. In cloud manufacturing environment, IP refers to the confidential information (product design, process, etc.) of industrial design and manufacturing. Therefore, the main objective of IP protection is to prevent leakage of confidential information in cloud manufacturing environment.

One of the prerequisites for cloud manufacturing is to share product information, which is the core IP of some businesses. Therefore, it is very likely that participants will face a dilemma in trying to balance protection of intellectual capital with the openness

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and information sharing needed to successfully carry out the joint tasks. To the best knowledge of authors, there has not been a satisfactory solution for protecting IP in cloud manufacturing environment, though some studies investigated the security [1, 4] and user privacy [2] issues.

This paper focuses on the protection of intellectual property in the cloud manufacturing environment. The emphasis is placed upon proposing a feasible mechanism to ensure the privacy of confidential information from service consumers and service providers. The reminder of this paper is organised as follows. The next section presents a brief discussion on the significance of IP protection in a cloud manufacturing environment and reviews related approaches reported in the literature. Section 3 proposes several strategies for maximum protection of IP from all parties in cloud manufacturing environment. Following these strategies, a privacy enhanced business process is also proposed. Section 4 further discusses the enabling technologies for IP protection. Section 5 summarises the outcomes of this research and discuss future trends.

2 Significance of IP Protection

The existing research on cloud manufacturing has recognised the significance of data security and user privacy in a cloud manufacturing environment. However, there is very little work on these aspects. This section summaries the significance of IP protection by analysing the pain point for each party in the cloud and reviews the existing approaches.

2.1 Requirements on IP Protection

In cloud manufacturing, there are two fundamental business roles, namely service consumers and service providers (Fig. 1). Consumers request manufacturing services from the cloud, whereas service providers receive orders or sub-orders from the cloud system by outsourcing resources [2].

Fig. 1. High-level business interactions in cloud manufacturing [2]

From the technical perspective, requests from service consumers should contain the specifications of a product design, which is often in a form of computer aid manufacture file (like .dxf file for 2D design and .asm file for 3D design). After a design file is uploaded to the cloud, it will be sent to potential service providers for assessment and then some of them will be selected as the service providers. This process inevitably discloses product design to unwanted parties in the cloud. On the other hand, intelligent cloud systems require manufacturing resources being connected to the cloud and production activities being monitored all the time. In addition, some of the proposed system frameworks even ask service providers to provide detailed machining operations to the cloud for simulation and cost estimation purposes. In fact, this is not a good practice for manufacturers. Knowledge on optimal machining processes is often regarded as intangible assets of a business. Storing this information on a remote server potentially put it at risk.

It has to be noted that the cloud manufacturing environment is a much more open environment than traditional PLM environment. In cloud manufacturing, model models, resource capability information and other business-critical information are all stored remotely in the cloud. For a manufacturing project, a global search and match process of task-service pairs is required to be carried out. In contrast, in the conventional PLM environment, there is a clear closed boundary for product data and knowledge exchange.

In summary, the requirements around IP protection in cloud manufacturing can be extracted as follows:

1. Complete product designs can only be seen by authorised users.
2. Complete product designs can only be visible to confirmed service providers.
3. Only a minimum amount of data should be sent to relevant service providers.
4. Exclusive know-how about manufacturing resources should not be visible to service consumers.

These basic requirements should be taken as ground rules when designing a manufacturing cloud.

2.2 Approaches to Achieving Data Security and IP Protection

Data security is one of the bottlenecks that hinders the application of cloud manufacturing [2]. The security and privacy management in cloud manufacturing environment is still in the early stage. This is because things are more complicated in cloud manufacturing environment. Xu [1] point out that manufacturers are more concerned about the confidentiality and privacy of their data.

Lu et al. [2] discussed the importance of authorisation mechanisms for resource access in cloud environment. Resource sharing in cloud manufacturing is conditional: each service provider makes resources available, subject to constraints on who, when, where and what can be done. Access policies change dynamically over time, in terms of the resources involved, the nature of the access permitted, and the participants to whom access is available. A semantic web-based approach is proposed for setting resource access policies. By defining unique sharing policies for each manufacturing resource, enhanced privacy can be achieved as only authorised users can have access to a service in the cloud.

Kim et al. [5] proposed a multi-level modelling technique based on feature-based modelling and mesh simplification to enable information protection in computer-aided collaborative design. The techniques are integrated with an access control mechanism to enable role-based user authorization. In a more recent research, Deng et al. [6] proposed an original approach to decompose product structures for the purpose of controlling IP leakage risk in supply chains using design structure matrix.

Following the notion of information partition in collaborative environment, Wang and Xu [7] proposed a product data exchange mechanism based on STEP/STEP-NC data models to provide information with the right level of detail to partners in a supply chain. In this mechanism, data extracting algorithms were developed to generate data packets.

3 IP Protection Strategies for Cloud-Based Business Interaction

This section discusses the overall strategy for preventing IP leakage in a cloud-based environment. As this is a new topic in cloud manufacturing research, we first present some general rules for protecting IP and then examine how rational business processes can enhance data confidentiality.

3.1 Rules of Thumb for Protecting IP in Cloud Environment

As mentioned earlier, service consumers send product designs to the cloud for matched manufacturers. This process can potentially put product designs at risk. Similarly, service providers need to detail the capability of manufacturing resources, which can disclose manufacturing know-how to other parties. In addition to diffusing critical knowledge, the open environment may allow a partner a window to gauge the strengths, weaknesses, and strategic orientation of its competitors, providing advantages in future competition with them. Therefore, this issue put service consumers and service providers in a dilemma in trying to balance protection of intellectual capital with the openness and information sharing needed to successfully carry out the product development tasks.

In terms of approaches to securing intellectual property, the most common strategy is the trusted-entry approach. This approach only works well for the first tier of trusted partners; the control of document is lost as the production activities move farther to multiple tiers of suppliers. Nevertheless, there are still some general rules to follow in complex engineering environments, especially in cloud manufacturing environment.

It is best to share as little information as possible for all the parties in cloud manufacturing. This means for service consumers, it is better to outsource only peripheral items, keeping all core IP at home. Even for a product design, it is not necessary to share all the details with manufacturers at the bid point. Only a simplified version of the product manufacturing information is required for potential manufacturers to tell if they are able to take the job. For service consumers, they only share a minimum amount of information for resource description and service monitoring. The detailed manufacturing processes for a task cannot be disclosed to other parties.

A second strategy is to break up the IP – not giving all of it to any one business entity, which is especially critical for service consumers. In other words, a cloud manufacturing system should balance the centralisation of manufacturing activities with the separation of whole IP into multiple pieces. The optimal scenario is to let a contract manufacturer see one part of the overall design and give it only the information needed to do the job.

3.2 Privacy Enhanced Business Process in Cloud Environment

Following the above strategies, we highlighted the critical business processes requiring special attention on IP protection in cloud manufacturing as in the following UML sequential diagram (Fig. 2). This business process is a simplified version of the business interaction process in [2].

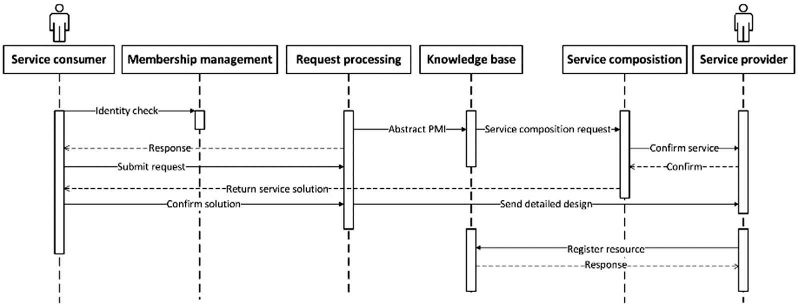

Fig. 2. Simplified business process in cloud manufacturing environment

A typical service provision process is as follows. A service consumer submit a service request to the cloud by uploading a customised design file. This design file is often in a computer-aided manufacturing file, such as .dxf file, .step file and .asam file. During this process, the membership management module checks the identity of the service consumer before sending a request to the request processing module. The request processing module provides a comprehensive analysis for service requests by comparing new service request with historical data. The manufacturability of a service request is assessed in this process, and thereafter a response is sent back the service consumer. If a service request passes the assessment process, the PMI (Product Manufacturing Information) parser in this module is triggered to convert the product information in user-uploaded file into a simplified PMI file following an abstract product data model. This process is critical to the protection of product designs as only abstract PMI information is extracted for down-stream decision-making processes. This abstract file only contains a small portion of the original product data that is enough for manufacturing resource selection. Once this PMI file is generated, it will be sent to the knowledge base for resource searching and matching. When feasible manufacturing resources are outputted, the service composition module goes through all the possible combinations of service units and the best solutions are send to the service consumer for reviewing. Once the service consumer confirms the final decision, the detailed product designs will be passed to participated service providers for service provision. It has to be noted that in this process, only the right amount of information will be send to service providers. The data a service provider receives is only enough for processing the anticipated tasks. On the other hand, a service provider updates available manufacturing resources in the knowledge base by changing their physical descriptions and working schedule. Manufacturing know-how regarding a specific manufacturing resource is not part of the required descriptive information.

4 Enabling Technologies for IP Protection

The business processes in Fig. 2 reveal that there are at least two technological challenges to be addressed for protecting intellectual properties in the cloud environment. These challenges are (1) developing a unified data model to represent abstract PMI information, and (2) developing a unified scheme for representing manufacturing resources without disclosing detailed manufacturing process for each resource.

4.1 Data Model for Simplification of Product Design

The most straightforward approach for protecting IP in a product design is to hide the detailed geometrical information in a design. Feature-based approach can be a potential solution. Feature technology is integral to the integration of CAD/CAM. This is because almost all CAPP systems function on the basis of features. One critical step in process planning is to covert a geometric model of lower-level entities (lines, points, etc.) into a feature based model of higher-level entities (holes, pockets, etc.). Hence, there is a need to develop a description model for all the manufacturing features. Parameters on all the machining features of a product are the main data that are required for selecting the right manufacturing resources. This means a mechanical part is described as a combination of a list of elementary machining features. For each of the machining features, the required attributes are the information merely sufficient for determining feasible manufacturing resources that can be used to carry out the required machining process. This approach potentially reveals little information about the geometry of a part.

Manufacturing features can be classified by means of manufacturing processes, namely milling feature, turning feature, and holemaking feature. There are several machining features under each category. For example, milling features include pocket, slot, planar surface, chamfer, etc. (Fig. 3).

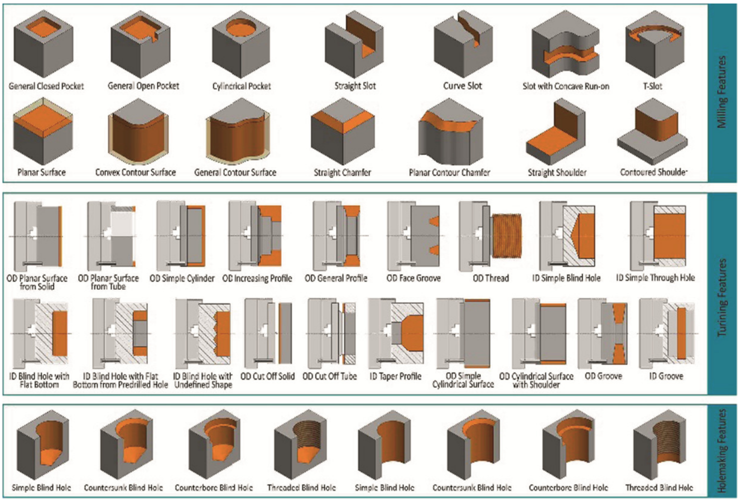

Fig. 3. Classification of machining features

Feature-based product description creates a way of meta-data modelling for service requests. It has to be noted that the feature-based approach introduced in this paper is different from the feature-based approaches used in commercial CAPP systems or STEP-NC data format. In STEP-NC file, features are still in geometrical representation. For instance, for the feature of General outside profile, the contour of the spare is given by the attribute feature_boundary, which is a type of profile. This means the detailed shape of a profile is still given in a STEP-NC file. In contrast, in the meta-data model the definition of a profile only pays attention to the minimum radius in the concave corner, which is one of the critical attributes for selecting feasible cutters. Figure 4 gives an overview of the level of detail for three different data description methods. CAD files contain all the details of a product design. STEP-NC file simplifies the product design, neglecting the detailed geometry of an overall workpiece and some geometry information of some features. This could compress a CAD file to 80 % of its original volume. If these machining features are further simplified as only providing the key information for selecting manufacturing resources, the whole file can be compressed down to 50 % of its original volume. In this way, most of the geometrical information of a product design is removed, and the associated core IP is protected.

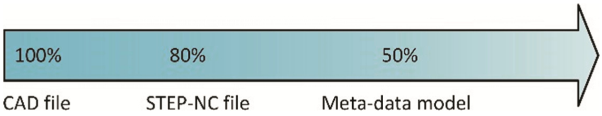

Fig. 4. Level of details for different data description methods

4.2 Description Framework for Resource Virtualisation

Protecting the IP associated with a manufacturing resource is equivalently important. One feasible approach is to exclude manufacturing know-how and detailed manufacturing process as part of the description model. The description of a manufacturing resource should include its technical properties and functional capabilities. Take CNC milling machine as an example. Technical properties include its manufacturer, manufacturer instructions, machining envelope, control system, maximum spindle speed, mass, etc., whereas functional capabilities include planar face milling, 3D free-form surface milling, drilling, boring, pocketing, etc. These data should be all the information for describing a manufacturing resource.

5 Conclusions

Intellectual property protection is critical to business success in cloud manufacturing environment. This paper analysed the requirements of intellectual property protection in cloud manufacturing environment and proposed some strategies for preventing IP leakage. Furthermore, several technological approaches were proposed for implementing a privacy enhanced cloud manufacturing environment. In general, it is best to share as little information as possible for all the parties in cloud manufacturing. This means for service consumers, it is better to outsource only peripheral items, keeping all core IP at home. For a product design, only the information for selection of manufacturing resources can be disclosed at the bid point. For service consumers, they only share a minimum amount of information for resource description and service monitoring. A second strategy is to break up the IP – not giving all of it to any single business entity.

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A Modeling Framework for Resource Service Sharing in a Cloud Manufacturing System

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Abstract. Cloud manufacturing (CMfg) is a novel business paradigm with resource service (RS) sharing being one of the most important purposes. From the perspective of enterprise business interactions, how to achieve full RS sharing is an important research issue in CMfg as it plays a critical role in enhancing the performance and efficiency of a CMfg system. However, the research on CMfg RS sharing is challenged by the complexity of a CMfg system, mainly coming from the vast number of involved enterprises and their complex business interactions. In this paper, we propose a modeling framework for CMfg RS sharing by regarding a CMfg system as a complex system and elaborating the problem from the perspective of complex systems modeling and simulation. We summarize systematically the factors that need to be considered for building a system of CMfg RS sharing, which is followed by the modeling procedure.

Keywords: Cloud manufacturing · Complex system · Modeling framework · Resource service sharing

1 Introduction

CMfg is a new manufacturing business paradigm aiming to achieve large-scale resource service (RS) sharing and efficient enterprise collaboration [1,2]. The extent and effect of CMfg RS, which depend on both technological and business factors, to a great extent, determine the performance and efficiency of a CMfg system.

CMfg, through building a common platform and the aggregation of large-scale manufacturing services, provides an excellent support for RS sharing. Through the CMfg platform, any two enterprises can establish business relations and share resources and services. In addition, CMfg provides a good support for various forms of enterprise collaboration (such as random one-off trades, virtual enterprise, extended enterprise) through building a flexible service sequence.

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Hence, a CMfg system is a highly dynamic system with constantly changing cooperation relationship between enterprises. More importantly, each enterprise is an adaptive entity in terms of the adaptive decision-making on RS sharing according to internal (e.g., resource utilization, revenue) and external conditions (e.g., supply and demand of resources). All of those make a CMfg system a complex adaptive system.

Currently, there is rare work on CMfg RS sharing and the related research is far from enough in revealing CMfg RS sharing methods and mechanisms. In this aspect, complex systems modeling and simulation provide an effective means. Though building a quantitative mathematical model of CMfg RS sharing, we can simulate the RS sharing process systematically and accurately. In this paper, we propose a modeling framework for CMfg RS sharing by comprehensively summarizing the relevant factors, and presenting the modeling procedure.

2 Literature Review

Li et al. [1] first systematically proposed the concept of CMfg. Thereafter, CMfg received much attention from researchers and practitioners. He and Xu [3] provided a comprehensive summary of existing architecture and frameworks of CMfg, as well as the latest research advancement on CMfg key technologies and service management. Xu [4] suggested two types of cloud computing adoptions in the manufacturing sector, manufacturing with direct adoption of cloud computing technologies and CMfg. Tao et al. [5] studied utility modeling, equilibrium and coordination of demanders, providers and an operator. Tai et al. [6] analyzed the issue of CMfg enterprise cooperation. Cloud service trading model and trading flow [7] have also been investigated.

Resource, capability and demand sharing, enterprise collaboration, enterprise network as important research issues have been studied. Renna and Argoneto [8] proposed a game theory coordination mechanism for the capability sharing in a network of independent plants. Yoon and Nof [9] addressed the demand and capability sharing issue in a collaborative network of independent enterprises. Two collaboration modes, i.e., partial collaboration and complete collaboration have been comparatively studied. Argoneto and Renna [10] investigated capacity sharing in CMfg by proposing a framework for capability sharing in CMfg. Moghaddam and Nof [11] investigated the demand and capability sharing issue in a collaborative network of independent enterprises with dynamic best matching of supply enterprises and customers. Jagdev and Thoben [12] discussed enterprise collaborations, identified the key types of collaborations (supply chain, extended enterprise and virtual enterprise), and analyzed their essential attributes and operational characteristics. By carefully analyzing all the work above, it is not hard to find that resource and service sharing and enterprise collaboration taking the form of networks are the key for enterprises to stay competitive when confronting constantly changing market environment and customers' demands.

On the other hand, simulation has been widely adopted in manufacturing system design, operation, and simulation language/package development [13].

Cicirelli et al. [14] studied modeling and simulation of complex manufacturing systems using statechart-based actors. Fowler and Rose [15] presented the challenges in modeling and simulation of complex manufacturing systems.

3 Relevant Factors for Building a System of CMfg RS Sharing

In this section, we present the factors that are relevant for modeling a system of CMfg RS sharing, as shown in Fig. 1. According to the modeling requirements, the factors can be divided into five groups. (1) Enterprise-related factors. Because resource service sharing occurs among enterprises, it is natural and essential to consider the enterprise-related factors, which fall into three categories, resource service-related factors, utility or profit-related factors and other factors that do not belong to the previous two categories. (2) External order or market demand-related factors. Resource service sharing among enterprises occurs in the course of fulfilling requirement tasks. (3) Business relationship-related factors. We consider them as a separate category because they do not belong to any enterprise.

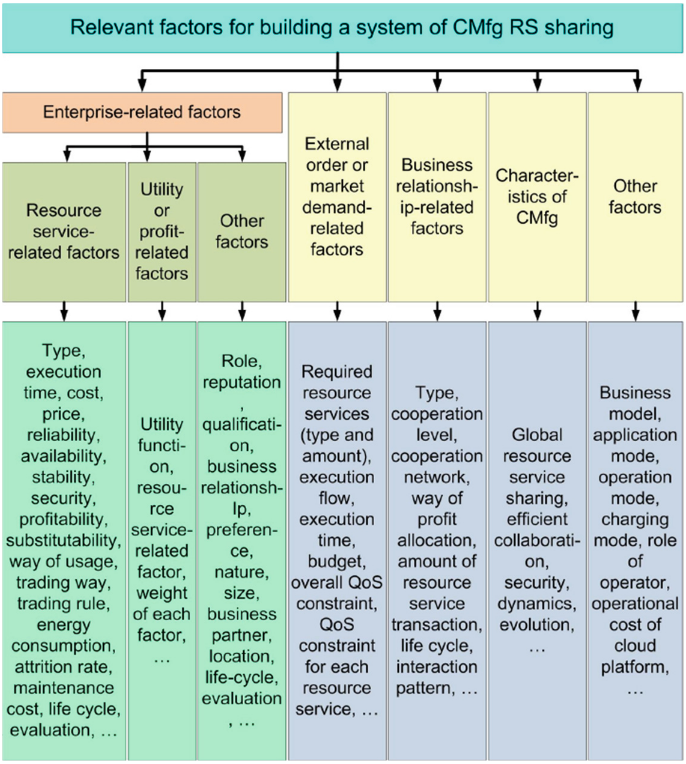

Fig. 1. Relevant factors for building a system of CMfg RS sharing

Different business relationships between enterprises can have different impacts on resource service sharing. (4) Characteristics of CMfg. The typical characteristics of CMfg that can influence resource service sharing should be considered. (5) Other factors. They are usually the macroscopic factors (such as business model and application mode) that need to be taken into account.

4 Modeling Procedure for a System of CMfg RS Sharing

This section describes the modeling procedure for a CMfg RS sharing system in detail (Fig. 2).

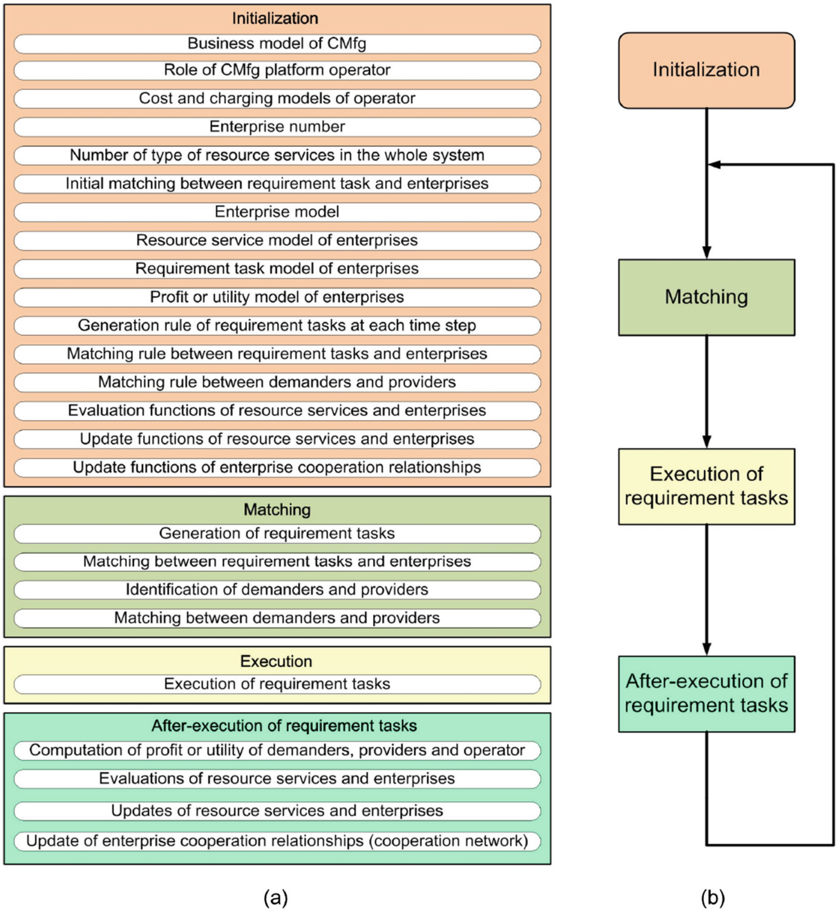

Fig. 2. (a) Activities in each procedure and (b) modeling procedure

4.1 Initialization

Much initialization work is needed, as shown in Fig. 2. First, we need to deal with the business model. CMfg supports various business models such as general RS exchange, virtual enterprise, extended enterprise. Because in this paper, we focus on RS sharing among enterprises, and thus the business model is business-to-business (B2B). For the operator, apart from providing functional services to both demanders and providers (as an intermediary), it can even provide manufacturing services (as a provider). CMfg has some operational cost, and thus needs to charge enterprises to maintain the operation of the CMfg platform. The point here is to determine the billing functions according to the overall cost.

In order to acquire reliable research results, there should be a huge number of enterprises in a system of CMfg RS sharing. Building a model with a very small number of enterprises may result in erroneous results. For example, if the number is small, the essence of enterprise cooperation network (such as structure and dynamics) cannot be well captured. It is also an important problem as to whether consider the type of RSs. It is a common practice to assume several abstract types of RSs or just ignore it when RS type is not critical for research results.

Building a proper enterprise model is crucial for the success of building a system of CMfg RS sharing. We can assume that each enterprise has several types of RSs. For each RS, attributes such as cost, price, execution period, reliability and availability should be considered. In addition, an enterprise can also have one or several RTs. Each RT requires one or several types of RSs. For RTs, we can either explicitly consider the execution flow or ignor it when the execution flow does not essentially influence research results. Each RT also has an execution period, which can be set randomly or computed according to the required RSs and the execution flow. The budget of a RT as a constraint for selecting suitable RSs should also be considered.

Utility or profit as an important driving factor for RS sharing is also very critical. In CMfg, an enterprise can obtain some utility or profit by fulfilling a RT, alone or cooperatively. Profit is usually related to price and production cost, while utility can comprehensively describe the extent of satisfaction of an enterprise. For profit, we need to specify production cost and RS price, while utility, we need to determine the factors concerned (Fig. 1) and then design a utility function.

In this paper, we assume the periodic business interactions among enterprises, which are driven by periodic RTs. Hence, how to generate RTs at each time step is an important issue. The number of RTs and the total amount of required RSs need to be considered. The following approach provides a feasible solution. At each time step, Np_t RTs are generated, where $0 < p_t \leq 1$ is a probability used for governing RT density, and N is the number of enterprises in a CMfg system.

After the generation of RTs, the next step is to properly allocate them to the enterprises involved. In the real world, an enterprise which brings a higher utility to customers can win orders. Hence, the RT allocation is actually a process of preferential selection of the enterprises with high-quality RSs. The key is how to determine the related factors and the selection function.

RS supply-demand matching is a core issue in this modeling framework. Because in CMfg, there are a very large number of demanders and providers submitting their requests and idle RSs simultaneously, it is a typical many-to-many matching problem. A successful matching depends on: (1) characteristics of RSs. RS type, cost, price, QoS (including reliability, availability, etc.) can affect the mutual selection between demanders and providers. (2) decision-making on RS sharing. In CMfg, an enterprise can choose to host a RT or participate in the RTs hosted by other enterprises. For a provider, hosting a RT is always preferable. However, when there is no RT, sharing the idle RS with the demanders can be profitable, which, however, decreases the likelihood for hosting a RT in the future (which usually is more profitable). In this case, the careful decision-making as to whether or how many RSs are shared is needed. (3) matching algorithm. There are primarily two solutions: developing a parallel algorithm to deal with all requirements simultaneously or adopting a serial algorithm that deal with the requirement successively. The former endows each enterprise with equal chance to access the RSs while in the latter case, the chance is different. Whatever the algorithm, the matching between demanders and providers is a mutual selection process. (4) RS transaction rule. It mainly refers to the self-defined rules by enterprises for the owned RSs. For example, a demander may have a specific requirement as to the required RSs in terms of QoS, price and location. (5) RS transaction manner. The real RS transaction process may take many forms, including negotiation, auction, etc. Game theory can be a powerful theoretical tool for the matching between demanders and providers [8,10].

In order to foster an open and fair transaction environment, evaluation (including RS evaluation and enterprise evaluation) is essential. The key is to design proper evaluation functions. In CMfg, RSs and enterprises dynamical change over time [16]. The former includes improvement of RS QoS, elimination of RSs, generation of new RSs, etc., while the latter includes enterprise expansion, downsizing, elimination and generation, etc. For the process of RS or enterprise elimination, the key is to build a mathematical function, especially the function relation between maintenance (operation) cost and profit of RSs (enterprises). For the process of improving RS quality or purchasing new RSs, the key is to determine the function relation between RS improvement or purchasing cost and the investment. With the development of a CMfg system, based on the transaction of RSs, an enterprise cooperation network can be formed which evolves over time. Hence, the update includes the addition of new cooperation relationship, increase of cooperation weight, update of the amount of traded RSs, update of cooperation level and so forth. Complex network provides an effective approach for modeling the enterprise cooperation network [17].

4.2 Matching

There are two types of matching: matching between RTs and enterprises, and matching between providers and demanders. First, we need to generate RTs according to the generation rule, and then allocate them to enterprises. At this moment, some enterprises may have insufficient RS to fulfill their RT while others with few or no RTs have excess RSs. The former are referred to as demanders while the latter providers. Though sharing RTs and RSs, both demanders and providers can have a higher profit. The next step is to match demanders with providers according to the pre-defined matching algorithm. After matching, enterprises fulfill their RTs collaboratively.

4.3 After-Execution of RTs

At the end of each time step, a certain RTs will be completed. At this moment, each enterprise computes its profit or utility based on the profit or utility function. The operator also computes its profit or utility. At the same time, demanders evaluate the shared RSs and demanders and providers can also mutually evaluate. A CMfg system may also have an evaluation system. Finally, an enterprise may also improve their RSs or eliminate the inferior RSs, whose maintenance cost is higher than the profit they bring. The enterprises that cannot make profits may also be eliminated from the system. According to the RS transaction, enterprises update their cooperation relationship, which can have important influence on future business interactions (e.g., partner selection).

5 Conclusions

In this paper, we propose a modeling framework for RS sharing in CMfg. The relevant factors are systematically summarized, and the procedure for modeling a system of CMfg RS sharing is presented.

RS sharing is one of the most important purposes of CMfg, which determines the performance and efficiency of a CMfg system. Hence, the research on methods and mechanisms of CMfg resource service sharing is significant, which, however, is challenged by the complexity of a CMfg system. In this regard, complex systems modeling and simulation provide a feasible and effective means. In order to apply this approach, we need to first find out the influencing factors for modeling a CMfg RS sharing system, as well as the basic modeling procedure. However, so far, there is no work directly dealing with such an important research issue. The current work, to some extent, bridges this gap and thus can provide some guidance for the future research on CMfg RS sharing.

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Integrate Product Planning Process of OKP Companies in the Cloud Manufacturing Environment

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Abstract. In today's competitive market, OKP companies operate in the "engineer-to-order" business mode, whereby analysing the "voice of customer" promptly and accurately in the early design stage determines the success of product development. However, OKP companies have limited resources. They may not be able to afford the cost of the complicated Quality Function Deployment (QFD) product planning process, nor can they obtain abundant CRs information effectively in traditional internet-based environment. This paper proposes a QFD-based approach in the cloud manufacturing (CMfg) environment to enhance OKP companies' product planning process. CMfg (a newly emerged manufacturing paradigm) utilizes advanced information technologies and business mode, which may provide sufficient and cost-effective resources to OKP companies. The interaction process among different cloud service roles is introduced in detail, which contains six main parts: pre-process, identify CRs, competitive marketing analysis, determine final importance ratings, mapping CRs to engineering characteristics (ECs), and customer-centric decision making.

Keywords: One-of-a-kind production · Cloud manufacturing · Product planning · Quality function deployment

1 Introduction

One-of-a-Kind Production (OKP) companies aim to produce customized products based on the requirements of individual customer while maintaining the quality and efficiency of mass production [1]. Analysing customer requirements (CRs) accurately and effectively in the product planning stage is critical for the survival of an OKP company [2]. Quality function deployment (QFD), introduced by Akao [3], provides a systematic way (named House of Quality (HoQ)) to catalogue the perceived CRs and to translate them into engineering characteristics (ECs) in the product planning stage. However, OKP companies are mostly Small or Medium sized Enterprises (SMEs), they might not afford the high cost of complicated QFD process, nor can they obtain sufficient customer information effectively in the web-based environment [4].

This paper proposes a QFD-based approach to enhance OKP companies' product planning process in the CMfg environment. For OKP companies, one key benefit of CMfg is the "pay-per-use" mode. They can pay a periodic subscription or utilization fee

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with minimal upfront costs [5], which they may either out sourcing the QFD product planning process to a team of experts or utilizing online software-as-a-service (SaaS) to deal with it in an cost-effective way. Another key benefit is the utilization of cloud-computing information technology. OKP companies may get abundant product planning resources from multiple sources such as social media (e.g. Facebook), crowdsourcing, resource pooling and etc. [6]. The rest of the paper is organized as follows. Section 2 provides a review of cloud manufacturing aspect and QFD-based product planning. Section 3 proposes the QFD-based product planning interaction process of OKP companies in the CMfg environment. Section 4 summarizes the main work of this paper and the future work.

2 Literature Review

2.1 Cloud Manufacturing

Cloud manufacturing is a newly emerged manufacturing paradigm, Li et al. [7] defined it as a computing and service-oriented manufacturing model developed from the existing advanced manufacturing models and information technologies. It aims to realize a full-scale sharing and circulation, high utilization, and on-demand use of various manufacturing resources and capabilities by providing safe and reliable, high quality, cheap and on-demand used manufacturing services for the whole lifecycle of manufacturing [8]. Though there is not a standard definition for CMfg, most of the current definitions share some common traces, such as manufacturing resource, capability, services and platform [6, 7, 9, 10]. The main characteristics of CMfg include on-demand, self-service, ubiquitous network access, rapid scalability, resource pooling, and virtualization [6]. With the cloud approach, there is little need for enterprises to make capital investments in manufacturing equipment, or even recruiting engineer experts. Instead, they have the flexibility to manage their own businesses, and could have instant access to business solutions on “pay-per-use” [5]. Though much work has been done in the CMfg area, there is no emphasis on the product planning stage.

2.2 QFD-Based Product Planning

Quality function deployment (QFD), introduced by Akao [3], has been a widely adopted customer-oriented methodology in assisting product development process. It provides a systematic way to catalogue the perceived needs of the customer and to translate them into design specifications, all over product planning, product design, process design, and production planning [11]. The key element of QFD is a combined chart of HoQ to map the CRs (the ‘WHATs’) into ECs (the ‘HOWs’) that must be adjusted to fulfill the customer needs in product planning stage, and subsequently into parts characteristics, process plans, and manufacture operations [12]. In general, QFD-based product planning contains four steps: (1) identify CRs; (2) conduct competitive analysis; (3) determine final importance ratings of CRs; (4) map CRs into ECs.

3 QFD-Based Product Planning Interaction Process in the CMfg

In the CMfg environment, the proposed QFD-based approach of product planning interaction process is shown in Fig. 1. Cloud service infrastructure provider, as a third-party provider, hosts virtualized computing resources over the Internet; Cloud service platform provider, is a third-party provides a platform allowing service provider and demander to develop, run and manage Web applications without building and maintaining the infrastructure; Cloud service provider, is an entity that provides services in the cloud service platform; Cloud service demander, is an entity that consumes services offered by the cloud service provider. OKP companies, acting as the service providers, are integrated intelligently in this distributed environment through cloud-based platform system with graphical user interfaces (GUIs). Thus, there is a big reduction of investment on the up-front costs. The proposed process includes six main parts and each part contains several steps, which is introduced as follows.

3.1 Pre-process

Users request their cloud services (Step 1). If uncertain about their request, they first interact with the infrastructure provider. It offers the search engine with abundant storage of data for them to narrow down their request scope (Step 2). After searching, the infrastructure provider retrieves the historical information with a list of potential platform providers (Step 3) for users to select a proper one according to their preferences (Step 4). However, if they are capable, they may skip the Step 2 to Step 4, and directly interact with the specific platform provider.

Then, the platform provider would be responsible for assessing customer requests through the process of request acquisition (Step 5), request retrieval (Step 6) and request allocation (Step 7 and 8) [5]. The request acquisition is responsible for capturing and deriving useful user information by online inquiry and quoting. Request retrieval is carried out based on the historical design information stored in the service database so at to find out the feasible service providers (known as “service composition”) [10]. This process helps enhance resource allocation by modifying unreasonable service requirements to those that the system is able to undertake. Therefore, system efficiency is enhanced and service quality is guaranteed. Request allocation is conducted after comparing the initial service requirements with the design capabilities of the product design resources in the system. User requests are allocated intelligently to the prospective service providers according to the selection of the users.

3.2 Identify CRs

In order to satisfy customer needs and gain profits, OKP companies need to take considerable efforts to identify and acquire CRs effectively (Step 9 and Step 10). There are many methods available to collect CR candidates, including focus group, individual interviews, listening and watching, complaints, natural field contact, warranty data, feedback, affinity diagram, and cluster analysis [13]. Then customers are asked to express their perceptions on each CR, as the fundamental importance ratings of CRs. Due to the cloud-based environment, OKP companies may get sufficient CRs information through resource pooling, crowd sourcing, social media and etc.

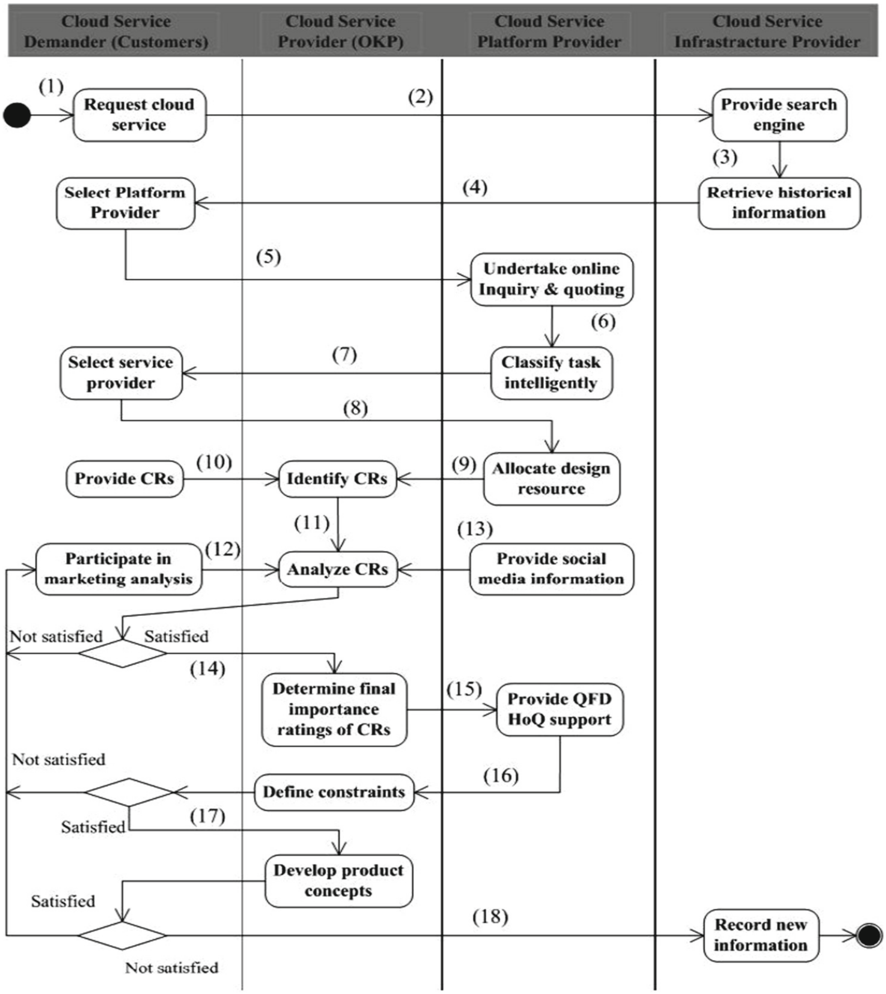

Fig. 1. Product planning interaction process in CMfg

3.3 Undertake Competitive Marketing Analysis

Due to the networked environment, both marketing analysts and customers can easily participate in the marketing analysis process through GUIs (Step 12). The platform provider could offer related design information by social media (Step 13), such as competitors' information, customer view histories and etc.

The competitive marketing analysis of CRs (Step 11) can generally be obtained by analyzing relative performance estimations of a corporation and its competitors from customers' perceptions. It utilizes entropy method to obtain the competitive priority ratings of CRs [14]. Then, the improvement factors of CRs will be estimated by the engineers in five perspectives: financial, customer, internal-business processes, learning and growth, and feasibility in a qualitative and quantitative way [13].

3.4 Determine Final Importance Ratings of CRs

In order to determine the final importance ratings of CRs (Step 14), conjoint analysis [15] is widely utilized. Also, to deal with the imprecise information of CRs, both fuzzy set based methods and rough set based methods are introduced to quantify the subjective information, such as fuzzy AHP [16], fuzzy weighted average [17] and rough number method [18]. They can be implemented in the cloud environment as a SaaS for OKP companies to purchase in a "pay-per-use" mode.

3.5 Map CRs into ECs

After Step 14, designers can map CRs into ECs, and transfer the final importance ratings of CRs into importance ratings of ECs by QFD product planning HoQ, which is supported by the platform provider with a team of experts (Step 15). OKP companies may either choose to out sourcing the complicated QFD process or inquire experts with specific knowledge. Accordingly, designers define the constraints of ECs (Step 16) and develop product concepts (Step 17) to customers' satisfaction. Finally, new design information is stored in the cloud server for knowledge re-uses (Step 18).

3.6 Customer-Centric Decision Making

Customers need to make their own decisions along the interaction process, i.e.: perceptions towards the CRs (Step 10), fundamental importance ratings of CRs (Step 12), marketing analysis results of CRs (Step 14), the prospective ECs (Step 16), and the design concepts (Step 17). Each step needs to be satisfied by the customers through online negotiations [19]; otherwise, the analysis process needs to be re-conducted from the step of providing and identifying CRs (Step 9 and Step 10).

The above interaction process improves the response speed by connecting customers and service providers in the cloud-based platform collaboratively. Thus, resources can be efficiently utilized by them, which enhance business performance. Also, cloud service platform provider provides online SaaS and social media to support the QFD HoQ while OKP companies only need to pay-per-use. It effectively overcomes their shortage of limited resources, and reduces the cost of complicated product planning.

4 Discussions

Aiming to enhance the OKP company product planning process, this paper proposed a QFD-based approach to integrate it in the CMfg environment. The approach took advantage the advanced CMfg technologies, which overcomes the challenge of achieving sufficient customer information by utilizing resource pooling, crowd sourcing and social media in the networked environment. Also, it shows how to undertake complicated systematic QFD-based product planning in a cost-effective way by out sourcing the service or utilizing online SaaS and inquire experts in a "pay-per-use" mode. Moreover, the QFD-based interaction process among customers, OKP companies, platform providers and infrastructure providers was introduced in detail, which provided the guidelines for OKP companies to be involved in the CMfg environment. In the future, the proposed approach will be developed with a system framework and a software implementation to facilitate OKP companies' product planning process in the CMfg environment.

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Big Data Based Analysis Framework for Product Manufacturing and Maintenance Process

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Abstract. With the widely use of smart sensor devices in the product lifecycle management (PLM), it creates amount of real-time and muti-source lifecycle big data. These data allow decision makers to make better-informed PLM decisions. In this article, an overview framework of big data based analysis for product lifecycle (BDA-PL) was presented to provide a new paradigm by extending the techniques of Internet of Things (IoT) and big data analysis to manufacturing field. Under this framework, the real-time lifecycle data of products can be active perception and collection. Considering the challenges of processing the lifecycle big data into useful information and exchange it among various lifecycle phase, a graphical model of big data mining was designed to achieve knowledge discovery. Finally, a case has been used to illustrate the proof-of-concept application of the proposed BDA-PL.

Keywords: Product lifecycle · Manufacturing · Maintenance · Big data analysis · Data mining

1 Introduction

Complex product manufacturers have attempted to adopt Internet of Things (IoT) and big data analysis technologies for improving the efficiency of their PLM, and increasing company's profitability and reduce the consumption of products through establishing Product Service Systems (PSS).

Recent developments in wireless sensors and communication technologies have created a new era of the IoT [1]. At present, more and more manufacturing enterprises began to widespread use IoT technology to implement and manage their business. In PLM, IoT technology can give opportunities to access and manage product data and information over the whole lifecycle [2]. In order to apply the IoT to PLM, it needs several technologies related to product identification, sensors and wireless tele-communication. Jun et al. [3] introduces an overall framework for RFID applications in PLM. Xu et al. [4] focuses on the research of closed-loop product information tracking and feedback in wireless technology-enabled from the modeling point of view. Georgiadis and Athanasiou [5] studied predictive maintenance and remanufacturing application based on closed-loop PLM.

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With the widely use of IoT technology and smart sensor devices in PLM, it creates amount of real-time and muti-source lifecycle data. These data were high volume, high velocity and high variety, which belong to typical big data. It has been already caused people's extensive concern in economic, academia and manufacturing. In terms of manufacturing, big data analysis will significant impacts to product Research & Development (R&D), manufacturing, service improvement and recycling, etc. At the same time, it can also effectively promote the development of service-oriented manufacturing, green manufacturing (GM), sustainable production and consumption.

Big data research in manufacturing is still in its infancy in communication. McKinsey [6] published article "*How big data can improve manufacturing*". In-depth analysis of the issues in how big data and advanced analytics to make manufacturing more rationalization. Through the analysis of several cases, to illustrate how big data and advanced analysis applications to provide assistance for business decisions.

In modern manufacturing environments, vast amounts of data are collected in enterprise database from the whole lifecycle. Data mining has emerged as an important tool for knowledge acquisition from the manufacturing databases.

To discover unknown priority dispatching rules for the single machine scheduling problem, Bayesian algorithm are used to find hidden rules through large amounts of structured or unstructured data [7]. To address traditional performance evaluation problem of suppliers in the supply chain, Chen et al. [8] proposes an integrated model by combining K-means clustering, feature selection, and the decision tree method into a single evaluation model. Magro and Pinceti [9] presented a technique to improve the accuracy of the predictions using the rough set theory. Mavridou et al. [10] established a model applied neural network algorithm to identify bearing faults in wind turbines. Purarjomandlangrudi et al. [11] presented a data mining approach called anomaly detection to discriminate defect of rolling bearing failures.

From above literature review, main limitations can be summarized as following:

- Previous researches mainly focus on how to apply the IoT related techniques to one phase of the PLM, and the overall solution for the whole 2 lifecycle were seldom investigated.
- Little effort has been made to apply the solution of big data to manufacturing, especially to PLM or PSS. Lacking of overall system architecture of big data solution.
- Most data mining applications were only focus on one stage of whole lifecycle. Little effort has been made to data integration mining for the lifecycle.

By addressing the above limitations and questions, the research reported in this paper was concerned with big data based manufacturing applications specifically in manufacturing (including Research & Development and Manufacturing, RDM) and maintenance (including Operation and Maintenance, OM) process (hereinafter abbreviate as MMP) of product lifecycle. The focus was placed upon developing system architecture of the big data solution, and discussing the key technology related to the solution.

Several steps are taken. First, an overall framework of BDA-PL was proposed in Sect. 2. Second, key technology related to the framework was discussing in Sect. 3. An application case for axis compressor MMP was designed and demonstrated in Sect. 4. Conclusions were drawn in Sect. 5.

2 Overview of Big Data Based Analysis for Product Lifecycle

Figure 1 shows an overview of the proposed framework. This framework was consistent with a normal MMP. That is, for beginning of lifecycle (BOL), a product manufacturing factory has one or more production lines. Different production lines were often responsible for different production processes. For middle of lifecycle (MOL), the product was leased or sold by the manufacturer. While using the product, a customer may face several situations: the product may need maintenance after some use; the product may have some quality problems and need to be returned in compliance with the leasing contact; the product may come to the end of its life.

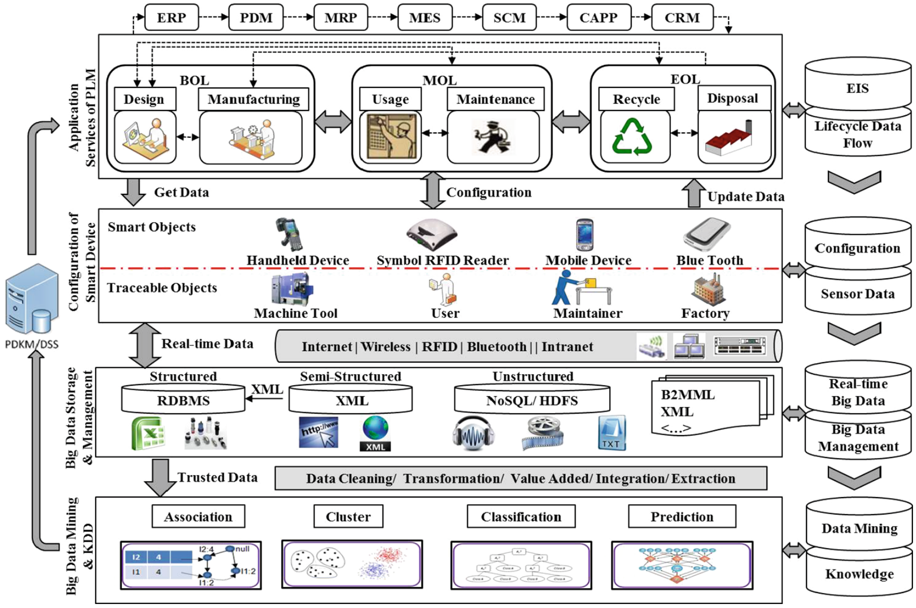

Fig. 1. Overview framework of BDA-PL

According to the big data analysis hierarchy, the proposed BDA-PL framework includes following core components:

- Application service of PLM: This layer was used to provide important real-time applications based on the integrated knowledge that mining and discovery from the lowest layer. It can be regarded as the top-level services of the PLM.

- Big data acquisition and integration: Based on the configuration of the smart device in manufacturing things and product, the real-time and complete lifecycle big data can be sensed and captured.
- Big data storage and management: Product lifecycle data consist of structured, semi-structured and un-structured data. Distributed Data Base System (DDBS), XML and Hadoop Distributed File System (HDFS) can be used to manage and store structured, semi-structured and un-structured data, respectively.
- Big data mining and Knowledge Discovery in Database (KDD): By using the theory of data mining to find valuable knowledge from lifecycle big data. Combined the knowledge with product data & knowledge management (PDKM) system and decision support system (DSS) to form a closed-loop mechanism of knowledge sharing and feedback.

Compared with existing PLM, active perception of manufacturing things, real-time monitoring of product status, value discovery of big data, dynamic optimization of PLM were the significant characteristics of the framework for BDA-PL.

3 Key Technologies of Big Data Based Analysis for MMP

Big data based analysis for MMP refers to the method of multiple disciplines such as information, communication, knowledge discovery and intelligent decision, etc. This paper was illustrated mainly on the realize ideas and methods of the key technologies for MMP.

3.1 MMP Big Data Acquisition and Integration

Configuration of the various smart devices or product embedded information devices (PEIDs) (e.g. RFID tags, sensors) for manufacturing things and products were the foundation of real-time and multi-source big data capture.

During production phase, PEIDs can be deployed to manufacturing things, key components and products to collect real-time data of work in process (WIP) and key parts. For example, RFID readers was equipped in the fixed position such as CNC center and key equipment of assembly line, nevertheless, RFID tags was equipped in the manufacturing resources such as key parts and components. During usage and operation stage, these PEIDs and smart sensors that have been embedded (equipped) in the key components or proper locations of the product can be used to real-time monitor and capture the OM big data of product.

A huge amount of real-time data sensed at the PEIDs cannot be directly used in the up-level EISs and lifecycle management layer. So, all data produced by various departments and software have to be integrated. By information fusion technology such as definition of data relation and middleware technology, then transformed the multi-source and heterogeneous data into standard information (e.g. B2MML/XML) that can be used by PLM decision-making to realize multi-source data value-add.

3.2 MMP Big Data Mining Mechanism

A graphical model of MMP big data mining was designed as shown in Fig. 2. The model consists of four layers from the bottom to the top.

- Data layer was used to store the big data of MMP. The data were stored in different types of databases according to different application demand.
- Method layer mainly refer to data mining model. It was responsible for extracting suitable data from data layer and mining valuable knowledge from the data.
- Result layer was a set of data mining result. According to different application demand, suitable mining model and original data were selected to conduct data mining. Finally, achieve the knowledge set of different lifecycle stages and different application index.
- Application layer was also a demands layer, namely applied the knowledge to achieve the requirements of enterprises.

What we can see from the above analysis was that the big data mining graphical model of MMP was a close-loop structures that starting from the application demands, and ultimately meets the application of enterprises.

4 Case Study

This section demonstrates the usage of the proposed framework with an actual product involved, which was a kind of axial compressor manufactured by company A. The company also provides application-oriented product service for this product, in other words, the company sells its function instead of the product, e.g. through sharing and

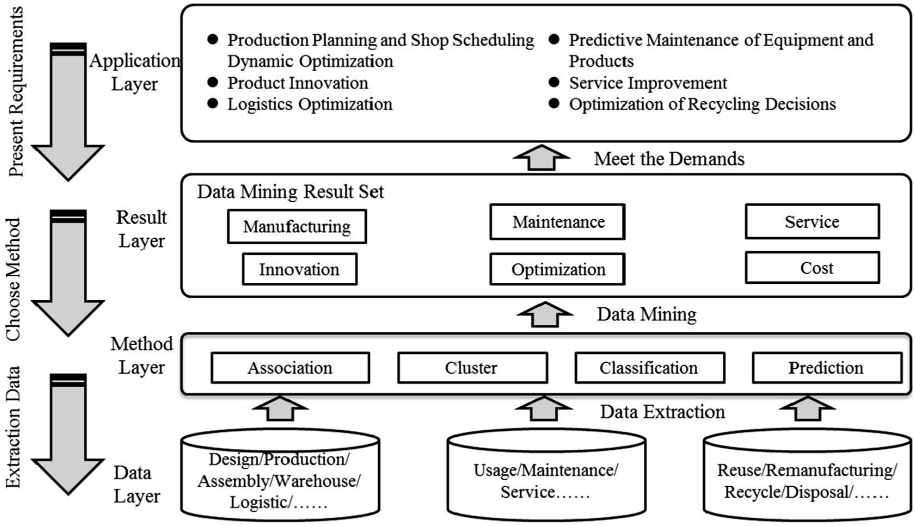

Fig. 2. Graphical model of MMP big data mining

leasing. The usage status data can be real-time collected and remote monitored by company A to improvement product design, optimization production and predictive maintenance.

Here we focus on the MMP for the critical component rotor and blades of the compressor. These two components were particularly suitable since compressor was often works under a condition of high pressure and high temperature, and easily causes the compressor to go into surging zone. When surge occurs, the signals such as flow rate, pressure and temperature, which symbolize the surge, will exhibit phenomena that were impossible under normal conventional conditions.

4.1 Compressor MMP Big Data Acquisition

Create a Smart Environment for MMP with PEID-Enabled Smart Objects. For simplicity of understanding but without lost of generality, a hypothetical MMP for the compressor as shown in Fig. 4. It consists of two plants and one warehouse, and the compressors were rented by customers. Company A provides specialized service for these customers such as specialized maintenance, remote on-line diagnoses and supply spare parts.

Figure 3 also shows a deployment of PEIDs in the MMP. UHF RFID, RFID tags and smart sensors were adopted to manufacturing resources, key components or key position of axial compressor for tracking the real-time data. The deployment information was shown in Table 1.

The warehouse consists of smart shelves, each of which is equipped with PEIDs (collectively as 1). Locations on the shelves are tagged.

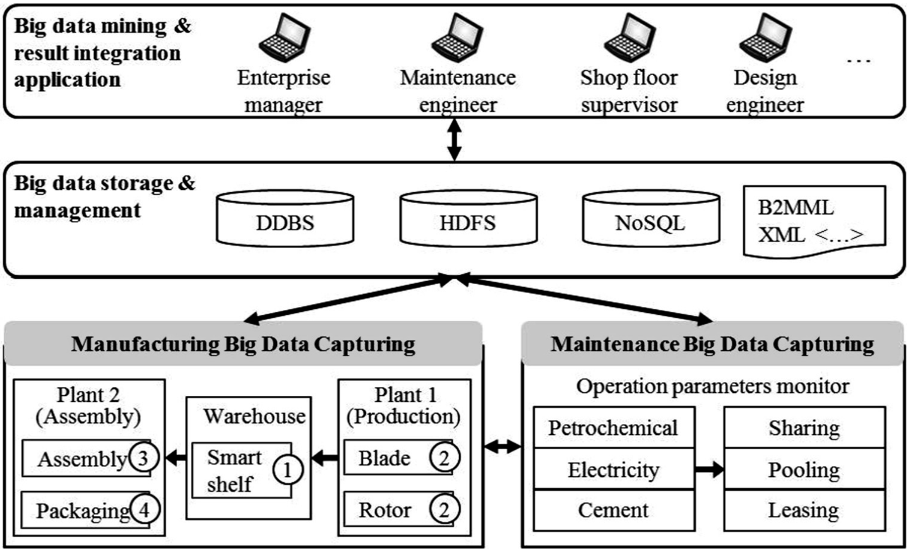

Fig. 3. Overview of the case study
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Table 1. Deployment information of PEIDs in manufacturing shop floor and product

PEIDs	UHF/Sensors	Manufacturing recourses/Location	Objective
RFID reader	UHF	Machine	Track the pallets
RFID reader	UHF	Assembly line	Check in materials and report assembly tasks
Tag	UHF	Pallet	Track the information of pallet with materials
Tag	UHF	Critical parts	Track the real-time data from WIP to product
Sensor	Differential pressure sensors	Convergence device	Monitor flow rate of gas
Sensor	Piezoelectric velocity sensors	Both ends of rolling bearing	Monitor vibration of rotor
Sensor	Temperature sensors	Embedded in blades and rotor	Monitor temperature of gas

Plant 1 was a parts production plant. Some parts of compressors were manufactured in this plant and delivered to the warehouse. The PEIDs (collectively as 2) were conFig.d during manufacturing process. For example, UHF RFID tags were attached on the blades and rotors during production process to track the real-time data from WIP to products, however, smart sensors were embedded in blades and rotors or conFig.d in the proper locations of the compressor to monitor and collect the real-time field data (e.g. temperature and pressures of the gas). To procure the required real-time field data, the PEID readers were also allocated to the appropriate position near the location of the compressor and its components.

Plant 2 was assumed to be a simplified compressor assembly line. Two workstations were involved in addition to the line supervisor. Accordingly, two PEIDs (marked as 3–4) were deployed to these two workstations. Same as plant 1, sensors can be conFig.d in proper locations of the compressor during assembling process.

Acquisition of the MMP Big Data. Based on the configuration of the smart environment for MMP, the real-time primitive data of PEIDs equipped to the manufacturing resources and products can be captured.

When a pallet comes to the machine, this event can be tracked by the UHF RFID reader installed at the machine. Next, UHF RFID reader check materials needed to according to this process task. If the materials were well prepared, the processing task can be executed at this machine. During the process stage, the tagged critical component's status can be tracked by the RFID UHF reader installed at the machine. Therefore, the real-time data of components and manufacturing resources can be captured. The assembly plant is not included for discussion here as the working principles are basically similar.

OM process was the phase where compressors were used by customers. Flow rate data was one of the key data to prevent the surge of compressor. In addition, the vibration of the rotor and the temperature of the compressed gas were also important symbol to surge phenomena. Therefore, through real-time monitored and captured the usage status data such as flow rate, pressure, temperature and vibration, compressor surge can be effectively prevented. As has been noted, some smart sensors have been equipped in the proper locations of the compressor can be used to monitor and collect use status data of compressor.

4.2 Data Mining Results Integrated Application of MMP

The big data mining results of MMP were not only useful to themselves, but also useful to other stage of the lifecycle. For example, design departments need to draw lessons from the evaluate result of supplier selection to select better supplier. Maintenance or service departments need to understand the quality factor of production to provide better sale service and maintenance service. Data mining results of marketing and customer demand data can be used by R&D departments to development new products. Easily damaged parts and supplier selection evaluation data mining results of service departments can be used by R&D departments to select better supplier and improvement design.

5 Conclusions

This paper has presented an innovative framework where IoT technologies and big data analysis technologies were combined to form a BDA-PL for sharing information and knowledge among actors of PLM. Two contributions are important in this research. The first contribution was the framework of BDA-PL and its key components. Under the new big data based lifecycle management strategy, lifecycle managers can use advanced analytics tool to take a deep dive into real-time and historical process data, and then optimize the factors that prove to have the greatest effect on lifecycle management. The second contribution was a novel conception of combine big data analysis with product service, which was illustrated in the case.

The proposed framework of BDA-PL just provides a new kind of useful infrastructure to improve production and maintenance efficiency by using the MMP big data. Future research works will focus mainly on how to use the advanced big data analytics tool to mining and identify hidden patterns from the sensed MMP big data for optimal production and maintenance decision.

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Development of a Product Configuration System for Cloud Manufacturing

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Abstract. For Configure-to-Order manufacturing firms, Product Configuration System (PCS) is one of a key components. PCS has been introduced for decades and its technology has matured, providing the industry with a set of usability standards and best practices. However, even the state-of-the-art PCS performs poorly in terms of connectivity, customisation freedom management and implementation. In this regard, this paper first reviews the impact of manufacturing paradigms on product customisation and take Cloud Manufacturing, a nascent manufacturing model, as a disruptive technology to surmount existing obstacles. Then, a general architecture of PCS for Cloud Manufacturing (CM-based PCS) is proposed to conduct configuration reasoning based on cloud-sourced configuration knowledge, to diversify configurable options by introducing proper Cloud Manufacturing services and to fulfil configuration orders through a cloud-based design and manufacturing platform.

Keywords: Product configuration · Cloud manufacturing · Everything-as-a-service · Ontology

1 Introduction

With emerging disruptive technologies and changing of Customer Needs (CNs) and market demand, manufacturing industry has experienced several paradigms. Mass Customisation (MC) emerged from the 1980s, emphasising the need to provide outstanding service to customers in providing products that meet CNs at a low cost [1]. Due to trend of globalisation, paradigms complying with more specific CNs emerged, such as one-of-a-Kind Production (OKP) emphasising the "market-of-one", and Mass Personalization (MP) aiming to reveal latent CNs [2].

Recently, a new service-oriented manufacturing model, Cloud Manufacturing (CM), emerged. As a nascent paradigm, CM is considered as a promising paradigm that will change the way manufacturing businesses operate. In the literature, Cloud Manufacturing-related definitions have been elaborated by different researchers. Main stream definitions of CM contain key words like networked manufacturing, ubiquitous access, multi-tenancy and virtualization, big data and the IoT, everything-as-a-service (e.g., infrastructure-as-a-service, platform-as-a-service, hardware-as-a-service, and software-as-a-service), scalability, and resource pooling [3–5].

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It is obvious that the evolvement of manufacturing paradigms is affecting the way of producing customised products. To achieve increased customisation requirement, manufacturers' resource and capability for design and manufacturing are met with challenges. Customisation freedom, to a certain degree, depends on the volume of manufacturing resources at hand, so new emerging manufacturing paradigms will boost in-depth customisation.

Comparing to conventional manufacturing paradigms, Cloud Manufacturing makes manufacturing firms more accessible to external manufacturing resources. From this point of view, Cloud Manufacturing is a remedy bridging the gap between diverse CNs and insufficient internal manufacturing resources and capability. Obviously, manufacturing enterprises, in particular Small and Medium-sized Enterprises (SMEs), can deliver more in-depth customisation by adopting Cloud Manufacturing.

Product configuration is an activity of customising a product to meet the needs of a particular customer. Product Configuration System (PCS) is a tool to conduct an activity of customising a product to meet the needs of a particular customer. To utilise manufacturing resources in a "cloud", a new generation PCS is a necessity for configuration in a cloud environment.

2 Challenges of Developing the Next Generation PCS

2.1 Issues of Existing PCS

With the introduction of AI and cloud technologies, cloud-based PCS is currently the most advanced. Recently, numerous PCS vendors have launched their "cloud-based product configuration solutions", in which cloud concept is embedded.

In fact, those cloud-based PCSs in use are far from being perfect. Firstly, none of cloud-based PCSs could quickly respond to changes in the production systems and the supply chain. Such a drawback results in an array of issues like non-support of dynamically processing Request for Quotation (RFQ) and lower degrees of product customisation freedom to customer. Besides, the cost of the maintenance and management of configuration system is truly high especially when the configurator aims at structural and compositional configuration of a complex Engineering-to-Order (ETO) product. It is because any change of manufacturing capability or disruption of supply chain may incur momentous adjustment of configuration options and pricing/quote. Another factor restricting the application of PCS is that implementing a new PCS requires significant and potentially painful changes in the way the order acquisition and fulfilment activities are organised, and necessitate a high initial investment in terms of man-hours.

2.2 Future of PCS

Main stream ERP vendors (e.g. SAP and Infor), CAx software vendors (e.g. Autodesk) and some other software vendors (Tacton, KBMAX and Mycustomizer) have delivered their cloud-based product configuration systems. With features of PaaS and IaaS, these cloud-based solutions enable manufacturing firms to provide engineers, sales reps, and end customers with web and even mobile access to a configuration as a thin client (i.e. with nothing to install). Those cloud solutions only enhanced accessibility and computing capability of PCS, but made very little difference to above-mentioned gaps.

As mentioned in Sect. 1, phasing in Cloud Manufacturing will facilitate more in-depth product customisation. Meanwhile, manufacturing resources and capability encapsulated as cloud services in Manufacturing Cloud is promising to revolutionise PCS in future. For instance, numerous manufacturing services could greatly increase the customisation freedom of products; an open architecture PCS platform integrated with Manufacturing Cloud is much easier for an enterprise to develop a brand new PCS or to upgrade dated one. As manufacturing services can be published in terms of real-time information, any changes happened in supply chain and outsourced supply chain are able to be taken into account in each configuration.

For those reasons, this research considers Cloud Manufacturing as a disruptive technology to upgrade its precedents and focuses on developing Product Configuration System for Cloud Manufacturing (abbreviated as CM-based PCS in following paper). In comparison with conventional cloud-based PCSs getting access to computing cloud, storage cloud and etc., CM-based PCSs further integrate with Manufacturing Cloud which encapsulated a wide range of manufacturing services stemmed from distributed manufacturing service providers. Such connectivity to manufacturing resources and capability makes CM-based PCS able to react to dynamic requirements from customers, and meanwhile enhances configurability of products by discovering new manufacturing services which can be applied to the development of new product variants.

3 Implementation of CM-Based PCS

Nowadays, ever-increasing resources from the plant floor and headquarter are virtualised and encapsulated as cloud services, and next generation applications (e.g., PCS) definitely require connectivity to ubiquitous clouds. Integrating a PCS with Manufacturing Cloud will facilitate scalability and utilisation of facilities [6]. So far, there is no literature on any systematic methodology of implementing CM-based PCS.

3.1 Integration with Manufacturing Cloud

The research utilises the cloud computing concept and service-oriented principles to enhance conventional PCS technology. To achieve that, the concept of Manufacturing-as-a-Service (MaaS) and Design-as-a-Service (DaaS) are embedded here. Based on the concept of MaaS, to fulfil product configuration, production systems on the basis of accessibility of PCS can be integrated with manufacturing services via a certain Cloud-based Design and Manufacturing (CBDM) platform [7]. It provides users with a level of product customisation freedom that is directly integrated to the available manufacturing capabilities of production sites within a cloud manufacturing infrastructure. Meanwhile, manufacturing services stemmed from the visualisation of pool of manufacturing resource are promising to boost the capability of product design within configuration process by creating a dynamic co-design environment for the interaction between customers and manufacturers.

Manufacturing services may be internal (i.e. the manufacturer itself) or external (i.e. supplier, outsourced supplier, etc.). Manufacturing Cloud can be classified similarly by introducing the concept of cloud computing embracing four types of deployment models, including (1) private cloud: a centralised management effort in which manufacturing services are shared within one company or its subsidiaries; (2) community cloud: a collaborative effort in which manufacturing services are shared between several organisations from a specific community with common concerns; (3) public cloud: a set of manufacturing services in which manufacturing services are available to the general public [7]. To seek proper manufacturing resource, manufacturing firms would typically give priority to their internal manufacturing resources, then, if necessary, cooperation within community would be another good choice, and an anonymous supplier from public cloud will be the last option.

3.2 Architecture of the Reasoning Engine

Considering incremental changes and updates on products due to new technology advances and the expansion of the Internet, a configuration model supports knowledge reuse and sharing is crucial. In order to utilise ubiquitous cloud and realise configuration based on CM, an ontology-based approach is adopted in this research.

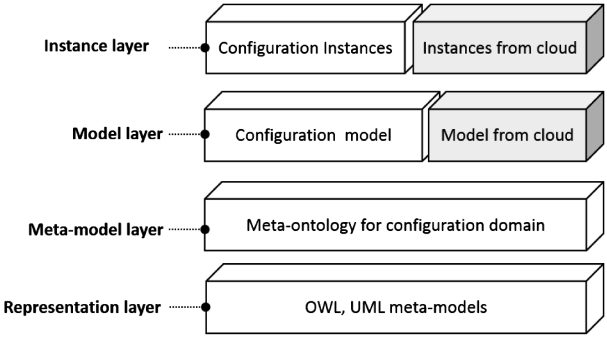


Fig. 1. Four-layer modelling architecture

Ontology is a formal, explicit specification of a shared conceptualisation. There has been literature of addressing the modelling of product configuration knowledge with an ontology-based approach in which structural knowledge is formalized in OWL (Ontology Web Language) [8] and constraint knowledge in SWRL [9], (Semantic Web Rule Language). Through the transformation of configuration knowledge into Jess facts and Jess rules, actual configuration processes are carried out with the support of Jess [10], a rule engine for the Java platform.

To encourage reuse of configuration models and flexibility in representing knowledge, the presented modelling approach for product configuration knowledge follows four-layer architectures [11]. Unlike a usual ontology-based configuration engine, the instance layer and the model layer are integrated cloud-sourced knowledge for extension in this research (see Fig. 1). The difficulties in modelling product configuration knowledge can be dramatically reduced by constructing configuration models based on existing configuration knowledge instead of starting for scratch.

The advantage of OWL-based configuration models is that the reuse of configuration models can be ensured since OWL, as an ontology language, supports knowledge reuse and sharing. This is especially crucial, considering incremental changes and updates on products due to new technology advances.

3.3 Prototype of the CM-Based PCS

To integrate the ontology-based PCS with Manufacturing Cloud, we propose a novel way to obtain constraint knowledge in SWRL by extracting and parsing distributed configuration knowledge stemmed from the resource pool of manufacturing resources. The thorny problems here include: (1) to establish a communication mechanism enabling the interaction between PCS and Manufacturing Cloud; (2) to depict configuration-relevant manufacturing resources and external inventory information in a unified way which supports the reasoning of Ontology-based PCS engine; (3) to archive CM-based request for manufacturing (RFM), including production documentation and product information model, in an easily accessible and retrievable manner.

The communication mechanism, to address the first issue, proposed in this paper is shown as Fig. 2. According to the diagram, the interaction between PCS domain and

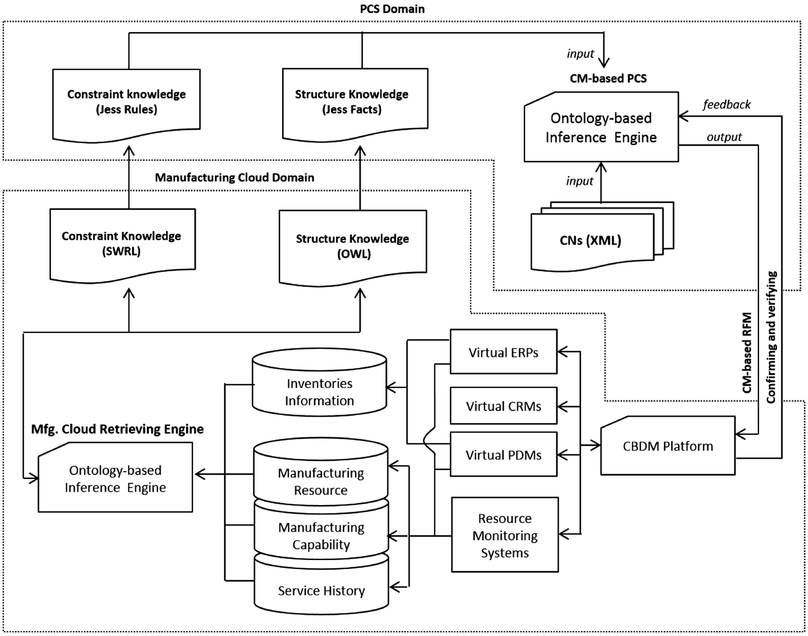


Fig. 2. Communication between PCS and Manufacturing Cloud

Manufacturing domain mainly depend on the introducing of Manufacturing Cloud retrieving engine which is actually an ontology-based reasoning engine.

To address the second issue, a shared ontology for all service providers describing available product catalogues, inventories, manufacturing resources and manufacturing capability is proposed. In this way, supplementary configuration knowledge from cloud encoded in the format of OWL and SWRL could be transformed into Jess facts and rules for inference. The advantage of OWL-based configuration models is that the reuse of configuration models can be ensured since OWL, as an ontology language, supports knowledge reuse and sharing. The Jess rules mentioned in this diagram are developed by using the Extensible Style-sheet Language Transformations (XSLT) to perform the transformation from XML documents to Jess files.

After configuration reasoning, the CM-based PCS will generate not only a configuration but also a CM-based RFQ which may include request of procurement and outsourced manufacturing task enabled by manufacturing service provider via CBDM platform. This research utilise the interoperability of the STEP format to carry necessary information the RFM needed. In consideration of increasingly large product model, a new edition of Part 21 of ISO 10303 is adopted to archive and compress (in ZIP format) possible gigantic RFM information in configuration of complex ETO product. Part 21 is a specification for how to format entities describing product data [12]. It is a public domain file format for the geometry of assemblies and is widely used by industry to describe design and manufacturing specifications for airplanes, automobiles, ships, buildings and other products. This research archive RFM data by Part 21 Edition 3, so a parser capable of automatically interpreting configuration results into an EXPRESS schema is necessary to generate RFM.

4 Case Study

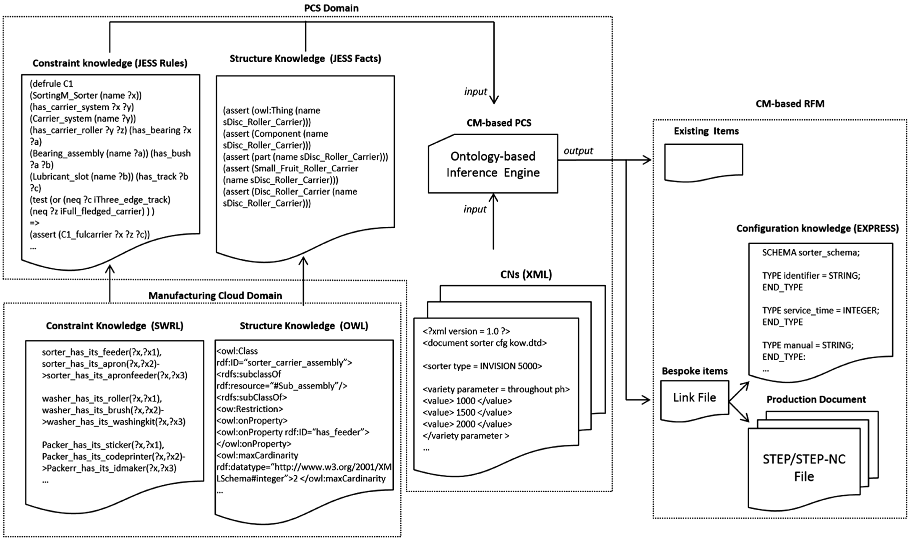
To implement and validate methodologies proposed in this paper, this work chooses a local manufacturing firm, Compac Sorting Equipment (abbreviated as Compac in the following paper) to conduct a case study. Compac's headquarter is located in Auckland, New Zealand, and its branches and suppliers are around the world. Compac is a manufacturing firm producing sorting machines which are ETO products with high complexity. Typically, a sorting machine produced by Compac is a streamline machine system mainly including infeeding, sorting and grading, bagging and packing sub systems. To be specific, an infeed system is capable of tipping, washing and treatment of fruits, sorting and grading sector support sorting fruits by weight, colour, density, size, shape, surface defects and internal properties of fruits.

One thorny issue is configuration rules coding due to the complexity of their product. The company is working on developing a traditional rule-based configuration system. However, as above mentioned, knowledge reuse and sharing is essential in a configuration in cloud environment. This research therefore transforms their codes into the ontology model of product configuration and associated rules in parallel.

As above-mentioned methodologies, this research adopts ontology-based PCS to tackle configuration task, and the ontology model of the main component of sorting machine are built. The ontology model proposed is modularised according to the features of the sorting machine which typically consist of a sorter, washer and packer. The constraint knowledge is modularised as different cluster. The essential data for CM-based RFM is compressed as a ZIP archive.

As Fig. 3 shown, a configuration is generated according to CNs and cloud-sourced knowledge, then configuration result is compressed in accordance with P21 Edition 3.

This case study only establishes a prototype of product configuration system for cloud manufacturing. Due to the complexity of products, a complete PCS for a whole streamline equipment required more endeavour to achieve. Even so, the current prototype has demonstrated that such a methodology of developing CM-based PCS is practical and feasible.



```
(defrule C1
(SortingM_Sorter (name ?x))
(has_carrier_system ?x ?y)
(Carrier_system (name ?y))
(has_carrier_roller ?y ?z) (has_bearing ?x
?a)
(Bearing_assembly (name ?a)) (has_bush
?a ?b)
(Lubricant_slot (name ?b)) (has_track ?b
?c)
(test (or (neq ?c iThree_edge_track)
(neq ?z iFull_fledged_carrier) ) )
=>
(assert (C1_fulcarrier ?x ?z ?c))
...
```

```
(assert (owl:Thing (name
sDisc_Roller_Carrier)))
(assert (Component (name
sDisc_Roller_Carrier)))
(assert (part (name sDisc_Roller_Carrier)))
(assert (Small_Fruit_Roller_Carrier
(name sDisc_Roller_Carrier)))
(assert (Disc_Roller_Carrier (name
sDisc_Roller_Carrier)))
```

```
sorter_has_its_feeder(?x,?x1),
sorter_has_its_apron(?x,?x2)-
>sorter_has_its_apronfeeder(?x,?x3)

washer_has_its_roller(?x,?x1),
washer_has_its_brush(?x,?x2)-
>washer_has_its_washingkit(?x,?x3)

Packer_has_its_sticker(?x,?x1),
Packer_has_its_codeprinter(?x,?x2)-
>Packerr_has_its_idmaker(?x,?x3)
...
```

```
<owl:Class
rdf:ID="sorter_carrier_assembly">
<rdfs:subclassOf
rdf:resource="#Sub_assembly"/>
<rdfs:subClassOf>
<ow:Restriction>
<owl:onProperty>
<owl:onProperty rdf:ID="has_feeder">
</owl:onProperty>
<owl:maxCardinarity
rdf:datatype="http://www.w3.org/2001/XM
LSchema#integer">2 </owl:maxCardinarity
...
```

```
<?xml version = 1.0 ?>
<document sorter cfg kow.dtd>

<sorter type = INVISION 5000>

<variety parameter = throughout ph>
<value> 1000 </value>
<value> 1500 </value>
<value> 2000 </value>
</variety parameter >
...
```

```
SCHEMA sorter_schema;

TYPE identifier = STRING;
END_TYPE

TYPE service_time = INTEGER;
END_TYPE

TYPE manual = STRING;
END_TYPE:
...
```

Fig. 3. Product configuration of sorting machine

5 Conclusions

This paper has first presented the survey on existing commercial cases of product configuration solutions and a literature review on technologies associated with PCS. The research concluded that even state-of-the-art product configuration tools are far from being satisfactory and the introduction of cloud manufacturing has the potential to enhance conventional PCS by boosting connectivity, enabling customisation freedom management and facilitating implementation with a low effort. To integrate Manufacturing Cloud with PCS, this paper proposed a methodology for implementing CM-based PCS. In order to utilise huge amount of cloud-sourced configuration knowledge, an ontology configuration model has been adopted to realise knowledge reuse and sharing in a ubiquitous cloud. The prototype of CM-based PCS proposed here is accessible to internal and external manufacturing resources via Manufacturing Cloud. Meanwhile, inclusive manufacturing services could enrich configuration options to some extent. Most importantly, an open architecture platform based on general ontology configuration model could be developed to reduce the cycle of PCS implementation. This research validates methodologies through a case study of complex ETO products.

The prototype of CM-based PCS described in this paper promises to transform existing PCSs into full-fledged cloud solution. Nevertheless, it has some limitations. For example, ontology models in this paper were built manually. This is because so far there has not been an effective way to generate ontology automatically. Additionally, further study has been planned to retrieve, filter and optimise available cloud services in complex cloud environment.

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ICMS: A Cloud-Based System for Production Management

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Abstract. Modern production industry calls for a new generation of production systems. As a novel information technology, Cloud provides new service models and business opportunities to manufacturing industry. In this research, a Cloud-based manufacturing system is developed to support distributed production management. Recent Cloud manufacturing approaches are reviewed. The Cloud-based production management and localisation mechanisms are proposed and evaluated during case study. It is shown that the Cloud-based manufacturing system is capable of supporting distributed and customised production services and managements.

Keywords: Cloud manufacturing · Cloud · Production management · Cloud production · ICMS

1 Introduction

In recent years, Cloud has become a popular technology which gains huge market success globally. Cloud concept indicates a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction [1]. It provides elastic and flexible supports for service-oriented production models. Based on NIST's definition, Xu [2] extended the Cloud concept to manufacturing, which is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing resources (e.g. manufacturing software tools, manufacturing equipment, and manufacturing capabilities) that can be rapidly provisioned and released with minimal management effort or service provider interaction. In practice, it is possible to utilise Cloud model to improve the performance of current production systems. In this paper, Cloud-based manufacturing research is reviewed, and a Cloud-based system is developed to support flexible, customised and sustainable production managements at high level.

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2 Literature Review

Recently, Cloud-related production research has been conducted world-widely to explore Cloud-based manufacturing models and solutions. In general, these research works can be categorised into two types, i.e. Cloud computing in manufacturing industry, and Cloud manufacturing systems. In this section, these two types of research are reviewed and discussed respectively.

2.1 Cloud Computing in Production Industry

The Cloud technology offers on-demand service access and resource pooling on the computing market. Thus it is a natural thinking to utilise Cloud applications in manufacturing directly. In this type of research, computer-aided or web-based manufacturing applications are deployed in the computing Cloud, which can be considered as a *manufacturing version of Cloud computing*. These applications are implemented at two levels of system, which matches two service levels of Computing Cloud, i.e. Service and Platform levels.

At the *Software* level, production software-as-a-service is particularly suitable for Small and Medium-sized Enterprises (SMEs) since it offers on-demand services with lower entry barriers and initial investments. Manufacturing software applications, e.g. Design [3–5], Visualisation [6], Simulation [7], and Enterprise Resource Planning (ERP) [8, 9], were deployed on the Cloud to realise remote access and flexile billing.

At the *platform* level Cloud computing technologies were adopted to support the whole supply chain [10, 11]. Qualitative results supported the assertion that information processing requirements and information processing capability affected intention to adopt Cloud computing. Multiple models were developed to examine both information processing requirements and capacity, which eventually influenced the firm's desire to adopt Cloud-based supply chain innovations [8, 12–15].

2.2 Cloud Manufacturing Systems

In this kind of Cloud approach, the production system is established based on service-oriented architecture of Cloud system. It reflects the *infrastructure* level of Cloud approaches. Li et al. [16–18] first suggested a high-level manufacturing system based on Cloud. The manufacturing Cloud aimed to share and utilise manufacturing abilities over a configurable and virtual manufacturing network [19, 20]. Lu et al. [21] proposed a hybrid Cloud structure that allowed companies to deploy different cloud modes for their periodic business goals. During the implementation of Cloud manufacturing systems, it needs to be noted that the performance of the system also needs to be monitored and measured in a standardized and quantifiable manner [22].

Wang and Xu [23–25] proposed a Cloud-based Manufacturing system to support production service integration and interoperability. The manufacturing Cloud was also extended to the remanufacturing sector for electronic wastes managements [26, 27]. However, despite Cloud-based manufacturing achievements above-mentioned, there is still a lack of research in a Cloud system which is able to support production managements as a whole solution. Thus in this paper, the Interoperable Cloud Manufacturing System (ICMS) is presented along with the management structure and modules.

3 ICMS for Production Management

The ICMS system architecture is illustrated in Fig. 1. Physical production resources are integrated in the system in terms of production services. The *Cloud layer* works as the service coordinator and supervisor of the whole production system. Cloud users and administrators access to Cloud over the network, with the help of standardised Application Programming Interface (API). Inside the Cloud layer, the Smart Manager mechanism is the core execution module which interacts with Cloud users, and executes the service packages accordingly. The Cloud database maintains information regarding Cloud user, Cloud service packages, service histories, and most importantly resource profiles that are utilised to schedule and execute Cloud services. These specifications guarantee the capability, availability and feasibility of production facilities at the Physical Resource level.

At the *Physical Resource Layer*, production tasks assigned by Cloud are taken by control units of production devices, e.g. Robot-as-a-Service (RaaS) unit and Machine-as-a-Service (MaaS) unit. Robot operation systems (ROS) and CNC controllers interpret the production documents from Cloud into process working steps and then controlling signals that directly drive physical devices eventually. In this top-down approach, human operators are also able to interact with the Cloud layer via devices like smart phones, PCs and PDAs. Real performance on shop-floor is monitored by range cameras, sensors, smart meters and device controllers. Monitoring results are fed back to Cloud for service supervision and future improvements. Thus, it forms a closed-loop production system.

Between the Cloud layer and Physical Resource Layer, *Local Servers* are optional due to two main reasons. First, during the monitoring process, shop-floor sensors generate huge amount of data dynamically, e.g. power, current, vibration, and force readings. It is inefficient to stream all raw data to Cloud directly, since most contents are not essential but generate heavy network traffics. Thus a local PC or server is necessary in this case to play as the data filter and pre-processor. Raw data is locally filtered and processed by the server, and then uploaded to the Cloud. It thus balances bandwidth loads and Cloud data management.

Second, in some cases the local server needs to work as an interface between Cloud layer and Physical Resource Layer. In practice, many commercial controlling units (ROS and CNC controller) are designed as a semi-closed system. To some degree it guarantees the robustness and safety of the unit. However these systems are difficult to interact with the Cloud directly. Thus in these cases, a local PC or server is needed to interact with operation systems at low level via user interface on one hand (over local network in most cases), and communicate with the Cloud via the Internet on the other hand.

The communication methods between production facilities and Cloud are shown in Fig. 2. Localised production plan is possible thanks to Cloud databases and local monitoring devices. For instance, detailed industrial robot specifications are kept in the

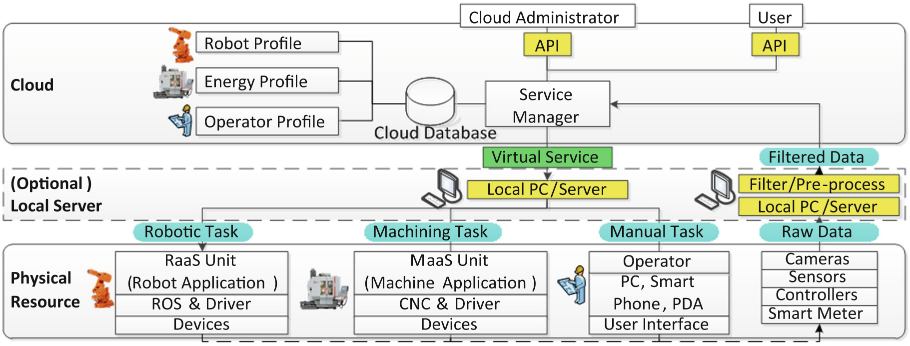


Fig. 1. ICMS system architecture

Cloud, including reach envelope, handling capacity, working range and energy history (Fig. 2a). When path planning and optimisation is needed, the Cloud is able to pull the data regarding positioning, kinematics/joint status from shop floor and profile specifications in Cloud database. Then the Cloud is able to take heavy computing task and output optimised path to the robotic cell.

As a specific type of resource, human resource can be integrated with ICMS also, considering physical and ergonomic factors of individual operators specifically (Fig. 2c). Exclusive human factors differ among individual operators, e.g. height, weight, strength, handedness (left or right), and other ergonomic factors. Before an operator starts to work, his or her staff barcode can be quickly scanned and the personalised ergonomic specification can be identified in Cloud database. Based on these profiles, a personalised work plan is generated. It is especially helpful during the implementation of human-robot collaborations, since robot movement strategies can be adjusted based on human factors aforementioned.

4 Implementations and Case Study

To validate and evaluate the proposed production system based on Cloud, ICMS is implemented based on previous research works [28–30]. In the Cloud that hosts virtual environments and service modules. 32 cores and 132 gigabyte memories are deployed to provide the computing power for the proposed system. In this research, java applet is utilised to develop the user interface since it offers light weight environment of ICMS and mobility among different systems/environments. MySQL databases are established to maintain production specifications mentioned above.

To secure the safety of the Cloud system and privacy of users, Secure Sockets Layer Virtual Private Network (SSL VPN) is utilised to provide protected remote access to the Cloud. ICMS's Cloud production service flow is shown in Fig. 3. A user firstly accesses to the Cloud environment through VPN over the Internet. Command dashboards are developed for Cloud administrators and users respectively as indicated in Fig. 1. A Cloud administrator is able to manage broadcasted services, customer orders and user profiles remotely.

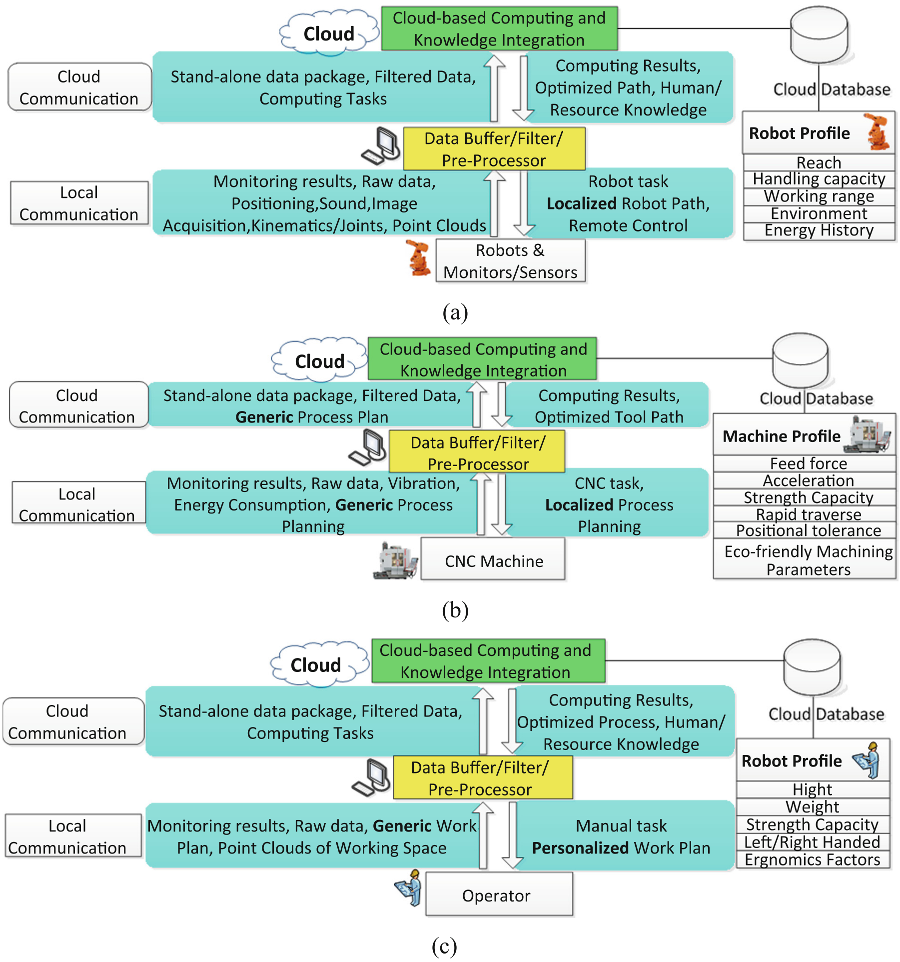
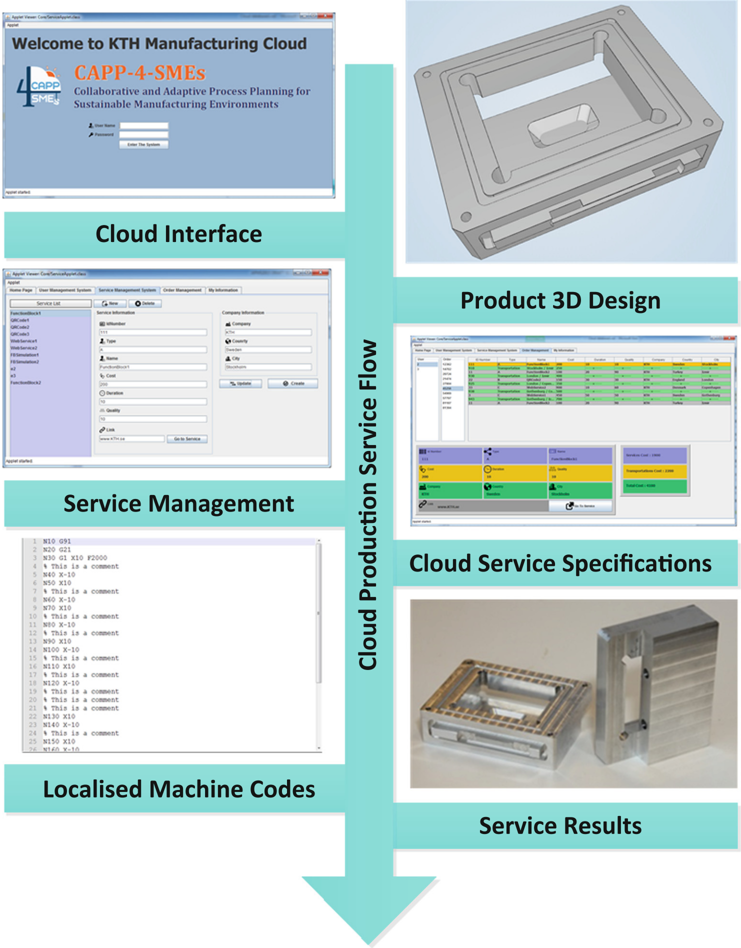


Fig. 2. Localised production plan based on cloud

After the product 3D design is uploaded to the Cloud, the user's requirements of machining service are interpreted by the smart manager mechanism. Multiple candidate solutions are identified in Cloud database. Among multiple machining providers, the user is able to filter the candidate pool based on different preference criteria e.g. price, duration and quality priority.

Being part of the Cloud service, process planning is generated based on generic feature information from the product 3D design. After the machining service provider is determined, generic production document is converted to localised NC codes which are specifically amended for the chosen machine and cutters based on technical specifications maintained in physical resource database (Fig. 2). It forms a from-design-to-production environment on the Cloud.



```
N10 G91
N20 G21
N30 G1 X10 F2000
% This is a comment
N40 X-10
N50 X10
% This is a comment
N60 X-10
N70 X10
% This is a comment
N80 X-10
% This is a comment
N90 X10
N100 X-10
% This is a comment
N110 X10
% This is a comment
N120 X-10
% This is a comment
% This is a comment
% This is a comment
N130 X10
N140 X-10
% This is a comment
N150 X10
N160 X-10
```

Fig. 3. Cloud production service flow

5 Conclusions

Morden production industry calls for a new generation of production systems. Nowadays fast-changing ICT technologies have dramatically altered the way people think and do business. However, most of current production systems still function as twenty years ago. As a disruptive technology, Cloud offers an environment with remote access, resource pooling and customisation. In this research, a Cloud-based system is developed especially for production management. Integration mechanisms of physical resources are proposed, and customised production planning methods are developed and validated by the case study.

It has to be admitted that security concerns exist among current and potential Cloud users due to possible data leakage and destructive cyber-attack. In this research, SSL VPN is thus utilised to maintain security and safety of Cloud system and data. In the future, Cloud-based production systems can learn from successful web-based businesses, e.g. online banking, stock market and e-logistics. To guarantee the privacy of Cloud services, more information technologies can be adopted in the future, including encryption, private keys, firewalls and so forth.

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Cloud-Based Production Logistics Synchronization Mechanism and Method

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Abstract. It is inevitable that the dynamic is occurs in the operation of the production logistics (PL). Production logistics synchronization (PLS) can solve the dynamic of production logistics operation process by collaboration the both or among of the production, shipping and storage. Cloud manufacturing mode can quickly respond to the shortage of resources in the production logistics operation process, and provide cheap cloud resource services, such as cloud forklift. This paper is aimed at the problem for the dynamic of production logistics operation, and the dynamic of production logistics is classified. The PLS mechanism and cloud-based PLS information framework are established. By using collaboration optimization (CO) method, the optimization method of PLS is put forward. Finally, the PLS optimization model of production and storage is presented with an industrial case, and the effectiveness is also demonstrated and analyzed.

Keywords: Production logistic synchronization · Dynamics · Cloud manufacturing · Collaborative optimization

1 Introduction

Production logistics (PL) refers to the warehousing, packaging, transportation, and other logistics-related activities which directly serves for production processes, ranging from raw materials purchasing, shop-floor manufacturing, as well as the circulation of semi-finished or finished products [1]. Production logistics is divided into the pre-production logistics (storage, shipping, production) and post-production logistics (production, shipping, storage). Production logistics of this paper is specifically for the post-production logistics. Inevitable uncertain factors of production logistics operation process (such as emergency order, delivery in advance, equipment failure and worker absenteeism) bring dynamics to the production logistics system, which will affect the

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production, shipping and storage in a part or multiple parts and lead to production logistics system is not working properly, or even stop running, which brings a great challenge to the enterprise decision-making and implementation and greatly increases time and cost of production logistics. There are two aspects impact of dynamic mainly to the production logistics system: the first is that it disrupts the original production logistics plan, and lead to the result deviates from a pre-determined goal; the second is that it sometimes leads to the lack of the ability of production logistics system resources, and it is difficult to add new resources, and the cost is very high.

Production logistics synchronization (PLS) means, in the presence of certain execution dynamics, some parts or the whole PL systems will be real-timely triggered to make adaptively collaborative decision which takes the dynamics into consideration and generates an updated execution plan for the next execution stage [2]. Therefore, under the premise of uninterrupted production logistics operation, the production, shipping and storage of the two or the three can be collaborated, and the whole of production logistics operation can be achieved optimization.

In addition, in recent years, the cloud manufacturing and related technology has provided the solution for the PL system rapid organization resources and the dynamic response of the resources requirement. Cloud manufacturing (CM) provides a service-oriented manufacturing platform to organize the manufacturing resources over internet and enable users to consume on-demand manufacturing services [3]. In CM, various manufacturing resources and abilities can be intelligently sensed and connected into the wider internet [4]. At present, some progress has been made in the application of cloud manufacturing. Xu [5] encapsulates the distributed resources into CM services under centralized management, and offer CM services as product design, manufacturing, testing and management. Wang and Xu [6] proposes a service-oriented and interoperable Cloud manufacturing system. Ren et al. [7] presents a public cloud manufacturing system for small- and medium-sized enterprises (SME).

Therefore, this paper will study how to solve the impact of the dynamic production logistics system to achieve the purpose of optimizing the PL operation by CM and collaboration optimization method [8, 9].

The remainder of the paper is organized as follows. Section 2 will analysis for the production logistics dynamics types. Section 3 will conduct the PLS mechanism. The overall PLS optimization method and mathematical model will be introduced in Sect. 4. Section 5 gives a case for the study the method. Conclusions are summarized in Sect. 6.

2 PL Dynamics Analysis

The different dynamics of production logistics operation have different influence on the system. To take effective method to deal with the dynamic of production logistics, we need to classify the dynamics firstly. This section will analyze the dynamic of production logistics from two aspects, which is range of impact and degree of the impact.

2.1 Classification in Dynamic Impact Range

From the range of dynamic influence of the production logistics system, the dynamic of the production logistics can be differentiated into the global and partial dynamics. As shown in the left part of Fig. 1, when the dynamic interfere with the three subsystems as the production, distribution, warehousing, and trigger the response of the three subsystems, which is defined the global dynamic, for example like emergency ordering, delivery changing, etc. As shown in the right part of Fig. 1, when the dynamic interfere one subsystem, and this subsystem triggers the other subsystem or all of them to respond it, we call it the partial dynamic, such as workshop equipment failure, reworking, forklift failure, the road unavailable, etc.

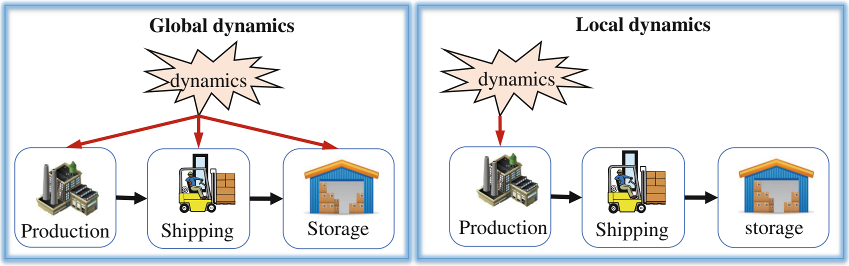

Fig. 1. Global and local dynamics

2.2 Classification in Dynamic Impact Degree

The sensitivity of dynamic in different time and state of production, distribution and storage is different, therefore, the impact of the dynamic on the production logistics system can be differentiated as the first level dynamics and the second level dynamics. When the dynamic affection level of the production logistics system is still in the capacity of the current resources range, we define it the first level of dynamic. For example, when forklifts increase of 10 pallets of transport tasks suddenly or a forklift failed, and the forklift resources of the system is still redundancy, so this dynamic can be cope with. When the dynamic affection level of the production logistics system is out of the current one or more subsystems resource capacity, we define it the second dynamic. For example, the current configuration of the forklift are in the saturated state, even this time increase of 1 pallets transport task urgently, it will inevitably cause the production logistics system disorder and delay delivery.

3 PLS Mechanism

3.1 Synchronization Mechanism

The PLS mechanism as shown in Fig. 2. PLS can generate varied synchronization sequence while according to the quantity of different synchronization starting point and subsystem. Therefore, we need to determine the starting point and the sequence of PLS. The global dynamic synchronization process shown in the left of Fig. 2. Firstly, we should judge the starting point of the PLS, and the basis of judging the starting point is the constraint strength of the subsystem. For example, the target of the production subsystem is to complete the order of that day, which must be completed, and the target of other subsystems is variable, in this time, the production subsystem is the starting point. Secondly, starting point to determine the synchronization sequence of production logistics and start synchronization other subsystems, such as the production synchronization shipping or shipping synchronization storage. The local dynamic synchronization process shown in the right of Fig. 2. For the local dynamics do not need to determine the starting point of the synchronization, It is only a need to identify the dynamic generation point and this point is the starting point for the production of logistics synchronization, such as production, while the starting point of the synchronization from the production subsystem.

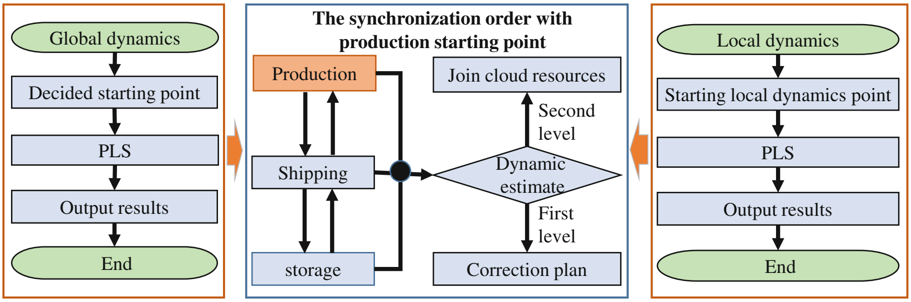

Fig. 2. PLS mechanism

The sequence is the production as the starting point, and the synchronization between shipping and storage is to describe the different dynamic levels, which contains three steps, as shown in the middle of Fig. 2.

- Step 1 is dynamic level estimate. If the dynamic is the first level then execution steps 2, else if is the second level then execution steps 3.
- Step 2 is to correct the plan. It is the first level dynamic processing method. This step only corrects the results of the pre-decision based on the allocated resources, such as the finished offline time, storage tasks, forklift transportation tasks, etc.
- Step 3 is to join cloud resources. This step is the second level dynamic processing method. The logistics resources can be virtualized cloud resources by cloud resource management platform, such as forklift, warehouse, production equipment, etc. Through the cloud resource platform adds cloud resources, re-planning tasks, which can solve the problem of the shortage of resources capacity caused by the dynamic.

3.2 PLS Information Framework

Based on the above explanation, a framework is developed based on the above mentioned mechanism, which is put forward by the authors' research team [2], as shown in Fig. 3. The bottom part of Fig. 3 is the physical resource layer and the smart object layer, through equipping the physical PL resources with a series of IoT devices (such as PDA, mobile, PAD etc.) and IoT tags (such as RFID, sensor, barcode etc.), the original resources can be transformed into smart objects (PL-SO) which have the ability of real-time information perception, transmission, and task processing. The left part of Fig. 3 is CM infrastructure, which defines the management, organization and service hierarchy of CM resources. It includes three layers.

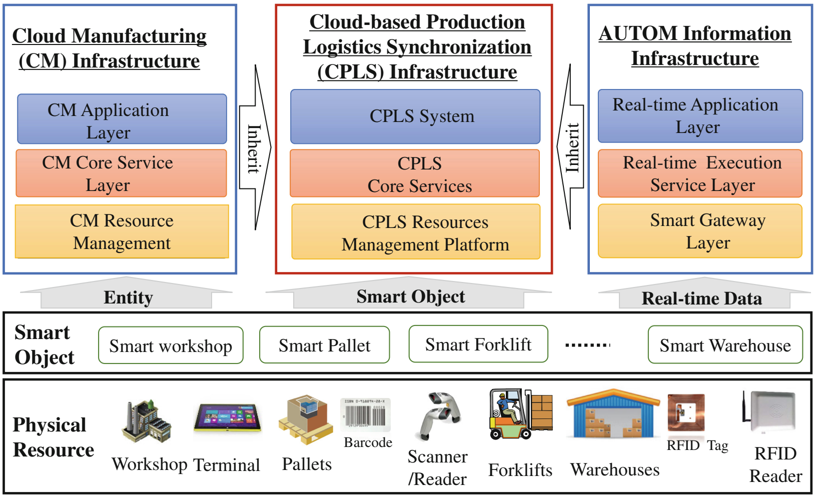

Fig. 3. Cloud-based PLS information framework

During the production logistics process, dynamically triggered two level dynamics will lead to the continuous involvement of uncertain manufacturing resources from the cloud. Due to the uncertain types, interfaces and capabilities of the various cloud resources, it is difficult to maintain a highly efficient operation. Thus, heterogeneous resources must be encapsulated by IoT technologies in a standard way, based on which a set of standards and measures for real-time information collecting, processing, and transmitting could be established. Finally, the major services and applications could be developed based on the standard real-time information to effectively support the production logistics process management. This paper extends AUTOM [10] to deal with the real-time PL information from cloud-managed PL resources. A brief representation of AUTOM is shown in the right part in Fig. 3, which consists of three layers.

4 PLS Optimization Method

PLS is a multiple subsystems coordination optimization problems, due to the process of synchronization has emphasized the dynamics, the independence of the decision-making model and the agility which come from the decision-making. Collaborative optimization (CO) [11] is a kind of stratified two-layer MDO method, which has system level optimization function. For the subsystem, which the analysis and optimization design is within the space of each subsystem. It's suitable for the subsystem variable much more than the subject (subsystem) variable, which applies to solve the multidisciplinary design optimization problem that has the goal of system level design. Therefore, this paper uses CO to solve the PLS optimization problem.

4.1 PLS Model

The mathematical model of the production logistics synchronization system is established by using the CO optimization method as follows.

1. System level optimization model

$$\min f(z) \tag{1}$$

$$\text{subject to} \quad J_i^* = \sum\nolimits_{j=1}^{s_i} \left(z_j - x_{ij}^*\right)^2 = 0, i = 1, 2, 3 \tag{2}$$

   The variable $J_i^*(\mathrm{z})$ is the consistency equality constraint for the system, z is the system optimization variable, z_j is the design variable for the j system, s_i is the design variable quantity of the i subsystem, and x_{ij}^* represents the optimization results of the design variable j of the subsystem i.
2. Subsystem level optimization model

$$\min J_i(x_i) = \sum\nolimits_{j=1}^{x_i} \left(x_{ij} - z_j^*\right)^2 = 0 \tag{3}$$

$$\text{subject to} \qquad c_i(x_i \leq 0), \quad i = 1, 2, 3 \tag{4}$$

   The variable x_i is design vector of the subsystem i, x_{ij} is the design variable j of subsystem i, z_j^* is the expected value of the design variable j for the system assigned to the subsystem i, and $c_i(x_i)$ is a system level constraint.

The optimization structure of the above mentioned mathematical model is shown in Fig. 4.

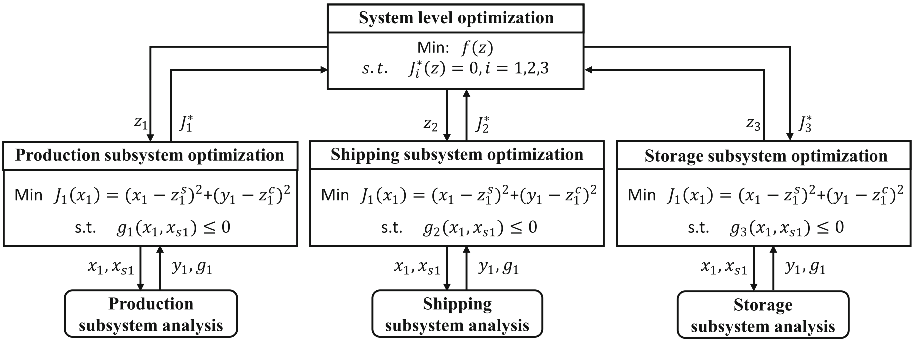

Fig. 4. Structure of production logistics collaborative optimization

4.2 Constraints Relaxation

The collaboration optimization method for the consistency constraint of the system level optimization problem is the equality constraint. But the consistency of equality constraint is too strict for the subsystem. Therefore, the system level equality constraints are changed to inequality constraints, so that the system level has feasible solution domain [11]. After the deformation, the system level constraints become the following inequality.

$$J_I^* = \sum\nolimits_{j=1}^{s_i} \left(z_j - x_{ij}^*\right)^2 \leq \varepsilon, i = 1, 2, \ldots, n \tag{5}$$

Through adding the relaxation factor ε, ε is smaller, which indicates a higher degree of consistency for the subsystem level, and means the performance of the cooperative optimization method is improved.

5 Case Study

The case company is a large-size old-brand paint making company in China. At present, the application process of the PLS optimization method is illustrated with the two parts of its production and storage, as shown in Fig. 5. After receiving the orders, the production need to develop production scheduling, and the warehouse need to arrange storage location. However, the production process or storage process often occurs dynamic, such as product line early or delay, equipment failure, workers absenteeism, the storage location unavailable etc. It lead to that the scheduling and the storage location planning results are poor, and the cost of PL operation is high. To solve above problems, the author's project team has done two aspects of work. First, according to the operation process of the company PL, using Internet of things and CM technology to develop a PL management system interconnect between workshop and warehouse, and realize the transparency of management; Second, this paper studies the PLS optimization method is applied to above two links. This section focuses on the second part of the research.

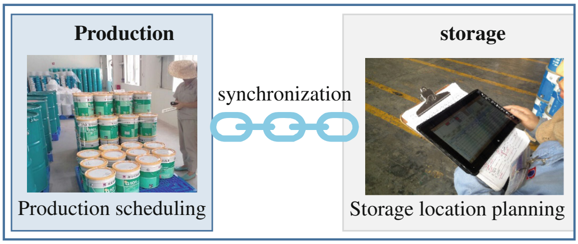

Fig. 5. Production and storage synchronization

5.1 Collaborative Optimization Model

This case is based on the synchronization between production and storage (i.e., production scheduling and storage planning) and the CO model is established.

System Model. The system model can be established as follows.

$$\min F = t_1 + t_2 \tag{6}$$

$$\text{Subject to } J_1 = (t_{11} - t_1)^2 \le \varepsilon \tag{7}$$

$$J_2 = (t_{22} - t_2)^2 \le \varepsilon \tag{8}$$

The objective function (6) is the minimum customer waiting time. Constraint (7) and (8) are system consistency constraints, t_{11} is the system level design variable for the production subsystem, t_{22} is the system level design variable for the storage subsystem, t_1 and t_2 are system level design variables.

Production Subsystem Model. In this case, the production subsystem optimization problem is how to plan the orders processing sequence on the equipment, so that the production task completion time is shortest. According to the practical of production, the variables shows in Table 1.

Table 1. Variables and definition

Variable	Definition	Variable	Definition
i	Order number	j	Process number
K_i	Processing unit number of order i	D_{ij}	Equipment number of the process j for order i
WT_{ij}	The processing time of the process j on the equipment for the order i	x_{ijkd}	The processing unit (i,j,k) on the equipment $D_{i,j}$ processing and the value is 1, else is 1.
$T_{f_{ijk}}$	The time of processing start and end	$N_{t_{ijk}}$	The next processing time after the processing unit (i,j,k) in the equipment.

Following the above parameters and variables, a mathematical model of production scheduling could be established as follows.

$$\text{minf} = \left\{ \max_{\forall d \in D} \left\{ max_{\forall i \in I, j \in J, k \in K_i} \left\{ x_{ijkd} * T_{f_{ijk}} \right\} \right\} \right\} \tag{9}$$

$$\text{Subject to} \quad \sum\nolimits_{d \in D_{ij}} x_{ijk} = 1, \forall i \in I, j \in J, k \in K_i \tag{10}$$

$$\mathrm{T}_{f_{ijk}} - \mathrm{T}_{b_{i(j+1)k}} < 0 \forall i \in I, j \in \{1, 2\}, \mathrm{k} \in K_i \tag{11}$$

$$T_{f_{ijk}} - T_{b_{ijk}} = WT_{ij} \forall i \in I, j \in J, k \in K_i \tag{12}$$

$$N_{t_{ijk}} - T_{f_{ijk}} > 0 \forall i \in I, j \in J, \mathrm{k} \in K_i \tag{13}$$

The objective function (9) is the minimum completion time of a batch of orders, $max_{\forall i \in I, j \in J, k \in K_i} \left\{ x_{i,j,k,d} * T_{f_{i,j,k}} \right\}$ means the completion time for all processing units on the equipment D, $\max_{\forall d \in D} \left\{ max_{\forall i \in I, j \in J, k \in K_i} \left\{ x_{i,j,k,d} * T_{f_{i,j,k}} \right\} \right\}$ means the completion time of all processing units for all the equipment. Constraint (10) defines that a processing element is allocated to an equipment. Constraint (11) gives that only before the neck of the order has processed and then the after the neck of the order can be processed. Constraint (12) defines that once a processing unit begins processing and cannot be interrupted. Constraint (13) guarantees that only after the current task is finished and the next task can be started by the equipment.

Storage Subsystem Model. In this case, the storage subsystem optimization problem is how to distribution the storage location for the order and make the utilization rate of the warehouse is the highest, and its parameters and variables shown in Table 2.

Table 2. Variables and definition

Variable	Definition	Variable	Definition
t	Time list of waiting input order	j	Storage location number
i	Order of waiting input	V_j	Capacity of storage location j
Q_i	Quantity of pallets for order i	E_j	Consumption time of output from storage location j
IT_i	Input time number for order i	x_{ij}^t	Time list t put the order i in the storage location j or not, the value is 0 or 1
OT_i	Output time number for order i	w_{ij}^t	The $w_{ij}^t = 1$ means the quantity pallet of order i in the storage location j, if $x_{ij}^t = 0$, then $w_{ij}^t = 0$

Following the above parameters and variables, a multi-objective model of storage location layout could be established as follows.

$$\min f_1 = \sum\nolimits_{j=1}^{L} U_t^j \tag{14}$$

$$\max f_2 = \sum\nolimits_{j=1}^{L} F_t^j \tag{15}$$

$$\max f_3 = \sum\nolimits_{t=1}^{T} \sum\nolimits_{j=1}^{L} \sum\nolimits_{i=1}^{S} \left(E_j x_{ij}^t w_{ij}^t\right) \tag{16}$$

$$\text{Where } F_t^j = \begin{cases} 1, & x_{aj}^t w_{aj}^t + x_{bj}^t w_{bj}^t = V_j, \qquad \mathrm{j} = 1, 2, \ldots, \mathrm{L}, \\ 0 & \qquad\qquad\qquad\qquad\quad \text{and } \mathrm{a, b} = 1, 2, \ldots, \mathrm{S} \end{cases}$$

$$U_t^j = \begin{cases} 1, & x_{aj}^t w_{aj}^t + x_{bj}^t w_{bj}^t > 0_j, \qquad \mathrm{j} = 1, 2, \ldots, \mathrm{L}, \\ 0 & \qquad\qquad\qquad\qquad\quad \text{and } \mathrm{a, b} = 1, 2, \ldots, \mathrm{S} \end{cases}$$

$$\text{Subject to} \quad \sum\nolimits_{\mathrm{j}=1}^{L} x_{ij}^t \leq 2\mathrm{j} = 1, 2, \ldots, \mathrm{L}; \mathrm{t} = 0, 1, 2, \ldots, \mathrm{T} \tag{17}$$

$$\sum\nolimits_{a,b=1}^{S} x_{aj}^t w_{aj}^t + x_{bj}^t w_{bj}^t \leq V_j, \mathrm{j} = 1, 2, \ldots, \mathrm{L}; \mathrm{t} = 0, 1, 2, \ldots, \mathrm{T} \text{ and } \mathrm{a} \neq \mathrm{b} \tag{18}$$

$$\sum\nolimits_{\mathrm{j}=1}^{L} x_{ij}^t w_{ij}^t = P_i, i = 1, 2, \ldots, S \text{ and } \mathrm{t} = 0, 1, \ldots, \mathrm{T} \tag{19}$$

The objective function (14) is the minimum total quantity of storage location. The objective function (15) is the maximum times of full storage location. The objective function (16) is the maximum loading efficiency. Constraint (17) ensures the quantity of each storage location puts orders no more than two. Constraint (18) defines the total number of pallets cannot exceed the capacity of the storage location. Constraint (19) gives the total quantity of pallets for sales order.

Structure of Model. The structure of CO model is shown in Fig. 6. The collaborative between system level and subsystem level is t_1, t_2,t_{11}, t_{22}. The system initial variables is t_1, t_2. Where t_{11} is a collaborative variable for the production subsystem which indicates the completion time of a batch of order, t_{22} is a collaboration variable for the storage subsystem which means the order at the warehouse time.

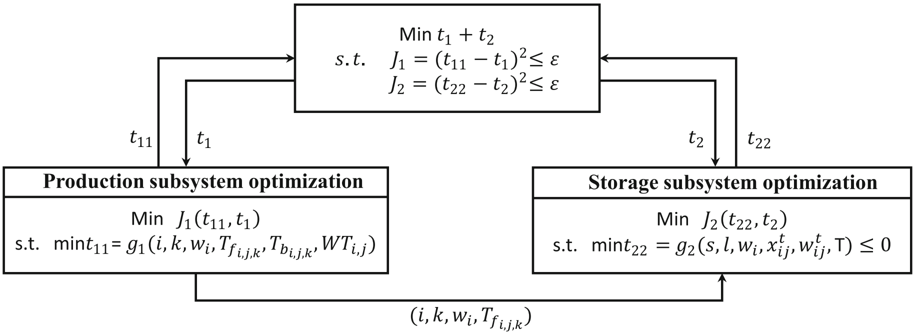

Fig. 6. Structure of production and storage CO model

The (i, k, $T_{f_{i,j,k}}$, w_i) is the array between production subsystem and the storage subsystem, The variable of the array contains the order number, the order processing unit, the processing completion time, and the number of pallets. These variables are the input parameters of the storage subsystem. Based on these input parameters, the storage subsystem obtains the most reasonable distribution results. Each subsystem involves only its local constraints, on the basis of meeting constraints, and its goal is to reduce the differences between the system level and the system level as far as possible. The system level optimization problem has two consistency constraints, and are respectively corresponding to two subsystems.

5.2 Example

Initial Information. The initial data of this example comes from the company. The order information is shown in Table 3 and the warehouse information is shown in Table 4.

Table 3. Order information

Order number	Demand quantity(t)	Processing time (min)	Tray quantity of product
1	1.5	80/120/70	19
2	2	90/100/80	25
3	1	80/90/75	13
4	1.5	80/70/90	19
5	1	100/110/100	13
6	2	90/100/80	25

Table 4. Warehouse information

Storage location number	Name	Capacity	Area	Outbound efficiency
1	A1	20	Dispatch area	2
2	A2	20	Dispatch area	2
3	A3	20	Dispatch area	2
4	A4	20	Dispatch area	2
5	A5	20	Dispatch area	2
6	B1	8	Full area	1
7	B2	8	Full area	1
8	B3	8	Full area	1

Results Analysis. The initial values of the parameters t_1 and t_2 of the 5.1 sections are set 0, the relaxation variable ε is set 10^{-4}, and the initial information is brought into the mathematical model. The results of the calculation are shown on the left of Table 5 by the Matlab software. To illustrate the effectiveness of PLS optimization method, this paper chooses the deterministic optimization method for comparison. Its calculation results are shown on the right of Table 5.

Table 5. Storage subsystem optimization results

Order number	Tray quantity	PLS optimization method			Deterministic optimization method		
		Input list	Output list	Storage location	Input list	Output list	Storage location
1	19	5	6	A5	3	3	A3
2	25	3	4	A3/B1	2	4	A2/B1
3	13	2	2	A2	2	1	B1/B2/B3
4	19	1	1	A1	1	2	A1
5	13	4	3	A2/B1,B2	4	4	A1
6	25	3	5	A4/B2	5	6	A5/B3

From the results can be seen, in terms of storage location occupancy, all the pallets take up 7 storage location of the total which the warehouse adopt the PLS optimization method, and the storage location B3 is empty. While the warehouse adopt the deterministic optimization method, total takes up 8 storage location, and all the storage location are taken up. In terms of the full times of storage location, all the storage locations are full by PLS optimization method, but the quantity of full storage location is 7, and storage location A4 is not full by deterministic optimization method. From the results of the comparison, it can be seen that the production and storage synchronization method can improve the utilization of the storage location.

6 Conclusion

Synchronization mechanism and the optimization method is proposed in this paper to solve the dynamic production logistics problem of production logistics operation of the among production logistics multiple-subsystems. The dynamic of production logistics is divided into local dynamic, the global dynamic, first level dynamic and second level dynamic. For different dynamic, from the qualitative point of view, the PLS mechanism and cloud-based PLS information architecture are proposed. From the quantitative point of view, CO-based PLS optimization method is proposed. Finally, based on example of an enterprise of production and storage, establish optimization model of synchronization of production and storage, and the results show that the proposed method enhances the utilization of the goods. The methods of this paper have practical guidance for solving the problem of the dynamic problem of the operation of production logistics. In the future, the method for synchronization problem of multiple-subsystems of difficult PL dynamic and is studied.

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Ontology-Aided Production - Towards Open and Knowledge-Driven Planning and Control

Towards Ontology-Aided Manufacturing and Supply Chain Management – A Literature Review

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Abstract. Semantic technologies are recognized as crucial in those domains, which intensively exploit information and communication technologies (ICT) and automation technologies (AT). Ontology engineering means can facilitate new functionalities, organizational structures and processes. Intra- and inter-organizational integration of different layers, functions, domains and processes may be simplified or enabled. Knowledge-driven solutions can be also facilitated. This paper investigates functional aspects of ontology-aided manufacturing and supply chain management by a literature review. The purpose is to assess potential for further research and to suggest its future key directions, aiming at novel solutions in terms of structures, controls, processes and functionalities.

Keywords: Ontology · Manufacturing management · Supply chain management · Semantic integration · Knowledge-driven management

1 Introduction and Methodology

This work investigates advantages of ontologies as the means for semantic integration of operations management activities, particularly as facilitators of new provisions in terms of novel structures, processes and controls. Semantic technologies are recently recognized as crucial management technologies for those domains, which intensively exploit ICT and automation [27]. Ontologies support intra- and inter-organizational integration of different domains, functions, layers and processes. Ontologies enhance changeability, in reference to business resources and processes.

The main streams of industrial development in recent decades were to major extent supported by innovations in the ICT and AT area. The key enabling technologies with this regard were: smart/mobile solutions, Web services, Service-Oriented Architectures (SOA) and semantic technologies. In parallel, mostly due to globalization and technology revolution increasing openness was affecting various areas, hence driving complexity, like: spatial spread, networking, coupling, variability etc. These qualitative changes tended to act as generic determinants for considered developments. Hence extraordinary challenges and opportunities arise concerning development of operations resources, processes and systems. Handling various aspects of complexity provides another major issue for managing globalized operations.

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This paper provides literature review based state-of-the-art of using ontology-aided manufacturing and supply chain management. A functional, but not technical perspective is focused on. The objective herein is to assess the need and potential for further research and to suggest its future key directions, particularly aiming at novel solutions, i.e. in terms of structures, processes and controls. This research goes in parallel with a similar one, of industrial requirements but as seen by industries [21].

The number of published ontologies for manufacturing and logistics is limited. Many of them target specific areas, and only few address management and control manufacturing and logistical operations. All of them are reviewed below. Principally their scope, depth and targeted use are commented. Only the most representative papers from different research centers are refereed.

2 Literature Insights on Manufacturing Management Ontologies

This section reviews all ontologies for manufacturing operations management, that were accessible to the author.

The ontology of Soares et al. [26] focuses on production planning and control in a virtual enterprise to improve human communication and to support specification of system requirements. It is founded on meta-ontology, whereas the concepts are defined by natural language and object models.

Lemaignan et al. [16] presented MASON ontology (Manufacturing's Semantics Ontology), which is built upon three head concepts: resources, operations and entities. For each class several subclasses were defined.

Dassisti et al. proposed an ontology-based model which follows IEC 62264 standard [8]. It includes models for: (a) Product Definition; (b) Materials; (c) Equipment; (d) Personnel; (e) Processes Segments: it contains process segments that list the classes of personnel, equipment, and material needed; (f) Production Schedule: made up from one or more production requests; (g) Production Capability; (h) Production Performance. Extended conceptualizations were provided for two of the above classes.

Cândido et al. described the ontology for shop floor assembly [5]. Two categories of concepts were proposed: modules and skills. Modules represent physical processing units or their aggregation, i.e. compositions of workstations. Workstation is a composition of transforming, flow or verification units. Two constructs "composed-of" and "is-a" are used to describe compositions and specialization relations. Skills represent abilities to perform operations. The basic element which uses ontology as a model for reasoning about objects and their relations is the Manufacturing Resource Agent (MRA). This agent searches ontology after instantiation for skills it supports. MRA agents can form coalitions to provide combined skills. In such case a Coalition Leader Agent coordinates execution of elementary actions by coalition members.

Obitko et al. proposed ontology for Agent-Based Manufacturing Systems [20]. The basic categories in it are: (a) customer order, (b) production plan, (c) workstation, transportation and material handling. All of them reuse classes and properties from the Core Ontology that for example separates physical and information resources. There are also other ontologies, such as ontology for the configuration of the system.

Battista et al. [3] proposed a modeling framework which incorporates: (1) product and planning data (BOM - Bill of Materials, process charts, MPS (Master production Schedule), calendars etc.); (2) operations and equipment data; (3) production and inventory control policies; (4) distinction between physical and information layer. Although the above framework is not named as ontology, the authors advocate for using ontology of manufacturing system including the proposed elements.

Garetti and Fumagalli suggested three layers within their P-PSO ontology [11]: physical, technological and control. The main classes are: part; component (system structure); operation; controller (decisional element for production planning and control, i.e. be person, PLC or software); operator; subsystem (service class for grouping objects of classes). The ontology includes sound taxonomy of the transporter and storage subclasses. Apart of the controller class the control aspect of the P-PSO ontology incorporates following classes: rule (logic of decision making: algorithm, heuristic, simple rule or knowledge-based rule); order (to be produced or purchased); production plan (set of orders generated by controller for time frame; it can be divided into sub-plans); batch; task (action of controller on component, part and operation classes, i.e. translation of controller actions at the physical level; e.g.: dispatching).

Al-Jumaili et al. investigated possibility of using ontologies in the context of eMaintenance aiming at easier exchange and better quality of maintenance data [1].

Krupa [14, 15][1], developed in 1980s a complete conceptual framework for manufacturing and logistics rooted in the theories of sets, graphs, automata artificial intelligence formal linguistics. It uses two basic categories for describing the domain: resources and tasks. It is distinctive by many features, of which some were never addressed by the literature. The key of them are:

- Semiotic interpretation of resources (in terms of classes, objects and denotations).
- Distinction of transformation operations on the resources. Distinction of transformation-informative, structural and functional relations of resources. Distinction of systemic transformation operations on the resources.
- Consideration of other structuring formalisms for resources than those rooted in the theory of sets, e.g. collectivities of resources.
- Functional and automata-based interpretation of dynamic behavior of resources.
- Distinction of global/local (a priori, a posteriori) discrepancies between properties.
- Distinction of tacit (procedural) and explicit (structural) representation of tasks.
- Distinction of different forms of representation of tasks: procedural, predicate, operator, space of states, hypergraph, logistical model, mixed representations.
- Use of scenarios and logistical models of tasks and reasoning about them).

Although the term ontology was not used in Krupa's framework, it meets common definitions of ontology, i.e. it is a formal explicit description of concepts in a particular domain. It is descriptive in the Seidewitz's sense [25], and also prescriptive. To note, the dyadic construct of tasks and resources proposed by Krupa preceded the SOA paradigm.

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[1] Krupa has mostly published in research reports of limited circulation. His contributions were summarized in the later of refereed publications.

Vegetti et al. [28] and Giménez et al. [12] proposed an ontology for complex product modeling, which was expected to provide foundations for a distributed product data management supported by Semantic Web technology. The ontology suggests three abstraction levels for representing product-related concepts: product family, variant family and product (or physical item). A common formal vocabulary concerning product data that formalizes both processes of information aggregation and disaggregation that occurs during production planning activities is a focus herein.

Alsafi and Vyatkin [2] proposed an approach to achieve fast reconfiguration of modular manufacturing systems, based on an ontology-based reconfiguration agent. The agent uses ontological knowledge of the manufacturing environment for the purpose of reconfiguration without human intervention. It infers facts about the manufacturing environment from the ontological knowledge model and then decides whether the current environment can support the given manufacturing requirements. The knowledge model is based on previously mentioned MASON ontology.

All ontologies reviewed above are discussed together with the supply-chain ontologies in Sect. 4.

3 Literature Insights on Ontology-Aided Supply Chain Management

This section reviews all ontologies for supply chain operations management, that were accessible to the author.

Daniele and Pires Ferreira described core ontology for logistics focusing on the concept of physical resource [7]. A limited taxonomy of resources and their structures and some axioms in reference to relations between resources have been proposed.

Scheuermann and Hoxha proposed intelligent supply chain management (SCM) based on a combination of Semantic Web technologies and SOA [24]. They introduced dedicated ontology to semantically annotate logistics services using a three-layered model: (1) logistics ontologies providing foundation for defining formal semantics of consensual logistics knowledge; (2) semantic logistics service descriptions used for representation of atomic logistics services for description of service features and utilization of logistics ontologies of Layer 1 for semantic annotation; (3) atomic logistics services composed into complex logistics processes. This model includes elements to describe both, declarative and procedural aspects.

Madni et al. introduced the IDEON ontology to support design, reinvention, managing and controlling collaborative distributed enterprises [18]. IDEON integrates multiple perspectives, like enterprise context view or process view. It is presented in UML and conforms to simple taxonomies of resources and activities.

Leukel and Kirn developed a logistics ontology based on the SCOR model to capture core concepts of inter-organizational logistics [17]. The proposal facilitates description of activities in logistics and provides relations and attributes.

Haugen and McCarthy [13] proposed an extension of the REA (Resource-Event-Agent) Ontology, which was originally designed for the accounting domain, to support Internet-based supply chain collaboration.

Fayez et al. proposed a representation of the SCOR model for supply chain simulation developed in the OWL language [10]. The ontology captures the distributed knowledge being required to integrate several supply chain views in order to support the construction of simulation models. A further study of SCOR representation by means of ontology engineering is presented by Zdravković et al. [30].

Chandra and Tumanyan applied an ontology to systematically record knowledge about organizational and problem-specific issues for SCM [6]. They proposed an information modelling framework to create a taxonomy of supply chain problems and operations to alleviate operational uncertainty.

Pawlaszczyk et al. introduced an enterprise ontology to optimize inter-organizational and distributed co-operations [22]. It is distinctively tailored to the mass customization environment and enables modelling of different scenarios concerning development or implementation of mass customization.

Ye et al. proposed a supply chain ontology (SCO) to enable semantic integration between heterogeneous supply chain information systems [29]. The supply chain setting is a web-based or virtual enterprise with no specific industry focus. The ontology is implemented in the OWL DL using the skeletal method to capture concepts and relationships of the domain. A rule-based approach is presented to map semantically similar terminologies between SCO and application ontologies.

Engel et al. proposed an ontology-based, knowledge-assisted platform to collaboratively create, adapt and control supply chain networks [9]. Such a platform is expected to reuse domain knowledge captured in previous supply chain projects and support simulation of various network configuration.

Mettler presented a formal ontology containing some concepts for analyzing manufacturing networks as service systems [19]. The ontology consists of sixteen key constructs like business areas, functions, roles, partners, goals, success factors, performance indicators, incentives, various resources and processes. For every construct a short description, exemplary instances or sub-classes, and the relations to other constructs is defined. They are formalized using OWL and RDF.

Sandkuhl et al. [23] investigated integration of information systems and production planning systems in enterprises with physical systems, like automation and control systems, into Cyber-Physical Systems (CPS) with focus on the logistics domain and on the service-oriented approach. The core proposal is a generic architecture for Logistics-as-a-Service systems (LaaS), representing elements of the logistics network as services. It is enriched with concepts from competence management and ontology matching. Ontology-based competence profiles are proposed for representing individual and organizational competences. Ontology matching contributes to configuring and finding resources in LaaS. Within the ontological representation of services and competences, multi-lingual ontology matching was also proposed.

Brock et al. discussed application of semantic modeling to allow free flow of models that are used along planning and control within a logistical network [4]. Their approach is intended to improve the productivity of logistical modeling in reference to operations management and control.

All ontologies reviewed in this section are discussed all together with the manufacturing ontologies in the next section.

4 Findings and Conclusions

Most of the publications reviewed in the two preceding sections address focus on some narrow or specific aspects, or are limited to few, and often abstract concepts. Many of them provide a limited description of ontologies and remain high-level. Other apply ontology languages upon existing models. Such narrow focuses are somehow understandable, as papers normally have to be of a limited size. But after a closer analysis of details in these publications it is unquestionable that most authors do not target anything else but rather initial and rough vision of the ontology.

Almost all papers avoid important but difficult aspects of the domain, e.g. details of planning and controlling operations, dynamics and behavioral issues of production networks and supply chains, etc. The non-hierarchical paradigm is also rarely addressed. Under-specifications are never incorporated into discussed conceptualizations.

Most publications lack rich formal semantics. Description logic is rarely used. Limited taxonomies usually lack formal axioms. Decision making is mostly not discussed. The service-oriented paradigm is bypassed or even neglected. The potential of semiotic interpretation of resources, tasks and other classes is rarely explored.

The most important research gap identified is in reference to the dynamic behaviors of systems and processes within the domain. It particularly refers to representation of complexities and discrepancies that may arise along planning, controlling or execution of operations. Among them the following are typical: correlations, interdependencies, synchronizations, static and dynamical (temporary) fits and conflicts, blockings, starvations etc. The roots of them are analyzed by the literature to a very limited extent, if at all, like e.g.: layout driven limitations to flows; dynamic transformations of temporarily coupled resources and tasks (orders, flows etc.). Only one of the reviewed papers considers distinction of enduring and perduring classes of the resources and tasks and it indirectly provides spatiotemporal mereotopology of transforming operational tasks and resources.

On the other hand, all reviewed publications exhibit enabling potential of ontologies. However, it is mostly understood narrowly, i.e. in reference to direct advantages of ontologies, like provision of better performance, improved changeability, and other gains from utilization of knowledge or new functionalities. Systemic advantages that may lead to novel solutions in terms of system architectures, processes and controls are rarely investigated, and if at all than not in-depth. There are good reasons to argue that research concerning ontology-aided operations management for manufacturing and logistics is not as advanced, as – to compare - in the field of medical informatics.

The above conclusions fully justify following recommendations for further research concerning the discussed domain:

1. Development of core ontology for manufacturing and logistics operations management that could facilitate domain, sub-domain or application ontologies.
2. Development of ontologies equipped with spatiotemporal and mereotopological transformational abstractions to represent dynamic and spatial complexities arising along operations management, and exploiting advantages of the SOA paradigm.

3. Development of new conceptualizations for various and diverse structures of resources (from systems to collectivities), processes (aiming changeability), and planning and control of operations (using alternative and novel control structures and rules, like heterarchical, distributed, herd or local controls).
4. Addressing cross-organizational operations management (i.e. beyond MRP/ERP).
5. Exploiting advantages of localized, globalized or outsourced (public) intelligence, and also the potential of merging ontologies and Big Data capacities.
6. Adapting current mode of operations management to local and temporary factors.

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Webservice-Ready Configurable Devices for Intelligent Manufacturing Systems

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Abstract. This paper takes closer look at inner structure of an *eScop* RTU device, a highly configurable PLC-like embedded device developed in Node.js environment for low level physical layer of Intelligent Manufacturing Systems.

Keywords: Structured text · Control system · Embedded device · Web service · IEC 61131-3

1 Introduction

Embedded system for Service-based Control of Open manufacturing and Process automation (*eScop*) is a system that aims to overcome the current problems of production systems integration at shop-floor control level by semantically integrating embedded devices. The main idea behind the *eScop* architecture is to use embedded devices together with an ontology-driven service-oriented architecture (SOA). This approach allows the system to be automatically configured based on the ontology using embedded devices at the physical layer. This reduces setup time during which the manufacturing system stops.

2 *eScop* Device

eScop system is based on embedded devices – *eScop* devices. Profile of these devices is introduced in [1] where basic behavior and REST interface of device are described. Purpose of this article is to give closer insight into inner structure of *eScop* device.

Components of *eScop* Device (or *eScop* Remote Terminal Unit – RTU) are depicted in Fig. 1. Apart from the REST-API, *eScop* device consists of three components that enable the device to execute scripts written in Structured Text. Structured Text Language(STL) is one of five languages supported by the IEC 61131-3 standard and is designed for programming PLC devices.

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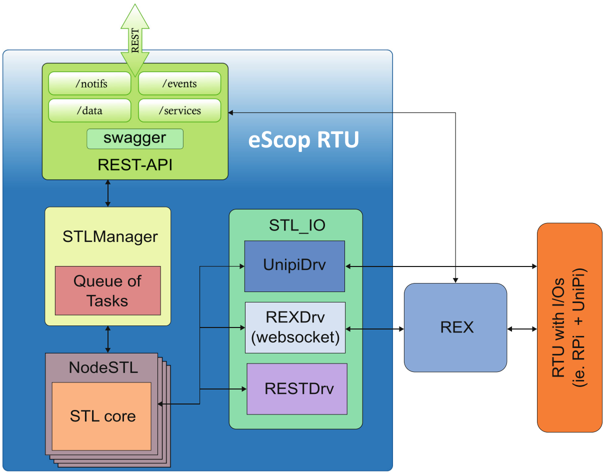

Fig. 1. *eScop*RTU device

3 STL Parser/Interpreter

One of the main goals to reach when developing *eScop* device was to create easily reconfigurable PLC like device. Configuration of the device is done through scripts written in Structured Text.

An STL Parser/ Interpreter was created using Bison and Flex. Bison is a general-purpose parser generator that converts an annotated context-free grammar into a deterministic or generalized parser [2]. Flex is a tool for generating programs that perform pattern-matching on given text [3].

Detailed description of STL Parser/Interpreter interface can be found in Table 1. First part of the interface contains functions for manipulation with STL files in interpreter like loading new file to interpreter or removing file from interpreter. Second part of the interface contains functions for calling STL functions. STL interpreter currently also supports functions with parameters that are passed into the function by reference. These references can be created and destroyed by functions PushArray() and PopArray(). This mechanism is necessary for calling functions with arrays as parameters or with in-out parameters that serve as input and also as output.

The function for calling STL functions `CallFunction()` has an option to specify how many instructions in STL language should the interpreter process. This enables to suspend the STL function execution and gives the option to trace the program's execution and can be used for debugging purposes. If function's execution has not finished, `CallContinue()` function must be called to continue the execution.

Last part of interface contains functions for handling events. Event is raised when the STL Interpreter reaches instruction `EVENT(X)`, where `X` is an integer that identifies the event. Raising an event will cause the interpreter to stop execution and give the programmer opportunity to react to this event. This mechanism was later generalized for defining external functions. External functions are defined as functions that are only declared in STL file but they are implemented elsewhere. External function in STL file is declared by its header with specified parameters and with an instruction `EXTERN` in its body. This specific instruction is just a macro for raising special event that denotes external function execution. Example of definition of external function can be found in Code snippet 1.

Table 1. STL Parser/Interpreter interface

File manipulation interface	
AddStl()	Loads new file into the parser and returns list of functions it contains
RemoveStl()	Removes specified file from the parser
ResetStl()	Resets parser. Used when errors occur
Function handling interface	
CallFunction()	Calls specified STL function
CallContinue()	Continues execution of the function if the execution have not finished by calling CallFunction()
PushArray()	If a parameter should be passed to the function by reference than this function must be called before actual call of the function to push parameter to the interpreter and obtain reference (pointer)
PopArray()	After argument passed in by reference is not used anymore than this function should be called to clean up
Events and Extern functions interface	
GetEventFunction()	Returns function that the event was raised in
GetEventParam()	Returns parameters of function that the event was raised in
GetEventArray()	Returns parameters passed in by reference

4 Integration of STL Interpreter with Node.js

STL Interpreter is a component where computing power is very important aspect. That is also one of the reasons why this component is implemented in `C` programming language. However for the development of *eScop*device was chosen the Node.js runtime environment mainly for its event-driven architecture and a non-blocking I/O API that optimizes an application's throughput and scalability. Now the question has been raised how to integrate these two environments together.

Node.js supports two options how to use libraries written in `C/C++` from JavaScript code. First of them is to use FFI (Foreign Function Interface) mechanism and that allows to call a function from one program in another program

```
FUNCTION readRelay:INT;
   VAR_INPUT
    id:INT;
   END_VAR
   VAR_IN_OUT
    value:BOOL;
   END_VAR
   EXTERN;
END_FUNCTION
```

Code snippet 1. Declaration of external function in STL.

usually even across programming languages. Using FFI involves loading shared library at runtime and marshalling the arguments of function from one program to another before each call. This mechanism is very simple to use but not very efficient.

The other option is to write a specific so called native addon in `C/C++` that wraps functions from desired library. This addon than can be used in JavaScript code in same manner as any other JavaScript object. This approach is about hundred times faster than FFI but developer needs to handle every conversion between JavaScript types and `C/C++` types by himself.

The approach using FFI might still be useful for calling functions containing heavy calculations and/or if these functions are not called very often but for the purpose of *eScop* device its performance is insufficient. That is why it was chosen to implement native addon for Node.js that serves only as a thin wrapper for STL Interpreter. This wrapper is denoted as NodeSTL component in Fig. 1.

5 STL Manager

A Service Manager Core component was introduced in [1]. This component is partially implemented by the component STL Manager that manages adding and building services simply by using NodeSTL component and its STL Interpreter to load STL file and expose functions defined inside as new services.

5.1 Task Management

STL functions can be designated as one of three types of services defined by [1] as *process*, *operation* and *query*. Execution of services defined in STL files must be controlled to avoid deadlocks and collisions in STL interpreter. Thus a simple task management have been introduced.

Every service invocation creates a task that is assigned a priority based on its service type. The task is than pushed to a priority queue and executed once it is popped as the first in line. Task management algorithm also uses the concept of specifying how many instructions should the STL Interpreter execute. That enables the manager to suspend task before it has finished and execute task with higher priority.

Number of instructions to execute depends on the priority of task. For example services designated as *query* should be very fast performing only small number of instructions. Thus they should have high priority and high number of instruction to be executed since these services probably should not be suspended at all. On the other hand services designated as *process* are usually long life services performing large number of instructions and thus should have small priority and small number of instructions to execute since these services should be suspendable in case that new tasks with higher priority occur.

To avoid deadlocks and collisions, it was decided to use one STL interpreter per STL file with assumption that every interpreter can have only one function running or in pending state. The STL Interpreter can be taken as a critical section and each executed task blocks every other task coupled with the same interpreter.

However this approach can lead to so called Priority Inversion Problem. That is a situation when task with higher priority is blocked by a task with lower priority. This creates a deadlock since lower priority task cannot continue its execution since a task with higher priority occurred. Thus The Basic Priority Inheritance Protocol suggested in [4] was adopted. Simply put this simple algorithm assigns the lower priority task with the highest priority of the tasks that are blocked by it. Due to this change of priority the lower priority task can be executed first and thus unlocks the interpreter for task with higher priority as soon as possible.

6 STL_IO

Since the *eScop* device should serve as PLC like device it must be able to read physical inputs and write to physical outputs. Raspberry Pi was chosen as a hardware platform in combination with UniPi.

Raspberry Pi is a low cost single chip credit-sized computer based on BCM2835 unit. It can be used in many ways as regular computer but in addition it also features GPIO (general purpose input/output) pins that serve as a physical interface between Raspberry Pi and other devices [5]. To make Raspberry Pi more PLC-like device a UniPi board was added. UniPi board was designed with Raspberry Pi in mind. It features 8 relays, 14 digital inputs, single channel 1-wire interface, 2 analog inputs, one analog output and Real Time Clock module [6].

For communication and for handling of physical signals were developed 3 drivers that a developer can use. STL_IO is a component that serves for registering and deployment of drivers to STL Interpreters. With these drivers can *eScop* device communicate with many already existing real world systems.
STL_IO drivers:

1. *UniPiDrv* - This driver serves for reading digital inputs and setting relays on UniPi board. It allows the system to read input signals and control physical processes.

2. *RESTDrv* - This driver allows to call various REST services by serializing inputs to JSON data format in request and deserializing JSON data from response. It allows the system to communicate with various systems on network.
3. *RexDrv* - This driver communicates with the system REX – Control System for Advanced Process and Machine Control [7]. It allows the system to manage real-time control processes in REX.

6.1 Drivers Implementation

Drivers use the mechanism of calling external functions in STL Interpreter introduced earlier. STL file contains declaration of external function and its implementation lays in the JavaScript code. An example of external function declaration can be found in Code snippet 1 and its implementation in Code snippet 2. It is a function taken from *UniPiDrv* driver for reading relays on UniPi board.

The implementation in JavaScript is a function that takes 3 arguments. First argument is an array of inputs, second is an array of outputs and third is a callback that must be called after execution of external function is finished. The reason for using callback is that the function can be asynchronous as it is in our example in Code snippet 2. Callback takes a return value of the function in STL as argument.

Few special attributes are set under the function implementation. They serve like annotations. First annotation is mandatory and helps to distinguish regular JavaScript functions from those implementing external functions. The rest of annotations are optional and allows to specify data types of external function parameters and return value in STL. This helps to ensure that both the STL code and JavaScript code use same data types right after compilation of STL file. This prevents from using incompatible drivers during STL function execution.

7 Pragmas

As it was stated before services should be divided by their type into tree classes: *process*, *operation* and *query*. Every service is than represented by a STL function. The information about the type of service must be presented in STL source code. It was therefore decided to introduce *pragmas* as a way to annotate STL source code. Example of service function annotated with pragmas is in Code snippet 3.

Pragmas can be viewed as additional comments inserted into code but unlike comments that are ignored by the interpreter, pragmas are recognized and can affect the behavior of the program. The IEC 61131-3 only states that pragmas exist, they are delimited by curly braces ({ ... }) and contain attributes separated by comma but their definition is implementation specific.
Pragmas attributes:

- *name* – Specifies an alias to identify service. Use only if it is different than name of function.

```
STLExtern_Unipi.prototype.readRelay = function(inputs, outputs, callback) {
    unipi.readRelay(inputs[0].value, function(err, value) {
        if(err){
            console.log('Reading relay failed.');
            callback(-1);
        }else{
            outputs[0].value = value;
            callback(0);
        }
    });
};
STLExtern_Unipi.prototype.readRelay.isSTLExternFunction = true;
STLExtern_Unipi.prototype.readRelay.inputs
    = [ new STLParameter({type:'INT', name:'id'})];
STLExtern_Unipi.prototype.readRelay.outputs
    = [new STLParameter({type:'BOOL', name:'value'})];
STLExtern_Unipi.prototype.readRelay.rtnValue
    = new STLParameter({type:'INT'});
```

Code snippet 2. Implementation of external function in JavaScript.

```
{type='process',schedule='periodic',period=1000,externFunction="postService",description="myDescription"}
FUNCTION serviceName;
    VAR_INPUT
        {description="this is my input"};
        value:INT
    END_VAR;
  .  .  .
END_FUNCTION
```

Code snippet 3. Example of function with *pragmas* annotation.

- *description* – Should contain user friendly description of service.
- *type* – Specifies type of service (*process*, *operation*, *query*). This attribute can also contain type '*event*' that denotes that this function is not a service but an event.
- *schedule* – Specifies the scheduling of the service in case it is a *process*.
  - periodic – Service is called periodically by the device in the defined period.
  - continuous – Service is called cyclically without sleep between calls.
  - init – Service is called upon device initialization.

  - exit – Service is called upon termination of the device.
  - error – Service is called when error happens on the device.
- *period* – Specifies the period of calling the service in *ms*.
- *externFunction* – Specifies the identifier of external function in JavaScript if the name differs from the name of function declared in STL. This allows to use one external function from driver for multiple STL functions.

Pragmas can also be used to annotate parameters of function however no specific format was defined for it yet.

8 Conclusion

The purpose of this article is to give closer insight into inner structure of *eScop* device. These units' functionality is controlled by scripts written in Structured Text language. This article describes components developed for this functionality such as STL Parser/Interpreter for interpreting Structured Text code, STL-Manager for task management and collection of drivers for control of physical signals and for communication with other devices. *eScop* Device framework can be used for managing and seamless expanding of Intelligent Manufacturing Systems. Software was tested on Raspberry Pi and will be part of INCAS pilot application described in [8].

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Ontology for Service-Based Control of Production Systems

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Abstract. The paper illustrates a production systems ontology that models the discrete manufacturing, process production and the logistics domains. This ontology is used to allow semantic interoperability within a control architecture based on semantically-enriched Web Services that has been developed within the European funded project eScop. This architecture would facilitate the responsiveness and agility of the manufacturing companies, helping them to be more competitive thanks to the higher flexibility and re-configurability of their production systems.

Keywords: Manufacturing systems ontology · Interoperability · Open automation · Semantic representation · Flexibility · Re-configurability

1 Introduction

Researchers agree on the importance of the benefits that ontologies, being conceptual representations of different domains [1], provide to the fields when they are implemented. One of the fields in which ontologies seem promising, but are not yet widely applied, is the industrial engineering. Ontologies may provide a representation of the production systems as an aid for industrial engineering uses. Indeed, it is a long time since researchers have expressed the need for an ontology to contribute to this field: already in the nineties, Schlenoff stated the main benefits that come from an application of such an ontology [2]. The ontologies are developed for different uses, in fact each is characterized by a different representation potential and level. There are some that are high level, or “foundational”, that express generic concepts that should be shared among different fields and that are used to bridge among different ontologies; their importance is remarked by [3]. An example of these is the DOLCE upper ontology [4]. Others are more specific for a domain and a use, as shown in a recent work by Fortineau et al.: in this work, it is made clear how wide is the range of applications of ontologies within the industrial engineering: they cover product, services and processes and their life cycles (from development phases to end of use) [5]. In the mentioned work, there is a strong prevalence of ontologies for the product development, because activities involved in this phase require the collaboration of people from different fields and with different expertise and backgrounds: in such a context, an enormous benefit brought by ontologies

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is the creation of a shared, explicit and common vocabulary to express the required concepts [6, 7]. The potential of ontologies in the industrial engineering field is not limited to this role of vocabulary sharing instrument, in fact they can add semantics to the information that is exchanged between different systems and applications at different levels [8, 9], this is the basis for interoperability, defined by Ide and Pustejovsky as when "two systems have the ability to automatically interpret exchanged information meaningfully and accurately in order to produce useful results via deference to a common information exchange reference model", in other words, "the content of the information exchange requests are unambiguously defined: what is sent is the same as what is understood" [10]. The application proposed in this work takes this perspective, by exploiting the semantic content of ontologies for interoperability into service-based communication networks of embedded systems. A recent ontology of the production systems is presented to this end. This comes as an evolution of early works carried out at Politecnico di Milano in the direction of the development of a conceptual representation of the production systems [11, 12], basing also on other works [13–15]. These can be in fact considered as precursors of more recent production systems ontologies, such as the P-PSO (Politecnico di Milano – Production Systems Ontology), an object-oriented structured representation of the domain of the manufacturing systems described in [16, 17]. P-PSO is aimed to be a meta-model of the manufacturing systems domain, since it specifies the entities (objects) a manufacturing system is composed of, their attributes (parameters) and the relationships between them, and the necessary constraints, thus defining a standard way to describe any manufacturing system. P-PSO is developed and evolved to be "a common information exchange reference model" for a control architecture based on semantically-enriched Web Services, developed with-in the European funded project eScop.

This paper presents the evolution of the P-PSO (Sect. 2) and its deployment within a service-based shop floor control architecture (Sect. 3); eventually (Sect. 4), it frames these results within the wider context of higher flexibility and re-configurability in production systems, thus motivating its use in relationship to the industrial engineering field.

2 MSO Ontology Illustration

The P-PSO ontology, mentioned in the previous section, has evolved into the Manufacturing System Ontology, in short MSO, that is a domain ontology for the representation of production systems, that covers the domains of logistics, discrete and process production. MSO model includes many concepts from the P-PSO, at the same time presenting differences on three levels:

(i) on the domain level: the MSO includes the domains of process industry and logistics that were not covered in the P-PSO (that only represents discrete manufacturing systems); this can be achieved thanks to the fact that the high level domain-crossing classes are defined for all types of industry, while the specific industry classes are defined as specialization of the high level common objects;

(ii) on the use level: as it is explained in Sect. 4, the MSO is used for the control of the production system; while the P-PSO is a general taxonomy not built for a specific use, but it can support design, simulation, planning and scheduling, performance assessment and data integration in the manufacturing field [17];

(iii) on the modelling level of the control and visualization aspects:
   - in P-PSO the control aspect defines all the entities and relationships that exist among the concepts that are needed to perform control, in the MSO instead the control is only defined at a conceptual level, because it is just a knowledge storage support for a control software that acts outside of the ontology and only retrieves information from it: therefore, there is no need to represent how the control software works, also because this is not standardized enough to have a generalized data structure;
   - P-PSO does not have any concept related to the visualization and display of information; while in MSO this is present, providing modelling of elements that are needed for a proper management of visualization of the manufacturing systems to enhance awareness of the system by operators.

As in P-PSO, the developed ontology MSO covers different aspects within the manufacturing and process industry domain: the physical aspect, the technological aspect, the control aspect, the visualization aspect, that will be later detailed. The classes of the MSO ontology are represented in Fig. 1, as a screenshot from the used ontology editor, which shows them in alphabetical order. Therefore the different aspects do not have a clear visual separation in this view, but can be understood from the names of the classes. As mentioned above, each of these classes has attributes, relationships and constraints that are necessary to define the overall structure of the manufacturing systems domain but are not shown in Fig. 1 due to space constraints.

- owl:Thing
  - mso:Body
  - mso:Component
    - mso:Container (10)
    - mso:Controller
      - mso:RTU (10)
    - mso:Fixture
    - mso:Graphical_Interface (12)
    - mso:Operator
      - mso:Control_Operator (1)
      - mso:Processor_Operator (1)
        - mso:Assembly_Op
        - mso:Manufacture_Op
        - mso:Transportation_Op
    - mso:Processor
      - mso:Discrete_Processor
        - mso:Assembly_Machine
        - mso:Inspection_Device
        - mso:Machining_Center
      - mso:Flow_Processor
        - mso:Filter
        - mso:Pump
        - mso:Reactor
          - mso:Drier
          - mso:Heat_Exchanger
          - mso:Mixer
        - mso:Rotary_Kiln
    - mso:Sensor
      - mso:Barcode_Scanner (2)
      - mso:Conductivity_Sensor
      - mso:Flow_Meter
      - mso:Moisture_Sensor
      - mso:Photocell (31)
      - mso:Pressure_Sensor
      - mso:Tank_Level_Sensor
      - mso:Temperature_Scanner
    - mso:Storage
      - mso:Discrete_Storage
        - mso:Combined_Buffer
          - mso:Sequence_Buffer (4)
        - mso:Single_Buffer
          - mso:Random_Buffer
          - mso:Sequential_Buffer
            - mso:FIFO_Buffer
            - mso:LIFO_Buffer
      - mso:Flow_Storage
        - mso:Silo
        - mso:Tank
    - mso:Tool
    - mso:Transporter
      - mso:Discrete_Transporter
        - mso:AGV
        - mso:Fork_Truck
        - mso:Manual_Trolley
        - mso:Sequence_Buffer (4)
        - mso:Table_Module
          - mso:Crossing_Morein_MoreOut
          - mso:Demultiplexing_Onein_MoreOut (2)
          - mso:Multiplexing_Morein_OneOut (1)
        - mso:Unidirectional_Conveyor (4)
      - mso:Flow_Transporter
        - mso:Pipe
        - mso:Pump
        - mso:Valve
  - mso:Condition
  - mso:Configuration
  - mso:Data
  - mso:Datapoint
    - mso:Data_Source (30)
    - mso:Placeholder
  - mso:Decision_Point
  - mso:Document
  - mso:Element
    - mso:Screen (1)
    - mso:Vis_Object (11)
    - mso:Vis_Shop_Floor_Layout (1)
    - mso:Vis_Table (1)
  - mso:Element_With_Position (13)
  - mso:Header
  - mso:KPI
  - mso:Message_Element
  - mso:Notification
  - mso:Operation_Activity
  - mso:Orchestration_Operation
  - mso:Orchestration_Process_Template
  - mso:Parameter (235)
  - mso:ParameterModel (42)
  - mso:ParameterModels (6)
  - mso:Parameters (11)
  - mso:Picking_Order_Row
  - mso:Picking_Order_Sequence
  - mso:Position (26)
  - mso:Process_Routing
  - mso:Product (10)
  - mso:Request
  - mso:Response
  - mso:Routing_Operation
  - mso:Service (4)
  - mso:Subsystem
    - mso:Discrete_Subsystem
      - mso:Department
      - mso:Station (10)
    - mso:Flow_Subsystem
      - mso:Diagnose_System
      - mso:Lubrication_Unit
      - mso:Measurement_Station
      - mso:Pumping_Unit
  - mso:Symbol (11)
  - mso:SymbolModel (6)
  - mso:Transportation_Routing (10)

Fig. 1. The MSO ontology classes

2.1 The Physical Aspect

The basic objects of the physical aspect of the MSO ontology are the *"Component"* class (that represents a physical object in the production system) and the "*Subsystem*" class (composed of more than one components together).

The *Subsystem* class is specialized into sub-classes that are typical of the process production or of the discrete manufacturing. An example of discrete subsystem is the Station, the place where the processor or an operator is physically working.

The *Component* class can be specialized into sub-classes: (i) *Transporter*, any type of conveyor and movement device performing a transportation (i.e. logistics) function, moving material along places of the manufacturing process; examples are: AGVs, conveyors, fork trucks; (ii) *Processor*, identifies entities performing a manufacturing or process function by using an energy source and/or an operator activity; examples are: machining centers, inspection devices, assembly machines; (iii) *Storage*, representing any entities performing a storage (i.e. logistics) function, it means that they are able to keep material for later use in the manufacturing process; types of storage are: tanks, buffers, automated storage and retrieval systems; (iii) *Operator*, any type of person that perform activities in the manufacturing system and interact with other components; this class needs a specific approach, since operators can carry out different types of operating activity (for instance processing, transport, inspection, maintenance) and also carry out no-less-important control activities, like support and supervision over any type of component; (iv) *Sensor*, any type of sensing device used to capture the current status of a physical variable; (v) *RTU,* Remote Terminal Unit, any type of electronic control device that interfaces physical objects of the controlled production system; (vi) *Tool,* entities used by a processor to perform an operation on a product; (vii) *Fixture,* entities that are used to position, hold, support, locate and clamp the product in a three dimensional space; (viii) *Container*, representing the box in which products lie when they flow into the system. The *Transporter, Processor and Storage* classes, through the specialization association, are sub-divided into flow type and into discrete type, in order to address both the process industry and the discrete manufacturing industry, respectively.

2.2 The Technological Aspect

In the technological aspect, the developed ontology separates two different routings concepts: the *Transportation routing* and the *Process routing*. The former represents the physical displacement cycle that the product or the material must perform in order to finish its production: the Transportation routing is therefore composed of *Stations* (subsystems that were defined in the previous Sect. 2.1) that the product or material must visit in order to be completed. The Process routing instead defines is the production cycle in a more traditional sense: it is composed of the operations to be performed and defines the order in which they must act on the product or material. There is a link between the two routings, because specific operations are performed in specific stations. However, while an operation is linked to only one station, there can be more than one operation in each station, for this reason it is important to keep the two routings conceptually separated. The ontology also represents the fact that each production operation is composed of one or more elementary activities, featured with a number of information and characteristics that must be stored (such as needed instructions, needed equipment, required operator skills, input materials and others) and, in order to know if one activity has finished and the next one start, a condition must be met (which is modeled and stored in the ontology).

2.3 The Control Aspect

The control aspect includes all the classes that store the knowledge and the information required for the proper activities of the control software. For instance, it stores information about the product, the customer orders (due dates, quantities, etc.) and about the services that must be called to perform an operation and service parameters that describe the services, such as service URL and type, the meaning of the service and its availability. The role of services in the control of the production system using this ontology will be explained in Sect. 3.

2.4 The Visualization Aspect

The visualization aspect supports the human-machine interface (HMI) screens by presenting the information about the system in a clear and effective manner using graphical representation and retrieving the necessary information from the ontology. The ontology stores all the information needed for the visualization of the system and it can be retrieved or updated by the visualization provider based on queries from visualization agent. The visualization knowledge in the ontology includes the information on composition of the screen and the link between the visual elements and real components or data of the system. All the *Components* in the system have a graphical interface which is composed of *Elements* that represent them in the visualization screen. The *Element* class represents the visual elements like screens for operator display, shop floor layout, table and so on. The elements are linked to some position on the screen, that are defined in terms of X-Y coordinates, or in terms of rows and columns. Moreover, elements have visualization parameters like sensor values, temperature, etc. that are needed to show information interesting to the operators.

3 Role of MSO in the eScop Architecture

The developed ontology, presented in Sect. 2, has a practical implementation within the scope of the European Artemis funded project "eScop", acronym for Embedded systems for Service-based Control of Open manufacturing and Process automation. This project is aimed at proposing a solution for the current problems of production system flexibility and even agility, by allowing a more rapid reconfiguration and an easier integration of production system elements at shop-floor control level. This is done with the inclusion of semantic content into the control level of the devices and applications through the use of the developed ontology presented in Sect. 2, that allows interoperability among devices from different vendors.

The core idea of the project is to put embedded systems in communication with open standards, such those of the web, in a Service-Oriented Architecture (SOA) network where each device offers Web Services on the network. This allows to reach the open automated manufacturing environment that has been depicted by [18].

The role of the developed ontology in this architecture is that the SOA control architecture can be automatically configured thanks to the continuously updated ontological content, while the embedded systems allow this architecture to operate in the production system environment. Figure 2 presents the software architecture of the control system employed in the eScop project. From the picture, it can be understood that the layers needed for the control are five. *Physical Layer (PHL),* composed of the physical devices and their service-enabled device control units that put them in communication with the rest of the shop floor and control the equipment at local level. *Representation Layer (RPL),* composed of the developed MSO Ontology model in which the knowledge about the configuration and the current status of the production system is stored, and of the Ontology Service that is the software application that allows to expose the ontological knowledge as a service in the network, in particular it is the Ontology Service that queries the ontology to retrieve the information within stored. *Orchestration Layer (ORL),* incorporating the role of the control software that invokes, orchestrates and coordinates the services offered by the devices in the system to perform the necessary production activities; it is made of 2 components: (i) Service Composer, which receives task needs and decides how to orchestrate the system in order to fulfill task needs, and (ii) Orchestrator service which does the orchestration process to ensure its successful execution. *Visualization Layer (VIS),* used for the human-machine interface with the operator on the line. *Interface Layer (INT),* completing the architecture, being the module that communicates with external software and applications.

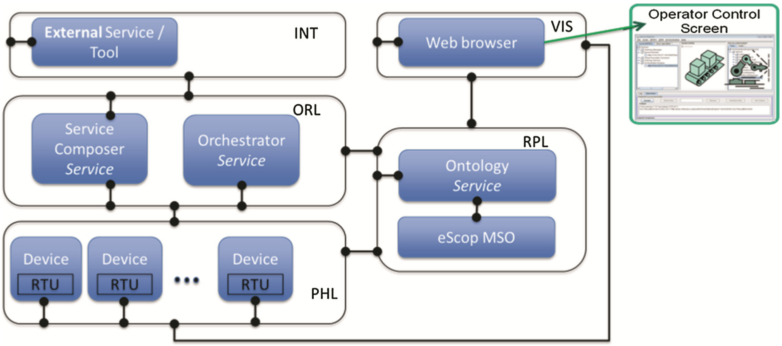

Fig. 2. Positioning of the ontology into eScop architecture

In such an architecture the role of the developed ontology is clear: it receives information from the field devices in the physical layer and supports the orchestration layer with knowledge that is necessary to make the proper control decisions; in addition it supports visualization by providing the necessary information to be displayed for the operators (please see the connectors that link one layer with the others in the Fig. 2).

4 Conclusions

The paper proposes a new ontology for the production systems domain and a possible application in the context of a service-based control architecture of the production systems. The result of the implementation of the Manufacturing Systems Ontology presented in Sects. 2 and 3 is a modular, fully open software solution for the operational control of manufacturing equipment in production systems allowing the many benefits of remarkable industrial relevance: (i) easier and faster commissioning of new plants, (ii) support of the "plug and produce" inclusion of new equipment, (iii) replacement of traditional control based on hierarchical hardware architectures by a single level cohort of embedded systems and a series of software control levels. These are in line with the progressing research needs to reach higher responsiveness and agility in manufacturing companies: companies are searching ways to be more flexible and even more agile to reconfigure their production systems in a quicker way, in order to face the increasing competition at a global scale and to face the more demanding consumers requests in a timely fashion [19, 20]. The automation paradigm may be one of the facilitating factors for higher flexibility and re-configurability because an automated control software update, based on the semantic content of the ontology, can be achieved that does not require the intervention of the human programmer whenever the physical production system undergoes any change [21]. For this reason, research in this direction has enormous industrial interests and many possibilities for improvement can be considered. For example, it is worth envisioning even the use of the MSO in the context of a scalable production, released by means of small production units integrating their own logistics, which is a concept drawn within Factory of the Future visions. Another possible application could be to enlarge the potential of MSO towards enhancing not only the production system flexibility – which is a base target – but also the agility and, thus, re-configurability of an organization of production plants operating in changing environments and spread in a given geographical scale, defined according to the target market.

Future steps include the application of the MSO ontology and the open automation architecture for the control of production systems to industrial contexts in the discrete manufacturing, in the process production and in the logistics to validate the expected benefits discussed in this paper. Further work can be directed at studying how to enlarge the distributed systems basis on which the developed ontology can be applied.

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Technology Evaluation Using Modified Integrated Method of Technical Project Assessment

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Abstract. This paper proposes a method of evaluation of novel technologies, like ontology engineering based solutions, in conditions when a paradigm based on the balance of economy, society and environment is adopted. The evaluation applies a holistic approach. The proposed method is based on the idea of integrated efficiency evaluation of technical and organizational projects. Its key elements are the assessment measures and the management control procedures.

Keywords: Technology evaluation · Integrated evaluation method · Controlling

1 Introduction

Numerous studies research technologies with regard to: implementation, justification, evaluation, and selection [3]. In order to evaluate of technologies different tools are used: data envelopment analysis [8], strategic models [7], fuzzy models [1]. The purpose of this paper is to redesign the integrated method of evaluation, which originally addressed flexible automation [5], to enable evaluation of technical and business projects considering the 'new economy' paradigms, which involves perspectives of environment, society and economy, and includes the aspect of sustainable development. In order to explain the idea of the method controlling was selected as a supporting tool. Controlling proposes the permanent deviation analysis of targets, and assessment of technology along the design and application phases [9]. The evaluation is preceded by creation the measures, planning the targets and possible deviations, adopting the measuring tools, selecting the guidelines for decision processes. The conditionings for creation of the measures for technical projects evaluation are presented herein.

2 Integrated Method of Technical Projects Assessment

The integrated method was devised by the author in 1989 [5]. Its aim was to permit evaluation of technical and organizational projects of flexible automation. In order to conduct the process of method adaptation to the contemporary conditions, it is

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necessary to redefine the answer to question ‘what determines such an evaluation’. It seems that the leading elements that condition the construction of an evaluation are:

- the method of approach to the evaluation according to the binding paradigm in economy and management,
- defining the impact areas of technical and organizational project that are under evaluation, which may change due to development and globalization,
- the successive changes of criteria regarding the selection of the management methods or techniques, due to the necessity to take into account the behaviour of environment, that is characterized by fast changes and growing global character [5].

In order to meet the three determinants one needs to take into consideration the fact that evaluation of technical projects should follow a holistic approach, be comprehensive and integral. The holistic approach refers to the Aristotle’s paradigm that the whole precedes its parts, so the holistic approach prevails over partial approaches. Comprehensiveness means that all possible factors of the phenomenon (project) are addressed. Integral means that various aspects and links of system elements are addressed (e.g. by the evaluation system). The definition of rules and stages of the evaluation process is as important as the features of evaluation methods and needs a lot of technical information [2].

Considering the adopted paradigm that regards the balance between economy, society and environment, the evaluation process of technical and organizational projects may comprise various number of stages. The traditional process consists of five stages characterized by sequential operations:

- identification, i.e. devising the holistic specification,
- arrangement of features according to importance (proper weights),
- overview of potential evaluation methods,
- selection of an evaluation method,
- conduction the evaluation.

The structure of this procedure has a universal character and may be used for many types of production and service processes, as well as when adopting it to modern and complex technical projects, like those exploiting the means if ontology engineering. The links between the mentioned procedures are presented in Fig. 1.

The rules of evaluation process include not only the procedure stages within the process and the characteristic of the evaluation process itself (Fig. 1). They also include some aspects of the evaluation process:

- the characteristics of the technical and organizational project, which is being evaluated, particularly with regard to complexity, novelty and size,
- time span of technology (or project) implementation or exploitation,
- the social and cultural characteristics of the users.

The above named features are much consistent with the ontology-aided technologies and solutions, which exhibit a high degree of such characteristics like: novelty, complexity and coupling, openness, networking, changeability, intelligence [10].

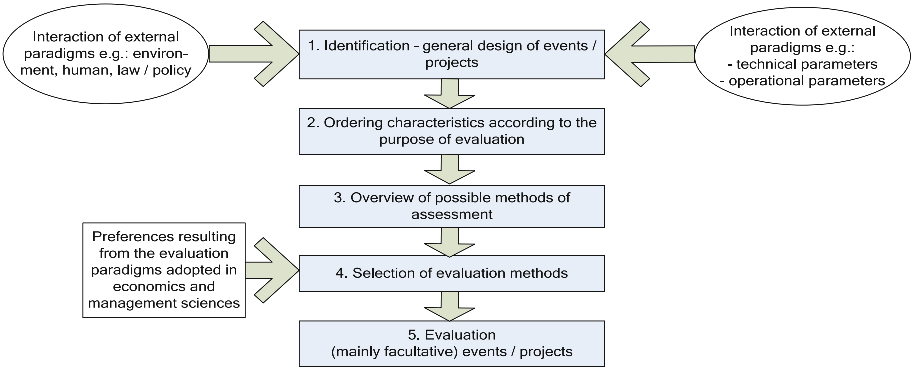

Fig. 1. The structure of evaluation process of technical and technical and organizational projects

3 Modification of Integrated Method of Technical Projects Assessment

Having outlined the most important rules of the evaluation process we can now present the selected evaluation method that will comply as much as possible with the mentioned determinants and rules. Such a method seems to be the modified integrated method of efficiency evaluation of technical and organizational projects [5].

The integrated method has two main features, which encourage to adopt it, such as complexity and the organized choice of measures according to the rules of modularized structure. Module is understand as a distinctive element of system performing a specific function, which may be interchangeable into one that fulfils the same function, but of different internal structure. The adoption of the module requires a precise description of its coupling with other modules. The modular structure of the modified integrated method of technical project evaluation is presented in Fig. 2.

The modified integrated evaluation method follows the ontological approach, as it complies with the rules of formal knowledge representation. Adopting such an idea may be particularly useful for complex technical solutions, like ontology-aided solutions [12]. The use of this method may also facilitate knowledge communication between humans and technical applications.

Regarding applications it can be characterized by the basic formal categories of ontologies, i.e.: classes/concepts, objects (subjects), relations, attributes (properties), events, rules. The proposed evaluation method may facilitate the effective and efficient information and knowledge processing. It may also act as a surrogate of very wide and complicated knowledge. It has also a descriptive character. It may be useful in the area of designing, implementation and exploitation of technical solutions, as well as for technology, production and logistics evaluations [11].

Having presented the idea of modified integrated evaluation method of technology efficiency or technical projects we can start its detailed description. The method consists of six modules that comprise the specific sets of measures. It includes the following modules:

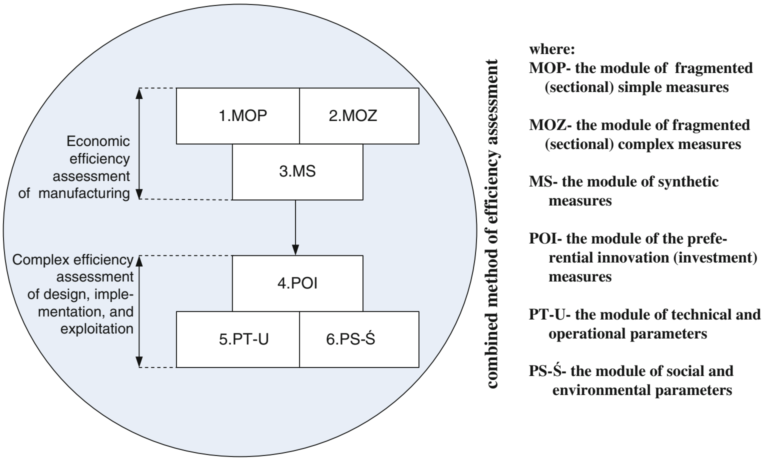

Fig. 2. The structure of the modified integrated method of technology evaluation

1. Fragmented (sectional) simple measures (MOP) - a set of measures that characterize the basic inputs to the production process i.e. technical and technological equipment, all kinds of materials and resources, human factor etc.
2. Fragmented (sectional) complex measures (MOZ) - a set of measures which characterize the relations between basic economic sizes typical for production, i.e. capital labour ratio, material intensity, labour intensity, efficiency, productivity etc.
3. Synthetic measures (MS) - a set of measures which characterize in a holistic manner the production process and its results, i.e. the costs in various cross sections, the financial result, various types of profits etc. They should pay particular attention to the level and character of the technical solution e.g. through diverse taxation of the financial result which, as a result, defines the profit level.
4. The preferential innovation (investment) measures (POI) - a set of measures that characterize (evaluate) innovative solution which has the form of an investment project, taking into account social and economic policy of the specific country, conveyed through tax burden, subsidies and grants, fiscal and monetary policy etc. The determinants of the size of the innovation measures (indicators) include e.g. interest rates, tax thresholds and rates, etc.
5. The module of technical and operational parameters (PT-U) - a set of measures that characterize production or service output applying for the description mostly performance parameters (usage) i.e. functionality, universality, durability, the cost of use etc. The relations and accidents happen according to previously observed rules among these typical ontological attributes.

The module of social and environmental parameters (PS-Ś) - a set of measures that characterize influence of product or service on some social and environmental parameters. Compliance with them should ensure the proper state of the environment in the future. Ontological approach is also adopted here, reflected in the observation of relations and accidents happening according to the previously observed rules, and a possible response to the ongoing changes, if they are not coherent with the desired condition of the society and environment.

Due to the topic of publication more attention is paid to PT-U and PS-Ś measures modules than others in the following part of the paper. In-depth analysis was devoted to the environment elements that are determined by the choice of measures and their later level, as well as the future dynamics expressed through the proper indicators. We may observe it, in reference to both modules, by detailed analysis of conditioning of modules operation (Fig. 3).

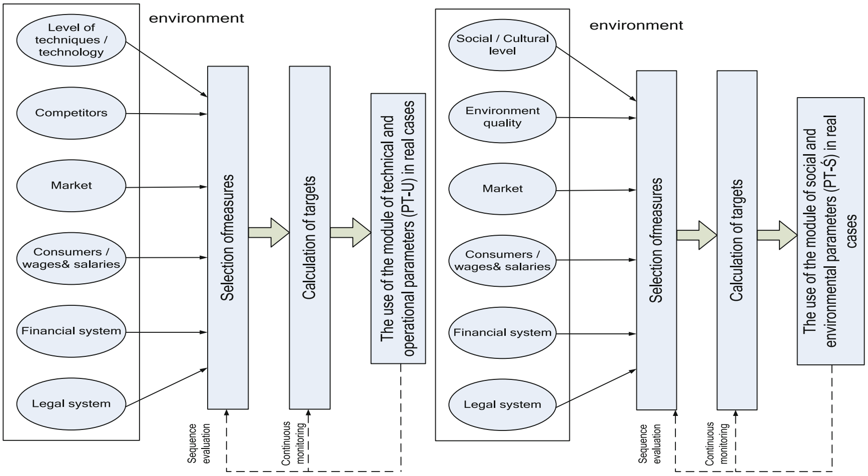

Fig. 3. Operations conditioning of the module of technical and operational parameters PT-U and social and environmental parameters PS-Ś

The structure of both modules of measures (PT-U and PS-Ś) may be subject to change because of: ongoing technical and technological progress, the characteristic of the evaluated products and services, from the perspective of the evaluated features, the change of the desired condition of environmental, legal, cultural and social requirements. In recent years, changes have been occurring in shorter time intervals. Sometimes they have a turbulent character, which makes difficult to adopt them within the operational evaluation system. As a result, it increases the risk of obtaining unsatisfactory society or environment condition, due to the applied method.

4 Application of Controlling in Technology Evaluation

The continuous application of PT-U and PS-Ś measures modules requires the use of controlling and its philosophy. It may be defined, adopting ontology rules, as the system of correlated rules, methods, techniques and projects that are intended for internal control system, aiming to obtain the desired outcome. Controlling may be also understood as an integrated subsystem of managing, planning, control and information, which supports the adaptation and coordination of the whole management system [6]. The idea of controlling has been presented by a number of authors in their works. However, the most precise presentation is by Kuc, who states that "controlling as an integration platform of methods and management techniques, not only allows identifying quickly the place of unexpected changes and their reasons, but is also helpful when taking remedial measures. As a result of such possibilities, ideas appear such as management by controlling" [4].

In production management, if one adopts ontologies, it is necessary to: clearly determine strategic and operational goals of the organizational unit, plan general and specific tasks, and define relations which may occur between them during the goal realization, define the implementation methods. In order to achieve that, the modified

Table 1. Example controlling setting of technical and operational measures (PT-U)

Specification of the monitored measures	The size (values) of measures/the preferred timetable				
	Target values at the end of t period (year)	Cumulated values at the end of particular stages (e.g. quarterly sub periods)			
		t1	t2	t3	t4 = t
1. **Measures of technical parameters (design/production)**					
1.1. Measure of material requirements	+		+		+
1.2. Size (shape) measure	+		+		+
1.3. Force (power) measure	+		+		+
1.4. Speedo	+		+		+
1.5. Compatibility	+		+		+
2. Measures of operational parameters (design/production)					
2.1. Exploitation measure	+	+	+	+	+
2.2. Productivity measure	+	+	+	+	+
2.3. Usability measure	+	+	+	+	+
2.4. Complementarity level	+	+	+	+	+
2.5. Durability	+	+	+	+	+
3. Measures of economic parameters expenditures and costs (production)					
3.1. The measure of minimum expenditures reg. the performance of technical functions	+		+		+
3.2. The measure of minimum expenditures reg. the performance of exploitation functions	+		+		+
3.3. The measure of minimum costs of operational function	+		+		+

Note: + defines the values, i.e. indicators (parameters)

Table 2. Example of **c**ontrolling table of social and environmental measures module (PS-Ś)

Specification of the monitored measures	The size (values) of measures/the preferred timetable				
	Target values at the end of t period (year)	Cumulated values at the end of particular stages			
		t1	t2	t3	t4 = t
1. **The measures of social aspect of communication**					
1.1. The value of investment in environmental protection	+				+
1.2. The level of social awareness regarding social relations, environmental protection	+				+
1.3. The level of Internet use (the average time of Internet use)	+				+
1.4. The utilization rate of product capacities (e.g. mobile phones, computers etc.)	+				+
2. The measures of social aspect of development					
2.1. Availability and quality of public infrastructure	+				+
2.2. GDP per capita in PPP	+	+	+	+	+
2.3. The level of public security	+	+	+	+	+
2.4. The amount of free time	+				+
2.5. Availability and quality of cutting-edge durable goods	+				+
3. The measures of the level of healthcare					
3.1. The rate of disease (the number of new patients/total number)	+				+
3.2. Mortality rate (deaths/number of people)	+				+
3.3. Mortality rate (deaths caused by disease/number of people)	+				+
3.4. Prevalence rate (number of patients/total number)	+				+
3.5. Average lifespan	+				+
4. The measures of nature condition					
4.1. Forest condition	+	+	+	+	+
4.2. Agricultural soil condition	+	+	+	+	+
4.3. Post-industrial devastation	+	+	+	+	+
4.4. The usage of nonrenewable resources	+	+	+	+	+
5. The measures of air quality					

(*Continued*)

Table 2. (*Continued*)

Specification of the monitored measures	The size (values) of measures/the preferred timetable				
	Target values at the end of t period (year)	Cumulated values at the end of particular stages			
		t1	t2	t3	t4 = t
5.1. Total dust	+	+	+	+	+
5.2. Sulphur dioxide (SO2)	+	+	+	+	+
5.3. Nitrogen oxides (Nox)	+	+	+	+	+
6. The measures of water quality					
6.1. Total nitrogen	+	+	+	+	+
6.2. Total phosphorus	+	+	+	+	+
6.3. Nitrates	+	+	+	+	+
6.4. Water oxygenation	+	+	+	+	+
6.5. The pH of water	+	+	+	+	+
7. The measures of waste management					
7.1. Plastic waste	+	+	+	+	+
7.2. Agricultural and food waste	+	+	+	+	+
7.3. Hospital waste	+	+	+	+	+
7.4. Industrial waste	+	+	+	+	+
7.5. The rate of waste processing	+	+	+	+	+
7.6. The rate of waste utilization	+	+	+	+	+

integrated method of efficiency evaluation may be useful, as well as the adoption of controlling philosophy for the stage of realization of goals.

Having outlined the controlling idea and definition, one may present controlling tables prepared according to the modified combined method of efficiency evaluation regarding PT-U and PS-Ś modules (Tables 1 and 2).

The tables include the basic measures that belong to two groups: technical and operational, and social and environmental. They have been presented according to their peculiarities. They have a universal character.

In order to verify the functioning of the modified integrated method of efficiency evaluation of technical projects e.g. houses, modern, integrated production or logistic systems etc., it is necessary to continue practice oriented research that should constitute the next stage of research work.

5 Conclusions

To resume, it must be noted that the significance of the topic is quickly growing. It results from high intensity of implementation of novel technologies, products and services, in the area of ICT, biomechanics, communication etc. The evaluation method is based on ontological approach and adopts the paradigm that includes the balance of economy, society and environment. As a complex and universal method it should be elaborated and implemented as fast as possible. A research regarding its functioning in a representative context, should be conducted.

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Towards Ontology-Aided Manufacturing and Supply Chain Management – Insights from a Foresight Research

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Abstract. Ontologies attract growing interest as a mean for semantic integration of knowledge, applications, models and systems. This particularly applies to the ICT and automation intensive industries. The paper discusses possible novel ontology-aided solutions for managing manufacturing and logistics operations, which result from a foresight research of industries. The professionals from European companies along semi-structured interviewing and brainstorming provided a range of suggestions, mostly in terms of functional requirements. Some novel solutions have been derived and conceptualized this way.

Keywords: Ontology · Semantic integration · Manufacturing management · Supply chain management · Foresight research

1 Introduction

Manufacturing and logistics are recently exposed to the rapid growth of openness and networking. The outcome is increased complexity and variability of systems and processes. In parallel many innovations in information and communication technologies (ICT) and automation technologies (AT) are being implemented. Among the key enabling technologies there are: Web services, smart appliances, semantic technologies et al. The particular areas of ongoing and suggested development can be referred as the seven Internets (Fig. 1). The evolution of Internet towards the Semantic Web may eventually provide a core public infrastructure for information exchange for other Internets [1]. Some of them are advanced and undergo intensive development, like the social Internet or e-commerce. Other are still rather futuristic concepts than reality, e.g.: the Physical (logistical) Internet [2] or the Internet of Things and Systems. To note, many similar concepts are also discussed, like the Industrie 4.0 [3], which assumes future industrial systems to be built upon Cyber-Physical Systems (CPS) [4].

It is argued that major issues and challenges which may arise along development of seven Internets could be resolved by the means of ontology engineering [5–7]. It is considered as an enabler for novel systemic solutions and functionalities for manufacturing and supply chain management [8, 9], which is the focus of this paper. However, it is argued that cross-organizational and externalized solutions require modified abstractions and formal extensions to enhance the capacities of existing ontologies [7].

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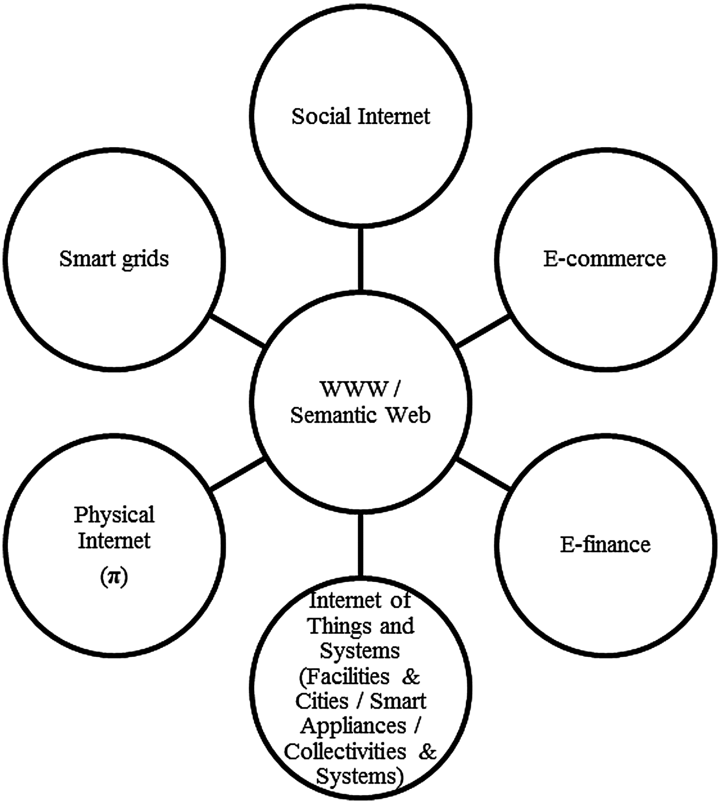

Fig. 1. Semantic web of seven internets

This paper presents and discusses results of a foresight research, which involved professionals from European industries. They were used to conceptualize a range of novel functionalities and systemic solutions for management of manufacturing and supply chain operations, which are presented in this paper.

2 Methodology

The research aims future needs and requirements, as seen by industries, with regard to the systemic solutions and functionalities for management of manufacturing and supply chains that could be eventually facilitated by the means of ontology engineering. From the available methods semi-structured interviewing of experts followed by brainstorming was chosen to protect dependability of results, to efficiently drive creative thinking, and to get high value-effort ratio along the research. It could not be presumed in advance that all professionals involved into the research have a competence in the ontology engineering. Therefore all of them have been equipped with a prior required knowledge of that kind. Obviously the experts were not expected to provide insights that could directly target detailed aspects of ontology engineering.

Considering the purpose of research following categories of companies were identified as those having expertise in the area of interest:

1. Users of advanced ICT and AT technologies from discrete and process industries;
2. Providers of ICT and AT solutions (software, hardware);
3. Manufacturers of automated equipment;
4. Integrators of supply chains and manufacturing systems (ICT and AT solutions).

The following sectors were approached: automotive, petrochemical, chemical, cement and electro-power generation. The expertise from telecom sector on architectural and communication solutions was considered as a potential source of important insights. The structure of interviewed experts in terms of rank and respective type of expertise is presented below in Table 1.

Table 1. Rank-based structure of interviewed experts

No.	Rank of expert	Number	%
1	CEOs	4	5
2	CTOs	5	7
3	Other CxOs	1	1
4	Σ CxOs	10	13
5	Middle level managers	15	20
6	Engineers	47	67
Σ		72	–

Each company was approached by phone, then a formal letter was e-mailed, including a brief description of research and a list of guiding ideas on ontology engineering, and questions. Finally meetings were arranged at the company sites. The results of each interviewing were initially processed, than compiled and systemized. During the meetings questions provided in advance have been used to lead the interviews together with other direct, indirect, and ad hoc questions. This way many assessments, forecasts and recommendations could be obtained. Brainstorming was normally happening in case of some questions. All interviews were precisely documented, in most cases recorded. The questions provided in advance were tailored according to the company category and mostly focused around the following topics:

- New systemic solutions, in terms of structures, layouts, architectures, material and work flows, planning and control principles, patterns of serviced demand, etc.;
- New functionalities, including those driven by smart appliances, embedded appliances, and other novel ICT technologies, internally provided or outsourced;
- Other core novelties expected for open, knowledge-aided operations management; eventual impacts and outcomes from integration of seven Internets;
- Knowledge management; cognitive aspects; issues of utilization and maintenance;

- Various discrepancies and couplings, especially arising along processes;
- Human-machine interfaces (HMI) and human-systems interdependencies;
- Possible insights for developing foundations and means of ontology engineering;
- Business models and deployment patterns for new solutions.

The variability of gathered opinions was compiled and synthesized. Controversial opinions were not ignored. Although the number of interviewees was moderate, using statistical analysis as a basis for justification of conclusions was assessed as of minor importance. Key systemic solutions and functionalities that were derived from the research results were then conceptualized as ideations. They are presented later on.

3 Findings and Conclusions

The feedback received from experts did not differ much with regard to their hierarchical position. Not surprisingly the engineers exhibited a bit more interest in technical aspects, while the top level managers rather focused on systemic and functional aspects. The visible difference of interests and focus was linked to the type of industry, mainly with regard to the distinction of process and discrete industries.

Most interviewed experts recognize ontologies (or semantic expression of information) as an efficient representation and communication mean for open knowledge-driven manufacturing and logistics. In particular ontologies are expected to facilitate semantic integration of distributed smart (i.e. intelligent) applications, this way enabling various novel systemic solutions and functionalities.

Many interviewees named ontologies as generic vehicles for description of all conceptualizations and models to found applications used along operations management. This feature enables evolution of applications, following internal extensions and external provisions of knowledge and makes possible qualitatively new ways of communication and integration. Consequently ontologies are expected as enablers of new smart solutions for managing operations, which may self-adapt in a run-time mode. Therefore various changeabilities and novel functionalities can be also facilitated.

Concerning openness and interoperability in operations management, it was suggested that new concepts might be required to facilitate the novel solutions for operations management. Apart of ‘material’, or ‘real’ items, like facilities or all flowing items, virtual spatiotemporal items should be possibly conceptualized, considering mereotopological expressions, like: (i) virtual systems and capacities; (ii) spatiotemporal demand/task structures (projects, orders etc.); (iv) processes and flows; possibly all ‘movable’ or ‘trackable’ items could be subject of such considerations; (vi) spatiotemporal interdependencies concerning coordination patterns, e.g.: synchronizations, time-rigidness etc.; (vi) components of tacit knowledge.

Concerning planning and control principles and related functionalities, that could be a subject of knowledge-driven operations management, the following abilities are commonly recognized as most required and fundamental:

- Distributed/non-hierarchical/externalized/localized planning and control; e.g. by: self-management of subsystems or devices or orders; self-management of herds of devices or orders, e.g. through bargaining, auctioning and similar mechanisms;

- Ontology-aided planning and control, e.g.: bulking, issuing, accepting, initiating, prioritizing and dispatching orders, based on flexible processes/routings;
- Adaptive ongoing consideration of performance and operational targets;
- Adaptive ongoing consideration of conditioning and contextual factors.

Following the above findings a range of other most required ‘smart’ abilities and functionalities was also suggested by the experts: (i) limited intelligence of embedded appliances, at least to support mostly requested self-adaptations to current local circumstances, e.g.: breakdowns, bottlenecks, blockings, starvations; (ii) capacities of local self-diagnostics and early-warning; (iii) aggregation of local data to support externally supported inferencing (e.g. from clouds, using Big Data technologies), like failures forecasting, optimized process control, setting standard times etc.; (iv) simple learning capacities, e.g. in reference to input-output control of manufacturing cells.

Direct communication between devices and other items (e.g. machine-to-schedule or truck-to-depot) together with the use of web based interfaces (appliances and users should be able to access Internet from any device or HMI, like: laptop, tablet, phone etc.), were commonly recognized as the basic for open communication and an enabler of some new functionalities.

Concerning functionalities to be eventually thrived from or built upon exploitation of tracking technologies, the following two were suggested as particularly important: (i) intelligent reporting/notifications about progressing processes or along forwarding; (ii) handling routings/routes in local memories of movable items; (iii) using creatively data about exact position; e.g. it could enable counting products in exact container or provide possibility to read a real-time position of each palette; each of those data could be stored and then analyzed in case of disruptions.

It must be underlined in reference to all above presented findings, that the experts from process industries exhibited a very focused pattern of interests. Automated process control and maintenance management are experienced as the two major concerns of plant management, while external logistics is in most cases considered a secondary issue, the following functionalities attracted the major attention of the experts: (i) adaptive or optimized process control, sometimes supported by distant links, even from different installations, which cannot be normally facilitated by existing massive and hierarchical control systems; these could help to reduce energy consumption, emissions, waste reduction etc.; (ii) extended diagnostic capacities, in particular early warning; these could much facilitate preventive maintenance and protect against outages and catastrophic events; (iii) improved monitoring abilities, also by HMIs and following the item (ii).

Interesting insights were provided by the telecom sector, which is highly advanced in research aiming at IP based integration of different technical equipment (not just of mobile phones), by means of cellular and other ICT technologies. The telecom experts suggested that smart phones can operate as networked embedded devices, being more efficient and cheaper than common comparable AT solutions. E.g. a collection of mobile phones can operate like a local network (at a site), in a peer-to-peer mode, using any interface/interfacing protocol and different modes of communication.

The telecom experts also recommend some technologies developed by their sector, which can eventually support process control under non-deterministic circumstances, particularly in case of failures or breakdowns of networked resources. For such purposes the Erlang open-source language has been developed, which targets programming of non-deterministic controls, e.g. with regard to flows in networks under unavailability of some resources.

Some interviewed suggested applying an open source approach for production ontologies, at least for the core ontologies that could be publicly shared. The issue of who and how should maintain them was noticed. Other experts suggested impossibility to develop a unified core ontology for the domain. E.g. they suggested impossibility to handle unique control models, considering specific complexities of exact systems. Anyway, core shared ontologies were suggested as a probable realistic solution.

The above synthesis of findings, which were obtained along the foresight research, provides comprehensive and consistent guidelines for various ontology-aided innovations addressing operations management. They could be straightly used for conceptualizing some novel solutions and functionalities presented in the next section.

4 Novel Ideations for Systemic Solutions and Functionalities

This section presents some novel ontology-aided systemic solutions and functionalities, which could be developed for manufacturing and supply chain management. All of them were derived or conceptualized from the results of foresight research. Apart of enabling use of ontologies using some novel ICT and AT technologies was also considered. The ideations to some extent overlap. It is a minor issue, as their role is to help identifying directions for further R&D. All of them may potentially provide significant advantages, in terms of functional capacities or performance, in relation to the existing solutions. They are realistic as all of them can be eventually implemented using the existing technologies, despite some requested R&D. They are as follows:

- (*A*) *Merging Electronic Markets with Manufacturers and Logistic Providers* (*or E-commerce + Production and logistics Internet*): Electronic markets could be integrated through Semantic Web services (e.g. clouds) with a pool of manufacturers and logistics providers (or logistics infrastructure, like the Physical internet). Different planning and/or coordination mechanisms could be exploited within such ecosystems, ranging from push-flows, through pull-flows, to limited ad hoc markets (e.g. auctioning et al.). Demand, material and other flows could be adaptively encapsulated along operations, thus thriving from the transaction economy of scale.
- (*B*) *Supply Chain-Wide Operational Alignment:* Overall planning and control service could integrate operational management of demand and material flows. Various mechanisms could be exploited, depending on the characteristics of demand, products, processes, and particularly in reference to the couplings and discrepancies. They could range from centralized to distributed and local, like in case (A). Similarly, different encapsulated flows could be applied along operations. The transaction economy of scale and utilization of resources could be significantly improved this way. Distortion of demand could be reduced, like the turbulences of flows. This kind of solution could be applied as a dedicated one or like a public service.
- (*C*) *Non-hierarchical and/or Distributed Management of Operations:* A manufacturing system or a supply chain or a logistical system could be operated mostly or

solely by smart appliances, embedded or assigned to various components of the system, both physical and virtual. E.g. demands (orders) could be managed and controlled by dedicated intelligent agents, who would solely supervise their execution (i.e. like self-manageable orders). The agents would apply for resources in a run-time mode. Similarly resources could be equipped with managing agents. The demand, work and material flows could be composed or adapted at a run-time. Relevant control mechanisms would be used by the agents, e.g. auctioning or prioritizing mechanisms, eventually supervision by operators or other users. Planning and/or coordinating agents could be involved in these activities. The above means that eventually flows and resources could somehow manage themselves.

- (*D*) *Herd Control of Operations:* Complex manufacturing and logistical demands could be distributed to various providers/vendors, then operating like a herd. Management and control could follow bio-mimetic and/or eco-mimetic imitations. Under some circumstances users (humans) could be subordinated to smart agents, who could actually control inter-organizational flows of demands or deliveries.
- (*E*) *New Functionalities:* Due to advantages of Big Data technologies or using the power of cloud computing new functionalities could be added for occasional or run-time use. Alternatively the existing functionalities can be provided in a more efficient and functional way, using a limited intelligence. E.g.: monitoring of resources, process planning, monitoring of processes, adaptive control of flows etc.
- (*F*) *Adaptive Management of Operations:* Modes of planning and controlling operations could be adapted to follow phase transitions of systems/collectivities and processes, or of the operational environment. E.g. dispatching rules in a manufacturing system could be changed according to the load or temporary bottlenecks, processes (routings) could be redefined in case of outages and jams, etc. Such types of functionalities are primarily enabled by the capacity of intelligence. It is worth to note, that anticipation of phase transitions can be significantly enhanced when considering extended environments, e.g. supply chain wide, and when exploiting Big Data.

The above ideations illustrate some novel solutions, which were conceptualized from the foresight research. All of them assume using ontologies for knowledge representation and communication, and for reasoning. This applies in particular to those aspects of operations, which refer to complexities. All ideations provide significant functional and performance advantages. They suggest directions for further R&D.

5 Summary and Further Research

The foresight research confirmed that ontology-aided solutions are much welcome by industries, which clearly exhibit a comprehensive pattern of needs and requirements that fir well to the existing or potential capacities of the ontology engineering. The outcomes from performed research can be exploited by further R&D effort in a threefold way: (i) translation to core, domain and application ontologies, to support particular solutions or functionalities; (ii) verification of fundamental abstractions and formalizations, then ontology languages, and further research along this line; (iii) R&D of novel systemic solutions and functionalities, which are enabled by the existing and expected capacities of ontology engineering; this way a feedback for (i) and (ii) could be obtained. Using the research findings with regard to (i) and (ii), the following topics can be suggested as of major importance: (a) expressiveness of ontologies, considering particular complexities, which are specific for the domain, which might have spatiotemporal or mereotopological nature; (b) theoretical (meta-mathematical) foundations for ontology languages; (c) methods and tools for ontologies, particularly in reference to abilities of distributed knowledge and intelligence (i.e. beyond querying). Another perspective for further research can be derived from requested functionalities and features of future solutions. They can be categorized as follows:

- Novel forms of networking, like non-hierarchical, segmented, collectivities, herds;
- Local, global, distributed, externalized intelligence;
- Novel foundations of planning and control, ranging from localized self-management (pull-flows), through collective distributed self-coordination, up to large scale forms, including centralized;
- New functionalities driven by diagnostic or adaptive abilities or other intelligence;
- New forms of encapsulation, i.e. other than data encapsulation; e.g. encapsulation of demands, flows, operations etc.
- New types of structures and infrastructures, up to economic institutions.

Finally, the ideations presented in this paper could be a subject of further R&D effort.

Acknowledgements. This work has been co-funded by the PSP 504/02105/1103/40.000105 grant of Warsaw University of Technology and by the EU ARTEMIS project no. 332946 “ESCOP - Embedded systems for Service-based Control of Open manufacturing and Process automation”. The author thanks to partners of the projects.

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Ontology-Based Finding of Feasible Machine Changes

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Abstract. In the event of a machine fault, feasible machine changes have to be reviewed by the operation scheduling and dispatching to avoid remarkable delays. In this approach, this is achieved by an automated identification of alternative machine tools and a reliable validation. First, a capable machine that satisfies the requirements of the NC program is searched within an ontology. Therefore, the ontology contains a description of all relevant characteristics of specific machine tools and expert rules to derive provided capabilities. Second, the NC program is validated on a virtual machine tool to ensure its accuracy.

Keywords: Computer-aided process planning (CAPP) · Computer-aided manufacturing (CAM) · Knowledge based system · Ontology

1 Introduction

The increasing amount of individualized products requires a highly flexible production system. In the field of metal machining, the needed flexibility is achieved by numerical-controlled (NC) machine tools. The wide spectrum of work pieces leads to the use of heterogeneous machine tools with different capabilities. However, most work pieces can be manufactured by different machines. In this case, the selection of the most economic machine tool at start of production for each manufacturing step is essential to realize competitive prices in high-wage countries.

2 Problem Analysis

2.1 Today's Lack of Resource Flexibility for Machining Processes

Machine Tool Selection. The appropriate selection of a machine tool for each manufacturing step is based on the expertise of qualified and experienced employees. This decision is taken days or weeks before start of production on the shop floor. The shop floor is a complex and an ever-changing environment. Hence, the selected machine might not be the most economical machine tool for the actual available resources [1]. Investigations have shown that 20–30 % of the initial process plans have to be altered before the start of production [2]. Common reasons for that are unpredictable conflicts and changes in the economic planning, organization and available capacities [3].

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Binding on Selected Machine Due to G&M Code. After a machine is selected, the computer-aided manufacturing takes place (CAM); this is the transformation of the work piece geometry into low level part programming as a sequence of machining operations (G&M code) referred to as NC program. The transformation depends on the machine's characteristics like the control type, axes and additional technical parameters [4]. Thus, machine specific NC programs have to be generated for different machine tools. Due to the missing interoperability between CNC machines, these can be executed correctly only on one kind of machine [5]. In practice, the NC program is generated only for the selected machine to avoid an additional effort.

STEP-NC, was introduced to overcome the incompatibility of NC programs. The aim is to replace traditional G&M code and its several vendor specific dialects. Despite many researches on it, STEP-NC has not become widely accepted in the industry and is still searching its market [4, 6].

In case of changed conditions in the shop floor the queued processes must be reallocated to alternative machines to avoid delays or failures in the following manufacturing steps. It is the task of the operations scheduling and dispatching to determine the start time and sequence of manufacturing processes as well as the allocation of resources. However, it is not possible to reallocate the machines easily, due to the described missing interoperability between CNC machines. This leads to a lack of short-term resource flexibility, which is a major restriction for the operations scheduling and dispatching also in highly flexible production systems.

2.2 Approach for an Intelligent Manufacturing Process Planning

This approach facilitates the pursuit of an automated selection and validation of alternative machine tools as a method of prevention. An ontology-based decision-making system identifies all capable machine tools, based on the requirements of the NC program. The machine tool change is approved by simulating the machining on virtual machine tools. The scheduling and dispatching selects the most economic machines with regard to the actual conditions in the shop floor. The early preparations of machine changes increases the resource flexibility without additional human work.

3 State of Research

3.1 Basics

Definition of Ontologies. In informatics ontologies are recognized as a formal representation model for terms and definitions. They provide a well-defined vocabulary to specify the meaning of elements in a knowledge area. They provide a foundation for a common understanding, for reasoning and knowledge reuse. The components of ontologies are concepts (classes), individuals (instances), relationships and axioms.

In the field of production, the use of ontologies is still a research topic, but the modular design offers a promising potential for the description of different aspects of production systems and the knowledge management [7, 8]. The formality of ontologies enables knowledge modelling that is comprehensible by machines and humans and provides automated conclusions, e.g. the classification of new resources, the composition and configuration of manufacturing processes and resources [7] or the autonomously review of action alternatives [9]. This enables an improved automation or assistance of recurring, but time and cost intensive activities of employees.

3.2 Relevant Research Areas

The presented approach deals with three research areas: Knowledge modelling of machine tools, selection of appropriate resources and reuse of NC programs.

Ontology-Based Modelling of Machine Tools. The knowledge modelling is the critical component for every knowledge-based system. The Manufacturing's Semantics Ontology (MASON) enables the description of relations between product, process and resource [10]. The focus lies on the specification of mechanical work pieces, the necessary manufacturing processes and the capable machines. An example application is the automated determination of manufacturing costs. The Manufacturing Service Description Language (MSDL) by Ameri et al. is the base for a standardized description of manufacturing capabilities of suppliers at different levels of abstraction. Focuses are technological aspects in a digital manufacturing market [11].

Selection of Appropriate Resources. This is part of the computer-aided process planning (CAPP), when it is supported by a planning software tool. These software tools often include macro programming, reuse of templates and knowledge-based searching. However, due to differences among manufacturing shops, the underlying knowledge model has to be customized for each shop floor, which makes these applications inefficient for small and medium sizes enterprises (SMEs) [12]. Approaches for the selection of appropriate resources on a higher level exists in the field of supply-chain-management (SCM). The MSDL was extended for a semantic supplier discovery in a digital manufacturing market [14]. Therefore a *SupplierProfile* describes the capabilities of a supplier and a *Request for Quote* describes the request of a customer. For the improvement of the matching process, Ameri et al. extended the Ontology with rules to model human expertise in the field of SCM [15]. Shea used the MSDL to propose the scenario of a cognitive machine shop. Thereby, the CAPP tasks are implemented in cognitive machines. Each machine "knows" its capabilities and generates a machining plan autonomously including executable machine code and requests for other necessary services to fulfill the demands [8]. Chi proposed a rule-based model for supplier discovery with an underlying ontology-based description of capabilities. The manufacturing suppliers are mainly characterized through the parts and products they produce and there is no direct reference to the manufacturing processes or resources provided by the suppliers [16].

Reuse of NC Programs. Schröder and Hoffmann proposed a tool to support the user by converting NC programs from one language to another. The parsing of NC blocks is implemented by regular expressions that are saved in external conversation rules files. In this way, different languages for each control can be integrated [17]. A new kind of

NC program processor (NCPP) for the integrated control of CNC systems was designed by Guo et al. [4]. Standard NCPPs handle only one dialect of G&M code, the presented concept of a NCPP deals with a variety of NC program inputs. Therefore, different NC specifications are stored in a dictionary and are used by the NCPP to interpret the corresponding NC program correctly.

3.3 Preliminary Conclusion

The selection of alternative machines should combine technological and economic considerations. Today, technological criteria (machine capabilities) dominate the selection and later economic factors (e.g. actual situation in the shop floor) are not considered due to missing interoperability of CNC-machines.

The existing solutions and research approaches for cognitive CAPP and SCM do not include these holistic considerations [12]. The approaches for an automated supplier discovery or a dynamic SCM reconfiguration are designed for rough requirements and exclude short-term economic factors (e.g. delivery time). In the field of CAPP, only a few researchers have addressed the aspect of automated machine selection [13]. It remains to be said that cognitive CAPP and SCM provide recommendations on the basis of a knowledge base, but the decisions still needs to be verified.

4 Ontology-Based Decision Making System

4.1 Enclosing Holistic Concept and Procedure

In the process planning, the manufacturing orders are prepared as working plans with sequences of manufacturing steps. Relevant for this approach are all machining steps on machine tools. The execution requires the generation of the NC program including raw part design, tool and fixture selection and setup planning (CAM data).

Based on this input information, Fig. 1 shows the following procedure in the framework of an intelligent process planning. First of all, the decision-making system finds alternative machine tools for each manufacturing step. In addition the system provides the adapted CAM data for each of the alternative machines. The decision-making system may consider the machine tools of one division, the whole factory and even subcontractors. The capable machine tools and their specific adapted CAM data are simulated on a virtual machine tool model to ensure an error free run. If the simulation fails due to collisions or other errors, this information is send back to the decision-making system for improvement. If the simulation is successful the machine and manufacturing data is stored in a repository as approved resource for this manufacturing step. The scheduling and dispatching selects the most economic machine tool, out of all approved machine tools, with regard to the actual conditions in the shop floor. If conditions changes, the scheduling and dispatching reallocates the resources on each manufacturing step. At start of production, the manufacturing process data is sent to the machine control and the setup data to the machine operator.

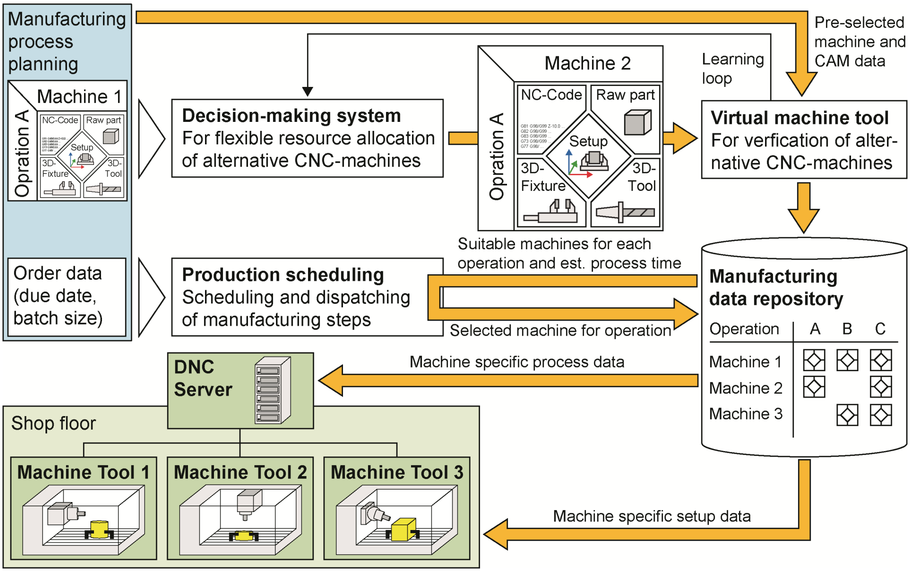

Fig. 1. Aspired workflow enabled by the ontology-based decision-making system

4.2 Overview of the Decisions-Making System

This paper focuses on the ontology-based decision-making system for the automated identification of capable machines, taking into account different machine configurations and applications. First, all capable machines are searched within the ontology based on the rough process description, derived from the CAM data. In the next step, the specific setup information and NC program is adapted for each machine, to overcome the interoperability. This includes the adaption of G&M code and setup plans for different machine configurations. The next two subsections deal with the underlying ontology of the first step, the second step is not considered here.

4.3 Knowledge Model to Describe Machine Tool's Capabilities

Top-Level Concepts. The ontology InVor is the core part of the decision-making system. It contains the specific machine characteristics and the expertise of experts to derive the resulting capabilities [18]. The ontology is described with the Ontology Web Language[1] (OWL), which is a W3C recommendation for the Sematic Web.

There are two sections in the ontology, which describe the basic machine description and the resulting capabilities. The basic machine description corresponds as far as possible to the machine components and auxiliary devices (tools, fixtures). Separate concepts are used to describe the auxiliary devices and the machines' components in detail, like the main driver, magazine, control, table, axes and spindle. Each concept has obligated and optional standard parameter which describe the characteristics of the

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[1] http://www.w3.org/TR/owl2-overview/.

component (comparable with the master data) and the static relations to other concepts. For example an axis is described by its orientation, traveling or turning range, feed rate and its connection to other axes or the tool attachment. The concepts are used like a template to instantiate individuals that describe concrete machine tools. This is similar to the class and instance concept in object oriented programming.

The top-level concept capability profile describes the resulting machining capabilities and thus the technical suitability to perform a specific NC program. Each machine tool has several profiles that exclude each other, for example, a not-rotating work piece makes better use of the work area. This is expressed by a separate capability profile with a larger work area, if the rotary table is not used. The capabilities of machines with more than one table or with a pendulum mode are described in the same way. The capability profiles are described in the orientation of the axis movements in the G&M code. The basic machine description model does not enable any automatic reasoning of the resulting manufacturing capabilities. The generation of all capability profiles by hand is costly and therefore not an option. For that reason, rules in the ontology InVor describe the externalized expertise of experts, which enables an automated reasoning of the resulting capabilities of a described resource.

Rules Integrate Expertise of Experts. The rules are modelled inside the ontology with the SPIN[2] (SPARQL Inferencing Notation), which provides a RDF compliant representation of rules and constraints on ontologies. This has the advantage that all information and knowledge is stored at the same location. The rules are located in the affecting concepts in the ontology and operate on different levels.

Figure 2 shows the two rule levels and the three stages of the ontology. The rules of the first level are used to enhance the basic machine description model. They cover the mappings between machines, tools and auxiliary devices and the creation of additional parameters that can be derived from the basic machine description.

For example all tools that fit into a specific machines' magazine or spindle are identified and linked, represented by an arrow in Fig. 2. The link between a tool and a spindle requires only the same type of tool holder; the link to a magazine additionally restricts the size of tools. Whereby, some tools require an empty adjacent pocket and reduce the overall number of tool places in the magazine. Furthermore, the use of certain tools or materials might restrict the feed rate or spindle speed of the machine due to technological limits. These restrictions can be described for generic tool types as dependencies or functions between standard parameters by rules, too. The resulting new parameters in Fig. 2 complete the basic machine description.

The rules of the second level utilize the enhanced machine description model and add all conceivable capability profiles. These contain all capability parameters that are not fixed (e.g. max. work piece weight of the table) and depend on the different machine configurations (e.g. pendulum mode, setup configuration). The capability requirements for a manufacturing step are derived from the G&M code and the raw part, therefore the description of capabilities is adapted to these requirements. This means that the capabilities profile describes the work piece dimensions and work area in the coordinate

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[2] http://spinrdf.org.

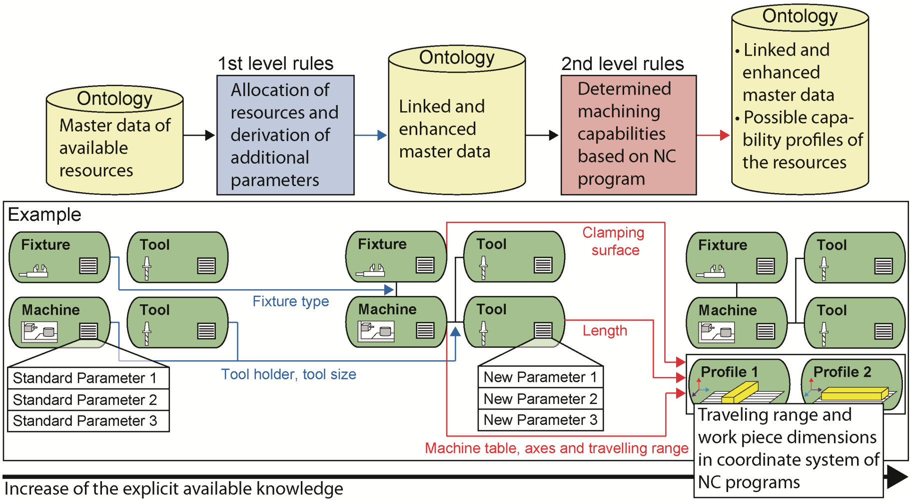

Fig. 2. Transformation of the machine characteristics to the provided machining capabilities

system of the NC program and not in the machines' coordinate system. Figure 2 illustrates this by two example profiles with a rotated work piece. Profiles 1&2 are based on the same physical axes of the resource, but the feasible rotation describes an alternative capabilities profile to fulfill the requirements of a specific work piece and NC program. The rules are not machine specific, but contain a filter under which conditions they should be applied. Condition means here: Machine components or characteristics that are necessary to provide a separate capability profile.

5 Conclusion

Against the backdrop of permanent changes of capacities in the shop floor it is very important to consider the economic efficiency of the previous selected machine tools. The decision-making system and the underlying ontology InVor support the determination of alternative machine tools on the basis of an existing NC program. The enclosing holistic concept provides the automatic arrangement and review of machine tool changes and increases the resource flexibility. In the case of machine down times, the production control is able to reallocate the manufacturing steps to alternative machines quickly and without human interaction. The first implementation has shown that the ontology-based finding of feasible machine changes is possible. Next focus is the integration with the operations scheduling and dispatching module. Experiments of other researchers have already shown that the number of identified suitable resources has a high impact on the efficiency of scheduling and dispatching [19].

The prototype implementation and case studies takes place in an innovation project in the Leading-Edge Cluster "Intelligent Technical Systems OstWestfalen-Lippe" (it's OWL) with DMG MORI and addresses the utilization of virtual machine tools on a cloud platform for the optimization of machining processes [20].

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Architecture for Open, Knowledge-Driven Manufacturing Execution System

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Abstract. Manufacturing Execution Systems (MES) are a bridge between the enterprise solutions and factory shop floors. MES allows the performance of contemporary factories by closer integration of the needs of enterprise stakeholders with the actual manufacturing hardware and software components. Considering different nature of the factories the application of MES has significant difference across industry. Such constrain requires a sophisticated solutions to contain the generality of application. Most of currently available solutions are proprietary and tightly coupled to the ecosystem of devices and enterprise resource planning systems. In current paper the architecture for the open, knowledge-driven MES is discussed. Authors argue that such MES will provide smart extensibility based on base-of-breed approach and hence will improve the quality of MES application, while reducing the introduction costs and system downtime due to reconfiguration.

Keywords: Manufacturing execution system · Knowledge-driven approach · Open architecture · Web services · Factory automation · Smart factory

1 Introduction

Contemporary factories enjoy significant benefits from the application of Manufacturing Execution Systems (MES). MES provides a link between the level of the enterprise planning and the level of the production shop-floors. Such connection introduces faster feedback between layers and new functionalities which without MES are to be done manually. The studies confirm the direct correlation between the employment of MES in enterprises and enterprise performance. For example, in the research made by Manufacturing Enterprise Solutions Association International (MESA) industry group and Industry Directions Inc. the MES-using companies have had the Key Performance Indicators (KPI) generally better than the companies without such systems (Manufacturing Execution Systems - Accenture 2010).

The MES solutions generally are provided by the companies already represented either on higher or lower levels of factory information systems (e.g. Siemens, SAP). This leads to orientation of the MES towards particular factory ecosystems and leads to

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issues of interoperability that restricts the possibilities for the choice. As it would be discussed further, the MES solutions should provide a wide specter of functions.

Different MES solutions naturally have different approaches to implement these functions, which vary in applicability in different factories. The particular case is possible where the company exploiting MES solution is satisfied by some of the functions but does not require others. Such cases lead to possibility to purchase only some parts of MES solutions. Nevertheless the possibility to get different MES functions from different providers are limited, and commonly lead to redundancy in the information system and customized integration which introduces additional costs to the MES solutions.

Furthermore, contemporary MES solutions are designed to satisfy the mass-production paradigm. This makes the existing solutions suitable for the big enterprises operating with large quantities of similar goods to be produced, but limits their application to the smaller ones which largely have more diversified portfolio. Last but not least, the MES solutions currently available on the market has significant cost for software itself, for the service of introduction of such solution to companies and for adjustment of business processes accordingly. Concluding, currently available MES solutions have some limitations for their applicability due to their cost, complexity, collateral changes and limitations casted on the enterprise.

In order to address the named constrains of MES solutions this article suggests a new architecture for it. New architecture developed in eScop Project[1] is based on the synergy of *embedded devices*, *service-orientation* and *knowledge-driven approach*. Furthermore, the concept of the architecture suggests the open nature of the solution. The MES following the suggested architecture should reduce the cost of introduction and maintenance of the solution to the enterprise, make it more applicable for mass-customization production and enhance the capability to handle changes in the enterprise, hence to make it cost efficient so it can enter the Small and Medium Enterprises (SME) level.

Embedded devices in suggested architecture are providing more dynamicity on the factory shop-floor keeping it loosely coupled to the MES solution. The factory shop-floor using proposed concepts would not require custom or tight integration with the MES reducing the cost of changes in it. Service-orientation serves the purpose to facilitate the loosely-coupled integration of the MES components as well as to integrate the MES in factory ecosystem. Knowledge-driven approach is employed to maintain the knowledge about system correct, organized, and accessible. Such knowledge about the system allows to facilitate the reconfiguration with little or no human interactions, and as result make the system capable to embrace the changes in factory ecosystem such as introduction of new production recipes, equipment or other components.

The following sections will present background followed by description of Open Knowledge-Driven Manufacturing Execution System (OKD-MES) concept. Section 2 defined concepts required for background. In the third section the architecture and concept for new MES will be described. Then the fourth section outlines conclusions and future work.

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[1] http://www.escop-project.eu/.

2 Background

The core technologies and concepts applied for the proposed architecture are discussed in this section.

2.1 Manufacturing Execution Systems

McClellan (1997) provides following definition for MES: "*A manufacturing execution system (MES) is an online integrated computerized system that is the accumulation of methods and tools to accomplish production*". The author argues on importance of **online** and **integrated** nature of the system. In this definition online means connection to upper (business planning and logistics) and lower (factory shop-floor control and monitoring) level systems, providing vertical integration of MES solution in factory automation hierarchy. Integrated nature of MES represents the horizontal integration of the MES solution on the level of Manufacturing Operation Management (MOM). The importance of both types of integration is supported by (Kletti 2007).

MES solution should provide a certain set of the functions to the enterprise which are generally located between Enterprise Resource Planning (ERP) systems and factory shop-floor. Dissimilar organizations have tried to provide a classification for such functions. The efforts of Manufacturing Enterprise Solutions Association (MESA), Verein Deutsche Ingenieure (VDI) and ISA-95 are generally coherent. The functions defined by MESA are following: *operations/detail scheduling, resource allocation and status, document control, dispatching production units, performance analysis, labor management, maintenance management, process management, quality management, data collection and acquisition,* and *product tracking and genealogy*.

Besides the need for implementation of the aforementioned list of functions in industry there exists a demand for the manner of MES implementation. Among such requirements in AMR researches from the end of 00's by R. Martin argues that future MES should use the web-services and have more flexible data model. MES users naturally desire to use most efficient tools for MOMs disregard of the solution owner. The future MES should provide modularization of the services to satisfy this need, argues Johnson in (2010). The modular MES may use the concepts of core and complimentary components. It is important to keep core interoperable and transparent for to maintain capability to develop the complimentary components. In same paper author states the possible role of cloud computing to optimize its costs.

2.2 Service Orientation and Web Services

The one of most prominent design paradigm for interoperable components is service-oriented approach (SOA). The core principles service orientation are presented in (Erl 2007) by Erl and are argued to achieve the goals such as increased ROI, increased organizational agility and reduced IT burden which are the benefits per se.

SOA is being commonly implemented in form of Web Services (WS). WS are using the web as a media for service interactions. There exist different standards to implement the WS. Among the most employed ones are RESTful services defined by Fielding in his thesis (Fielding 2000), WS-* specification by OASIS ("OASIS Devices Profile for Web Services (DPWS)" n.d.). RESTful web services are dominant in consumer internet. WS-* still maintain a big share in the enterprise integration solutions, but for some cases may be replaced with RESTful ones to reduce complexity. Web Services are advancing towards factory shop floor devices employing expanded capabilities of **embedded systems**.

2.3 Embedded Devices

Embedded devices in the factory shop floor may support the web service implementations. Among the examples there is a commercially available INICO S1000[2]. Besides the development of industrial computers and credit-card sized computers as Raspberry Pi[3] are providing a solid base for other WS-enabled devices. In eScop Project the Remote Terminal Unit (RTU) is being developed which should support RESTful web services in factory shop floor as well as execute control logic.

2.4 Knowledge Representation

Davis et al. (1993) is providing the wide and comprehensive description of Knowledge Representation (KR). Particular implementations of KR are developed in form of linked data, and in case of higher semantic complexity – in the form of ontologies. The realization of linked data and ontologies is based on certain XML based standards such as RDF and OWL. RDF representation is built of subject-predicate-object triples. More complicated formalization leads to wider reasoning capabilities in cost of limitations of representation. Each valid OWL representation is also valid RDF, but not vice versa. SPARQL Protocol and RDF Query Language (SPARQL) is a dedicated technology for manipulating the data in RDF based languages.

The possibility of RDF to OWL compatibility is an important benefit of this language family, as level of formalization may be adjusted without a need to change technology stack significantly. As well complexity of the data representation may be leveraged by creation of domain ontologies as it is proposed in chapter: Ontology-based modeling of manufacturing and logistics systems of this book. Overall Knowledge Representation together with Web Services concepts are successfully used for manufacturing domain. For example Ramis et al. in (2014) are offering an approach to use such combination for integration of an industrial automation system. In Puttonen et al. (2013) authors argue about the synergy of KR and WS for representation of a dynamic automation system and even composition of factory automation processes.

3 Architecture

The goal of development of OKD-MES is to provide Open solution, which employs Knowledge Driven approach to implement MES. Considering first term "Open" in this

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[2] http://www.inicotech.com/.

[3] https://www.raspberrypi.org/.

work it has both meaning of being open source solution, open to be studied, modified and distributed. Also it means open from perspective of Open Architecture, e.g. the OKD-MES should be open to addition or replacement of modules developed by community. Second part of definition is “Knowledge Driven”. Open Knowledge-Driven MES is being developed to be capable to understand the data within the system and hence to be capable to infer additional information based on reasoning mechanisms within OKD-MES.

- ***Open***. Beyond openness from point of view of rights, OKD-MES architecture should be open for modules extending its functionality. For this part the concept of Core MES functionalities and complimentary modules discussed in Johnson (2010) may be employed.
- ***Modular***. Considering relatively high complexity of MES solutions, the open and adaptable solution driven by community should be developed as a set of independent interoperable component to leverage lack of coordination.
- ***Knowledge-driven***. The complex, service-oriented and modular system which should dynamically adapt to new components and services should facilitate the knowledge about the system.

Architecture of OKD-MES core, presented on Fig. 1, includes 5 main components: Physical Layer (PHL), Representation Layer (RPL), Orchestration Layer (ORL), Visualization Agent (VIS), and Interface Layer (INT). Integration of OKD-MES core with shop floor equipment is provided employing functionality of PHL. Complimentary functions of OKD-MES are expected to be implemented as services and/or clients of OKD-MES core functionalities. Access to such core functionalities is provided via Interface Layer in order to provide required level of access to core. Finally services implementing core or complimentary functions of MES are able to employ a Visualization agent to provide user interface for the system.

3.1 Interactions Between Layers

As it was already mentioned, interface layer should be capable to define level of access of external service or user and enable this access to underlying services of OKD-MES core. It is also possible to use adapters in interface layer to connect the MES to providers and consumers which are not implementing RESTful WS or even are not services at all.

Physical layer should be capable to provide the information required to create representation of shop floor devices in the Knowledge Base of RPL. This information must include shop floor device description from manufacturing point of view as well as from service perspective. Directly or indirectly the information about equipment status is to be exposed by PHL to RPL.

Orchestration Layer should be capable to execute service on PHL in order to orchestrate service compositions. On other hand it should be capable to read some data from shop floor equipment if it is required for process definition. In some cases it may be required to subscribe for notifications from PHL in order to execute the service composition efficiently.

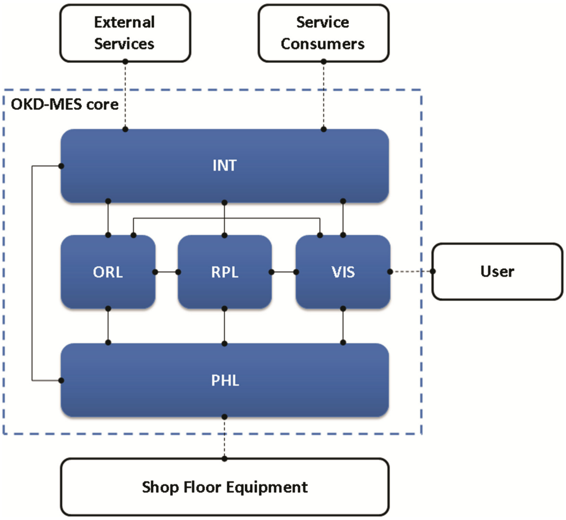

Fig. 1. OKD-MES core architecture

The definition of the executable processes in ORL may and should be abstracted from real service implementations and be concentrated on functionalities for the reasons of robustness and flexibility of the approach. Hence the mapping of these abstract services to their real implementations should take place. This on the mapping information related to service invocation should be provided. All required information connecting the syntactic and semantic description of the services is persisted in RPL. This mapping functionality is one of the main interactions between ORL and RPL. As well some information about process execution and status of the system is an important part of interaction of these two layers.

Interactions between Visualization Agent and RPL are required to generate the visualization screens on demand. Information about configuration of the screen including data points for subscription in other layers should be provided by RPL.

Interactions between Visualization Agent and PHL are to be mainly of subscription format. E.g. some information explicitly available in the device may be required. All interactions directed from visualization as input should be developed in a form of executions of certain services in the system.

3.2 Physical Layer

Architecture of physical layer is based on the concept that device functionality should be encapsulated in a service. The data from device should be accessible employing WS interface, the operations on devices may be invoked as services. For obvious reasons PHL should provide capabilities to discover and describe the service in order to enable loose coupled integration in overall system. Moreover some basic services as subscription should be implemented on Physical layer to enable event oriented behavior of the system. A more efficient and flexible solution is to provide an access to a runtime core. In the control programs running in PHL device runtime core events may be defined. The data consumers may subscribe to such events and be connected to more abstract data than one available from a simple I/O module. As well possibility to invoke the programs in PHL device directly using some data from service call is also more flexible approach.

The architecture of PHL developed for OKD-MES includes three main modules: Simple I/O module, Runtime Core and WS Toolkit. WS Toolkit enables web services functionality and may be connected both to Runtime Core and I/O Module. Besides already named service oriented functionality WS Toolkit may provide an interface for configuration of PHL. I/O Module is being employed as a bridge to real inputs and outputs of a device. Runtime Core is an architectural block on which the control logic is being executed. In case if PHL device is being employed as a bridge to some legacy device the Runtime Core may virtually be omitted.

3.3 Representation Layer Architecture

Architecture for Representation Layer is developed based on the services it will provide for other layers. Most of the services of RPL will have interaction with MSO such as CRUD (create, read, update and delete) operations on the Ontology model. Depending on the service consumer, the services can be separated into four modules in order to facilitate the development and maintenance, namely, Device Registration Module, Visualization Provider Module, Service Handler Module and Manager Module. These modules all need some internal functions in order to interact with MSO which is stored in an Ontology database. The components in the architecture are explained as following:

Device Registration Module: A service module to register or unregister eScop devices in the MSO through device catalogue. It enables access to device existence and their capabilities in the network. Mainly works with Physical domain in MSO. Visualization Provider Module: A service module to retrieve, update the visualization information, for example GUI components and their properties, in MSO according to the query from Visualization Agent. Mainly interacts with Visualization, Technological and Physical domains of MSO.

Service Handler Module: A service module to communicate with Service Composer, Orchestrator Services and Production Manager. The module should expose services to provide information requested from the Service composer, receive update requests from Orchestration service and receive update requests from Production Manager. The module must handle description of the services, configuration and status of the system, SPARQL over HTTP could be used for flexibility of the approach, but it is worth to mention it is necessary to introduce authorization and verification mechanism for SPARQL over HTTP in order to keep data integrity of the MSO. Manager Module: It provides configuration interface, model browser/editor and CRUD operation on MSO for IT staff or authorized users. SPARQL Query Factory: Basic common function to generate SPARQL queries. Ontology Connector: Basic Common function to execute SPARQL queries and return the query result.

3.4 Orchestration Layer Architecture

Architecture for Orchestration Layer is developed considering to provide control over system. Service Orchestrator has to enable execution of service compositions and providing information about the execution for other parts of the system. Orchestration of service compositions means that Service Orchestrator should include orchestration engine as well as other components required for interactions with other systems.

3.5 Visualization Layer Architecture

Visualization Layer has to provide a visualization agent capable to generate visualization screens based on a screen descriptions persisted in RPL. Moreover it is considered that employment of a browser as a visualization client for reasons of ubiquity in modern world.

Considering a need to provide visualization for dynamically composed screens, it is required to have a repository of symbols to which visualization descriptions may be linked. Dynamic Composition Module is to be using this symbol repository in order to generate visualization descriptions which can be transformed to browser readable format by visualization agent. Additionally Dynamic Composition Module of VIS has to create required subscriptions to data in the other parts of OKD-MES in order to represent in on visualization screen. Finally Visualization Agent is a part of architecture which has to transform the visualization screen description to a web page of some form, which can be displayed in browser being connected to a real data in the system.

4 Conclusion and Future Work

The general considerations for the architecture to be used in implementation of new Open Knowledge-Driven Manufacturing Execution System were outlined. The concepts can also be validated using online tools and simulator[4]. In order to increase the chances for the adoption of the proposed OKD-MES approach, tools and models have to be developed in a joint, collaborative manner between the experts. Online, web-based tools requiring no installation of dedicated software except a web browser make it possible for wide group of people with different skills to work together on the same project. This article provided a concise review of the main elements in OKD-MES architecture and the description of expected benefits. In order to achieve the benefits, many of World Wide Web Consortium[5] (W3C) standards are employed to allow communications at all the levels of the enterprise and problem domain modeling and dynamic use of the models at the system run-time.

Future work on the topic will be dedicated to describe in more details the layers of OKD-MES. Furthermore the improvements to architecture and its modules will be revealed in the course of integrating and extending OKD-MES core functions with the modules dedicated for certain MES functions in eScop architecture. The feedback from the first industrial pilots adopting the approach may also require further improvements in different layers of OKD-MES.

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[4] http://www.escop-project.eu/tools/.

[5] http://www.w3.org/.

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Product-Service Lifecycle Management: Knowledge-Driven Innovation and Social Implications

Guidelines for Designing Human-Friendly User Interfaces for Factory Floor Manufacturing Operators

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Abstract. Agility and fast reaction to changes is required in today's turbulent manufacturing environment. Unfortunately, the commonly used user interfaces (UIs) on the factory floor don't support such rapid reaction. Even though the human involvement improves agility and reactivity of production systems, it is also a source of uncertainty, especially when it comes to information inputting. Therefore, specific attention should be placed on human-friendly UI design, in order to improve the reliability of collected data and productivity of operations, as well as to make the workplaces more attractive for the future operators. This paper gives generic guidelines for human-friendly UI design and represents a case study in the context of manufacturing IT-system design.

Keywords: User-centric design · Human-friendly design · User interfaces · Manufacturing environment · Manufacturing IT-systems

1 Introduction

Human factors play a crucial role in manufacturing. The desire towards more agile and responsive manufacturing requires that real time information of the production plan, status and other relevant aspects is always visible for those who need it, when they need it. This, in turn, requires that the information is, on one hand collected from the production processes, and on the other hand displayed to the workers in a human-friendly way. Still common manual practices in information inputting, e.g. re-typing information from paper documents to IT-systems, don't allow real time transparency to the operations, neither provide reliable and timely information of the realized production.

The interviews conducted among 25 Finnish manufacturing companies [1] showed that even though the companies have not yet widely adopted proper manufacturing IT-solutions, such as Manufacturing Execution Systems (MES), there is a strong desire to increase the digitalization in manufacturing. MES would support real time data collection from the manufacturing operations in a digital format, and this data could be used throughout the organization for better and more synchronized management and control of the operations [2]. In order to mitigate problems relating to human perceptual and cognitive capabilities, as well as behaviour, a special attention should be paid on the design and selection of good and intuitive user interfaces (UIs) for the new manufacturing IT-systems.

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The novel ways of working on the factory floor should not only improve the efficiency and quality of operations, but also be pleasurable for the workers. To attract future operators, the manufacturing sector should target to social sustainability and adopt new UI technologies in order to be more appealing and accessible for youngsters who have grown into a digital world [3].

This paper discusses a study conducted in an ongoing LeanMES-project. The project's objective is to create a lean, scalable and extendable concept for a new type of MES that supports human operator in a dynamically changing environment. One target is to study novel approaches for intuitive user interfaces. The purpose of this paper is to draw the background for the development of UIs for factory floor operators by highlighting some relevant theory for user-centric design, and identifying and analysing the current challenges and needs of manufacturing companies. The focus of this paper is on information display and collection.

2 Research Method

The characteristics of a good design depends on the users, tasks and context of use of the designed technology (e.g. [4–6]). Therefore the research approach taken for this study was to analyse all these three aspects, namely users, tasks and context. The research, discussed in this paper, consists of the following steps:

1. **Interviews:** The data for the analysis was collected form the interviews conducted among 25 Finnish manufacturing companies mainly from machine building industry. In each company three types of personnel were interviewed to get a comprehensive view on the needs, current challenges and underlying context: (1) plant or production manager; (2) production worker and (3) main user of the production planning and execution system or IT manager. The questions focused on the everyday production planning and control, change situations, data collection and search, quality control practices and work instructions. For more information on the interviews, please refer to [1].
2. **Literature review:** Literature review on user-centric design, human-computer interaction, and existing and emerging UI technologies was conducted. The purpose was be able to take into account the relevant characteristics when making selections for proper input and output modalities, medias, technologies and display designs.
3. **Task analysis:** As LeanMES-project focuses on the information flows and visibility, the main focus in the task analysis was to map the required information inputs and outputs on different workstations and tasks. The purpose was not to perform this analysis for any individual company, but to generalize the results for machine building industry.
4. **Analysis of suitable input and output modalities, media and UI technologies:** While designing user interfaces, three selections need to be made: (1) Selection of the modality, which refers to the sensory channel that human uses to send and receive a message (e.g. auditory, visual, touch); (2) Selection of the medium, which refers to how the message is conveyed to the human (e.g. diagram, video, alarm sound); and (3) Selection of the technology to deliver the message (e.g. smart phone or workshop PC). These were analysed on the basis of the task requirements.

3 User-Centric, Human-Friendly User Interface Design

3.1 Human Characteristics Relevant for Usable Design

Based on [4], whether a system can be described being usable or not depends on four factors, namely anthropometrics, behaviour, cognition and social factors. Anthropometrics refers to the physical characteristics, such as body type and size, of the intended users. Behaviour refers to the perceptual and motivational characteristics of users, looking at what people can perceive and why they do what they do. Behavioural characteristics are mostly related to the sensation with the basic senses (sight, hearing, touch, smell and taste) and interpretation of the sensed stimuli. Cognitive factors include learning, attention and memory and other aspects of cognition that influence on how users think and what they know and what knowledge they can acquire. Social factors consider how groups of users behave, and how to support them through design [4].

Attention refers to the selective aspects of perception, which function so that at any instant a user dedicates his limited information processing capacity to the purposeful manipulation of a subset of available information [7]. According to [8] many studies have shown that it is easier to perform two tasks together when they use different stimulus or response modalities, than when they use the same modalities. According to multiple resource models, different attentional resources exist for different sensory-motor modalities and coding domains [8].

Mental models are used to understand systems and to interact with systems. Based on Ritter et al. [4] mental model can be considered as a representation of some part of the world that can include the structures of the world, how they interact and how the user can interact with them. Payne [9] simplified the meaning of mental models into “what users know and believe about the systems they use”. The model the user brings to the task will influence how they use the system, what strategies they will most likely employ, and what errors they are likely to make. It is therefore important to design the system in such a way that the user can develop an accurate mental model of it [4]. One important concept, which aids in building the correct mental model of the system, and therefore easing its usage, is the stimulus-response (S-R) compatibility. This means that there should be clear and appropriate mappings between the task/action and the response. It is typically seen as having physical aspects of an interface (e.g. buttons) and displays match the world that they are representing [7].

3.2 Guidelines for Designing Interfaces with Good Usability

Several authors have given guidelines and heuristic principles for designing user interfaces with good usability. In the following are collected the most relevant guidelines specifically for LeanMES-project’s purposes.

- *Usage of terms and language:* The system should speak the user’s language and use words they already know and which are relevant for their context. The UI should exhibit consistency and standards so that the same terms always mean the same thing. Consistent use of words strengthens the chances of later successfully retrieving these words from the memory [4, 10].

- *Use recognition rather than recall:* Systems that allow users to recognize actions they want to do will be easier initially to use than those that require users to recall a command [4, 10].
- *Favour words over icons:* Instead of displaying icons, words may be better. This is because retrieving names from memory is faster than naming objects [10].
- *Information reliability and quality:* The user should not be provided with false, misleading, or incomplete information at any time [11].
- *Show only information which is needed:* The system should be aesthetic and follow minimalist design, i.e. do not clutter up the UI with irrelevant information [10].
- *Provide feedback for the user:* The current system status should always be readily visible to the user [4, 10, 11].
- *Make available actions visible:* Make the actions the user can (and should) perform easier to see and to do [4].
- *Allow flexibility for different users:* The system should have flexibility and efficiency of use across a range of users, e.g. through keyboard short-cuts for advanced users [10].
- *Ensure that critical system conditions are recoverable:* The user should have the control and freedom to undo and redo functions that they mistakenly perform [10, 11].

In their book Wickens et al. [12] defined 13 principles for display design, which should be taken into account when designing the LeanMES UIs:

- **Perceptual principles:** (1) Make displays legible (or audible); (2) Avoid absolute judgement limits; (3) Remember that user's past experience affects to how the signals are likely to be perceived and interpreted; (4) Build redundancy to the system, i.e. present the same signal in multiple different forms or modalities; (5) Use discriminable elements.
- **Mental model principles:** (6) Utilize pictorial realism, i.e. make a display to look like the variable that it represents; (7) Put the moving elements to move in a pattern and direction compatible with the user's mental model.
- **Principles based on attention:** (8) Minimize information access cost by allowing for frequently accessed sources to be located at the nearest possible position; (9) If divided attention between two information sources is necessary for the completion of one task, make them to have close mental proximity; (10) Utilize different cognitive resources (e.g. vision and hearing) if multiple information must be presented simultaneously.
- **Memory principles:** (11) Replace memory with visual information; (12) Provide information predictively; (13) Utilize consistency among different displays.

Several things have to be considered when designing visual communications, such as web pages, different visual displays or dashboards. These include aspects such as typography (including typeface, its style, size, word spacing, leading, line length), colour, field of vision, page layout design, and amount of information on display. When using colour to show e.g. qualitative differences or highlight key data, it should be remembered that at least 9 % of population is colour-deficient. Thus, colour should not be used as an only cue [13]. Often the display size is limited, especially with hand-held devices. When evaluating how much information should be presented on the display screen, the demands from cognitive and visual perspectives may be contradicting. According to [14], presenting little information on a screen at time helps to avoid visibility problems resulting from high-information density. On the other hand, presenting as much information on screen as possible allows users to have maximum foresight (cognitive preview) of other functions on the menu, which should benefit information access from a cognitive point of view and minimize disorientation [14].

4 Results

4.1 Identified Challenges Relating to Information Inputting and Display

The performed interviews revealed multiple challenges relating to the current information inputting and display practices on the factory floors. The main challenges, encountered especially in small and medium sized companies, are summarized below:

1. The paper work orders and documents, still commonly used to control the production and to collect information from the factory floor (e.g. time stamps, quality data, measurements), were regarded as problematic, because they don't provide real time information of the operations and their status. In addition, the information written on paper must be re-typed to IT-systems, which is non-value adding manual work, prone to human errors.
2. Paper documents are cumbersome to update and they get easily lost, e.g. work instructions are not up-to-date and rescheduling or re-routing of the orders requires the production supervisor to go physically to each workstation to change the order of the jobs.
3. The current information inputting practices don't produce reliable, timely data of realized production. Many companies stated that the operators tend to forget to record the receipts or they do it only once a day. The existing UIs are cumbersome to use, or are not in the same physical location with the operator (e.g. shared computers). This has often led to such practice that the recordings are done in batches rather than immediately after the event that should be recorded.
4. The recordings or information search require often long sequence of numbers, e.g. serial, order or project number, to be manually typed to the system. This is time consuming and error prone activity.
5. The usability of the current IT-systems used in manufacturing is often poor. The operators may use substantial time of their day to searching for information.

4.2 Task Analysis

As LeanMES-project focuses on the information flows and visibility, not in human-machine collaboration in general, the main focus in the task analysis was to map the required information inputs and outputs of different roles in the factory. The roles were defined based on the tasks which are performed on different workstations. The following tasks/workstations were analysed: machining (milling and turning), sheet metal cutting, welding, assembly, as well as material receiving and shipping. The generic information needs and outputs on different tasks/workstations were systematically identified based on the interviews and workshops with industrial partners, and drawn as information input-output graphs (Fig. 1). These graphs didn't take a stand on if human involvement is needed or if machine can manipulate or produce the information automatically. The purpose was to allow different automation strategies and the allocation of the functions to either human or machine for example based on the Fitt's list (MABA-MABA approach) [4].

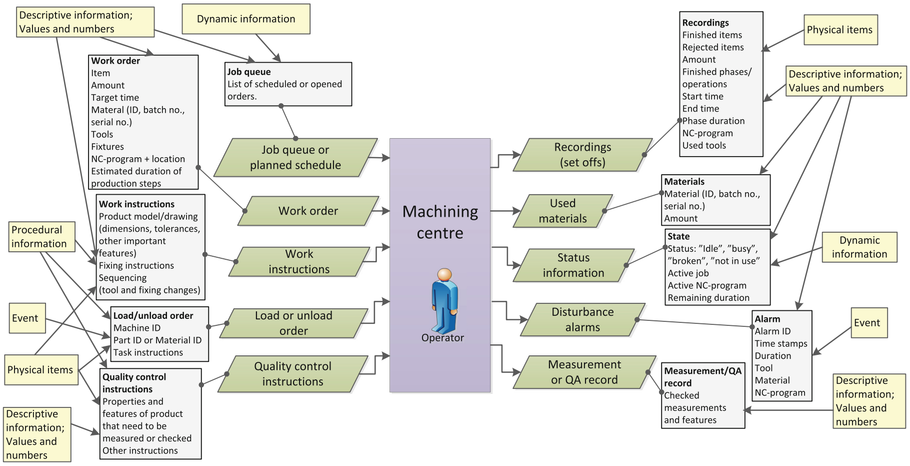

Fig. 1. Example of the information input-output graphs.

4.3 Example of Selecting the Modality, Media and Technology

The information elements in the input-output graphs were systematically categorized into physical items, spatial items, conceptual information, dynamic procedural information, events, descriptive information, values and causation, as exemplified in Fig. 1. Based on this division, suitable modality and media were suggested for each information element relying on the heuristics presented by [15]. Below one example is discussed.

In case of the machining centre's loading or unloading order, the attention of the operator has to first be captured. Especially in multi-machine operating mode, when the operator is performing multiple tasks simultaneously and doesn't have direct visual sight to the machines all the time, the suitable modality for capturing the attention could be auditory or touch (haptic). This way the operator can concentrate on the current task at hand, which most probably requires visual attention, and simultaneously receive information about the upcoming task by using other attentional resources than vision. Such output could be produced e.g. by smartphone in the operator's pocket or smart watch in his/her wrist alerting, vibrating and possibly giving spoken information about the upcoming task. After capturing the operator's attention and guiding him/her to the correct machine, the task procedure has to be instructed to him/her. For such information, containing a lot of details and information elements, vision should be used as a main sensory channel. As discussed in [9], multi-media work instructions have been proved more powerful compared to single media instructions. Therefore, the detailed task procedure may be shown as a sequence of still images, video or animation, supplemented with text-based or audio instructions. For displaying this information, larger screen is preferred next to the machine, as not so much information can be conveyed through small smart phone display without compromising the visibility. When the task is completed, the operator should record the task done through the same UI by just one click. The task status gets updated to the MES and the information is immediately visible to others.

5 Discussion and Conclusions

Human-friendly UI design is crucial when aiming for efficient operations. The identified challenges in Finnish manufacturing companies clearly show that there is a need for digitalization and adoption of new UIs on the factory floors. As noticed during the interviews, human involvement increases flexibility of the production system, but also causes uncertainty to the information management processes. In order to mitigate this problem, a special attention should be placed on good and intuitive UIs and human-computer interaction technologies. These UIs should bring the needed information to the operator without searching and allow effortless information inputting. This paper highlighted some important human characteristics and design considerations for user-centric UI design, especially from the manufacturing IT-systems' perspective.

The goal of the LeanMES-project is to support human operator especially from the information acquisition and inputting viewpoints. Therefore the task analysis presented in this paper concentrated on identifying the needed information elements, rather than identifying the detailed steps (or their sequence) that the worker needs to perform in order to achieve their manufacturing related goals. Example of the selection of the suitable modalities, media and UI technologies for the identified information elements was shortly presented. The future work will include testing and analysing the suggested media and technologies in real industrial contexts.

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Increasing Employee Involvement in Socially Sustainable Manufacturing: Two Methods for Capturing Employees' Tacit Knowledge to Improve Manufacturing Processes

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Abstract. Talented workforce is one of the main strengths in Europe to overcome the economic crisis and address the challenges ahead. The most valuable knowledge the employees have, is tacit and, therefore, hard to utilize in the companies. This paper presents two alternative facilitation methods to capture tacit knowledge related to the manufacturing process, thus allowing the employees participate in activities developing the manufacturing process and the development of positive company culture. The first method focuses on operational tacit knowledge, and the latter method extracts the production related tacit knowledge from the project members. Both of the methods use facilitation to guide the employees through the experience-based learning process and provide support for information and knowledge sharing.

Keywords: Employee involvement · Socially sustainable manufacturing · Tacit knowledge · Knowledge sharing · Facilitation · Experiential learning · Process development

1 Introduction

In the fast changing business environment, persistence in the same operating routines quickly becomes hazardous [1]. The organizations need to learn to adapt their routines, especially if the actions do not produce the intended outcome, or they produce an undesirable outcome. Organizations can learn when they have a shared vision of their aspirations and the future [2]. The vision requires management commitment, which is visible in the investment they made in resources and work processes, supporting learning in the organization [3].

In a socially sustainable corporate culture, the individuals can thrive, continuously develop their talents and use them in the industry [4]. When the work environment is stimulating, the employees are contributing themselves to the development of instructions and knowledge [5]. Internally generated ideas enable the employees to associate more strongly with the task, and to have greater commitment to it [6]. Committed

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employees are motivated and willing to put extra effort in their jobs [7]. As a result, they work more efficiently and improve their organizations' possibilities to succeed.

Also, socially sustainable organizations share knowledge between the organizational units [5]. Such an organization promotes participatory behaviour and encourages the employees to take a broader view on their jobs, and to consider a wider variety of information, inputs and constraints in their decision making process [8]. Organization should fight the Not-Invented-Here (NIH) syndrome and emphasize that everyone can have a good idea [5]. NIH refers to the bias against using knowledge from other sources, i.e. people hesitate to share what they have and to use what others have [9, 10]. Also, a democratic organizational climate leads to the free exchange of the ideas and to more opportunities for the cross-functional knowledge fertilization, thus preventing localized and isolated problem solving.

This paper presents two alternative facilitation methods, which allow the employees to capture tacit knowledge related to manufacturing process. The employees can participate in activities developing the manufacturing process and the development of positive company culture. Involving the employees in the process development, the company encourages socially sustainable corporate culture, where the employees can develop and use their talents. Also, the employees are invited to contribute to the development of instructions and knowledge. The first method focuses on operational tacit knowledge, and the latter method extracts the production related tacit knowledge from the project members. The methods also support experiential learning in the projects, as well as, information and knowledge sharing in the organization.

2 Tacit Knowledge in Organizations

An increasing number of the organizations use projects and team working to achieve the objectives, and to adapt to the changing business environment. Projects generate a vast amount of knowledge on the organizational processes, as well as, technical knowledge on the products [11]. Created knowledge is mostly tacit in nature and such knowledge cannot be taught, trained or educated, but it can be only learnt and the learning process takes time [13].

Physical face-to-face experiences are the key to conversion and transfer of tacit knowledge [14]. Reference [1] see that by sharing their individual experience and comparing their opinions with those of their colleagues, the project members can achieve an important level of understanding of the causal mechanisms intervening between the actions required to execute a certain task, and of the performance the outcome produces.

The problem of knowing who knows what, grows with the size of the organization and finding a person with relevant tacit knowledge may not be easy [15]. Small companies can list their employees' skills (e.g. related to manufacturing tools) in a spreadsheet and the production supervisor knows the staff, their skills and experiences, based on his experience [16]. Dependency on tacit knowledge only creates a huge risk for the organization. For example, especially small companies do not usually have proper manufacturing IT systems in use. When the manufacturing planning and control activities are done based on the tacit knowledge of the production planner or supervisor, then nobody knows how to update the manufacturing plan, if the person is absent. Often the Excel spreadsheets used for production planning and scheduling, are only available and understandable for the person who created them.

Another troublesome aspect of tacit knowledge, is its elusiveness [12]. There may not be effective ways in the organization to elicit tacit knowledge from the individuals, or the organization's culture might actively discourage knowledge sharing, either deliberately or incidentally [17]. Also, people may not be fully aware of their tacit knowledge or they do not have any personal need to make it explicit, or there is a potential risk of losing power and competitive advantage, when making tacit knowledge explicit [12]. Especially in small manufacturing companies, systematic practices for capturing and sharing tacit knowledge are rare [16].

Some authors (e.g. [18]) think that tacit knowledge needs to be made explicit for sharing, thus making codification an essential step in leveraging the value of knowledge in the organization. Knowledge codification allows knowledge to be accessed and used by some others, sometime in the future, and it is not dependent on the personal networking [19]. However, the effort to reduce tacit knowledge nearly always skews knowledge and separates it from its vital context [11].

3 Learning from the Past

The organization cannot learn from the projects, unless the project members' knowledge is articulated and transferred to the others [20]. Knowledge from project to project flows through direct and detoured transfers [21]. The mediums of direct transfers are mainly employees, who directly move to the next project with knowledge achieved from the previous project. Detoured transfers occur through e.g. knowledge repositories, company manuals, training programs and work processes.

Lessons learned is any form of knowledge, gained from the direct experience, successful or otherwise, to improve the performance in the future [21]. Everyone benefits from reviewing past activities and decisions, to learn what worked, what did not, what can be changed and what must be managed. Usually, the projects are not willing to invest much time in the learning activities, because that time is taken away from other responsibilities, which have a higher priority [9]. Therefore, the learning process needs to be prompted and structured, to be meaningful and useful for the projects.

In most business organizations, failure and fault are virtually inseparable, and examining past activities in depth is emotionally unpleasant and can chip away the individual's self-esteem [22]. In the end, learning from the past is reliant upon the project members' willingness to admit mistakes or deficiencies in their actions, to engage in conversation about those issues, and to subject themselves and their experience to the constructive criticism of their peers [3].

The willingness to expose oneself is related to the perceived quality of their peer relationship. Therefore, the way the project evaluation is facilitated, is crucial [12]. Facilitation is a process in which a person, the facilitator, helps a group of people complete their work and improves the way the group works together [23, 24]. Facilitation can reduce the cultural, professional or organizational barriers, which make communicating difficult [25].

Facilitation also emphasizes learning from the process. This requires that the participants are offered tools to reflect on their experience [24].

3.1 Capturing Operational Lessons Learned

A facilitation method was created for capturing the lessons learned in the project teams, to improve the project routines either in the own project (in the later phase of the project) or to propose new ways of working for some other project [26]. The described facilitation method accommodates two approaches to learning: social constructive approach (e.g. [27]) and experiential learning theory (e.g. [28]). It also uses ideas from the model of single-loop and double-loop learning (e.g. [29]), the 4i framework of organizational learning [30] and the theory of organizational knowledge creation (e.g. [31]).

The facilitation method to capture operational tacit knowledge is divided into three phases: activities prior, during and after the workshop [26]. Prior the workshop, the facilitator and the project leader discuss the facilitation method, the project group, the workshop goals and the practicalities. Workshop activities are illustrated in Fig. 1.

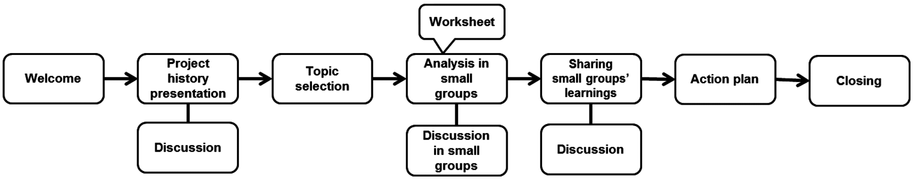

Fig. 1. Phases in lessons learned workshop

The workshop begins with a project history presentation, which defines the timeline of the activities under discussion, as well as, establishes a common ground for the conversations in the workshop. Then, the workshop participants select the topics for further analysis, to be done in the small groups, as well as, the target project for the learnings. The participants decide themselves, which topics are discussed and analysed in small groups. This allows the participants to concentrate on what they believe is important. The analysis includes a scale question related to the project performance and brainstorming ideas. The participants are assigned to small groups and they use a worksheet to document

- Activities and invested resources, which contributed to the project performance concerning the selected topic.
- Activities the project did not perform or resources they did not have, but which could have contributed to the project's success.

They also describe how they would have acted if they had the knowledge they currently have and all the resources available. The template guides the participants to convert their tacit knowledge into explicit, and document it. Each small group presents their analysis and the others have a possibility to comment on the results. Then, the participants plan how they are going to proceed with the captured lessons learned.

After the workshop, the project implements the agreed plan, and either transfers the learnings to the identified target project, or uses the improvement ideas to modify the project's own routines. The participants review the meeting minutes and the minutes they are made available for others in the organization. The captured lessons learned and the improvement ideas are also delivered to the function or team responsible for the operational development in the organization, because the ideas can be used in improving the organizational routines.

Example A: A manufacturing project was preparing for mass-production phase. Members from the target project, i.e. a similar manufacturing project in their early phase, were invited to the workshop to ensure efficient knowledge transfer. The project was the first of a kind in the organization, and there had been many challenges and issues, which the participants wanted to discuss. The analysed topics were related to the product data management and the cooperation with the customer. The created improvement ideas formed a basis for a discussion related to the needed changes in the operational mode to support the new type of projects.

3.2 Capturing Production Related Knowledge

In this facilitation method, the project members model and analyse the production process and share their experiences on the production using Design Reasoning Pattern (DRP) principles [32]. With the help of a facilitator, the participants make the production phases and sub-deliverables explicit by modelling the existing production process into logical information flow and focusing only on value adding elements. The method is divided into six phases, which can be divided into several workshops. Phases in the method are illustrated in Fig. 2.

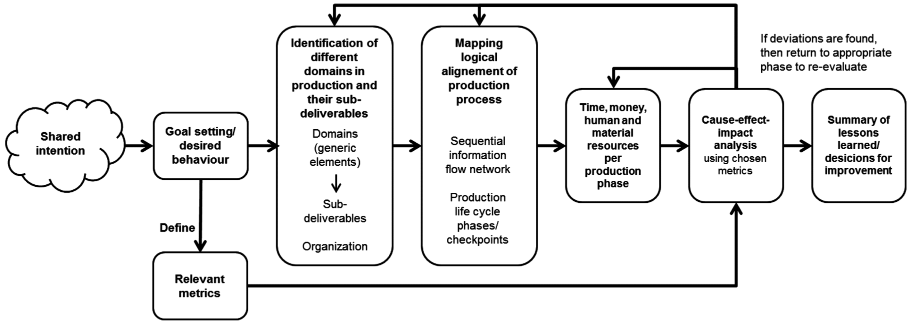

Fig. 2. Phases in the design reasoning method

First, the participants define the goals for the analysis. Then, the broader domains (i.e. functional areas of the production or organizational areas), list of sub-deliverables for each domain and the design decision elements are mapped. In the third phase, the identified elements are aligned into a process description by dividing the sub-deliverables into life cycle phases and linking deliverables into a logical sequential flow. Also, the relevant checkpoints in the production are defined.

In the fourth phase of the method, the participants define time, money, human and material resource allocations into production phases, to identify the whole spectrum of production process' information, material, work and control flows and the critical path of the process. Then, the explicit production process is analysed with chosen metrics (e.g. how much of the current errors in the production are caused by lack of information of right product specifications or by inefficient information transfer within production process or what are critical production phases to be improved). Finally, the participants are able to identify the important learnings, the points of potential improvement in the production process and the solutions to make the improvements happen.

Creating the logical relations between the design elements allows the participants to develop a shared understanding regarding the production process. More importantly, by joining the different experiences of the participants together not just makes tacit knowledge explicit, but creates totally new knowledge for participants. DRP also helps the project to create a common language which, in turn, facilitates knowledge sharing in the project.

Example B: A company was trying to find the root cause for a problem in a new manufacturing line. The problem solving had already taken over 1700 man hours and the root cause for the problem was still unknown. Then, the company used 70 man hours to create a model with the DRP method and re-test the manufacturing process. The root cause for the problem was located outside the scope the quality system related parameters. The company estimated that the created DRP model was worth of one man year of labour.

4 Conclusions

Both facilitation methods support the idea of learning organization, which is seen as one of the important aspects of socially sustainable manufacturing. If the employees learn from their experience, then they can suggest modifications to the ways of working. Additionally, the employees are involved in defining the routines they ought to follow. Presented facilitation methods increase tacit knowledge sharing, as well as, enhance communication and openness in the organization, thus leading to better understanding of the whole, i.e. how a person's work and decisions affect to everything else. The methods also support shared leadership in projects and provide better possibilities for employee involvement, as all project members can contribute to defining common plans or ways of working. This, in turn, increases employees' motivation and commitment to the organization, and provides opportunities for the organization to succeed.

In manufacturing companies, capturing lessons learned can be used to suggest the most effortless, yet effective, ways of working or to agree common rules. Design reasoning patterns produce new system level knowledge and enhance the employees' understanding regarding the manufacturing functionalities and the dependencies between them. For example, it has been noted that in the production environment the production operators are not able to make self-directed decisions e.g. related to the feasible order of the jobs. This is partly due to the lack of real time information transparency (IT system issue) but also lack of understanding of the whole. Therefore, making the factory floor workers to participate to such facilitated sessions could be beneficial for the company to enhance the production to flow and to reduce lead time.

The presented methods could be combined so, that the production development needs are analysed with the DRP method and then, as part of the change process, the earlier production changes are analysed with lessons learned method to find out the most effective ways of implementing changes. However, the methods require a supporting organizational culture, which may not be present in the small manufacturing companies at the moment. Also, the DRP method might be too complex for a small manufacturing company which does not have own product development functions. Additionally, the methods do not directly enhance the availability of production related information needed for design for manufacturing, design for assembly and design for assembly automation.

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A Study on Social Assessment in Holistic Lifecycle Management

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Abstract. Sustainable manufacturing has been focus of the industry for some time. Due to the holistic nature of sustainability not only the manufacturing processes but the whole life cycle and the environmental, economic and social aspects of the product should be taken in to account. In order to leverage from the concept of sustainability it is necessary to involve it in decision making process in the supply chain. It is essential to have an evaluation procedure so as to involve it in decision making which should be capable of assessing economic, environmental and social performance of the product. Unfortunately the social dimension of sustainability is the least developed and even neglected because it is difficult to evaluate due to its quantitative and subjective nature. The social aspects of holistic life cycle approach will be presented in this paper.

Keywords: Sustainability assessment · Holistic lifecycle management · S-LCA

1 Introduction

Several definitions of sustainability have been proposed, over time. The World Commission on Environment and Development declaration reads: "*sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with the future as well as present needs*" (Jovane et al. 2008).

There is now a well-recognized need for achieving overall sustainability in industrial activities, arising due to several established and emerging causes: diminishing non-renewable resources, stricter regulations related to environment and occupational safety/health, increasing consumer preference for environmentally-friendly products, etc. In particular, the manufacturing sector, which lies at the core of industrial economies, must be made sustainable in order to preserve the high standard of living achieved by industrialized societies and to enable developing societies to achieve the same standard of living sustainably (Jayal et al. 2010).

Sustainable manufacturing must respond to; economic challenges, by producing wealth and new services ensuring development and competitiveness through time; environmental challenges, by promoting minimal use of natural resources (in particular non-renewable) and managing them in the best possible way while reducing

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environmental impact; social challenges, by promoting social development and improved quality of life through renewed quality of wealth and jobs (Jovane et al. 2008).

The problem of finding a balance between the economic, social, and environmental values of human development is now at the heart of the debate that involves men of culture, men of faith, economists and politicians, who are working together to tackle the problems of globalization. At the center is a reflection of the responsibilities of politics and economics that is related to the imbalance of the world's social and economic order, putting in danger the ultimate goal for a civil society which is to guarantee an acceptable human condition that may be 'shared', starting from the common membership of a network of international relationship that is central to our age (Pepe 2007).

In the last few decades, ethics in business activities has become part of the wider concept of CSR, which is developing from a good idea to a critical part of business activity. CSR has become important in terms of consumers' perceptions, so it has become important for all consumer-oriented firms. Corporate social responsibility (CSR) is a broader concept and not limited to supply chains, but to the companies' overall treatment of human beings and the environment. Broadly speaking, the construct of CSR as we know it today has two main characteristics. Firstly, it describes the relationship between business and the larger society. Secondly, it refers to a company's voluntary activities in the area of environmental and social issues (Andersen and Skjoett-Larsen 2009).

Usually, studies of supply chain management have concentrated on economic issues, such as finding ways to minimize the operational costs or to maximize profits. Sustainable supply chain management (SSCM) may be defined as the strategic, transparent integration and achievement of an organization's social, environmental, and economic goals in the systemic coordination of key inter-organizational business processes for improving the long-term economic performance of an individual company and its supply chain (Carter and Rogers 2008).

All over the world, companies make business decisions every day which affect people and environment, directly through their own operations, or indirectly through the value chain of their business. Increasingly, these companies are confronted with questions, e.g. from customers, consumer organisations and other NGOs, regarding their social performance. Society's expectations to companies to assume a wider responsibility for the social impacts of their business activities is a challenge that has been accepted by companies that wish to conduct business in a more responsible way. Many companies, thus, see themselves in need of a tool which can help them make informed decisions about their social impacts throughout the life cycle of their products (Dreyer et al. 2005).

Holistic life cycle approach is an evaluation methodology which takes into account the whole life cycle of a product and generates performance characteristics (technical, environmental, economic and social) of a product or product system. The life cycle data is collected from all the actors of value chain and transformed into performance characteristics, which may further be used for decision making. The social aspects of the evaluation procedure are presented in this paper.

2 State of the Art (Social Life Cycle Assessment)

Social sustainability sees the development of society as a way of ensuring the participation of all members of society. This involves creating a balance between social forces with a view to achieving a livable society that is sustainable in the long term. As regards training, this means, for example, offering equal opportunities when it comes to accessing learning content irrespective of the geographical location of individual members of society. Manufacturing processes in mass production require workers who have an elementary education and need additional customized training programs that are independent of specific manufacturers and products (Marxer et al. 2011).

The technical system produces many effects (positive and negative) upon human well-being, which are experienced as social impacts by stakeholders (for instance, workers, consumers, local society, etc.) involved in the life cycle. Assigning these effects to one functional unit highlights the balance between the advantages (the units of service provided) and often the drawbacks (for example, quantities of health destroyed).

Social impact refers to consequences caused by activities corresponding to various stakeholders. As far as social impacts are concerned, the consequences may be derived from three dimensions: behaviors (specific behavior/decision) social-economic processes (the socio- economic decision e.g. investment decision) and capitals (human, social, cultural context) (Sanchez Ramirez and Petti 2011).

When referring to the causes of social impacts, this generally implies three dimensions behaviors (social impacts are those caused by a specific behavior), socio-economic processes (social impacts are the downstream effect of socio-economic decisions), and capitals (social impacts relate to the original context (attributes possessed by an individual, a group, a society e.g., education level) (Benoît 2010a).

Those three dimensions are not exclusive and have dynamic relationships: socio-economic processes have effects on behavior that may also be rooted in the attributes possessed by an individual or a group. Since the social impacts are often perceived as being very complex and subjective, it is not recommended to define attributes of relationships unilaterally and from there define a set of related indicators isolated from the stakeholder context. As for environmental impacts (cf. the doubts expressed by the non-believers of human-induced climate change), defining social impact categories needs to go through a subjective and inter-subjective process, preferably at the international level (Benoît 2010a).

The methods available for working with social aspects in the supply chain include stand-alone tools as well as guidelines and standards. The difference between tools and standards are not clear-cut, and either or could be used as point of departure for improved social performance. The most established method is social impact assessment, but as the focus on social impacts within business (and within society at large) has increased over the last few years, so has the number of methods for assessing, reporting and improving performance with regard to these impacts. The most important methods are; Social Impact Assessment, Social Accountability 8000 Standard, The Global Reporting Initiative, UN Global Compact, Social Life Cycle Assessment of Products, ISO 26000: Guidance for social responsibility (Palme 2011).

A social and socio-economic Life Cycle Assessment (S-LCA) is a social impact (and potential impact) assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle. It is stated that: 'The ultimate objective for conducting an SLCA is to promote improvement of social conditions and of the overall socio-economic performance of a product throughout its life cycle for all of its stakeholders'. Thus, according to this statement, SLCA should be developed in such a way that its use in some way creates a more socially beneficial situation for the stakeholders in the product life cycle (Jørgensen et al. 2012).

S-LCA allows increasing knowledge, providing information for decision makers and promoting improvement of social conditions in product life cycles (Benoit et al. 2010b). S-LCA helps inform incremental improvements but does not in itself provide a breakthrough solution for sustainable consumption and sustainable living. Those topics go well beyond the scope of the tool. S-LCA provides information on social and socio-economic aspects for decision making, instigating dialogue on the social and socio-economic aspects of production and consumption, in the prospect to improve performance of organizations and ultimately the well-being of stakeholders (Benoît 2010a).

One important feature to be emphasized is that social impact is not directly linked to the production chain process of a product, it is not determined by physical flows, unlike the E-LCA, but from the way it interacts with the stakeholders. Therefore, the identification of all stakeholders involved on the product/service life cycle is a fundamental issue when performing an S-LCA (Sanchez Ramirez and Petti 2011).

3 Social Evaluation in Holistic Life Cycle Approach

Holistic life cycle approach is a product evaluation procedure, which takes into account the whole life cycle of the product (material extraction, production, use and disposal) and provides performance characteristics (technical, environmental, economic and social) in order to have a broad perspective about the all activities of the product and processes. HLA may provide valuable information in order to be used in decision making and reduces the risk of decision making.

LCA, LCC and S-LCA are combined in HLA. The methodologies involved in HLA have life cycle perspective thus avoids burden shifting. Since all the activities through the life cycle of the product is taken into account, their performances may be evaluated separately.

LCA and LCC is performed based on the unit processes concerning the product, however S-LCA is performed based on the interaction of the life cycle actors with the stakeholders around them. In order to combine LCA, LCC and S-LCA, the three methodologies should have the same system boundaries. The same LCI could be used for LCA and LCC, since the data needed for both methodologies are quantitative. LCI for S-LCA contains quantitative and qualitative data, and also data regarding to the stakeholders out of the value chain. A separate LCI should be prepared for S-LCA. Additionally, in some conditions the system boundaries for S-LCA should be extended in order to involve the missing stakeholders.

Social performance characteristics are evaluated by social life cycle assessment (S-LCA). The guideline provided by UNEP are followed in S-LCA. Figure 1 illustrates the assessment framework for S-LCA.

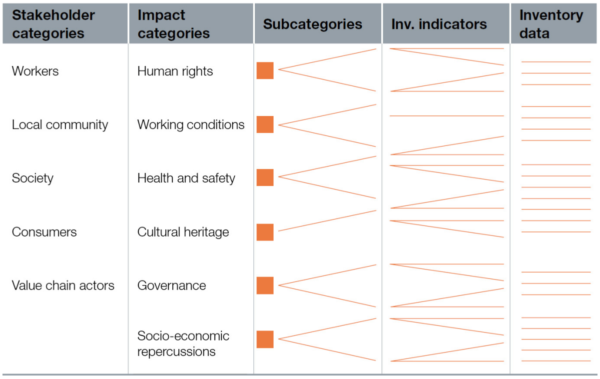


Fig. 1. Assessment system from categories to unit of measurement

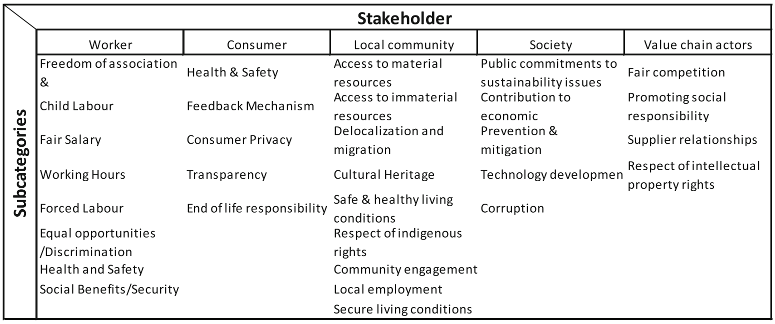
A stakeholder category is a cluster of stakeholders that are expected to have shared interests due to their similar relationship to the investigated product systems. Additional categories of stakeholders or further differentiations or subgroups can be added in order to have more detailed and precise subcategories of a specific stakeholder of concern may be identified (Benoît 2010a). In spite the fact that, the environmental and economic aspects are related to the life cycle actor itself, social impacts may be occur in five main stakeholder categories presented in Fig. 1, at each life cycle actors location. Additionally, it is necessary to note that the scope of S-LCA should be defined carefully because it will determine the number of companies that will be involved and contributed in the evaluation, and the amount of data that should be handled.

The aggregation of the sub categories is another issue since there will be qualitative and quantitative data will be collected during the study. This means the performance characteristics will also be both quantitative and qualitative.

Figure 2 shows the subcategories for S-LCA. The first think to do is to decide on the subcategories that will be included and excluded in the assessment and justify the decision. Second step is to collect inventory data concerning the sub categories. And finally, aggregate the data in a way that the alternative scenarios may be evaluated.

4 Case Study (SUWAS)

The SuWAS project (Sustainable Waste Management Strategy for Green Printing Industry Business) is an ECO-INNOVERA project aiming at the economic, social and environmental assessment of the deployment of a new technology at EU scale. This technology is patented and owned by the University of Alicante. The patent concerns the process to recover the waste-ink components of the (solvent-based) flexographic



	Stakeholder				
	Worker	Consumer	Local community	Society	Value chain actors
Subcategories	Freedom of association &	Health & Safety	Access to material resources	Public commitments to sustainability issues	Fair competition
	Child Labour	Feedback Mechanism	Access to immaterial resources	Contribution to economic	Promoting social responsibility
	Fair Salary	Consumer Privacy	Delocalization and migration	Prevention & mitigation	Supplier relationships
	Working Hours	Transparency	Cultural Heritage	Technology developmen	Respect of intellectual property rights
	Forced Labour	End of life responsibility	Safe & healthy living conditions	Corruption	
	Equal opportunities /Discrimination		Respect of indigenous rights		
	Health and Safety		Community engagement		
	Social Benefits/Security		Local employment		
			Secure living conditions		

Fig. 2. Subcategories for S-LCA

printing industry to generate secondary products. It is an alternative to the current costly (120 Euros/ton) mandatory incineration (hazardous waste). A general overview of the system under study is shown in Fig. 3.

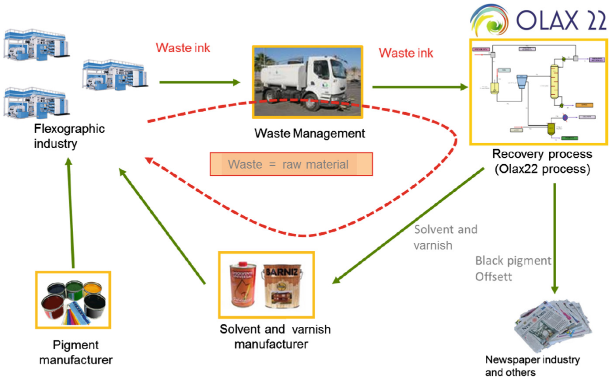


Fig. 3. Overview of the system, with outputs

This study focuses on the end-of-life of waste-ink from the flexographic industry, including waste collection and treatment. This is a ‘gate to grave’ approach which does not consider the whole life cycle of the product (this would be a cradle to grave approach). The upstream life cycle stages of ink (production and use phases) have not been included into the study since; a) ink is considered as a waste, b) they are similar between the compared scenarios and would not provide any insights for the analysis.

The subcategories included in the social evaluation are shown in Table 1.

We cannot adhere to the system boundaries of the LCA and LCC study, because the recycling of the waste ink will reduce the need for imported ink from China. In this case, it is necessary to extend the system boundaries and include the ink production stage in the assessment.

Table 1. Subcategories selected for SUWAS

• Worker • Fair salary C_{FS} • Working hours C_{WH} • Health and safety C_{HS} • Consumer • Health and safety • End of life responsibility • Local community • Access to material resources • Delocalization and migration	• Safe and healthy living conditions • Local employment • Society • Public commitment to sustainability issues • Contribution to economic development • Technology development • Value chain actors • Promoting social responsibility • Supplier relationships

Three scenarios were evaluated for processing waste ink; (1) it is incinerated in the waste disposal company, it is recycled in the printing facility, and it is recycled in the waste ink recycling company. These scenarios are evaluated in the region of UA in Spain, and EU level deployment of the process. Some of the performance characteristics for workers and the necessary information in order to evaluate them are shown in the Table 2 below.

Table 2. Performance characteristics for workers

Performance characteristics		Required data	
Fair salary	C_{FS}	Salary of the workers Minimum living wage	$C_{FS} = \frac{Salary\ of\ workers}{Min.\ living\ wage}$
Working hours	C_{WH}	Weekly working hours Authorized working hours	$C_{WH} = \frac{Weekly\ working\ hours}{Auth.\ working\ hours}$
	C_{OT}	Overtime reported weekly	$C_{OT} = Weekly\ overtime\ reported$
The cost of man hour	C_{MH}	Salary of the workers Weekly working hours	$C_{MH} = \frac{Salary\ of\ the\ workers}{Monthly\ working\ hours}$
Health and safety	C_{HS}	Number of incidents monthly Avg. number of incidents in the sector	$C_{HS} = \frac{Incidents\ reported\ monthly}{Average\ number\ of\ incidents}$

Comparison of the performance characteristics for three scenarios are illustrated in Fig. 4. The workers in the second scenario have better conditions than the other scenarios, since they have better salary then the others, the working hours seem to be fair, and it offers a safer environment to work. However, it should be noted that the man/hour cost is higher in this scenario. In economic point of view, this scenario exhibits a higher labor cost, but the share of the labor cost among the other LCC items should be identified.

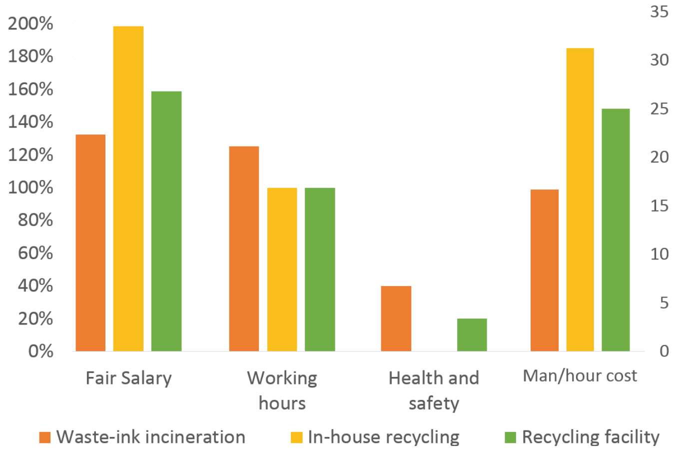


Fig. 4. Comparison of performance characteristics for Workers

5 Conclusion

Appraisal of sustainability requires a holistic approach that takes into account the whole life cycle of the product system and combination of a number of methodologies that evaluates the economic, environmental and social aspects of sustainability. Social sustainability which is one of the three pillars of sustainability, has been discarded not only because it is difficult to evaluate but also environmental and economic aspects have gained more attention in the last decade. Social-LCA aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle in order to promote improvement of social conditions and overall socio-economic performance of a product for all its stakeholders. Stakeholders and subcategories should be determined carefully and elaborately so as to be able to evaluate the social performance of the product implicitly.

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Towards a Human-Centred Reference Architecture for Next Generation Balanced Automation Systems: Human-Automation Symbiosis

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Abstract. Human-centricity in manufacturing is becoming an essential enabler to achieve social sustainable manufacturing. In particular, human-centric automation can offer new means to increase competitiveness in the face of new social challenges for the factories of the future. This paper proposes a Human-Centred Reference Architecture that can structure and guide efforts to engineer Next Generation Balanced Automation Systems featuring adaptive automation that take into account various criteria in the operating environment such as time-lapse, performance degradation, age-, disability- and inexperience-related limitations of operators to increase their working capabilities.

Keywords: Balanced automation systems · Human-Centred manufacturing · Reference architecture · Level of automation · Social sustainability

1 Introduction

According to the European Factories of the Future Research Association (EFFRA) Roadmap 2020, *human-centricity* will be a prerequisite for the factories of the future seeking to increase flexibility, agility and competitiveness in the face of new social challenges (e.g. demographics). Thus, future manufacturing enterprises will need to be proficient in assisting ageing, disabled and apprentice operators by using evolved information and communication technology capabilities in order to enhance their understanding and thus enable better execution of advanced manufacturing operations [1]. Importantly, this endeavour is likely to require the *dynamic* (re-)configuration of automation levels driven by the operator execution limitations (gaps) in advanced production management systems in order to enhance competitiveness and compensate for age-, disability-, and inexperience-related limitations of operators to increase their working capabilities.

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In this paper, the authors contrast the Tayloristic paradigm of Balanced Automation Systems characterised by a selected mix of independent automated activities and human activities, having humans at subservient roles to machines and automation – (e.g. supervisors [2]), towards a *human-automation symbiosis* [3], or Next Generation Balanced Automation System – characterised by the cooperation of machines and automation with humans, and designed not to replace the skills and abilities of humans, but rather to assist humans in being more efficient [3].

The authors explore the bodies of knowledge of intelligent (smart) automation systems [4] and the Enterprise Architecture discipline [5, 6] to propose a Human-Centred Reference Architecture for engineering the Next Generation Balanced Automation Systems, featuring *adaptive automation* [7].

2 Current Efforts to Evolve Balanced Automation Systems

The basic principle leading to the envisioned Next Generation Balanced Automation System is *human-centricity*, meaning that "humans should never be subservient to machines and automation, but machines and automation should be subservient to humans" [2].

According to Tzafestas [3], the *human-automation symbiosis* necessary to achieve sustainable development in human society can only be secured by the use of intelligent (smart) automation systems and interfaces, where the assumed 'intelligence' allows inclusion of the explicit representation of human goals and plans and thus constitutes the basis of human-machine interaction. Hence, *human-centred design* should go beyond the traditional human factors that merely focus on helping operators manage their workload in a healthy and safe manner, to a higher humanistic level such as job inclusion and satisfaction.

Furthermore, according to Hancock et al. [8] the idea of having machines and automation adapt to the cognitive and physical demands of humans in a momentary and dynamic manner *(adaptive automation)* – is one of the most important ideas in the history of human-automation interaction research towards social sustainability[1] [8, 9]. In this sense, adaptive automation aims to optimise cooperation and to efficiently allocate labour (cognitive and physical) and distribute tasks between the automated part and the humans in the system [10]; importantly, this paradigm also allows the user and/or the machines to modify the level of automation by shifting the control of specific functions whenever predefined conditions are met [11].

Adaptive automation will help improve a manufacturing system performance in a sustainable way by providing different types of automation solutions ranging from pure

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[1] *Social Sustainability* – "the freedom to choose at any stage in life between different forms of work (work arrangements, field of work) or lifestyles, while being at all times entitled to individual social security" [8].

manual to fully automatic[2] [12] according to human-centred automation criteria[3] [13], thus making it possible to rely on humans and automation to *jointly* achieve production objectives. Essentially, assistance is to be provided in an adaptive and dynamic manner and *only when required* (i.e. to help an operator in difficulty to perform his/her tasks according to the expected quality of performance). Nevertheless, the functional state of the operator is to be continuously monitored in order to provide the assistance (aiding) only when necessary and in an unobtrusive manner, i.e. without interfering with the operator's cognitive and physical resources [8]. Thus, one can use *advanced trained classifiers* [14] relying on psycho-physiological measures (neuro-ergonomics) in order to determine when an operator *actually* requires assistance and subsequently to prompt the advanced manufacturing system to provide an appropriate type and level of automation facilitating optimal operator performance.

Hence, the main envisaged goals of *adaptive automation* are to prevent errors and to reduce out-of-the-loop performance by preserving an adequate level of situation awareness [15] and mental workload, while providing a crucial perception of empowerment materialised into an appropriate level of freedom for the operator [16].

3 Towards a Human-Centred Automation Reference Architecture

Tzafestas [3] argues that the design and engineering of cooperation between human and machine or automation system must start from the very beginning and permeate all lifecycle phases of the system. Consequently, *human-automation symbiosis engineering projects* that design such systems must *also* implement processes that observe the *human-centricity principle*, in the context of their own lifecycle.

It is hereby argued by the authors that an optimal way to integrate the lifecycle and human aspects in a *human-centred automation reference architecture* is by involving the Enterprise Architecture (EA) body of knowledge. For the purpose of this work, authors adopt the mainstream definition of EA, seen as a holistic *change management* paradigm that bridges management and engineering best practices, providing the "[…] key requirements, principles and models that describe the enterprise's future state […] EA comprises people, processes, information and technology of the enterprise and their

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[2] *Levels of Automation* – "the allocation of physical and cognitive tasks between resources (humans and technology), described as discrete steps from 1 (totally manual) to 7 (totally automatic), forming a 7 by 7 levels of automation matrix containing 49 possible types of automation solutions" [12].

[3] *Criteria* – (1) Allocate to the human the tasks best suited to the human, and allocate to the automation the tasks best suited to it (2) Keep the human operator in the decision-and-control loop. (3) Maintain the human operator as the final authority over the automation. (4) Make the human operator's job easier, more enjoyable, or more satisfying through friendly automation. (5) Empower or enhance the human operator to the greatest extent possible through automation. (6) Support trust by the human operator. (7) Give the operator computer-based advice about everything he or she should want to know. (8) Engineer the automation to reduce human error and minimize response variability. (9) Make the operator a supervisor of subordinate automatic control systems. (10) Achieve the best combination of human and automatic control, where best is defined by explicit system objectives [13].

relationships to one another and to the external environment" [17]. Thus, EA considers the socio-technical aspect of systems [18], seen as composed of commitments assumed by voluntaristic people [19] in a complex organisational, political and behavioural context [20, 21]. Therefore, the authors argue that EA-based artefacts such as reference frameworks are capable to provide comprehensive 'shopping lists' of potentially applicable aspects and at the same time integrate all *necessary* viewpoints (as determined by the stakeholders for the project at hand) in a lifecycle-based set of models ensuring the consistency and sustainability of complex projects (with *human-automation symbiosis engineering* as a prime example).

In line with this stance, the authors propose the adoption of the Purdue Enterprise Reference Architecture (PERA) [5] and ISO14258 [6] (which places the PERA concepts within a conceptual framework enabling coverage and completeness assessment) as a starting point in building a human-centred automation reference architecture. PERA incorporates an *explicit* representation of the human role in any type of system and importantly, it also shows the *extent* of automation, defined as "the absolute extent of pure technologies in their capability to actually automate the tasks and functions of the […] system" [5, 22]. PERA also shows the relationship between the level of automation (of both the control and information systems and the production/service systems), and *its effect* on the human and organisational element of the enterprise [5].

In the following, the PERA lifecycle architecture (see Fig. 1) will be used in order to reflect a 'master plan' [5, 22] outlining the specifications of a *human-automation*

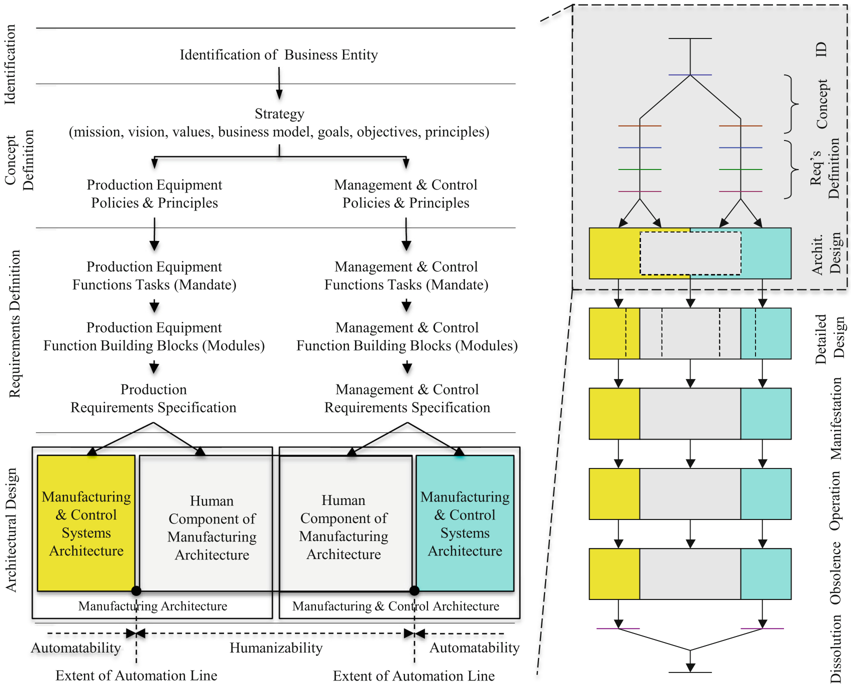

Fig. 1. The Purdue Enterprise Reference Architecture (PERA) [Complete set of lifecycle phases shown on right, current research scope on left]

symbiosis engineering project. The sample business entity selected for this purpose is a typical factory production line.

3.1 Identification Phase

At this phase, the architect (meaning a stakeholders group, including the operators) conducts the typical feasibility (e.g. economic and socio-technical) and SWOT studies at the production line in question in order to identify potential gains and benefits balanced against costs and risks presented by including the proposed workstation(s) in the *human-centric automation engineering program.*

3.2 Concept Definition Phase

- The *Mission* is to design and engineer a human-centred production system [23] based on a human-automation symbiosis paradigm that allows operators to feel empowered and in control of their workstation, while also fostering the optimal use of human competencies (knowledge, skills, abilities and behaviours). The system is also to compensate for operators' limitations, thus ensuring a socially sustainable working environment without compromising production objectives.
- The *Vision* is to provide adaptive balanced automation systems that comply with mainstream models of human-centred production systems [23] and factories [24].
- *Values:* Ergonomics, Human Factor, Occupational Health, Safety, Inclusiveness.
- *Strategy:* To develop a master plan featuring adaptive automation in order to achieve human-automation symbiosis in the workstations of a production system.

	Production Equipment	Management & Control
Policies & Principles (simplified)	• Manufacturing policies ○ Manufacturing goals ▪ Operational excellence ▪ Safety and health ▪ Inclusiveness ○ Manufacturing priorities ▪ Production control ▪ Quality assurance • Manufacturing principles ○ Human-centred manufacturing ○ Flexible manufacturing ○ Agile manufacturing ○ Human-computer interaction ○ Human-machine interaction	• Occupational health and safety policies [24] ○ Regulations ○ Laws • Flexible task allocation principles [25] [26] ○ Physical task(s) ○ Cognitive task(s) ○ Sensing task(s) • Shared and traded control principles [27] ○ Adaptive automation

3.3 Requirements Definition Phase

Special attention must be paid to human-automation interaction requirements [13, 28]:

	Production Equipment	Management & Control
Requirements (simplified)	• Operator(s) profiling [24] ○ Anthropometry ○ Functional capabilities ▪ Physical ▪ Cognitive ○ Knowledge ▪ Skills ▪ Expertise ○ Personal needs • Production system(s) profiling [24] ○ Production objectives ▪ Key performance indicators ○ Manufacturing Processes ▪ Flexible assembly operations ▪ Flexible assembly sequencing ○ Workplace ▪ Flexible hand tool(s) ▪ Flexible machine tool(s) ▪ Flexible workstation(s) ○ Governance (for operators) ▪ Level of authority ▪ Level of decision making	• Occupational health and safety strategies [24] ○ Shift work good practices ○ Safety equipment ○ Organisational incentives • Listing of human-automation interaction requirements [13] [28] • Flexible task allocation strategies [25] ○ Value stream mapping ○ Hierarchical task analysis ○ Levels of automation ▪ Physical automation ▪ Cognitive automation ○ Function allocation decision [26] ▪ Humanized allocation ▪ Flexible allocation ▪ Allocation by users • Hybrid automation invocation strategies [27] ○ Critical-event strategy ○ Measurement-based strategy ○ Modelling-based strategy
Building Block Modules (Simplified)	• Core technologies (modules) ○ Manufacturing technology ○ Automation and control technology ○ Robotics technology ○ Human-machine interface technology • Support technologies (modules) ○ Information technology ○ Communication technology ○ Management technology	• Flexible task allocation modules [25] ○ Human resources management ○ Operations management • Function (task) allocation module – decision support system [26] • Hybrid automation invocation modules [27] ○ Critical-event strategies: ▪ Emergency logic ▪ Executive logic ▪ Automated display logic ○ Measurement-based strategy ▪ Workload measurement ○ Modelling-based strategy ▪ Intent inferencing models ▪ Mathematical models ▪ Resource models
Networks (Simplified)	• Manufacturing processes flow diagrams ○ Assembly operations ○ Assembly sequencing • Quality criteria (checklist)	• Information flow diagrams ○ Production measurement ○ Production control ○ Operational planning ○ Operational scheduling

Bailey's [26] *function allocation catalogue* provides three human-centred strategies: *humanized allocation* (priority to the operator over the machine), *flexible allocation* (according to values, needs and interests) and *allocation by users* (operator chooses according to conditions), in order to support decision-making from the point of view of the ability of humans to perform.

According to Inagaki [27], in adaptive automation, functions (tasks) can be shared or traded between humans and machines in response to changes in situations or human performance. There are three classes of *automation invocation strategies:* critical-event, measurement-based and modelling-based.

3.4 Architectural Design Phase

The operations involved in a project or production line can be classified according to their purpose into mission fulfilment tasks and information management and control tasks; humans (including system operators) are inherently involved in all these operations for technological, economic and social reasons.

<table>
<tr><td colspan="2">Mission Fulfilment Task</td><td colspan="2">Information & Control Tasks</td></tr>
<tr><td colspan="2">Manufacturing Architecture</td><td colspan="2">Management & Control Architecture</td></tr>
<tr><td>Mechanised Tasks</td><td colspan="2">Human Implemented Tasks</td><td>Automated Tasks</td></tr>
<tr><td>Specification of equipment needed for adaptive control tasks of operators</td><td>Tasks of operators working with the adaptive automation system</td><td>Tasks of operators to be controlled by the adaptive automation system</td><td>Specification design of the adaptive automation system</td></tr>
<tr><td colspan="4">↺ Adaptive Automation ↻</td></tr>
</table>

According to Inagaki's [27] adaptive automation strategies, within the *critical-event strategy,* functions' allocations change when specific events (called critical-events) occur, e.g. in the human-automation symbiosis. Allocation of functions would not be altered if the critical events did not occur during the *human-machine system operation*; in this sense, function allocation within a *critical-event strategy* is *adaptive.* In *measurement-based strategies,* functions' allocations are *dynamic* between operators and machines so that the momentary operator workload (based on psycho-physiological measures) can be regulated around an optimal level. In *modelling-based strategies,* functions' allocations are based on operator performance models (intent inferencing models, optimal (mathematical) models or resource models) that can be used to estimate current and predicted operator state and to infer whether workload is excessive or not.

The ultimate aim of human-automation symbiosis is the achievement of adaptive automation across all workstations of a human-centred production system in order to allow a dynamic and seamless transition of functions (tasks) allocation between humans and machines that optimally leverages human skills to provide inclusiveness and job satisfaction while also achieving production objectives.

4 Human-Automation Symbiosis Scenarios

In contrast with the traditional view of automation, *adaptive automation* is designed to anticipate changes under active control of an operator while maintaining precise control of all background variables not currently of interest [10]; thus, dynamic allocation of task control [25–27] (in whole or in parts) crossing over various types and levels of automation should be considered to exist in a *continuum* between the manual and fully automated operational boundaries [11]. There is growing evidence pointing that beyond thinking of adaptive systems as co-workers, humans are increasingly expecting them to *display human behaviour*. Consequently, adaptive automation ventures into potentially uncharted territories, featuring new challenges for both users and designers that go beyond the traditional ideas of human-computer interaction and system design [29].

In the following sub-sections, the authors introduce three scenarios illustrating the way adaptive automation can help achieve human-automation symbiosis in the context of human-centred production systems [23] and factory models [24]. Naturally, the scenarios presented make use of the adaptive automation aspects structured in Sect. 3 using PERA, such as shared and traded control principles, flexible task allocation strategies, including levels of automation and function allocation decision and hybrid automation invocation strategies.

In relation to the latter aspect, c*ritical-event* function allocation should apply to all scenarios, while *measurement-based* and *modelling-based strategies* application may vary in their applicability. This is because the critical-event strategy is aimed to take care of the operator health and safety, as well as of the production objectives. Thus, a critical-event *emergency logic* involves automation invocation without human involvement e.g. if the operator violates occupation health and safety regulations. A critical-event *executive logic* invokes the sub-processes leading up to the decision to activate automation, with only the final decision requiring the human's approval, e.g. in case of a drop in performance. Finally, a critical-event *automated display logic* allows all non-critical display findings to be automated in preparation for a particular event (e.g. troubleshooting), so that the human can concentrate on the most important tasks to fix the critical event problem(s).

4.1 Senior Operators (Aging Challenge)

In this case, *adaptive automation* can help a senior operator in a twofold manner: either by increasing automation to compensate for ageing-related limitations and thus help keep with the physical and cognitive quality performance of the job, or by reducing the level of automation, on request, in order to provide the senior operator with a 'craftsman' experience and increase the level of job satisfaction. Furthermore, the operator may influence the functions allocation within the *measurement-based* strategy (e.g. by sharing and trading control) outside the 'optimal' level if this action does not compromise personal health and safety and the production objectives. Flexibility in functions allocation is allowed, but at the same time workload will be monitored in real-time in case of physical or mental over-stress (critical-event), so automation can take over. The *modelling-based* function allocation strategy (utilising models to estimate current and predicted operator state) has a very limited role in this scenario (if at all present) as the focus should be on recreating the craftsman experience or compensating for ageing-related limitations. In addition, by collecting senior operators' knowledge and experience in a particular task, the system could improve the learning curve of new operators by providing *adaptive* automated expert help [30], as also shown in Sub-Sect. 4.3.

4.2 Operator with a Disability (Inclusiveness Challenge)

Adaptive physical and cognitive automation can assist an operator with a disability to be able to perform 'normal' tasks (i.e. suitable for workers with no-disabilities). *Modelling-based* function allocations should be prevalent, based on models obtained from regular disability degree assessments, in order to allow the proper aiding and freedom of automation levels. *Measurement-based* function allocation could be used to fine-tune the level of automation based on the disabled operator condition.

4.3 Apprentice Operator (Learning Curve Challenge)

In this case, apprentice operators can learn new routines with (mainly cognitive) automation assistance. *Measurement-based* function allocation would play a major role here; as the operator learns and performs operations faster and with fewer errors, the system can gradually surrender automated tasks to the human side. *Modelling-based strategies* could also be used to achieve stability for specific periods of time (e.g. supporting regular performance reviews).

4.4 Summary of the Scenarios

It must be noted that scenarios such as those shown above vary in content depending on the specific application and may also have overlapping areas, depending on the particular lifecycle phase that the context system finds itself currently in. For example, the necessity to learn new tasks, typical to scenario 4.3 during Operation phase, can also manifest itself in scenarios 4.1 and 4.2, e.g. during Obsolesce and Decommissioning phases when humans may need to be trained in order to be re-assigned, or during Manifestation (Implementation) phase when design changes bringing new functionality for the system require new operator competencies.

5 Conclusions and Further Work

The paper has presented the use of modelling artefacts provided by an Enterprise Reference Architecture in order to guide and structure the efforts to define a Human-Centred Reference Architecture for Next Generation Balanced Automation Systems. After populating the areas deemed to be the most relevant to human-automation symbiosis, the paper has briefly illustrated the practical use of these aspects in several typical scenarios.

More research is required in order to delve deeper into the structured aspects provided by PERA, possibly by using other reference architectures that further subdivide these aspects and/or represent them orthogonally in relation to other aspects (e.g. Function, Information, Organisation, Resources, Risk, Economical, Hardware, Software etc. – see ISO15704 Annex A: GERAM [31]). This would provide more detailed guidance as to the available viewpoints and areas that may need to be addressed in specific adaptive automation projects, so as to advance the work towards the creation of a truly human-centred factory model.

This research work has been driven by EFFRA (industrial association) Roadmap 2020 that calls for *human-centricity* in the factories of the future.

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The Interplay Between Product-Services and Social Sustainability: Exploring the Value Along the Lifecycle

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Abstract. Our understanding of the interplay between product-services and social sustainability is still very limited. This paper sheds light on the interconnections between social sustainability and product-services throughout their lifecycle, and identifies a set of common topics and practices to be investigated by experts of Advances in Production Management Systems. In doing so, the paper sets the stage for future efforts aimed at exploiting the opportunities identified and exploring new synergies between product-services and social sustainability.

Keywords: Product-service · Social sustainability · Life-cycle · Stakeholders

1 Introduction

Today manufacturers are challenged "to align an understanding of the requirements of competitiveness with those that represent long-term sustainability" [1]. In this respect, increasing interest into two important phenomena is emerging. These are: (i) Product-Services (P-Ss), and (ii) social sustainability. A P-S is defined as "a system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models" ([2], p. 239). Recently, the definition has been extended by including all the three facets of sustainability. Accordingly, P-Ss "seek a balance between environmental, economic, and social concerns" [3]. Manufacturers have already understood and started to exploit both the economic and environmental sustainability benefits of P-S systems, however leaving social sustainability outside the P-S system unexplored and unexploited. Social sustainability refers to a company's voluntary contributions to positively influence the relationships with stakeholders [3]. Unfortunately, the two research streams have developed along parallel lines so far. Research on P-Ss has mainly focused on the economic and environmental dimensions of sustainability and overlooked issues related to stakeholder involvement and social aspects [4]. Social sustainability has been considered as add-on to core business and its potential has not been fully recognized and exploited [5]. Investigating how P-Ss and social sustainability interplay appear as a promising research as well as what win-win outcomes may emerge from considering them in a synergic way [4]. This paper moves forward in this direction and aims at contributing to the current debate by proposing a list

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of relevant practices and topics at the intersection between P-Ss and social sustainability in order to provide experts of Advances in Production Management Systems with clear insights for their further research and practices.

2 Literature Background

2.1 The Concept of Product-Service

Services in manufacturing are not a novelty anymore. Through time services in relation to products, called also P-Ss, developed under multiple different names. One of the most widely used terms is servitization defined as “market packages or bundles of customer focused combinations of goods, services, support, self-service and knowledge” [6]. As many different terms for P-Ss exist, also does multiple perspectives. The two most relevant for the purpose of this paper are related to: (i) the level of integration and relevance of the service in relation to the product within a customer bundle; (ii) the interaction between product and service life cycles throughout the three main life cycle phases (i.e. beginning of life – BOL, middle of life – MOL and end of life – EOL). The first perspective of depicting the P-S is through the level of integration and relevance of the service in relation to the product within a customer bundle. The second perspective is dedicated to depict how the product and service life cycles interact together throughout the three main phases: BOL, MOL and EOL. Moreover, the following elements in this perspective are researched: (a) identification of the contact points between the product and service life-cycles, (b) the starting and ending time of each cycle, (c) their length, (d) and the points of their mutual impact. In terms of interactions between the product life-cycle management (PLM) and service life-cycle management (SLM) there are four main relational structures [7]: (a) where the PLM impacts the SLM, (b) where the SLM impacts the PLM, (c) PLM and SLM are equally regulated and impacted, (d) where PLM and SLM are managed in an integrated way and the boundaries in terms of management are completely blurred. Nonetheless, according to previous researches, P-Ss are mainly described by the following characteristics:

- **Eco-Systemic Nature** (e.g. [8]): the cooperation of various actors with product and service related capabilities is needed through the P-S lifecycle.
- **High Value of People Management** (e.g. [9]): to conceive, create and deploy P-Ss, it is crucial to develop and sustain new skills and behaviours.
- **Continuous Relation with Relevant Stakeholders** (e.g. [4]): P-Ss enable the connections of workers, customers, suppliers and other actors of the ecosystem.
- **Dynamic Adaptation Potential** (e.g. [10]): P-Ss allow the possibility of dynamically and seamlessly adapt the P-S functions in the beginning, middle and end of life.

Those characteristics significantly differentiate between P-Ss and pure products. In fact, products (a) are usually based on manufacturing hierarchical supply chains rather than ecosystems; (b) cannot directly support continuous connections but have to rely on separated services such as maintenance.

These characteristics also distinguish P-Ss from pure services. In fact, services (a) require ecosystems that do not encompass manufacturing processes; (b) establish relationships with customers and suppliers that are intangible, not anchored to any material good (that may strengthen and maintain vital the connection).

2.2 The Concept of Social Sustainability

Even a cursory review of the literature shows that social sustainability is still a rather blurred concept [5], which, at the company level, partially overlaps and converges on other related topics, such as Social Responsibility (SR) [11]. These notions have evolved in a complex path of theories encompassing stakeholder theory, corporate social responsibility, sustainable development, triple bottom line, etc [12]. However, common to all of them is the reference to companies' voluntary contributions to positively influence the present and future relationships with stakeholders [3]. Social sustainability activities are usually reported grouping them into main themes, such as Labour Practices and Decent Work, Human Rights, Society and Product Responsibility [11]. However, they can be also classified with reference to the stakeholder group they target. The main stakeholder groups, relating to products and processes, taken into consideration in sustainability standards [11] are:

- **Employees.** Employees are at the core of social sustainability concerns, under the umbrella of Labour Practices and Decent Work.
- **Customers.** Customers are one among the most relevant social groups addressed under the main titles of Customer health and safety, Product and service labelling, Marketing communications, Customer privacy.
- **Suppliers** and **Communities.** In this regard, activities relate to the adoption of procurement practices incorporating social sustainability criteria as well as community involvement and development along the value chain.

Recently, the literature has been also enriched by the new contribution of [13] who describe the concept of "shared value". According to the authors, companies can create economic value for themselves "in a way that also creates value for society by addressing its needs and challenges" [13]. Accordingly, research attention has been progressively shifting from investigating if companies have the responsibility to act sustainably and if it pays to behave in such a way, to how companies can strategically engage stakeholders and integrate their requests into strategies, processes, management systems and outputs to achieve win–win outcomes for industry and society [14].

2.3 Product-Service and Sustainability

The general relations between P-S and sustainability is a well-known topic. However, when relating to sustainability, the concept of environmental sustainability is usually targeted (e.g. [15]), while societal considerations are often neglected. Nonetheless, quite a few authors already integrated social sustainability into their P-S models. For instance [16] proposes a Sustainable Product and Service Development model, which is the process of making products and/or services in a more sustainable way throughout their entire lifecycle. In practice this means to first test the feasibility of a P-S, while in the second step to optimize it in terms of sustainability, among which social impacts are also included. The authors even provide strategies to identify opportunities to maximize social performance, such as: (a) incorporate employee work conditions along the supply chain, (b) opportunities to respect and enhance regional, cultural and material diversity, (c) incorporate impacts of company activities on local and global communities etc. However, specific dimensions for social sustainability and especially in relation to PLM and SLM should be additionally identified, in order to enable its usage.

3 Opportunities at the Intersection Between Product-Services and Social Sustainability

Drawing on the literature depicted before, we have identified a set of topics at the interconnection between distinguishing characteristics of P-Ss and social sustainability. We have adopted a perspective on social sustainability, in line with the idea of "shared value" proposed by [13], which acknowledges that manufacturing is embedded in society and implies an integrated perspective on business and social objectives [17]. Furthermore, we have adopted a life-cycle perspective on P-Ss to identify more clearly at what stage the integration of social sustainability and P-S LM provides added-value. In the next paragraphs, the most essential dimensions of social sustainability are discussed in relation to the P-S and its life cycle phases. We have grouped these topics with reference to the main groups of stakeholders considered in the sustainability standards [11]: customers, employees, suppliers and communities.

3.1 Group 1 – Customers Related Practices

Social Culture and Information in P-S. Social lifecycle assessment initiatives promote the provision to customers of comprehensive information about the social impacts of products and services of all the actors in the value chain [18]. Standards also set requirements for "Fair marketing, factual and unbiased information and fair contractual practices" [19]. P-S continuous relation with suppliers and customers can enable the development of functions to inform customers about sustainable practices and promote socially sustainable choices. An example may be a washing P-S displaying data showing positive impact on social sustainability in the supply ecosystem.

Design for the Sharing Economy. The sharing economy improves sustainability by allowing a larger number of people to access goods and their functions. The eco-systemic nature, the continuous connection and the dynamic adaptability of P-S can fit the requirements of the sharing economy calling for robustness and flexibility to satisfy a variety of users. An example can be transportation P-Ss, based on shared vehicles and services for checking availability, booking shared journeys, etc.

Co-creation and Customization. It has been indicated as an opportunity to generate win-win solutions for the benefit of firms and customers [20], innovating service offerings and processes [21] in accordance with customers' needs and willingness. Through the provision of personalized and context-aware services, P-S nature may provide a stimulating setting for involving customers and ecosystem actors to further extend customization. Furthermore, P-S continuous connection allows customers to receive feedback and recognition in direct relationship with their contribution. Finally, through dynamic adaptation, they may be enabled to directly modify features of the P-S [17], generating a better customer experience.

Incorporation of Features for Health and Well-being, Protection of the Users. The core subjects and issues addressed by the SR [19] include "Protecting customers health and safety" and "Consumer data protection and privacy". In line with these concepts, exploiting continuous connection, novel P-Ss can be designed to promote, support and protect socially sustainable behaviors and lifestyles. An example may be equipment for preparing meals that guide in the selection, weighing and cooking of ingredients to deliver healthy dishes. The eco-systemic nature can also provide additional dimensions and value to these P-Ss. With reference to the cooking example, services related to specific diets may be provided by nutritionist, trainers, communities, etc. Finally, dynamic adaptation of the P-S might adjust the services to better match the needs and requirements of the individual users.

Customer Satisfaction and Feedback/Sentiment Analysis. Social sustainability pursues "Consumer service, support, and complaint and dispute resolutions" including measures to monitor customer satisfaction [11], beyond the correct handling of questions, complaints, the protection of the data and privacy. In several cases, P-Ss through continuous connection can accommodate features to capture and analyse the comments from the customers. Furthermore, characteristics of dynamic adaptation and machine-learning of the P-S during the usage to enhance customers' satisfaction and wellbeing could be explored as an extension of existing research on context-aware adaptable services for smart rooms or other applications [22].

In relation to customers, social sustainability has the highest impact during the MOL phase of the P-S. The role of the service, within the P-S bundle, is to provide information to consumers of the sustainable impact. However, the requirements expressing the socially sustainable perspective of the P-S is reflected in the BOL. Finally, in relation to customers, social sustainability can play the role of a trust-reinforcing lever.

3.2 Group 2 – Workers Related Practices

Stimulating Jobs, Workers' Growth, Well-being and Satisfaction. Health and safety at work, human development and training, labor practices are among the main concerns of SR [19]. At the same time, P-S requires high capability of people management in order to be successfully exploited. The deployment of practices that imply collaboration with stakeholders and in general an enhanced care for customers and society may contribute to develop new competences and attitudes among workers, as well as more stimulating jobs. According to the Service-Profit chain theory [24], service employee satisfaction impacts on customer satisfaction and loyalty and ultimately on revenue growth and profitability.

Enabled also by continuous connection, P-S may be considered as a promising arena to further stimulate and exploit the virtuous cycle that connects the health, wellbeing, satisfaction and personal growth of workers and customers. Furthermore, as the markets for eco-industries will double between 2010 and 2020 [25], increasing attention should be dedicated to workers employed in recycling and remanufacturing processes.

Social sustainability can also act as a lever to increase employee satisfaction rate and their loyalty in the BOL as in the MOL phases. In the BOL it is quintessential for employees and ecosystem partners, while in the MOL it is critical on the customer contact points, thus in the so-called front offices of the P-S system.

3.3 Group 3 – Suppliers and Communities Related Practices

Sustainable Procurement and Promotion of Social Responsibility in the Value Chain are among the core themes of social responsibility and sustainability [11]. In the P-S context, the respect of the human and working rights conditions along the supply chain and within the ecosystem that deliver the physical good and the services are particularly significant to support some of the strategies for social culture of the customers.

Human Capital and Skills Development, also become a fundamental practice that, given the eco-systemic nature of P-S, should be extended to all the actors and strongly pursued to ensure effective and efficient collaboration in P-S lifecycle. Furthermore, human capital is an essential to boost innovation and to deliver P-S providing high value and quality of experience to customers and users.

Communities Involvement and Development. In this respect, key business practices encompass donations, voluntarism, promotion social activities and performances to the benefit of communities. Given the eco-systemic nature of the P-S life-cycle, the scope might be extended to encompass other groups of practitioners, start-upper, interested in contributing to create additional social and economic value. For example, collaboration with local communities in the countries in which some parts are manufactured or involvement of communities with interests in particular types of food, in the example of the kitchen equipment P-S, might add value for the users. In fact, through continuous relation and dynamic adaptation consumers could benefit from a wider variety of recipes and be informed about social sustainability in the supply chain.

Due to a wide array of competences needed to provide a P-S, the role of social sustainability has potentially an economic impact on the long term. When dealing with a P-S, this subcategory does not play only a key role on the BOL of the product, but also on the MOL of the P-S. Namely, the service, as part of the P-S, is the element through which the continuous relation and the dynamic adaption are undertaken. Finally, social sustainability in the EOL phase of the P-S can increase indirectly the satisfaction of communities within the P-S manufacturing P-S ecosystem, which makes manufacturing activities even more community friendly.

4 Conclusions

Advancements in our current understanding of the synergies between P-Ss and social sustainability are crucial to progress towards creating "shared value" between industry and society. Unfortunately, the interplay between these two research areas has been largely overlooked. This paper sheds light on different connections between social sustainability and P-S from the design phase to the end of life, and identifies a set of new common topics to be explored by experts of APMS in their further research and practice. In doing so, the paper sets the stage for the creation of future synergic values based on the exploitation of the opportunities steaming out of the interplay of social sustainability and P-S. One such, is the role of the service, within a P-S bundle, as on one hand a potential generator of sustainable impact as on the other a lever through which its impact is communicated to relevant stakeholders.

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Visualization of Interactions Between Product and Service Lifecycle Management

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Abstract. The adoption of advanced manufacturing intelligence technologies offers opportunities for new profitable business models. The basis for this is the data that is related to the manufactured product, the physical components used for the manufacturing and the services that are applied in this context. In such a Product-Service System (PSS) there are several interactions and corresponding dependencies between physical products and services that have to be managed to obtain an optimal added value from the PSS. A first step is to make the informational interactions between Product and Service Lifecycle Management (PLM and SLM) transparent and visualize them. The objective of this paper is therefore to identify and visualize the interactions between SLM and PLM in general and as a subsequent step in a use case of a manufacturing enterprise.

Keywords: Product service systems · Lifecycle management · Service science · Service engineering · Servitization

1 Introduction

Manufacturing enterprises realize that services, in particular services that are built upon data generated along the product lifecycle and make use of the internet, become more and more important and provide new opportunities for revenues and growth.

However, many small and medium size enterprises (SME) in the manufacturing sector do not have a clear picture regarding the opportunities of combining such services with their products and are uncertain about the effects on their core business and their corresponding processes. So the objective of this paper is to support such enterprises to obtain a better understanding of those effects. It suggests a methodical approach to identify and visualize the interactions between SLM and PLM.

The combination of physical products and corresponding services is established for many years with growing importance [1, 2, 3, 6–9]. While initial approaches were product-centered, in the course of time the services became a more important and self-reliant part of the product-service combination. In some cases the physical product was even aligned to a service or parts of it were replaced by services, e.g. cloud services that

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replace hardware storage capacity. The approach of Product Service System represents this development [4, 5].

Goedkoop et al. defined that a PSS is "*a marketable set of products and services capable of jointly fulfilling a user's need*" and that it can be "*provided by either a single company or by an alliance of companies*". They pronounce that products and services can be equally important for the function fulfilment.

Although the concepts of product-service combinations are discussed in literature from different points of view, e.g. the different types of added value provided by the PSS [4, 10], the dependencies and interactions between the product and the service along their lifecycles are still not covered sufficiently. But these dependencies and interactions are relevant for SME when they have to decide if and how they are going to servitize their business. According to the objectives mentioned above this paper is going to fill a part of this gap.

2 Product and Service Lifecycle Management

Approaches like the Extended Product approach have shown that different services can be applied at different points of a product's lifecycle [2].

Therefore the concepts of Product Lifecycle Management (PLM) and Service Lifecycle Management (SLM) can be used as a framework for considerations regarding the dependencies and interactions between products and services in a PSS. The main objective of PLM and SLM is to provide a sound information basis to plan, control and coordinate processes and take decisions along the lifecycles of products and services. A holistic view of both PLM and SLM is necessary to involve all relevant aspects of the enterprise for an integrated development and management of PSS [7, 11, 12].

There are different concepts for Product Lifecycles and Product Lifecycle Management, for example concepts that are marketing driven and consider phases like development/introduction, growth, maturity and decline [13]. Since it is aiming at a better understanding of PSS this paper focuses on PLM concept that take the view of information management. Many of those approaches structure the lifecycles in the main phases Beginning of Life (BOL), Middle of Life (MOL) and End of Life (EOL) with corresponding sub-phases as described in the following list [14–16]:

- Beginning of Life: Product Ideation, Design/Engineering, Realization/Production/Manufacturing and Logistics/Distribution.
- Middle of Life: Use and Maintenance/Service/Support.
- End of Life: Re-use, Recycling, Remanufacturing, and Disposal.

Most traditional approaches assume that phases and steps in the lifecycle are connected in a sequential mono-directional manner, a waterfall cascading model.

However, in dynamic environments there could be loops, parallelism and multi-directional processes. The digitalization of all the PLM phases enables and fosters this development. That's why more recent approaches have recognized such loops and multidirectional processes, e.g. the Closed Loop PLM [17]. On the one hand this provides flexibility for the interactions with SLM on the other hand it increases complexity.

Service Lifecycle Management is a part of Service Science, Management and Engineering (SSME), which address the challenges coming from the servitization process [1, 8, 12]. SSME provides useful input for the manufacturing industry and helps to involve all the relevant aspects of service. A Service Lifecycle Management creates a connection between Management and Engineering and is an important discipline for providing and contributing specific knowledge about service. The three main phases of the Service Lifecycle are service creation, service engineering and service operations management. These three main phases are divided in 7 sub phases [18]:

- Service creation: Service Ideation.
- Service Engineering: Service Requirement Analysis, Design, Implementation, and Testing.
- Service Operation: Service Delivery and Evolution.

For a PSS lifecycles of products and services are linked and, as a consequence, the lifecycle managements have to be aligned to those links or even integrated.

3 Relations and Between Products and Services in a PSS

Products and services are related in different ways. Before these relation can be made transparent and can be planned, controlled and coordinated in a Lifecycle Management process, it has to be clarified what types of relations can generally occur in PSS. This describes a kind of solutions space that has to be covered by the Lifecycle Management. To define these types a literature research was done and existing concepts were analyzed according to the offered classifications of relations between products and services in a PSS.

There are already approaches considering the configuration of defined product and service component. Becker and Klinger [19] gave an overview of concepts and methods in this context. They summarize three main types of relations when it comes to the configuration of product-service combination: proposing, restricting and modifying. A product provides options for combinations with a set of potential services or vice versa. This is described as ***proposing*** options and alternatives. E.g. a Smart-TV is supported be a set of capable TVs from different producers. It is also possible that it is proposed that some product functions are ***substituted*** by services and or services are substituted by the product. The second type are ***restricting*** relations. They describe what prerequisites a service (product) has to fulfil when it should be combined with a certain product (or service) or characteristics of a service (or product) exclude it from such a combination. E.g. if the service addresses mainly food-industry, products that do not fulfil the corresponding hygienic requirements are excluded.

Services can ***modify*** characteristics of the products or vice versa when they are combined. E.g. the value that a product provides to its customer is increased by the services. These three types represent ***functional relations***.

Other approaches, like the Extended Product of Thoben [2], consider the different points in the lifecycles of products and services when there are relations between them. For example consulting services during the specification of a product in its BOL phase or refurbishing service in the EOL phase. Another more simple differentiation is that between pre-sales and after-sales like it used in many enterprises. Generally these relations cover the logical sequence of activities regarding the products and services. In many cases one activity provides material or informational input to another, e.g. the configuration services offers data from a social media feedback service and provides input for manufacturing of the product like a customized computer. This type can be describe ***process- and information-related*** relations.

An important aspect of PSS that is covered by many authors [10, 20, 21] are the business models (BM) for the PSS. Tucker for example differentiate between product-oriented BM where the products are sold, use-oriented BM where products are leased or rented and result-oriented BM where the customers pays for the obtained value, e.g. the achieved output of a machine. In the result oriented BM the customer pays only for the service, he does not have to care of the price of the product as such, e.g. the price of the machine. So the product has to be pay "internally in the PSS" by the revenues generated through the service. So a further type of relations can be described as ***economic relations***.

Many approaches assume that PSS are provided by collaborating enterprise networks [5, 20]. The implication is there is an organizational aspect of PSS. If product and service components are provided by different partners there are ***organizational relations*** between them. Some authors [4, 5, 20] pointed out that such relations between products and service become already relevant inside enterprises when product and service department are traditionally separated and the PSS approach requires change processes and a shift of culture. A special aspect in this context is the involvement of customers that is usually required for service delivery.

So, summarized, literature research and analysis brought up four main types of relations between products and services in a PSS along the lifecycles:

- Functional relations
- Process- and information-related relations
- Economic relations
- Organizational relations

4 Making Interactions Between Products and Services Transparent

The relations identified above are not just descriptive but require in most cases some actions. Since relations connect different elements these actions are usually interactions. Interactions can be defined as *reciprocal micro-processes between partners that are elementary for the accomplishment of the tasks in the processes* [22]. Following typical interactions can be relevant between PLM and SLM:

- Exchange of Information (e.g. information about available sensor data that can be used for a digital service).
- Coordination (e.g. synchronizing the change management for service with product development).

- Solving conflicts (e.g. identifying in-compatibilities at data interface and defining common standards).
- Negotiation (e.g. if parameters like the frequency of measurement does not fit together and adaptions have to be made on both sides to make product and service work together).

The different characteristics of products and services, e.g. regarding timespans in the lifecycles, the variety of potential combinations, and collaboration between partners in a network lead to a high complexity of PSS. One element of handling and, where possible, reducing this complexity is to manage these interactions for all four types of relations between products and services. Conventional approaches to consider and design those relations, such as a simple flowcharts, do not meet the specific requirements of this complexity satisfactorily. Typical problems are [23] that recorded relationships between tasks are simplified, relationships are ignored, iterations cannot be reflect adequately or that "coupled" activities are not representable.

Starting Point for the making relations between products and services visible should be the process- and information related relations, since these relations cover the whole lifecycles right from the early BOL till the EOL and provide the basis for the other relations. In addition this type of relation is causing manifold unplanned iterations and corresponding problems [23], e.g. information is provided at the wrong time or not suitable, modifications cause changes in the assumptions and data, inadvertently erroneous information or unrecognized false assumptions adopted for granted.

Although a flowchart has clear limitations it is useful to visualize the general process- and information-related relations. In Fig. 1 it can be seen at first sight where most interactions take place. In this practical example the prevailing strong interaction between product design and service design is obvious.

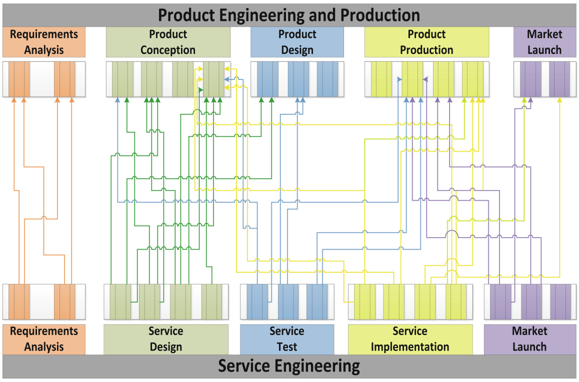
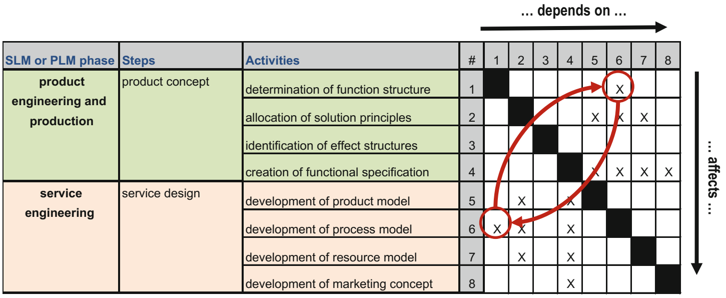


Fig. 1. Use case - manufacturing company [5]

Therefore, it is useful to consider this phase separately and create in a next step a Design Structure Matrix for it. Figure 2 is an example of this.



SLM or PLM phase	Steps	Activities	#	1	2	3	4	5	6	7	8
product engineering and production	product concept	determination of function structure	1	■					X		
		allocation of solution principles	2		■			X	X	X	
		identification of effect structures	3			■					
		creation of functional specification	4				■	X	X	X	X
service engineering	service design	development of product model	5		X		X	■			
		development of process model	6	X	X		X		■		
		development of resource model	7		X		X			■	
		development of marketing concept	8				X				■

Fig. 2. Design structure matrix – use case

In this example the determination of the product's function structure requires information regarding the process model for the services and the development of this process has to be aligned to the functions of the product. The reason for this information-related relation is another type of relation: functional relations.

This leads to general methodical pattern: Functional relations could have an impact on process- and information-related relations, so they have to be checked when process- and information-related relations are assessed.

The relations in the design structure matrix describe ***what*** has to be exchanged, coordinated, solved and negotiated. The next step is the question who should do that. Does the enterprise have the capabilities and capacities to do the process step on its own or is it necessary to involve capable partners. In this way the process- and information-related relations lead to organizational relationships.

The final type of relations, the economic relation, usually depend on organizational relation. If different partners are involved in the development and provision of product and service function it has to be managed how investments/costs and benefits are shared. In addition the functional relations provide the basis of revenues since the represent the value the customers pays for.

The following graphic gives an overview over these relations and shows that there also can be loops of adaptations, e.g. when functional relation are simplified because it is recognized if the organizational interactions become too complex to manage (Fig. 3).

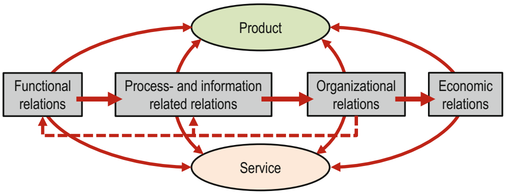


Fig. 3. Relations and their dependencies in a PSS

When these relations are generally identified they can be described in more detail according to the typical interactions (information exchange, coordination etc.).

5 Summary

Manufacturing enterprises that plan to servitize towards PSS need a sound understanding what effects the combination of their products with services has upon those products and upon their processes. This paper suggests an approach to make the potential relation and corresponding interactions between products and services transparent and to analyze them. Based on existing PSS approaches it has identified four general types of relations between product and service in a PSS: functional, process- and information related, organizational and economic. Between these types of relations there are dependencies that help to structure a step-wise analysis. The application on a use-case has shown that this approach could help to clarify the complex relations and interaction in a PSS. This approach could contribute to the further development of an integrated PSS lifecycle management.

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Social Implications of Introducing Innovative Technology into a Product-Service System: The Case of a Waste-Grading Machine in Electronic Waste Management

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Abstract. This paper examines the social implications of introducing a new technology into the product-service system (PSS) of electronic waste management (EWM). Using a previously established set of social sustainability key performance indicators (KPIs) targeting the operations level (i.e. impacts on EWM operators), social implications are examined in a case where a specific innovative new technology is introduced to replace manual sorting of e-waste into re-use, refurbish and recycle fractions. The social sustainability KPIs were applied to the case as a structured interview guide. The results showed that the KPI framework provided a good basis for examining the social impacts and also stimulated discussions about potential business impacts based on the human resources in the system. The framework showed that the implementation supported proactive social sustainability, but some additional conditions need to be addressed by the customer organization to make sure that potential risks (identified in the interview) are mitigated.

Keywords: Social sustainability · Key performance indicators · Product-Service systems · Electronic waste management · Social impacts

1 Introduction

The last few decades have seen an increased focus on the concept of sustainable development [1] in operations [2] due to global restrictions, legislations and customers' awareness of sustainability together with a global competitive environment. Considerable progress has been made with the environmental aspect, e.g. by implementing new "greener" technologies. Among the three sustainability "pillars", i.e. environmental, economic and social, the aspect of social sustainability has been widely acknowledged as the least developed [3–5], especially in the operations context. The literature provides a very broad scope for the social aspect ranging from a global to a local scale, sometimes without distinguishing that achieving social sustainability may

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require different approaches in developed and developing countries. To this end, solutions are sought both in the high-level strategic sense and the lower-level technological implementation sense. As a result, it has traditionally been difficult to define an operative scope for manufacturing companies aspiring to improve social sustainability on a factory level, although a distinction between "traditional" and "emergent" aspects of social sustainability has appeared in later years [6]. Some emergent social sustainability concerns in developed countries include demographic trends like aging populations with shortage of qualified labor as a result, and the increased importance of making manufacturing a more attractive future workplace option to attract new generations of workers [7]. Alongside this, many parallel developments drive incentives to further automate manufacturing processes, particularly those that are hazardous, monotonous or physically strenuous. Overall, social impacts on operators at factory level resulting from new automation technologies and business solutions, remains an important research topic.

There are several reasons for a manufacturing company to adopt product-service systems [8]. These can influence sustainable development by extending producers' "involvement and responsibility to phases in the life cycle, which are usually outside the traditional buyer–seller relationship, such as take back, recovery, reuse and refurbishment and remanufacturing." [8]. Regarding environmental and economical sustainability, an increasing industrial emphasis is being placed on the "end-of-life" (EoL) stage of consumer products. In some countries, producers of various consumer goods are tasked with the responsibility of taking care of the products once they have left the hands of customers and become waste [9]. Within the industry context, previous research efforts [8, 10] have addressed the environmental and economic impacts of implementing PSS, whereas other studies like [11, 12] have considered the societal impacts of it but without addressing implications for the factory operators specifically.

One particularly interesting form of PSS is Electronic Waste Management (EWM), a burgeoning industry that turns electronic waste from an environmental threat into a resource for society. According to [13], "today e-waste sorting is performed mostly by humans, as up to now they are the most flexible and self-learning resource available. Operators not properly equipped by protective devices get exposed to hazardous substances from electronics' segregation". However, technological solutions for waste sorting and grading are on the rise. Apart from the advantage that automating e-waste sorting can reduce human operators' unnecessary exposure to hazardous substances leaking out of e-waste materials, it remains to be examined what social impacts such a development can have on human operators at factory level.

Therefore, this study aims to explore the implications of social sustainability key performance indicators in a specific case of introducing a new technology (in the form of waste sorting equipment) into an EWM PSS. This is examined by using a framework of previously established social sustainability key performance indicators (KPIs) as a starting point [14].

2 Theoretical Framework

2.1 Product-Service Systems (PSS)

PSS is a term that has been defined as “a marketable set of products and services capable of jointly fulfilling a user’s need. The product/service ratio in this set can vary, either in terms of function fulfilment or economic value” [15]. Various authors have proposed different classifications of PSS [15–17], of which the three most distinct classification categories are product-related services, use-oriented services and result-oriented services. According to Mont [8], from a company perspective adopting a PSS can add to products’ value, base growth strategy on innovation, improve the company/consumer relationship, improve the total value for the customer by extending products’ life-cycle, extending products’ function through upgrading and refurbishment and also making the product useful after its life cycle ends through recycling or reuse, and also helps the company implement take-back legislations.

2.2 Socially Sustainable Work Systems

There is no wholly agreed-upon definition in literature of what constitutes a socially sustainable work system, but [18] defines it as a system that has achieved a high level in three main aspects: quality of work, quality of the organization and the quality of connections with the environment. To achieve a socially sustainable manufacturing work system that can combat the aforementioned demographic challenge, it should be able to meet the needs of both current and future employees. To that end, it should be able to attract different societal groups as potential workers, i.e. younger, elderly, women, disabled and in general support greater diversity. In [14, 19] the authors have used the key aspects of socially successful work systems from literature to develop a framework of social sustainability related KPIs, presented in Table 1.

Table 1. Key performance indicators of socially sustainable operations (adapted from [12, 17])

Key performance indicators	References
Labour code of conduct: • Occupational health and safety • No of absenteeism/fatalities • No of incidents/high risks related to occupation • Fair pay	[20, 21]
Personal development, talent management and career development	[7, 18, 20, 22–26]
Work design • Challenging and stimulating job • Participation • Empowerment	[7, 18, 22–24, 27, 28]
Work-life balance	[23, 29–33]
Employee turnover and satisfaction management	[23, 34–36]
Job security	[22]

3 Method and Case Description

3.1 Method

The overall research approach for this paper has been to perform a qualitative case study, incorporating a literature study, observations and interviews as we strived to explain a complex phenomenon under investigation [37]. General data regarding the EWM case were collected mainly through semi- and unstructured interviews and study visits to the EWM facility. After the initial studies the aforementioned framework of social sustainability KPIs from [14] was employed as a structured interview with a company representative who elaborated specific impacts on human stakeholders.

3.2 Case Description

EWM systems challenge the ideas of traditional business models, both by adding value to something previously considered worthless, and in this particular case, by the fact that their system components (equipment and personnel) are accessible partially as a product and as a service. This case studies the REFIND company, which has developed and introduced a new automation technology called the E-grader (Fig. 1) to sort, grade and recycle e-waste using optical sorting [38]. The E-grader is available both as an equipment for rent and as a service where customers (e.g. retailers of electronic consumer goods) send spent e-waste to REFINDs facility for sorting and grading into useable “fractions”. In other words, the E-grader itself is a PSS being implemented into another PSS (the EWM system) in a “nested” fashion. According to [13] the E-grader is able to distinguish much more rapidly than human workers which products are suitable to reuse, refurbish or recycle. During waste sorting, data regarding the products’ type, brand, model, year to market etc. are recorded automatically. Other data fields can be added based on the companies’ specific needs. By contrast, today’s manual e-waste sorting cannot store workers’ knowledge and WEEE items’ data into a structured data management system.

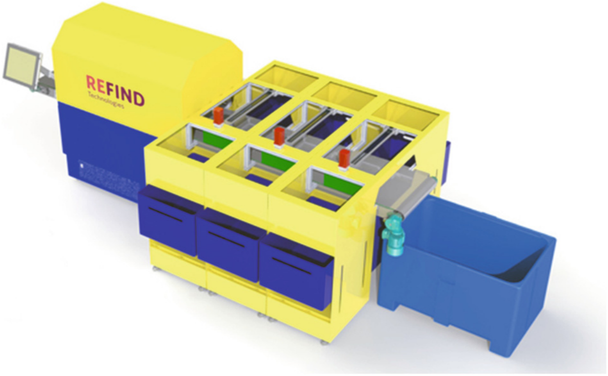

Fig. 1. The E-grader, an automatic equipment solution for e-waste sorting and grading developed by [38].

The environmental and economic aspects of the E-grader were the main drivers for its introduction as a solution for EWM systems. Some major motivations for automating the extraction of re-purposable fractions from e-waste are described in greater detail in [39] and include: the presence of valuable and rare earth materials in the e-waste products (e.g. copper, iron, steel, gold, silver and platinum); minimizing human and environmental exposure to hazardous substances that can damage health; and increased manufacturer responsibility for addressing the end-of-life (EOL) phase of their products.

4 Findings and Analysis

This section presents and qualitatively analyses interview data from the case company. Each topic heading reflects its corresponding indicator from Table 1, and words in cursive signal the relationship of findings to specific KPIs.

4.1 Labour Code of Conduct

For the sake of their *health and safety*, operators need to be carefully protected from exposure to dirt and toxic substances, which are typical for the manual electronics' segregation process of e-waste handling. Introducing the E-grader to the system will reduce the exposure of operators to acid-resistant substances. However, the operators need to be prepared and trained in terms of safety procedures and health issues regarding the new equipment, e.g. safety implications from loading, unloading, turning it on, etc. These tasks are not considered to be high-risk operations in general, but if the operators are not well-trained, *incidents* and accidents may occur. The effect on *absenteeism* numbers is two-fold. The rate of absenteeism related to health and safety issues will depend on the training level of operators as discussed above; numbers might even increase if training is not sufficient and accidents occur. However, since the new technology will affect the employees' satisfaction level and happiness and work-life balance, it could also reduce absenteeism. Due to the new technology's positive impacts on process efficiency, the company margin is expected to increase. Moreover the operators will perform higher-skilled tasks. Therefore, the operators' *salary* and the monetary incentives can be affected in positive way.

4.2 Personal Development, Talent Management and Career Development

As described in 3.2, adding the E-grader to the EWM process results in knowledge and intelligence being added to the sorting process. This can unlock more opportunities for *personal development* of the people working with the system, because the system stores and aggregates statistics on the sorted fractions. Once the data and different dimensions of it become accessible, the operators can explore the dataset, understand the statistics, make forecasts and "control" their cash flows. When operators "use their brain" as opposed to simply handling waste, managers have an opportunity for *talent management* by recognizing good ideas from workers and incentivizing them.

4.3 Work Design

Currently the manual tasks performed by operators are monotonous tasks. Introducing the E-grader to the system opens up for more diverse tasks and therefore more possibilities of job rotations. Moreover, people that work with the data management part are called to understand these data and map them properly. Therefore the job becomes more stimulating for them compared to pure materials handling. At the same time, the operators may experience more *participation* and *empowerment* as they are expected to independently come up with ideas, reports, findings and conclusions based on used electronics statistics. As the system adapts to new specifics within regulations and recycling schemes or market changes, operators will also learn new skills and will be *personally developed,* which can lead to more satisfied employees.

4.4 Work-Life Balance

The implementation of the E-grader can affect *work-life balance* due to the shift in the operators' responsibilities, but will also make some of the tasks location-independent and self-organised, particularly the tasks which pertain to analysing the data. This means that operators could take care of some non-loading-related tasks remotely, decreasing the need to spend time at the sorting facility, which will affect the *work-life balance*.

4.5 Employee Turnover and Satisfaction Management

Right now manual e-waste handling suffers from very huge *turnovers,* not only due to the menial work in itself but also due to the very low salaries. Introducing the E-grader and new tasks is expected to reduce the turnover because of higher job *satisfaction* and higher salaries caused by more profit.

4.6 Job Security

Implementing a technology that can replace several operators might *affect the number of jobs* in a negative way. On the other hand, as operators become more knowledgeable they will become more important assets for the company. Also, since the new technology can make the company more profitable, these two impacts can *secure the operators' jobs* in a positive and more sustainable way.

5 Discussion and Conclusion

Methodical approaches to examining social impacts of PSS remain scarce, but this case study indicates some promising first steps towards their development. The Social sustainability KPIs suggested by [14] made an efficient inquiry possible into social impacts of introducing a technological innovation to an EWM PSS. In this particular case, the framework clearly highlighted the advantages and disadvantages for operators of implementing the technology. This case also suggests that this PSS may have potential to support proactive aspects of social sustainability, something that is argued as very important in [14]. Based on the interview results, the authors note that some additional conditions, that the technology itself cannot not provide, need to be secured by the organization implementing the E-grader, in order to ensure a socially sustainable implementation:

- Education and training must be provided to employees using the equipment to prevent injuries and to make sure that the aggregated data is exploited well
- Workers must be made aware that new responsibilities are expected of them, such as analyzing the data and coming up with new ideas, in order to gain the advantage of more varied and meaningful work, increased participation and empowerment
- Tradeoffs between number of job opportunities and meaningful work content must be managed by companies.

In conclusion, the previously established list of Social Sustainability KPIs provided a helpful framework for inquiring about social implications in the implementation of a technological innovation in an EWM PSS, as demonstrated in this case.

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Performance Indicators for the Evaluation of Product-Service Systems Design: A Review

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Abstract. Recently, industries have shifted their focus on the combined ecosystem of products-services. The innovative business strategy of PSS provides an integrated solution that gives the potential for sustainability gains for both company and customer. Similarly to other business aspects, the PSS efficiency design is evaluated through performance indicators, during the phase of concept evaluation, which is the last phase before launching a product-service. This phase plays a critical role for the success of a PSS. A successful evaluation prevents design modifications or redesign, significantly reduces the cost and lead time of PSS development. There is however, limited work on integrated evaluation approaches for PSS design models, and also a lack of a collective accounting of the most important key performance indicators (KPIs) devoted on PSS. The present work attempts to contribute in these directions, and proposes a conceptual framework for the effective evaluation of PSS design using important KPIs.

Keywords: Product service system (PSS) · Key performance indicators (KPIs)

1 Introduction

The intensive global competition and technological advances force the actors of a supply chain to optimize their activities in order to deliver high-value products-services with low costs and diminished time-to-market. This optimization relies on waste elimination, improved process control, efficient manpower utilization, and employment of smart and flexible systems [1]. PSS is a value proposition strategy that offers products-services and is designed to be: competitive, satisfy customer needs, and have a lower environmental impact than traditional business models [2]. The importance of the shift towards selling functionality instead of products is illustrative by the fact that software and electronics add nearly 40 % to the cost of a new car nowadays, while this figure is bound to increase [3]. Moreover, measuring the performance of a PSS offering is crucial for a firm, since it influences its competitiveness in the market, its cost-effectiveness, and finally, its overall business performance [2, 4, 5]. Following the principle of “what cannot be measured cannot be improved” and the plan-do-check-act methodology [6], continuous monitoring of the implemented processes is required during the entire lifecycle of the system. Thus, the use of KPIs is necessary. KPIs can provide insights about the performance of a company and can facilitate decision

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making. Moreover, KPIs can be employed to reduce non-adding value activities, which comprise approximately the 60 % of a company's activities [7]. Due to the significant differences between products and services, the concept evaluation of PSS differs from ordinary evaluation problems. Product characteristics and service activities influence one another, creating difficulties in defining the weight factors of each evaluation criterion. However, there are few works concerning PSS performance indicators [8].

Except for limited research on integrated evaluation approaches for PSS models [9], there is a lack of studies that collect the main KPIs for measuring the efficiency of a PSS. The proposed work contributes with a collection and discussion of major PSS design models and existing KPIs that are appropriate for the PSS design activity.

2 PSS Design Models

The design models are simplified descriptions of the design process to assist the designer accomplishing the task. Although a great amount of literature work has been focused on PSS design models [10–32], there are surprisingly limited studies on integrated evaluation models for PSS [9], as well as collective accounting KPIs that could be used on PSS. In order for such a collection to be accomplished, the literature devoted to PSS design models and KPIs, is taken into account under a comparative review.

The review methodology that is followed to identify and collect KPIs for specific PSS designs is shown in Fig. 1. After examining the PSS design models, requirements for performance measurement are extracted, and finally, the KPIs that satisfy these requirements are classified. As Fig. 1 illustrates, the light gray area includes the major PSS design models, applicable and representative in the category that they belong to. The dark gray area consists of the requirements derived from these models. It is noted that some models belong to more than one category. The color coding is used to group KPIs under four general representative classes, namely KPIs for Business, Customers, Leanness, and Sustainability.

PSS is strongly related to sustainability and customer, thus, increasing sustainability and satisfying the customers should be the target of every PSS design model [2, 4, 5]. Several models [10–13] have been developed with dominant aims these two aspects, thus, evaluation approaches measuring them through PSS are of great importance. Sustainability has three pillars: (i) Environment, (ii) Economy, and (iii) Society [14], while customer perspective mainly contains requirements associated to satisfaction and acceptability [15]. Indeed, Fig. 1 depicts that the most frequent requirements of PSS models are Customer and Sustainability.

One of the first approaches to model PSS design [16], aims to synchronize the development processes of the products and the services, incorporating the input from the customer in the process. Under the same concept, the Propensity Framework [17] attempts to enable a synergy between products and services, via the Front-End of Innovation (FEI) process, and using evaluation criteria based on customer's expectations and user experience.

According to many researchers [18–20], in order to achieve a competitive PSS, the integration of physical product and services should be considered in the early phase

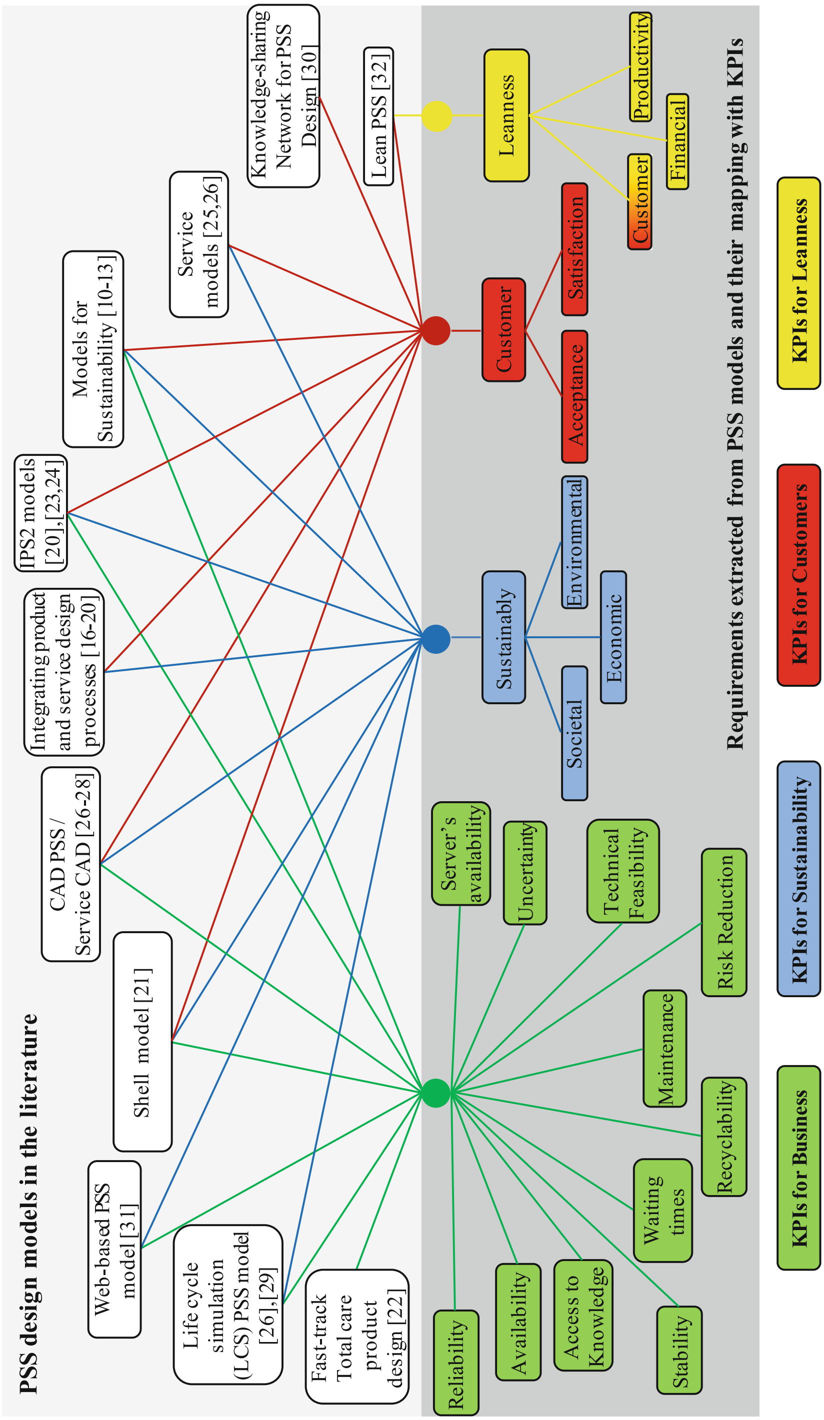

Fig. 1. PSS design models, evaluation requirements, and mapping of KPIs

of design. At these models, the customer value is also identified in the first phase of design. Similarly, in the Shell model [21], which is proposed for PSS Engineering development, the customer is considered in the beginning of the design giving explicit feedback to the design procedure of the model.

Inspired by the similarity between service design and hardware design process, the fast-track design process is proposed in [22]. Importantly, the authors stress that the use of this methodology ensures that the customer becomes fully aware of the value of the total care product business solution. Moreover, they present many PSS oriented requirements for performance measurement, namely service reliability, maintenance, stability, uncertainty, average waiting times, and reliability (short- and long-time). Finally, they outline the importance of quantitative performance measurements in the functional product provision.

Similar requirements are extracted by IPS^2 models [20, 23, 24], Service models [25, 26], ServiceCAD/CAD PSS [26–28], Life Cycle Simulation (LCS) [26, 29] design models, Knowledge-sharing network for PSS design [30], and web PSS [31] design models. In addition to the aforementioned requirements, the necessity of measuring the server's availability, risk, and knowledge-sharing aspects, has been also considered.

Moreover, lean product-service design approaches are another requirement for competitiveness. The lean approach focuses on eliminating non-value activities from processes by applying a robust set of performance change tools, and emphasizes on excellence in operations to deliver superior customer service. To grasp the lean approach in a service-company, senior managers must recognize that all organizations-anufacturing and non-manufacturing-ultimately deliver value to a customer in the form of a product and/or service [32]. Indicators of how lean is the system [33] are significant to establish such a design.

3 KPIs for Assessment of PSS Design

This section discusses the most appropriate KPIs for PSS assessment. The definition of KPIs depends on each problem's specific objectives, goals, and criteria [1]. Academic research has proposed a number of methodologies for developing and selecting KPIs according to the objectives of each company. The development of KPIs can follow the SMART principle i.e. being specific, measurable, attainable, realistic, and timely [34]. It is also crucial to notice that performance measurement systems should focus on what is important to measure and not simply what is easily measureable [35, 36]. According to these principles, an attempt to collect the appropriate KPIs for PSS design evaluation is carried out. KPIs are classified with respect to the direction of fulfillment requirements. These classes are the following: Customers (C), Business (B), Sustainability (S), and Leanness (L). Summarizing, Table 1 lists the KPIs that are associated to PSS design. It is commonly accepted that the realization of value in a PSS can only be achieved when customers are on focus and if services' evaluation is strongly connected to them [37]. Customer satisfaction and customer acceptance are among the most useful measures for several business strategies, and many researchers have developed measurement approaches and indicators for these purposes [38–45]. In this direction, the SERVQUAL scale [38] is introduced for assessing customer perception of service

Table 1. KPIs for PSS design assessment (Customer: C, Buisiness: B, Sustainability: S, Lean: L)

KPIs	Reference	Class	KPIs	Reference	Class
Satisfaction	[37–44]	C	Overall equipment effectiveness	[34]	B
Acceptability	[15, 39]	C	Technical availability	[34]	B
Acceptance rate	[42, 43]	C	Flexibility	[34]	B
Availability for production plan	[34]	C	Stability	[34]	B
Number of identified customer needs	[41]	C, L	Machine reliability	[34]	B
Consideration of customer needs	[41]	C, L	Service reliability	[34]	B
On-time delivery	[40, 42]	C	Service assurance	[34]	B
Rescheduling quota	[42, 43]	C	Team qualification	[34]	B, C
Efficiency of need identification	[41]	C, L	Feeling quality	[34]	B, C
Customer needs rate	[41]	C, L	Knowledge management	[54–57]	B
Requirement inconsistency	[41]	C, L	PS maintenance efficiency	[42, 52, 53]	B
Efficiency of collaboration	[41]	C, L	Development cost	[34]	B
Privacy	[41]	C, L	Service delivery costs	[43]	B
Product flexibility	[34]	C, B	Environmental quality cost function	[49]	S, B
Expansion flexibility	[34]	C, B	No. of bottlenecks	[40]	L
Energy efficiency	[46–51]	S	Scheduling inefficiency	[40]	L
Sustainable product-service efficiency	[51]	S	Defects detected in development stages	[40]	L
Lease/reuse	[50]	S	Requirement inconsistency	[40]	L

quality in service and retail companies. Additionally, another evaluation approach is proposed using importance-performance analysis, since the attributes of performance and importance are not independent variables, and the performance has a non-linear relationship with the overall satisfaction [44].

In the context of sustainability assessment of a PSS, most studies stress the ‘environmental’ aspect, probably since this aspect is measured relatively easily. There are limited methods that focus on measuring simultaneously all three sustainability components [45]. Environmental performance is usually connected with energy efficiency [46–49] and the level of material use in lease/reuse the PSS systems for waste prevention [50]. However, the consideration of social and economic dimensions are also important measures of sustainability [45]. In this direction, the Analytical Hierarchy Process is used in [51] to weight the importance of the indicators for each company under sustainability terms. The authors propose the use of sustainable product-service efficiency indicator, as to ratio of the product service value to its sustainability impact.

As shown in Fig. 1, the class of KPIs for Business is the most literature-stressed approach for the evaluation of PSS. The five phases of the PSS lifecycle, i.e. the planning, development, implementation, delivery and use, and closure are defined in [52]. Usually, the performance measure of these five phases falls under the customer-based measures. Particularly, the planning of the PSS is closely related to the customer as it includes the requirements, specifications, and the offer of a customised PSS. An indicator framework is the foundation of the measurement and monitoring of Industrial PSS (IPS^2) in the use-oriented business model [34].

While developing the indicator framework, the PSS performance, PSS lifecycle cost, and influencing factors have to be identified as major aspects for the provider. In order to evaluate better the IPS^2 delivery, a classification of performance indicators under the areas of delivery planning and delivery performance has been carried out [42]. The performance dimensions identified are: resource planning, management of the network partners, and IT system efficiency. The concept has been enhanced by introducing feedback loops in an IPS^2 control model.

Moreover, knowledge has a high importance for PSS providers and its availability is a challenge. The provider needs an adequate knowledge about the end-user's process as well as a concrete knowledge about the product. To satisfy these requirements, an approach for evaluating the knowledge within a company and to specify the required knowledge for providing a specific PSS is proposed in [54]. Furthermore, a conceptual model for assessing the readiness of collaborative networked organizations for PSS delivery is proposed in [55]. Finally, the terms risk and uncertainty have often been used interchangeably in industry [56]. A conceptual representation of risk and uncertainty is provided in [57]. The study proposes risk representation in relation to knowledge indeterminate and probabilistic or deterministic outcome.

4 Conclusions

This research work presents a collection of PSS design models and identifies the role and importance of KPIs in the PSS design. Secondly, it provides a collection of existing KPIs that are appropriate for PSS design, classifying them into customer-, business-, sustainability-, and leanness-based measures. This work could be a guideline for supporting the selection of appropriate KPIs for the evaluation of PSS. Further to that, taking into account the reviewed PSS design models [10–32], and their systematic reviews [5, 9], a conceptual framework for effective PSS design using KPIs is proposed (Fig. 2). According to this framework, the design procedure contains two main stages: (i) PSS design process, and (ii) PSS design expectations.

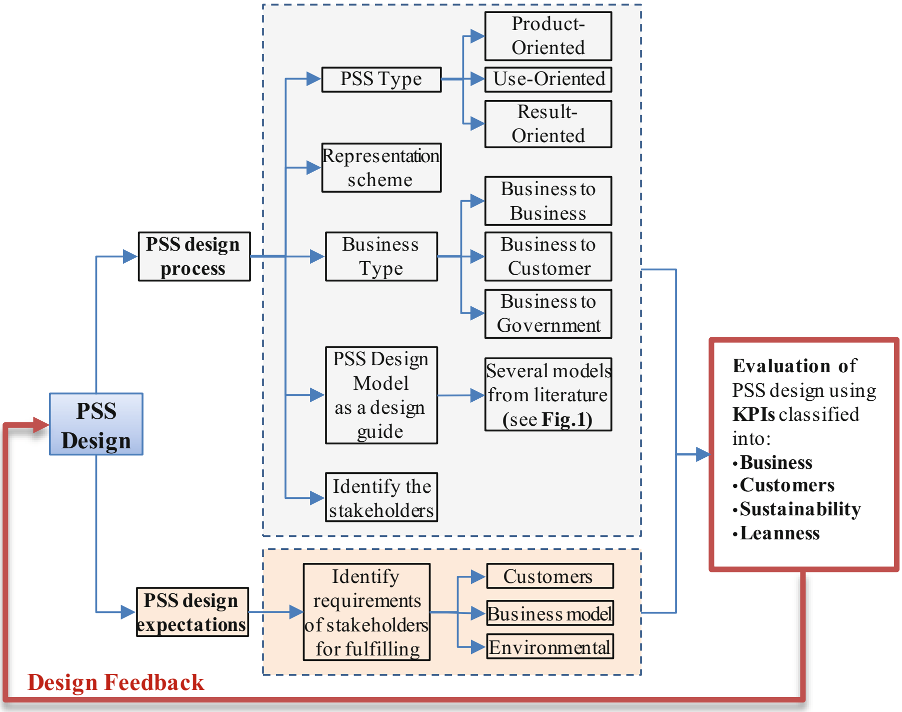

Fig. 2. The conceptual framework proposed for effective PSS design

The first stage contains the specifications of the PSS type (product-, use-, and result- oriented [5]) according the product/service to be developed, also contains the Business type (Business to Business, Business to Customer, Business to Government), as well as the identification of stakeholders involved in the PSS. Furthermore, for an effective design procedure, a comprehensive PSS representation schema should be included [9].

The second stage focuses on what requirements the stakeholders have, and which of these have to be considered and fulfilled. This stage sets the basis of the evaluation strategy that has to be followed. For an effective PSS model, the fulfilling of the requirements of: Customers, Business model (e.g. Leanness, Sustainably, financial aspects), and Environment (e.g. energy consumption, CO_2 emissions), has to be the main care. For this reason, the implementation of a comprehensive evaluation of the developed PSS model is needed, throughout their life-cycle, using appropriate KPIs. This KPIs give feedback to the designer for improving the PSS design.

Future work involves a systematic classification of evaluation approaches for PSS design and the formulation of KPIs in mathematical expressions together with mechanisms for their measurement.

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Service Engineering

Energy Consumption in the Food Service Industry: A Conceptual Model of Energy Management Considering Service Properties

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Abstract. This paper examines features of energy consumption in the food service industry considering the possible effects caused by properties of service such as intangibility, heterogeneity, perishability, and simultaneity. This study examines four food service businesses: restaurant services with a cook-chill system, restaurant services with a cook-serve system, delivery of prepared food services, and home-meal replacements. The service provision process is analysed along with the energy input for each process. Subsequently, a conceptual model of energy demand management considering the simultaneity of service is proposed as a first step goal to enhance energy demand management.

Keywords: Energy consumption · Food service industry · Restaurant · Service engineering · Simultaneity · Service production system

1 Introduction

The service sector plays a key role in economic activity today. As society becomes more conscious of sustainability, companies are required to conserve energy and natural resources. In the food service industry, which is part of the service sector, life cycle assessment (LCA) is currently expanding to address diverse product groups and production processes [1–6]. LCA involves cradle-to-grave analyses of production systems and evaluates inputs and outputs in all life cycle processes from upstream to downstream. Schau and Fet [1] state that food production has been much more energy intensive because of industrialization. In the food service industry, in addition to the operation's goals to improve efficiency [7, 8], centralized efficient operations in central kitchens [9, 10], replacement of efficiency-enhancing equipment [11, 12], and robots [13] are introduced to save energy.

Energy efficient production systems have been studied predominantly in the manufacturing industry. To improve process planning and operations, detailed changes in energy consumption are evaluated based on a processing condition. In terms of electricity, energy consumption of production machines is normally described as not

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constant over time. Each machine's consumption has its energy profile and is highly dynamic depending on the production process and the actual state of the machine [14]. Power levels during the productive modes of a selective laser sintering machine tool are described by [15]. The load profiles of single machines add up to a cumulative load profile for the process chain and determine the embodied energy of a product [16]. Process chain simulations considering energy profiles of the machines are proposed by [14, 17]. The energy simulation system [17] provides a function to visually evaluate dynamic changes in the energy consumption per unit of production throughput along a time progression.

Food service businesses provide a service-to-service production system that produce goods/foods. The service production system contains properties of service such as intangibility, heterogeneity, perishability, and/or simultaneity. Few studies, however, consider the properties of service for energy management. It is necessary to consider the possible effects caused by the properties of service in energy consumption and to capture the features of energy consumption. An earlier paper [18] reports to achieve energy saving for quick-service restaurants with an optimized kitchen ventilation system and innovative food preparation/storage technologies. This paper [18] proposes recommended energy efficient measures for quick-service restaurants. Hu et al. [19] investigate the indicators of energy conservation and carbon reduction in restaurants with the aim to promote the development of sustainable food tourism. However, these papers do not consider the effects of the properties of service in service provisions. In addition, the food service industry has several categories such as restaurants, home-meal replacement, delivery service, and so on. These services each have a specific service provision process, so it is expected that the features of energy consumption have different characteristics. Thus, the objective of this research is to examine energy consumption in the food service industry and capture the features of energy consumption considering the properties of service, as well as to propose a conceptual model of energy management as a first step goal to enhance energy demand management.

2 Energy Consumption in the Food Service Industry

2.1 Features of Properties of Service in Energy Consumption

In this section, the features of energy consumption in the food service industry are examined. It considers the possible effects caused by properties of service such as intangibility, heterogeneity, perishability, and simultaneity. Figure 1 describes an outline of the energy management system in the food service industry. For energy management, the first step is to visualize and capture the energy consumption feature. Improving energy efficiency and managing energy demand require several approaches, respectively. Improving energy efficiency is realized by reducing energy consumption per a functional unit or its created value. It is required to promote streamlining and/or reduce consumable input energy. On the other hand, energy demand management should consider not only efficiency but also how to operate and standardize energy consumption against the demand peak.

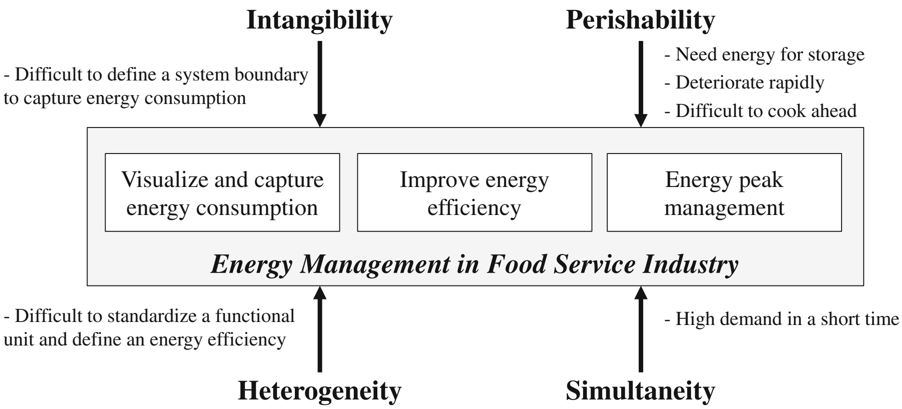

Fig. 1. Outline of energy management in the food service industry

Intangibility: The distinction between goods and services in a tangibility continuum classification is discussed by [20]. In the food service industry, dishes and related services are provided, and the dishes can be regarded as tangible goods. Bebko [21] indicates that fast food retailing may certainly fit into the category of differentiated goods/services because tangible food is being offered with the food preparation and delivery service. To capture and evaluate energy consumption accurately, it is necessary to define a system boundary. Intangibility may make it difficult to set the boundary for the evaluation in the service production systems.

Heterogeneity: Generally, in service provision processes, it is difficult to constantly serve produce. In a kitchen in a restaurant, service operations still have many hand-made processes that create value [22]. Generally, an index of energy efficiency is evaluated by measuring the amount of energy consumption and its produced value. The heterogeneity of service may lead to difficulty in defining its produced value because of unstandardized functional units.

Perishability: The storage time of food is very short, and food deteriorates rapidly in a large proportion of cases in the food industry, yet it is required to provide a fresh cuisine. Energy is a need for both warm and cold cuisines to keep the food either warm or cool. Further, difficulties in storing premade food inventories lead to the implementation of the build-to-order manufacturing system. A limited cooking operation can be implemented by batch production. Therefore, it has possible effects on energy demand management and controls energy demand.

Simultaneity: A degree of simultaneity in the food services industry is defined according to the location of consumption both spatially and temporally. Introducing a central kitchen system, batch production, and production lead-time can be regarded as influential factors.

Further, large fluctuations in energy demand occur because the restaurant service has high demand during the lunch and dinner hours. High demand in a short period may make energy demand management hard.

2.2 Targets

This paper targets four types of food businesses: (1) restaurant services with cook-chill systems, (2) restaurant services with cook-serve systems, (3) delivery of prepared food service, and (4) home-meal replacements. In this paper, a restaurant service with a cook-chill system is referred to as the system that cooks processed foods in the central kitchen. The restaurants with a cook-serve system carry out all of the cooking processes at the restaurant.

An investigation [23] reports the breakdown of energy consumption in a family restaurant located in Japan. In the report, the composition of energy consumption is 30.4 % for cooking, 24.5 % for cooling, 7.3 % for lighting, 18.2 % for hot water supply, and 8.6 % for supply fan. In this paper, cooking processes with major energy consumption are examined.

2.3 A Breakdown of Energy Consumption

Figure 2 shows a service provision process in each of the four businesses: restaurants with a cook-chill system, restaurants with a cook-serve system, delivery service, and home-meal replacements. A pentagon with white colour represents each service production process, and a pentagon with ash colour represents a process of customers. Each process consumes energy, and the amount of consumed energy differs according to the processes and their locations.

In the restaurants with a cook-chill system and a cook-service system, customers order and eat at the restaurant. Restaurants with a cook-chill system can divide cooking processes into a central kitchen and a restaurant, which separates where energy is consumed. Transportation and storing processes both require energy. In the cook-chill system, cook-serve system, and delivery service, major cooking processes are executed right after the customer orders. Therefore, the effects of simultaneity are large. For home-meal replacement services, food is cooked ahead of time at a food processing factory, and final cooking processes are done at the customer’s home. The processes are similar to the tangible goods production. From the above, it is described that these four food businesses have several features of energy consumption as well as effects caused by the service properties.

3 An Energy Peak Management Considering the Service’s Simultaneity

This section proposes a concept of energy demand management with regard to the simultaneity. Energy demand management is useful for energy cost savings, as the electricity rate structures are generally charged according to each consumer’s peak demand in the past year. In the food service industry, a cooking process is executed according to demand, and its simultaneity is determined by customer order. Therefore, it is difficult to standardize or shift the demand to control the energy peak.

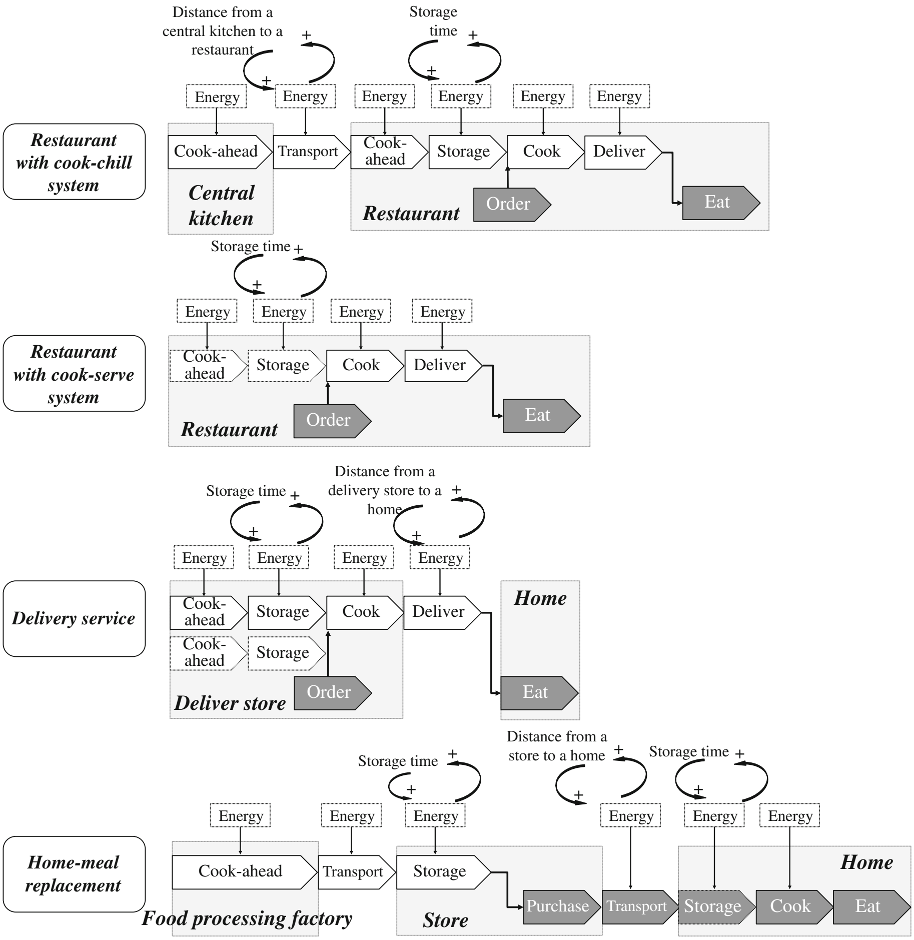

Fig. 2. A service provision process and the energy input within the four types of food service businesses

Figure 3 shows a biaxial model for energy demand management to control the energy peaks by changing a device and/or shifting energy sources according to the process. This model focuses on the substitutability of a cooking device and process. Changing cooking and/or energy sources can cause a shift and standardize energy demand in a high demand period.

As shown in Fig. 3, energy management measures are discussed according to the position in the biaxial model. In the first quadrant with high simultaneity and high substitutability of a cooking device, changing a cooking device and/or shifting energy sources of the device are beneficial ways to shift the energy peak. In food service production systems, service operations have many hand-made processes. Therefore, changing devices and/or energy sources can be considered as a feasible way for energy demand management. Some cooking devices such as a steamer, rice cooker, and oven

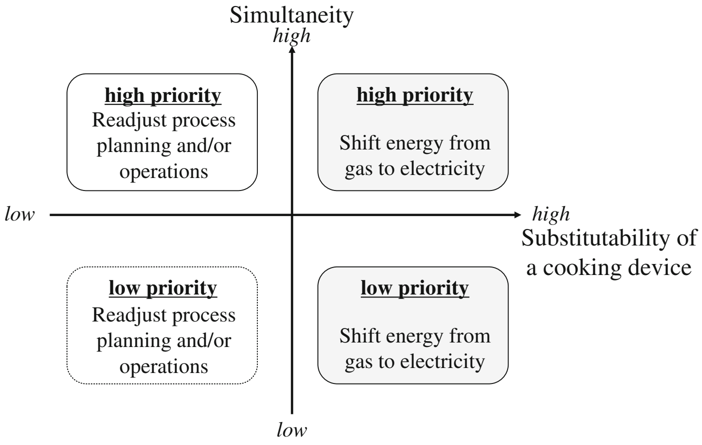

Fig. 3. A conceptual model of energy demand management regarding simultaneity

are commercialized, and they use either electricity or gas. These devices can be included as an example to manage operations by changing a device and/or shift an energy source from electricity to gas according to the energy demand. In the second quadrant with high simultaneity and low substitutability of a cooking device, readjusting process planning and/or operations are regarded as a beneficial area for energy management. A measure for the first and second quadrant is a higher priority.

4 Conclusions

This paper proposed a conceptual model of energy demand management considering the possible effects caused by properties of service such as intangibility, heterogeneity, perishability, and simultaneity in the food service industry. Four categories of food service business were examined through their energy consumption features at each service provision process. Developing a more detailed model and verifying the effectiveness of the model are the next steps of this study.

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Foodservice Management of Health Industries Based on Customer Satisfaction

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Abstract. To support managerial decision making, this paper investigates the linkages among service, timeliness, product quality, price reasonableness, and customer satisfaction in a hospital. Considering the practical needs, we proposed STQP-SERVQUAL (customer satisfaction model of hospital foodservice) on the basement of SERVQUAL. Data from 281 questionnaires was analyzed. Using structural equation modeling, the results suggest that service, timeliness, and product quality have a positive significant impact on patients' satisfaction with hospital foodservice. Moreover, the impact caused by price reasonableness is not significant. But price reasonableness is the lowest satisfied factor; it also calls for managers' attention. Theoretical and managerial implications are discussed. Although the case study is in a large hospital, the application of the results can be extended to other health industries.

Keywords: Foodservice · Customer satisfaction · SEM · SERVQUAL

1 Introduction

Since the enhancement of health care reform, people have paid more attention to hospital service quality. The demand for supportive service is increasing. However, according to some satisfaction researches [1, 2], foodservice is one of the most dissatisfied parts in Chinese hospital service. Supportive service becomes an important part that patients will consider. And high-quality service has become a requirement among hospitals [3]. To support managerial decision making, it's necessary to study on the factors which influence patient's satisfaction with hospital foodservice, and the influence degree of each factor.

Customer satisfaction involves an attitude or judgment toward a product or service that successfully provides a pleasurable level of consumption-related fulfillment [4]. Customer satisfaction is related to economic return [5, 6]. And economic return spurs an organization to develop. It's essential to study customer satisfaction for developing service quality of health industries. Furthermore, many researches show that customer satisfaction has obvious relationship with product quality and service quality [7, 8]. So improving service quality can be an effective way to increase customer satisfaction. SERVQUAL is proposed in 1988 by Parasuraman et al. [9]. And in 1991, they refined the original SERVQUAL instrument and reexamined its reliability and validity [10].

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Perceived service quality is viewed as the degree and direction of discrepancy between consumer's perceptions and expectations, including five dimensions: tangibles, reliability, responsiveness, assurance, and empathy [11]. Service quality has become an important research topic in various industries due to its significant relationship to cost, profitability, customer satisfaction, customer retention, and service guarantee [12].

Many researchers have studied on hospital service and derived their assess dimensions [13–16]. In addition, hospital managers often pay much attention to direct medical treatment, supportive service such as foodservice may be ignored. But as mentioned above, foodservice is one of the most dissatisfied areas in Chinese hospital service. Toward hospital foodservice, Zhang et al. (2009) [1] conducted a questionnaire survey on five dimensions of hospital service. They found that logistics management was the most dissatisfied part. Dubé et al. (1994) [17] proposed seven dimensions that represented patients' perceptions of foodservice: food quality, service timeliness, service reliability, food temperature, attitude of the staff who deliver menus, attitude of the staff who serve meals, and customization. They emphasized the need for a comprehensive and differentiated approach in measuring and monitoring patients' satisfaction with foodservice. Among these literatures, SERVQUAL instrument is widely used. Meanwhile, factor analysis and structural equation modeling is the most popular method used to study on hospital foodservice and some related fields [14, 15, 18] At the same time, some other methods are also used to study hospital foodservice. Such as the Entropy method [13], and fuzzy VIKOR method [16].

To sum up, with the development of health industry, the demand for supportive service is increasing, so it's necessary to study on hospital foodservice. With considering the particularities of hospital, this paper proposes satisfaction model of Chinese hospital foodservice based on SERVQUAL. Combined with descriptive statistics and SEM, this paper analyzes the influence factors of patients' satisfaction with hospital foodservice and the influence degree of each factor.

This paper is organized into four sections. Section 2 explains the research conceptual model, while the research methodology and data analysis are discussed in Sect. 3. The final section discusses the conclusions and managerial suggestions based on this research.

2 Hypotheses and Modeling

Until now, there are lots of hospitals with over 4000 beds in China [19]. Owning to a great deal of patients, the food supply system in Chinese hospital is quite complicated. Besides, there are still some problems in medical insurance system, so the price of hospital service is an important part that people will consider. Additionally, compared with the previous studies [3, 17], and considering the opinions of several experts, and patients, the main factors for evaluating hospital foodservice satisfaction are identified as: product quality, service, timeliness, and price reasonableness.

SERVQUAL has been widely used on assessing service quality. But considering the particularities of hospital, we modified SERVQUAL, and proposed STQP-SERVQUAL (see Fig. 1). Based on SERVQUAL items [9], and to make the items suitable for hospital foodservice, there are 18 items in our model. And the 18 items are classified into a total satisfaction dimension and four influence factors. In addition, a five-point (1,3,5,7,9) scale ranging from "Strongly agree" (9) to "Strongly disagree" (1) is adopted in our questionnaire. The items are as follow:

> Total satisfaction: 1. Total satisfaction. 2. Satisfaction on food quality. 3. Satisfaction on service quality; S–service: 4. The delivery staffs are willing to help customers. 5. The delivery staffs perform service dependably. 6. The foodservice department tries to give you individual attention. 7. The delivery staffs know your needs; P–price reasonableness: 8. The price on menu is clear and definite. 9. The price is reasonable; T–timeliness: 10. The foodservice department delivery meal at the time they promise to do so. 11. You receive prompt service from the delivery staff; Q–product quality: 12. The delivery vehicle and tableware are clean and neat. 13. There are abundant types of dishes. 14. There are plenty of vegetables in season. 15. The provided food is healthy balanced. 16. The nutrition of food can meet patients' need. 17. The provided food taste good. 18. The food temperature is appropriate.

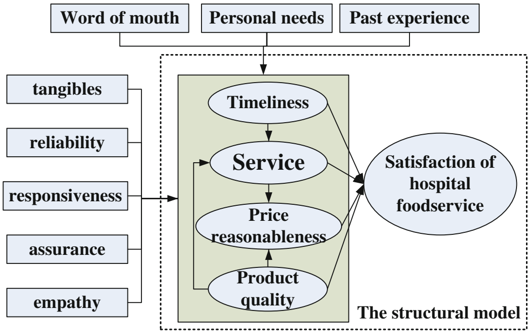

Fig. 1. STQP-SERVQUAL

There are some hypotheses to establish the model. Some researches show that product quality and service quality will impact customer satisfaction [7, 8, 20]. Service quality is considered the basis for customer satisfaction [20]. High product quality and service quality should archive high customer satisfaction.

H1: product quality has positive impact on patients' satisfaction with hospital foodservice; H2: service has positive impact on patients' satisfaction with hospital foodservice.

Timeliness is a kind of responsiveness, according to SERVQUAL [9, 10], responsiveness is one of the five dimensions belong to service quality. Timeliness is related to customer satisfaction.

H3: timeliness has positive impact on patients' satisfaction with hospital foodservice; H4: timeliness has positive impact on service factor.

For price reasonableness, Anderson et al. [5] suggest that price should impact customer satisfaction. They hold the opinion that value can be viewed as the ratio of perceived quality relative to price or benefits received to costs incurred. Customers' concerns about price fairness affect their product/service-choice behavior [21].

H5: product quality has positive impact on price reasonableness factor; H6: service has positive impact on price reasonableness factor; H7: price reasonableness has positive impact on patients' satisfaction with hospital foodservice.

Otherwise, we interviewed some patients. According to their opinions, the quality of products may influence perceived service quality in some degree. Because there are many customers mix the two kinds of qualities (product quality, service quality).

H8: product quality has positive impact on service factor.

3 Methodology and Data Analysis

The data was collected in April 2014, in a hospital in China. The 281 pieces of data came from 8 departments, with Cronbach's $\alpha = 0.951$. It shows good reliability. The sample data shows that the proportion of male and female is 1.1:1; patients are mainly over 50 years old.

3.1 Descriptive Statistics

The calculation method of satisfaction rate is as follow [22].

For a respondent, if he/she signed 7 or 9 to an item, it means that this respondent is satisfied with the item. For item i ($i = 1,2,\ldots,18$), set n_i as the number of respondents who have signed item i, and a_i as the number of item satisfied respondents, then the satisfaction rate of item i is calculated as: a_i/n_i. A respondent's score of a factor is calculated as his/her mean score of items belonging to this factor, if the score of a factor is bigger than or equal to 7, it means that this respondent is satisfied with the factor. For factor j ($j = 1,2,\ldots,5$), set m_j as the number of respondents who have signed items belonging to factor j, and b_j as the number of factor satisfied respondents, then the satisfaction rate of factor j is calculated as: b_j/m_j. A respondent's score of the overall service is calculated as his/her mean score of all items, if the score of overall service is bigger than or equal to 7, it means that this respondent is satisfied with the overall service. Set N as the whole amount of respondents, A as the number of overall satisfied respondents, then the satisfaction rate of overall service is calculated as: A/N.

See the results in Table 1. It shows that the mean scores of items are around 6. For factor satisfaction, Timeliness 74.38 % rank first, followed by Product quality 57.3 %, Service 52.67 %, and Price reasonableness 35.23 %. And from standard deviation, we can see that the highest value comes from Price reasonableness. The scattered options show that there are big differences among respondents' opinions about Price reasonableness. Additionally, the overall satisfaction rate is 52.67 %. It means that there are only half respondents feel satisfied with the overall foodservice.

3.2 Hospital Foodservice Satisfaction Model

Structural equation modeling (SEM) is applied to analyze the influence degree of every factor. In order to test a model's fit, some model evaluation criterions [23] such as the Chi-Square (χ^2) test statistic with respect to degrees of freedom, the Goodness of Fit

Table 1. Descriptive statistics

Factor	Cronbach's α	Item	N	Mean	Std Dev	Satisfaction rate	Factor satisfaction rate	Overall satisfaction rate
Total satisfaction	0.843	Item1	280	6.55	1.528	67.50 %	51.60 %	52.67 %
		Item2	280	6.12	2.243	55.00 %		
		Item3	281	6.81	1.991	69.75 %		
Service	0.964	Item4	280	6.5	2.216	61.79 %	52.67 %	
		Item5	281	6.85	1.969	71.17 %		
		Item6	280	6.4	2.287	60.71 %		
		Item7	280	6.16	2.297	54.64 %		
Price reasonableness	0.774	Item8	281	5.01	3.112	41.28 %	35.23 %	
		Item9	279	5.16	2.534	37.63 %		
Timeliness	0.755	Item10	281	7.58	1.813	83.27 %	74.38 %	
		Item11	281	7.26	1.957	76.51 %		
Product quality	0.895	Item12	279	7.2	1.968	73.84 %	57.30 %	
		Item13	278	6.2	2.375	56.83 %		
		Item14	278	6.03	2.365	52.16 %		
		Item15	279	6.5	2.161	63.44 %		
		Item16	277	6.44	2.092	62.09 %		
		Item17	279	5.96	2.171	50.18 %		
		Item18	277	7.25	1.958	77.62 %		

Index (GFI), Root Mean Square Residual (RMR), Residual Means Squared Error (RMSEA), the Non-Normed Fit Index (NNFI), and the Comparative Fit Index (CFI) can be used. If the χ^2/df value is less than 3, the model is considered a good fit. The smaller the RMR, the better it is. It is excellent when GFI, NNFI, CFI > 0.95, and RMSEA < 0.08. And it is acceptable when GFI, NNFI, CFI are in (0.9, 0.95), and RMSEA is in (0.08, 0.1).

A measurement model is initially conducted before estimating the structural model. Conformity Factor Analysis (CFA) is conducted to fit the model. In this sample, we remove item 18 for its component value is less than 0.55 while all other items' component values are higher than 0.6. We consider that item 18 have weak correlation with the factor. After data item reduction, the loading for all factors are sufficiently high. See the result in Table 2.

Table 2. Results of conformity factor analysis

Dimension	Number of cases	Number of items	Number of removed items	Cronbach's alpha	Component loading range
Service	280	4	0	0.864	0.72–0.83
Price reasonable	279	2	0	0.774	0.67–0.94
Timeliness	281	2	0	0.755	0.73–0.84
Product quality	277	7	1	0.895	0.62–0.83

The fit of the measurement model is acceptable, with χ^2/df = 2.069; RMR = 0.040, GFI = 0.93, NNFI = 0.98, CFI = 0.99 and RMSEA = 0.063. The reliability coefficients are acceptable for all dimensions ranging from 0.755 (Timeliness) to 0.895 (Product quality), indicating internal consistency in measurement items. The overall estimate of internal consistency is 0.951 for hospital foodservice. Then according to STQP-SERVQUAL (Fig. 1), we establish and test the structural model.

Establishing structural model is to find the relationship between each factor, test our hypotheses of STQP-SERVQUAL. According to the structural and measurement equations, implement the model on LISREL with maximum likelihood estimation procedure. The fit of the model is acceptable, with χ^2/df = 2.152; RMR = 0.040, GFI = 0.91, NNFI = 0.98, CFI = 0.99, RMSEA = 0.065. See the outcome in Table 3.

From the results of SEM, we find that according to the sample data, two hypotheses of STQP-SERVQUAL are not tenable, i.e. H3, H7. Timeliness has no significant direct impact on total satisfaction. Its indirect impact on total satisfaction goes through the variable “Service”. We can conclude that Service provide a buffer to the impact caused by Timeliness. On the one hand, good service will make up for dissatisfaction on Timeliness; on the other hand, bad service will worsen the influence caused by dissatisfaction on Timeliness. At the same time, Price reasonableness has no significant impact on total satisfaction. This result does make sense for patients usually think highly of nutrition, sometimes price seems less important. But the descriptive statistics remind us that Price reasonableness is the lowest satisfied factor. So Price reasonableness can’t be ignored either.

Furthermore, from Table 3 we can conclude: ①Service and Product quality have direct influence to total satisfaction. The influence degree of Product quality (0.73) is bigger, while Service’s is 0.51. ②Apart for direct influence, Product quality and Timeliness have indirect influence to total satisfaction. And by indirect effect, the influence degree of Timeliness (H4, H2) is 0.65 × 0.51 = 0.3315. ③For comprehensive influence, Product quality (0.73 + 0.48 × 0.51 = 0.9748) rank first, followed by Service (0.51), and Timeliness (0.3315).

Table 3. Standard estimates of the model

Hypothesis	Endogenous variable		Exogenous variable	Estimate	S.E.	t	P	Result
H1	satisfaction	←	product quality	0.73	0.12	6.17	0.000	Supported
H2	satisfaction	←	service	0.51	0.13	4.02	0.000	Supported
H3	satisfaction	←	timeliness	−0.14	0.12	−1.12	0.264	Not supported
H4	service	←	timeliness	0.65	0.1	6.69	0.000	Supported
H5	price reasonableness	←	product quality	0.43	0.12	3.76	0.000	Supported
H6	price reasonableness	←	service	0.25	0.08	3.04	0.003	Supported
H7	satisfaction	←	price reasonableness	0.07	0.07	0.96	0.338	Not supported
H8	service	←	product quality	0.48	0.1	4.71	0.000	Supported

4 Discussions and Conclusions

As high-quality service has become a requirement among hospitals, and to support managerial decision making, this paper investigates the linkages among service, timeliness, product quality, price reasonableness, and customer satisfaction in a hospital.

From the sample data, the results of descriptive statistics and SEM show that the satisfaction rate of Service is 52.67 % with influence degree 0.51. Service has a positive significant impact on hospital foodservice satisfaction (H2), but among Service items, item 7 "The delivery staffs know your needs" gets the lowest satisfaction rate. It suggests that the department should communicate more with patients, getting to know their needs. Timeliness has an indirect impact on hospital foodservice satisfaction (H4, H2) with satisfaction rate 74.38 % and influence degree 0.3315. Its indirect impact on total satisfaction goes through the variable "Service". Consequently, besides delivery on time, staffs should provide good service. Or patients will be dissatisfied with both Timeliness and Service. Product quality has a positive significant impact on hospital foodservice satisfaction (H1), with satisfaction rate 57.3 % and influence degree 0.9748. Product quality is the core of foodservice, it has highest influence degree. But the satisfaction rate is just over fifty percent, especially item 17 "The provided food taste good". This item gets the lowest satisfaction rate in Product quality. Foodservice department should work on it to make meals more delicious while ensure the nutrition and being suitable for patients. In addition, the impact on hospital foodservice satisfaction caused by Price reasonableness is not significant. Moreover, Price reasonableness gets the lowest satisfaction rate 35.23 %, and biggest standard deviation. It suggests that the department should analyze meal cost more precisely, expand ways to publish price information. Then make price more reasonable and clear.

In this paper, STQP-SERVQUAL was proposed to analyze influence factors of patients' satisfaction with hospital foodservice. The model covers food quality and service attitude which most past studies focus on. Moreover, considering the particularities of hospital foodservice, the model covers timeliness and price reasonableness. The results suggest that Service, Timeliness, and Product quality have positive significant impacts on patients' satisfaction with hospital foodservice. Moreover, the impact caused by Price reasonableness is not significant. The results in this paper are helpful for hospital managers and other health industries to improve foodservice satisfaction.

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An Analyzer of Computer Network Logs Based on Paraconsistent Logic

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Abstract. In recent years, the network vulnerability events draw the attention to the issue of the information management on the World Wide Web. The detected vulnerability was not only restricted to individuals, but also to enterprises and governments. Over the past decade, networks have become an affordable way for several computer services, but also a major challenge for network managers to maintain its operation. The main problem is the difficulty to deal with big amount of data generated by user requests, which in turn ultimately generate increasing information logs. Moreover, the dynamics of the services can lead to detect false positive and negative ones, so uncertainty is a theme to be considered. The employment of classical logic may not be adequate to solve problems of this nature. The aim of this paper is to present the development of a Paraconsistent analyzer, in order to extract some computer networks patterns of interest.

Keywords: Paraconsistent logic · Computer networks · Pattern recognition · Decision-making

1 Introduction

The computer networks currently constitute as the main form of transmitting data and services. Therefore, the task of monitoring the information has turn to be a key factor in technology sectors [1]. The information security issues have existed around since it has been created. However, as the technology goes further and information management systems become increasingly powerful, the issue of information security becomes also increasingly critical [2].

Considering its intrinsic nature, the network operation analysis is based on stochastic events. The argument for this type of methodology is based on the principle that human actions behave as random elements [3]. In fact, the variability of available services is considerable, and therefore the types of user behavior eventually follow this trend.

Some important elements should be considered in data traffic management, such as trustfulness, confidentiality, integrity and reliability [4, 5].

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Among the mentioned elements, reliability is the main object of analysis of this article. It can be defined as the capacity to provide access to information systems as soon as they are requested [4]. A system with low reliability ultimately leads to dissatisfaction and low user productivity.

The establishment of a set of criteria should be done to avoid false positives [6], which in turn may even lead to problems of a legal nature. For instance, a significant loss of network data packets can either be interpreted as a malicious attack, as may represent an intense use of the computer network.

It is possible to gather information from network logs of the data packets that pass through the network devices. Data extraction can provide the manager an important tool in decision making.

Some data may be considered interesting to the analysis of the packet traffic, among which are: the origin logical IP address, request time, response waiting time, type of obtained result, the amount of response data in the transaction and the destination logical IP address [7].

Due the stochastic behavior of the networks, the analysis methods based on classical logic may not be a suitable tool for this scenario [8]. A new logical system is needed to deal with it. Therefore, the Paraconsistent annotated evidential logic Eτ has a structure that becomes a natural technique to look for evidence of problems, whether caused both by the standard operation of the network or intentional elements [9]. In the latter case, it may be constituted by users or malicious application [10].

Once again, the use of Paraconsistent logic Eτ arises as a feasible alternative to take decisions under uncertainty, inconsistency and contradiction, in several areas such as robotics, electronics, traffic control, among others [11].

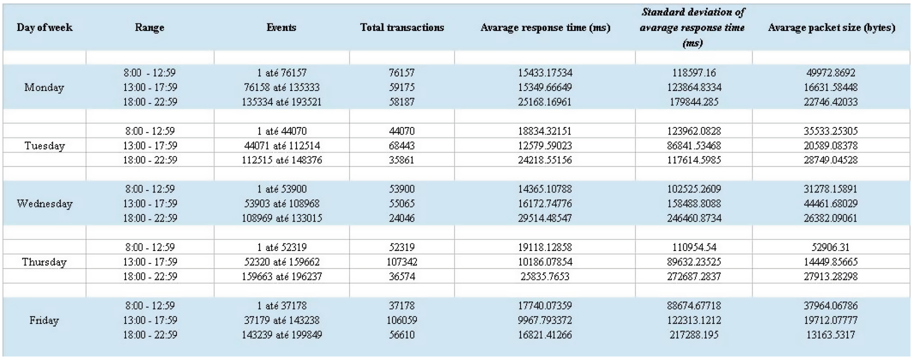
2 Methodology

The development of the proposal is based on the analysis of network data communication over five days and three ranges (mornings, afternoons and evenings), of five hours each. For each range, several parameters were obtained, among which: date and time of the request, the source IP address, destination IP address, type of connection made, the result of the request operation, response waiting time, amount of data response and total transactions.

From the network requests log, it was possible to extract network usage information expressed in Table 1.

Some significant information can be obtained considering the parameter “Standard Deviation” in association with “Average Response Time” as a measure of dispersion and “Average Packet Size”. In this case, it is possible to make an association between the lowest standard deviation (86841.53 ms), its average response time (12579.59 ms) and average packets size (20589.08 bytes), which leads to believe that in the period from 13:00 to 17:59 on Tuesday presented the network operating normally, with low response time, even though with a considerable amount of data in transit. On Wednesday, from 18:00 to 22:59, the network had its worst performance, having

Table 1. Network parameters obtained from transactions logs



Day of week	Range	Events	Total transactions	Avarage response time (ms)	*Standard deviation of avarage response time (ms)*	Avarage packet size (bytes)
Monday	8:00 - 12:59	1 até 76157	76157	15433.17534	118597.16	49972.8692
	13:00 - 17:59	76158 até 135333	59175	15349.66649	123864.8334	16631.58448
	18:00 - 22:59	135334 até 193521	58187	25168.16961	179844.285	22746.42033
Tuesday	8:00 - 12:59	1 até 44070	44070	18834.32151	123962.0828	35533.25305
	13:00 - 17:59	44071 até 112514	68443	12579.59023	86841.53468	20589.08378
	18:00 - 22:59	112515 até 148376	35861	24218.55156	117614.5985	28749.04528
Wednesday	8:00 - 12:59	1 até 53900	53900	14365.10788	102525.2609	31278.15891
	13:00 - 17:59	53903 até 108968	55065	16172.74776	158488.8088	44461.68029
	18:00 - 22:59	108969 até 133015	24046	29514.48547	246460.8734	26382.09061
Thursday	8:00 - 12:59	1 até 52319	52319	19118.12858	110954.54	52906.31
	13:00 - 17:59	52320 até 159662	107342	10186.07854	89632.23525	14449.85665
	18:00 - 22:59	159663 até 196237	36574	25835.7653	272687.2837	27913.28298
Friday	8:00 - 12:59	1 até 37178	37178	17740.07359	88674.67718	37964.06786
	13:00 - 17:59	37179 até 143238	106059	9967.793372	122313.1212	19712.07777
	18:00 - 22:59	143239 até 199849	56610	16821.41266	217288.195	13163.5317

obtained the largest delay in average response time (29514.48 ms) and slightly higher average packets size compared to the previous example (26382.09 bytes), with a standard deviation slightly below the maximum limit obtained (246460.67 ms). In this case, it may be viable to conclude that the network had dealt with operations problems.

However, during the computer network operation, handle dynamic and highly stochastic events may be a high complexity task. Therefore, a logical analyzer – Para-analyzer [12] will be used upon the data obtained to make an analysis under the light of an artificial intelligence tool. Four parameters shall be used as factors: average response time (R), its standard deviation (D), average packets size (P) and the total transactions (T).

The number of intervals that were selected for each parameter is based on the occurrence of significant variances in the evaluations of favorable and unfavorable evidences by the specialists. A larger number of intervals often presented very close or even repeated values, which in turn would generate unnecessary redundancy in this study.

It is considered that a low response time is a good indicator because it suggests that the network did not suffer consequences of a possible congestion and was able to answer its requests in an acceptable time. For this, three intervals shall be considered, based on the minimum and maximum values obtained from the network log: R1, R2 and R3.

A low standard deviation of the average response time also leads to the belief of a homogeneous network operation. In other words, no significant discrepancies between the hosts in operation were detected. Along with the previous factor, three intervals shall be considered: D1, D2 and D3.

The average packet size is also an important factor, but it has an element of uncertainty that must be considered. Networks with low average size packets may indicate little use, which can be considered a plus. Moreover, networks that suffer attacks should also have this tendency, since the data packets used for this purpose are individually small. Four intervals will be considered: P1, P2, P3 and P4.

Finally, the number of transactions may be considered a significant factor since a high value may suggest problems relating to malicious attacks or high degree of utilization of the network. Once again, four intervals shall be used: T1, T2, T3, and T4.

The concepts of Paraconsistent logic Eτ will be used from this point. According to Abe [12]: “The atomic formulas of the logic Eτ are of the type p(μ, λ), where $(\mu, \lambda) \in [0, 1]^2$ and [0, 1] is the real unitary interval (p denotes a propositional variable)”. Therefore, p(μ, λ) can be intuitively read: “It is assumed that p’s favorable evidence is μ and contrary evidence is λ.”. This will lead to the following conclusion:

- $p_{(1.0,\ 0.0)}$ can be read as a true proposition,
- $p_{(0.0,\ 1.0)}$ as false,
- $p_{(1.0,\ 1.0)}$ as inconsistent,
- $p_{(0.0,\ 0.0)}$ as paracomplete, and
- $p_{(0.5,\ 0.5)}$ as an indefinite proposition.

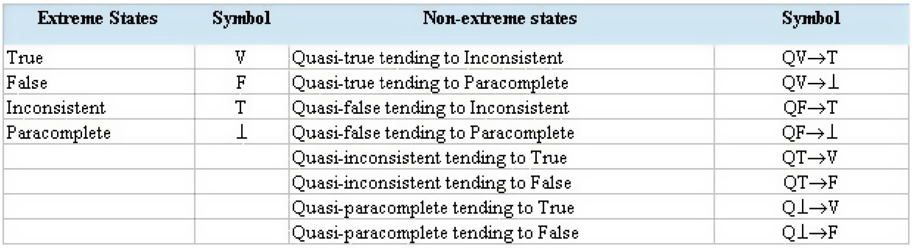
To determine the uncertainty and certainty degrees, the formulas are [10]:

- Uncertainty degree: $G_{un}(\mu, \lambda) = \mu + \lambda - 1$ $(0 \leq \mu, \lambda \leq 1)$;
- Certainty degree: $G_{ce}(\mu, \lambda) = \mu - \lambda$ $(0 \leq \mu, \lambda \leq 1)$;

An order relation is defined on $[0, 1]^2$: $(\mu_1, \lambda_1) \leq (\mu_2, \lambda_2) \Leftrightarrow \mu_1 \leq \mu_2$ and $\lambda_1 \leq \lambda_2$, constituting a lattice that will be symbolized by τ.

With the uncertainty and certainty degrees, it is possible to manage the following 12 output states, showed in the Table 2.

Table 2. Extreme and nn-extreme states



Extreme States	Symbol	Non-extreme states	Symbol
True	V	Quasi-true tending to Inconsistent	QV→T
False	F	Quasi-true tending to Paracomplete	QV→⊥
Inconsistent	T	Quasi-false tending to Inconsistent	QF→T
Paracomplete	⊥	Quasi-false tending to Paracomplete	QF→⊥
		Quasi-inconsistent tending to True	QT→V
		Quasi-inconsistent tending to False	QT→F
		Quasi-paracomplete tending to True	Q⊥→V
		Quasi-paracomplete tending to False	Q⊥→F

All states are represented in Fig. 1.

Initially, for each analyzed factor, the opinions of two experts in the field of networks shall be considered, both senior professional with a large experience in the field. For each factor, intervals will be taken and rated, with a certain degree of favorable evidence (represented by μ) and unfavorable evidence (represented by λ).

Also weights to each factor/intervals will be applied, considering the importance degree that each expert deems appropriate. The data from which the Paraconsistent algorithm will be applied is applied can be expressed in Table 3.

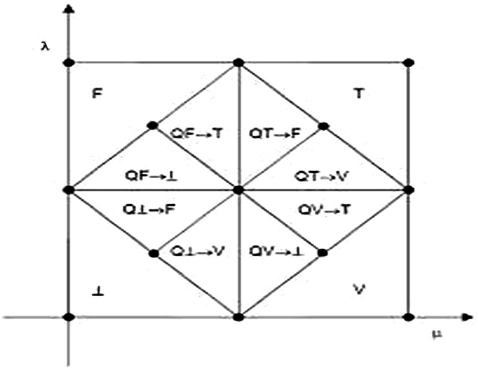
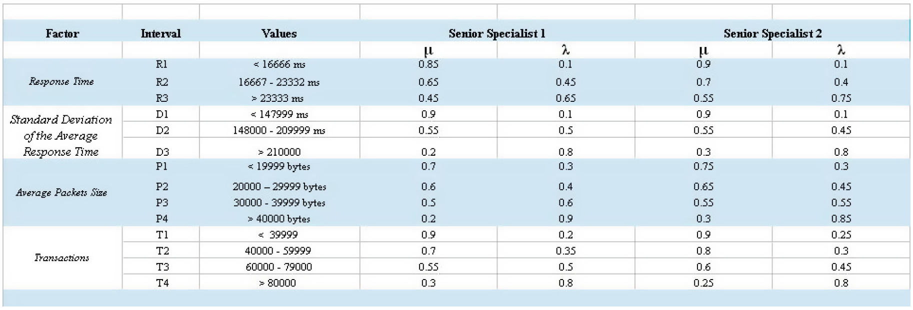


Fig. 1. All states in Lattice τ

Table 3. Distribution of factors and grades for the Para-analyzer algorithm



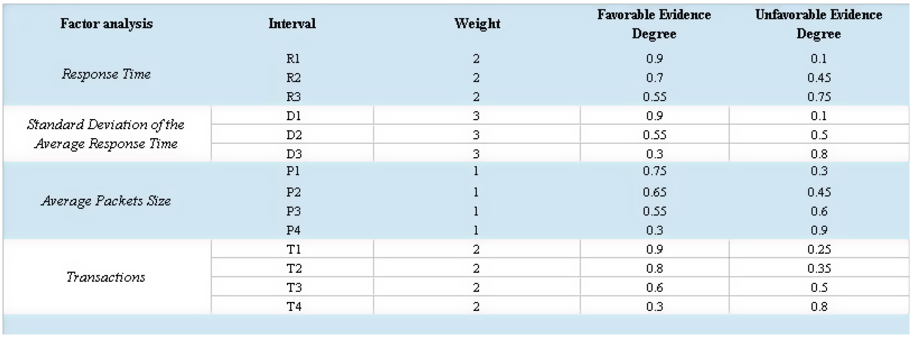
Factor	Interval	Values	Senior Specialist 1		Senior Specialist 2	
			μ	λ	μ	λ
Response Time	R1	< 16666 ms	0.85	0.1	0.9	0.1
	R2	16667 - 23332 ms	0.65	0.45	0.7	0.4
	R3	> 23333 ms	0.45	0.65	0.55	0.75
Standard Deviation of the Average Response Time	D1	< 147999 ms	0.9	0.1	0.9	0.1
	D2	148000 - 209999 ms	0.55	0.5	0.55	0.45
	D3	> 210000	0.2	0.8	0.3	0.8
Average Packets Size	P1	< 19999 bytes	0.7	0.3	0.75	0.3
	P2	20000 – 29999 bytes	0.6	0.4	0.65	0.45
	P3	30000 - 39999 bytes	0.5	0.6	0.55	0.55
	P4	> 40000 bytes	0.2	0.9	0.3	0.85
Transactions	T1	< 39999	0.9	0.2	0.9	0.25
	T2	40000 - 59999	0.7	0.35	0.8	0.3
	T3	60000 - 79000	0.55	0.5	0.6	0.45
	T4	> 80000	0.3	0.8	0.25	0.8

To study the proposition: “The computer network is functioning within normal operational limits”, values were tabulated and applied for the Para-analyzer algorithm, as seen in Table 4.

The factors listed above are not able to lead to important conclusions alone. In this case, the combined influence of the factors, with their respective applied weights, could contribute to a more appropriate response to the initial proposition. This is determined by the global analysis of the points that represent the Cartesian plane [13].

The global analysis is calculated considering the favorable evidences (μ) multiplied by their respective weights, and finally added. The same is done to the unfavorable evidence (λ) [13]. Considering the tabulated values, the global analysis obtained was 0.63 of favorable evidence and 0.48 of unfavorable evidence. With a minimum demand level of 0.5, it was observed that the factors were proved feasible for the R1 response time, D1 standard deviation of average response time, and T1 transactions. No average size of packets (P) interval showed viable result, as seen in Fig. 2.

Table 4. Favorable and unfavorable evidences and weights of first scenario



Factor analysis	Interval	Weight	Favorable Evidence Degree	Unfavorable Evidence Degree
Response Time	R1	2	0.9	0.1
	R2	2	0.7	0.45
	R3	2	0.55	0.75
Standard Deviation of the Average Response Time	D1	3	0.9	0.1
	D2	3	0.55	0.5
	D3	3	0.3	0.8
Average Packets Size	P1	1	0.75	0.3
	P2	1	0.65	0.45
	P3	1	0.55	0.6
	P4	1	0.3	0.9
Transactions	T1	2	0.9	0.25
	T2	2	0.8	0.35
	T3	2	0.6	0.5
	T4	2	0.3	0.8

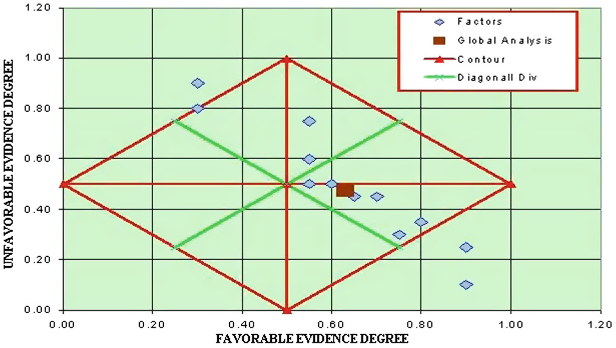
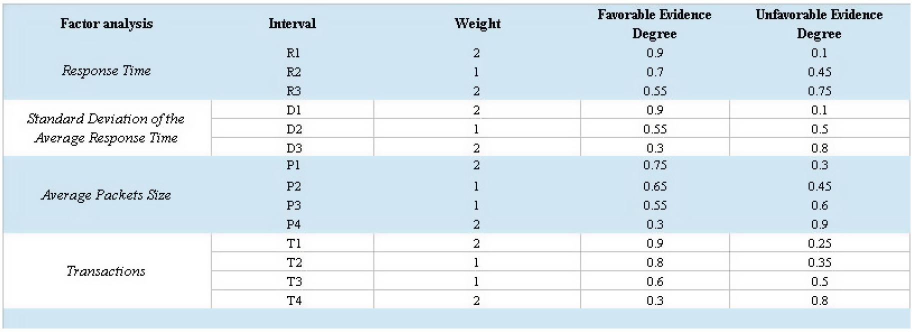


Fig. 2. Analysis of first scenario result by the Para-analyzer algorithm.

For comparison, another set of weights can be used where a higher weight is applied to each extreme position of the analyzed factor interval. The objective of this approach is to balance the weight factor to each other while applying a slightly lower relative weight in the intermediate intervals that may generate a higher level of uncertainty, as seen in Table 5.

In this second scenario, the obtained global analysis was 0.62 of favorable evidence and 0.49 of unfavorable evidence, which is slightly less than in the first scenario. With a minimum demand level of 0.5, it was observed that the factors that were viable remain the same: R1 response time, D1 standard deviation of average response time, and T1 transactions. Again, no average packets size factor interval (P) presented viable result, as can be seen in Fig. 3.

Table 5. Favorable and unfavorable evidences and weights of second scenario.



Factor analysis	Interval	Weight	Favorable Evidence Degree	Unfavorable Evidence Degree
Response Time	R1	2	0.9	0.1
	R2	1	0.7	0.45
	R3	2	0.55	0.75
Standard Deviation of the Average Response Time	D1	2	0.9	0.1
	D2	1	0.55	0.5
	D3	2	0.3	0.8
Average Packets Size	P1	2	0.75	0.3
	P2	1	0.65	0.45
	P3	1	0.55	0.6
	P4	2	0.3	0.9
Transactions	T1	2	0.9	0.25
	T2	1	0.8	0.35
	T3	1	0.6	0.5
	T4	2	0.3	0.8

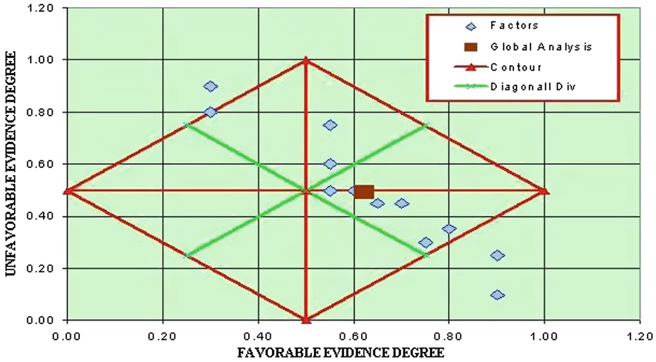


Fig. 3. Analysis of second scenario result by the Para-analyzer algorithm.

3 Analysis of the Results

From the obtained results, it can be observed that among the analyzed factors, the intervals R1, D1 and T1 gathered a common standard of viability. On the other hand, there was no significant influence on the factor P, in any of the intervals. All the evaluated scenarios showed inconclusive results.

The interpretation of the results leads to the belief that a network with reduced response time (R1), a low standard deviation of the average response time (D1) and small number of transactions (T1) are conditions that reflect the behavior of the computer network within normal limits. However, the average size factor package does not follow the same line of reasoning, and can be proven by its own data in the log, where a significant amount of data in transit was verified with a reduced response time. Therefore, it can be concluded that the average of the data packets may not be indicative of problems in the network, only an indication of intensive use of the infrastructure.

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Quality of Service in Small and Medium Enterprises

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Abstract. No matter the segment, enterprises are adding value to their final product through services. A service of quality can make the difference in the market. The purpose of this study is to determine whether the dimensions of SERVQUAL are adequate to the characteristics of the small business tourism segment in Brazil, whose customers are small and medium enterprises (SMEs). The research used a descriptive approach with a quantitative procedure, and the data was collected in two groups of customers. The conclusion was that the SERVQUAL questionnaire is an appropriate tool for the characteristics of SMEs and assesses the punctual quality of service. Besides, the inclusion of three questions of the SERVPERF questionnaire helped to identify whether the quality of service was converted into customer satisfaction or not. Additional research was suggested to identify why the service was considered of quality.

Keywords: Small and medium enterprises · Service · Quality · SERVQUAL

1 Introduction

Small and medium enterprises (SMEs) represent about 99 % of the active companies in the world and are the main source of employment. Also, it is appropriate to highlight the European Union with 66.7 % of the formal employment, and Brazil with 51.6 % of jobs generated in the private sector. Among the Brazilian SMEs, the service sector is the second with the major number of companies, representing 33 % of the market, second only to commerce. On the other hand, the tourism sector stands out representing in total contribution, considering direct and indirect activities, 9.3 % of Brazil's GDP [1–5]. The tourism sector includes a variety of companies, such as lodging and food services, transportation companies and travel agencies, among others. This article deals with the quality of service of small travel agencies.

Service is an activity in which the end result is not a physical product; it is directed to meet consumer needs. Some features of services stand out, such as: intangibility, simultaneity, heterogeneity and perishability [6]. Given these characteristics, a different quality measurement tool used for the assessment of product quality is required.

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The quality of service is directly related to the customer's expectation. It is a combination of what the client expected, what he found during the provision of the service and how much he was satisfied after the execution of the activity. If the initial expectation was exceeded, the service is considered of a good quality [7].

However, understanding how the customer assesses the quality of service demands specific techniques. Several tools can be presented, such as Grönroos Model, SERVQUAL Model, Perception-Expectancy Model, Evaluation of Service and Value Model, SERVPERF Model, Ideal Performance Model, among others [8].

Among the hitherto models presented, SERVQUAL arises as a widespread questionnaire in the academic work, because of its ease application and diagnosis ability [9]. This questionnaire aims to measure the customer's expectations and perceptions, and should be adapted according to the main business attributes and activities.

Given the importance that the SMEs have on the economy in general, and in the tourism sector in Brazil, this article is justified by the need to developing tools to evaluate the service quality of small companies. Due to the difficulty of empirical research in small service companies in Brazil, it draws attention the low number of articles on the subject, opening, therefore, a gap for studies.

The main objective of this work is to verify whether the dimensions of the SERVQUAL tool are adequate or enough to evaluate the quality of service of a small size enterprise, that belongs to the tourism segment, whose main customers are other small and medium enterprises (SMEs).

2 Literature Review

2.1 Service Quality

To understand the quality formation of service is crucial for an enterprise to achieve competitive advantage. Thus, a service provided with quality makes the customers more satisfied, resulting in loyalty to the company, positive divulgation for other costumers, new orders and consolidation in the market [10–12].

The improving of the service quality is linked to the enterprise's ability to evaluate intangible results, i.e., the customers' subjective judgment about the service. In this case, subjective means that the evaluation is influenced by prior experiences and personal needs. Specifically in the tourism sector, quality refers to the attributes of the service provided by a travel agent [13].

Indicators, such as quality level, are essential for the planning and control of internal processes of the enterprises. A clear reading of the indicators allows organizations to develop strategies and identify issues that will directly impact on their results [14]. For that reason, many scholars focus their efforts on developing tools that would allow measuring the quality of services provided. It is noteworthy that the SERVQUAL model, despite some criticism about its efficiency, is used as a basis for the development of other models [8].

The SERVQUAL questionnaire measures customers' expectation and perception of the service in 5 quality dimensions, Reliability, Promptness, Safety, Empathy and Tangible Aspects [12, 15, 16]. The same questionnaire captures the managers' vision of the quality dimensions, acknowledging the gap between managers' and clients' vision.

There are some critics of SERVQUAL model and Cronin and Taylor developed an alternative model, SERVPERF. This model considers the costumer's satisfaction a better metric to forecast the desire for a new purchase, improving then the SERVQUAL questionnaire to measure the costumer's satisfaction [17].

For this setting, the authors used the SERVQUAL questionnaire and three additional questions designed to evaluate the feelings toward the services provider: customer's satisfaction, total quality of services and the repurchase intention.

The SERVQUAL has become one of the most used models to measure service quality, and it has been adapted to the various application sectors, such as: retail companies, airlines, restaurants, hotels, online education, hospitals, internet services, banks, supply chain, public service, among others [12, 18].

Despite being widely used, including the tourism sector, in the literature for this study no articles with the application of the SERVQUAL in travel agencies were found, which opens a gap that this study aims to investigate.

3 Methodology

This study aims to identify the existence of correlations among variables within a population, analyzing a given phenomenon and trying to relate it to another. Fernandes and Gomes define that the descriptive research mode aims to "describe, analyze or verify relationships between facts and phenomena. That is, be aware of what, with whom, how and what is the intensity of the phenomenon under study" [19].

Data collection was performed at a specific moment, so the search is considered a cross-section in time and uses structured questionnaires with closed questions, in order to identify the quality of service purchased by a particular group of SMEs.

3.1 Population and Sample

The survey was conducted with SMEs who participated in International Missions carried out by a small travel agency, located in São Paulo and specialized in International Business Tourism for SMEs. We interviewed 29 entrepreneurs, being: 10 small and medium printing industries, from the Federal District, capital of Brazil, who participated in an International Mission to Shanghai/Dubai, and 19 small and medium enterprises from different economic sectors and from different regions of Brazil who participated in an International Mission to USA/Panama.

3.2 Data Collection

We adapted the SERVQUAL questionnaire and tested it with one of the travel agency owners. Some questions were revised to reflect the reality of the tourism sector and, in order to enlarge the possibilities of analysis, three additional questions of the SERVPERF were included.

4 Results

The average notes of the expectation and the average notes of the performance by each evaluated dimension were calculated. The differences between expectation and performance generated the column of GAPS presented in three tables, one for each traveling group, and one consolidating the results of both groups. The event's profile of the enterprises that participated was used to analyze the results.

The first result shown in Table 1 refers to the first group of entrepreneurs. This group, composed of small and medium enterprises, attended the world's largest retail trade fair, the National Retail Federation - NRF, which features lectures discussing trends in retail market, and went to technical visits to the local market. In Panama the participants visited the Colon Zone, place directed to make imports in small quantities and a great mix. The group's goal was to meet the trends of the retail market.

Table 1. Results of the search of the group USA/Panama (Source: Author).

Expectancy before the trip	Avg.	Performance after the trip	Avg.	GAP
The staff must be well-dressed	6.31	The staff was well-dressed	6.63	0.32
The enterprise has to be reliable	6.89	The enterprise was reliable	7	0.11
The enterprise has to generate business opportunities	6.47	The enterprise generated business opportunities	6.63	0.16
The enterprise has to fulfill the activities and schedules promised in the travel program	6.53	The enterprise fulfilled the activities and schedules promised in the travel program	6.95	0.42
The enterprise must inform to the customers the details of the activities that will be performed in the travel program	6.74	The enterprise informed to the customers the details of the activities that were performed in the travel program	6.89	0.15
The staff must always be available to help customers	6.63	The staff was always available to help customers	6.74	0.11
The costumer has to feel safe to travel with the staff	6.68	The costumer felt safe to travel with the staff	6.95	0.27
The staff has to be polite	6.68	The staff was polite	6.84	0.16
The enterprise will give individual attention to the customers	6.15	The enterprise gave individual attention to the customers	6.73	0.58
The staff will give personal attention to the customers	6.16	The staff gave personal attention to the customers	6.68	0.52
It was expected that the staff knew what the customer's needs were	6.0	The staff knew what the customer's needs were	5.95	−0.05
In the coming years my use of the enterprise will be:			6.21	
The service of the enterprise is:			6.58	
My feelings about the enterprise's services can best be described as:			6.58	

Analyzing the results of this group, the highlights are: (a) the highest average expectation column (6.89) was in the topic “The enterprise has to be reliable”; (b) the lowest average expectation column (6.0) was in the topic “It was expected that the staff knew what the customer’s needs were; (c) “the largest GAP (0.58) was between the topics “The enterprise will give individual attention to the customers” and “The enterprise gave individual attention to the customers”; (d) the lowest GAP (−0.05) was between the topics “It was expected that the enterprise’s staff knew what the customer’s needs were” and “The staff knew what the customer’s needs were”. The last three questions in the questionnaire evaluating the enterprise overall showed a very positive evaluation (6.21, 6.58 and 6.58), even having a dimension with a negative GAP.

The second result, shown in Table 2, refers to entrepreneurs who participated in the International Mission Shanghai/Dubai. This group was composed of small and medium enterprises of the printing sector, which participated in a specific fair of the graphic

Table 2. Results of the research of the group Shangai/Dubai (Source: Author).

Expectancy before the trip	Avg.	Performance after the trip	Avg.	GAP
The staff must be well-dressed	4.8	The staff was well-dressed	6.3	1.5
The enterprise has to be reliable	6.2	The enterprise was reliable	6.5	0.3
The enterprise has to generate business opportunities	5.2	The enterprise generated business opportunities	5.5	0.3
The enterprise has to fulfill the activities and schedules promised in the travel program	5.9	The enterprise fulfilled the activities and schedules promised in the travel program	6.5	0.6
The enterprise must inform to the customers the details of the activities that will be performed in the travel program	6.1	The enterprise informed to the customers the details of the activities that were performed in the travel program	6.5	0.4
The staff must always be available to help the customers	5.6	The staff was always available to help the customers	6.1	0.5
The costumer has to feel safe to travel with the staff	6.1	The costumer felt safe to travel with the staff	6.4	0.3
The staff has to be polite	6.5	The staff was polite	6.7	0.2
The enterprise will give individual attention to the customers	5.1	The enterprise gave individual attention to the customers	6.0	0.9
The staff will give personal attention to the customers	5.4	The staff gave personal attention to the customers	6.2	0.8
It was expected that the staff knew what the customer’s needs were	3.9	The staff knew what the customer’s needs were	4.8	0.9
In the coming years my use of the enterprise will be:			6.1	
The service of the enterprise is:			6.4	
My feelings about the enterprise’s services can best be described as:			6.3	

sector in Shanghai, and went to technical visits to specialized factories in printing equipment. In Dubai technical visits to the local market and to the embassy were made to understand the opportunities for the sector in this country.

The main results of this group were: (a) the highest average expectation column (6.5) was in the topic "The staff has to be polite"; (b) the lowest average expectation column (3.9) was in the topic "It was expected that the staff knew what the customer's needs were"; (c) the largest GAP with an average of 1.5 was in the topic "The staff must be well dressed" and "The staff was well dressed "; (d) the lowest GAP with an average of 0.02 was in the topics "The staff has to be polite" and "The staff was polite". The last three questions in the questionnaire evaluating the enterprise overall showed a very positive evaluation (6.1, 6.4 and 6.3).

The two groups were consolidated in Table 3, for general analysis.

The main results of the consolidated groups in Table 3 were: (a) the highest average expectation was in the column (6.65) in the topic "The enterprise has to be reliable";

Table 3. Results of the two research group consolidated (Source: Author).

Expectancy before the trip	Avg.	Performance after the trip	Avg.	GAP
The staff must be well-dressed	5.79	The staff was well-dressed	6.52	0.73
The enterprise has to be reliable	6.65	The enterprise was reliable	6.83	0.18
The enterprise has to generate business opportunities	6.03	The enterprise generated business opportunities	6.24	0.21
The enterprise has to fulfill the activities and schedules promised in the travel program	6.31	The enterprise fulfilled the activities and schedules promised in the travel program	6.79	0.48
The enterprise must inform to the customers details of the activities that will be performed in the travel program	6.52	The enterprise informed to the customers the details of the activities that were performed in the travel program	6.76	0.24
The staff must always be available to help customers	6.27	The staff was always available to help customers	6.52	0.25
The customer has to feel safe to travel with the staff	6.52	The customer felt safe to travel with the staff	6.76	0.24
The staff has to be polite	6.62	The staff was polite	6.79	0.17
The enterprise will give individual attention to the customers	5.79	The enterprise gave individual attention to the customers	6.48	0.69
The staff will give personal attention to the customers	5.9	The staff gave personal attention to the customers	6.52	0.62
It was expected that the staff knew what the customer's needs were	5.27	The staff knew what the customer's needs were	5.55	0.28
In the coming years my use of the enterprise will be:			6.17	
The service of the enterprise is:			6.52	
My feelings about the enterprise's services can best be described as:			6.48	

(b) the lowest average expectation was in the column (5.27) in the topic "It was expected that the staff knew what the customer's needs were"; (c) the biggest GAP at an average of 0.73 was in the topics "The staff must be well-dressed" and "The staff was well-dressed"; (d) the lowest GAP at an average of 0.17 was in the topic "The staff has to be polite" and "The staff was polite". The last three questions in the questionnaire evaluating the company overall showed a very positive evaluation (6.17, 6.52 and 6.48).

The topic with the greatest positive GAP was about the enterprise's staff way of dressing. It demonstrates the impact of the formalization in attendance, as in the agency all the staff works with suit and tie, which is not common in SMEs in Brazil.

The highest average expectation was placed on "confidence". It can be explained by the characteristic of SMEs in Brazil, in which the owners often centralize decisions and have difficulty to deliver a new project in other company's hands. These two issues arise a question about the understanding of what SMEs value in the service, since the organization emphasizes tangibles and customers seem to want confidence.

Open interviews with the partners of the company and with the business customers were made. The partners said that the most important topics were about (1) "the staff knowing what the customer's needs were" and (2) "the enterprise generating business opportunities". From the two topics, the first stands out as the topic with lower average expectation among the SMEs, which is an antagonistic result than expected; and the second topic did not have an average or relevant GAP. The clients acknowledged they had low expectations about the ability of a supplier to understand their problems.

The individual analysis per group has some specific features that are hidden in the consolidated analysis. This observation is made clear in the topic about "the staff knowing what the customer's needs were", in which the two groups evaluated the service in different ways.

Another topic that drew attention was the positive evaluation in the general context of the services quality provided, 6.52 in 7.0 points. Despite some quality flaws, the entrepreneurs were satisfied with the services provided.

5 Conclusion

According to the data analysis, some results will be used as the main connecting thread of this research in order to draw the conclusions of this study.

- The individual analysis of the results brings specific characteristics of the groups, which is lost when doing a consolidated analysis of all customers entrepreneurs;
  *Some characteristics of the SMEs in Brazil, such as trust, can be observed in the results
- Considering that the travel agency specialized in developing missions to internationalize SME's; the specific topics on business should have a relevant positive evaluation, which did not happen, but the result of the three last questions that assess the general quality of the service offered had a very positive result.

Thus, conclude that the SERVQUAL questionnaire was of value to determine characteristics of SMEs and the punctual quality of the service provided. The inclusion of the three questions of the SERVPERF questionnaire identified in general, whether the punctual quality of the service was converted or not in customers' satisfaction.

Analyzing the results, one can identify the necessity of a variable in the tool that shows the main reason that allowed the service of being considered of good quality, and the variable that best suits this purpose is related to "learning". This variable explains why business man were satisfied, even without closing deals, the essential objective of the trip, and would like to travel with the agency again. This conclusion was taken based on three topics: 1. The main purpose of the trips was to develop the internationalization of the enterprise; 2. The SMEs did not mark as relevant the expectation in topics related to business; 3. The participating enterprises of the missions had no experience with the process of internationalization.

This conclusion makes it clear that small and medium enterprises that would like to internationalize need more than the final result, import\export, they also have the necessity of filling out deficiencies of new knowledge, which opens a gap in the study focused on SME.

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Performance Measures at the Accident and Emergency Department in Denmark: The Issue of Unified Targets

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Abstract. The use of performance measures and how they effect in practice for accident and emergency department has been studied in a Danish hospital case. The main findings are that having unified performance targets has consequences for the actual flow of various incoming patients, organization structure, and workflow. Moreover, this study suggests that measuring process lead time and length of stay differentiated by sites and various patient flows will provide a clearer overview of the actual operational performance.

Keywords: Performance measures · Performance target · Emergency department · Case study · Danish health care system

1 Introduction and Background

Health care systems worldwide face the challenges in improving clinical quality, enhancing service levels, and expanding the access while at the same time being pressed to reduce costs [1]. In line with this, the Accident and Emergency departments (A&E) in Denmark have been merged into fewer larger units in order to formalize the organization structure and for patients with multiple diseases to be able to meet with the necessary health professional competencies and specialized equipment as early as possible [2]. Because of these public reforms, and that the A&E is the entering point of incoming patients when arriving to hospital for acute care, there is a growing attention from the public, politicians, regions and hospitals to measure and improve the A&E. More specifically, the National Board of Heath has set three performance measures and the Regions, responsible for hospital sector, have set respective targets. Two out of three performance measures are focusing on the waiting times in the initial phases of the diagnostic treatment while the last performance measure is related to the service of informing the patient about length of waiting time [3]. It is important to investigate the effect of setting the measures and targets towards the overall A&E goal of becoming more patient oriented and efficient.

When setting metrics, it should be linked to how the operation delivers value to its targeted customers [4]. Welch et al. (2011) [5] define such time intervals and show

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more ideal ones covering the main processes as well as subcycle processes and intervals respectively. Sørup et al. (2013) [2] conclude from their study that A&E time intervals such were the most recommended performance measures followed by patient centeredness and safety performance measures.

A stream in the literature addresses how the performance measures are used in A&E practice, what results they stimulate and under which conditions, and the challenges they entail [6–9]. Most of these studies are evaluating specific country-based A&E performance measures, taking a longitudinal perspective over several years, and considering several hospitals. For example, a number of papers focus on investigating the effects of setting a 4-hour target for length of stay in emergency departments by the English National Health service. Kelman and Friedman (2009) [6], focusing on the 4-hour rule, investigate two types of hypothesized dysfunctional consequences when setting targets (effort substitution and gaming). Their findings showed insufficient evidence of those dysfunctional effects. On the contrary, they identify dramatic wait-time performance improvements. Continuing the studies on the English NHS 4-hour rule, Mason et al. (2012) [7] focused on investigating the time distribution of patients within the target, and found out that establishing a target reduced the proportion of patients staying longer than 4 h, there were increasing number of patients departing within the last 20 min of the target interval, notably, the elderly. In addition, Weber et al. (2011) [8] identify organizational aspects (such as hospital-wide support and ownership) and the lack of that may have negative effects on staff, risks to patients, and may explain why targets fail to be achieved. Investigating in the Australian A&E target, inspired by the English 4-hour rule, Jones and Schimanski (2010) [10] find that the impact of the introduction of an A&E time target and the associated massive investments have not resulted in a consistent improvement across the hospitals.

To summarize, the existing literature on A&E performance measures is country specific and focusing more on the impacts of the targets on the overall A&E performance. Studies focusing on the Danish A&E performance measures are scarce. Jensen et al. (2007) [11] investigate the effect of optimized patient reception procedure for patients with broken hip. Therefore, there is a need to investigate the effects of the targets set by the Danish Regions for the operational performance of the A&Es. The purpose of this paper is to study the use of performance measures and address the challenges performance measures entail in practice based on a case study of a Danish A&E in Region North Jutland.

2 Research Design

This research is explorative and applying case study as the methodological approach.

In the Danish context, this case, A&E in Region North Jutland, represents an extreme case because it was one of the first in Denmark to start implementing the reforms and it featured one of the most advanced implementation and improvements [12]. Since, the context and the experiences in the case are critical, applying in-depth case study will enable us to study the issue in its edge, and allow us to gain rich and valid insights knowledge [13].

For this study, data regarding understanding the actual flow of patients was gathered through semi-structured interviews with nurses and doctors as well as observations of the various patient flows. The main analysis was based on documents and data sets derived from A&E hospital event-log system during the period of August 2014 to Marts 2015. Data has been gathered consisting of 17,470 unique entities (patients) from three datasets including patient arrival and departure timestamp, patient activity timestamps, and triage and specialty categorization data, respectively. The data has been cleaned in order to remove cases that were not recorded in all three datasets, cases treated at other departments than A&E, as well as cases with empty fields (we could differentiate between cases where we can see that a timestamp has not been recorded and cases with empty fields, probably as a result of system error. The second ones were removed from the data set). We ended with a data set of 16,229 unique entities. The data was analyzed inductively in order to investigate different issues related to timestamps affecting the performance measurement of the targets set. The analyses were focusing on the following issues:

- Quality of data registration – Analyzing the frequency of different timestamps registered such as "*arrival*", *"triage begins"*, *"triage ends" etc.* This analysis was also done by separating the accident and emergency patients in order to see the differences in these two sites.
- Order of timestamps – The intention of this investigation is to see if the timestamps registered are reflecting the actual or designed patient flow. The analysis included identifying the most frequent ordering of the timestamps registered.
- Fulfilment of performance measures – the dataset including "*arrival*",*"triage begins", "nurse begins", and "doctor begins"* has been composed in order to evaluate to what extent the performance targets are fulfilled. In the data set, 4,039 unique entities have the necessary timestamps mentioned above for this analysis. In addition, the performance fulfillment was identified at the accident and at the emergency unit respectively. A Mann-Whitney U test (non-parametric statistic test) was used to identify if there are significant differences in the performances at the two sites.
- Process lead time – a Mann-Whitney U test (non-parametric statistic test) has been used in order to compare the significant differences of process lead time of triage, nurse and doctor including length of stay for the accident and emergency units respectively. Significant results were considered those with a p value of less than .05 for all analyses.

For the analyses, a hybrid model has been used to identify and remove outliers. Data points are identified as outliers, if they are larger or smaller than $q3 \pm w(q3 - q1)$, where w= 1.5. Q1 and q3 are the 25th and 75th percentiles, respectively.

3 Case Description

The A&E North is a part of a Region North Jutland in Denmark, which has set the following three performance measures and their targets for all region's A&Es [14]:

1. The start of triage has to be within 15 min from the arrival. The target is reached in 95 % of the cases.
2. The diagnosing and treatment has to be initiated within an hour from arrival. The target is 85 % of the cases.
3. The patient has to be informed about the expected waiting time. The target is 90 % of the cases.

This second performance measure has been also defined as *"all the patients should be seen by an appropriate health professional within an hour"*, where doctors and nurses are defined as health professional [3]. In this case, the nurses are primarily the first contact that patients meet with health professionals. Thus, this study uses the timestamp *"arrival"* and *"nurse begins"* for the second performance measure.

In order to accommodate the variety of incoming patients the A&E North is divided into two sites each with own team of doctors and nurses but is managed by the same executive consultant (chief of doctor): accident site and emergency site. The emergency site is treating patients with medical related ill-condition and with high potential to be admitted. The accident site is treating patients with orthopedic injuries and with less complex symptoms of illness. The patient at the arrival will be met by the visitation nurse informing him/her about the expected waiting time. Based on given information, the visitation nurse refers to the site, which is most suitable for treating the patient based on the character of illness and symptoms. Following this, a triage nurse will examine the patient based on the triage procedure in order to categorize the patient into a triage code and a medical specialty. Patients with extremely critical health conditions are treated separately in trauma rooms by specialists from different specialties. After triage, the triage nurse, in most of the cases, also the responsible for the care of the patient during the stay at A&E. Bloodtests are conducted on all patients at emergency site. Patients, who need a radiology imaging such as X-ray to determine a diagnosis will need to be transferred to radiology imaging service units. When a doctor is available, he sees the patient. The A&E North has a bed ward facility of 32 beds for further observation of patients if needed. The total length of stay at the A&E is maximum 48 h, after which other departments in the hospital need to take the patient into care.

A&E North has an event-log system where different timestamps of activities are registered and it provides an overview of all current patients flow and status. In addition, it provides data for monitoring and analysis of the different performance measures. The staff has to register a timestamp from the work-station at the start and end of seeing a patient. *Figure* 1 presents the different timestamps and time intervals as they typically occur in A&E for each patient. The timestamps and time intervals above the timeline are for monitoring the three performance measures, whereas those beneath the timeline present the performance targets and other time intervals relevant for the analysis.

4 Analysis

4.1 Lack of Registration and Order of Timestamps

The analysis highlighted an inconsistency in timestamp registration in the event-log system. In general, timestamps of finishing an activity occur more frequently than

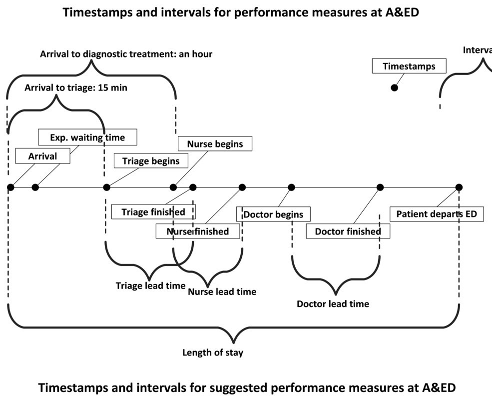

Fig. 1. Timeline of ED timestamps and time intervals for performance measures

timestamps connected to start of an activity. Absence of commencing timestamps for the triage activity are the most extreme case; the *"triage ends"* is the second most frequently used timestamp in the system with 88 % while the *"triage begins"* timestamp is registered in only 31 % of these cases.

The timestamps necessary for evaluating the second and third performance targets have been registered for 78 % and 88 % of all patients, respectively. In total timestamps for all three performance measures were available for only 25 % of all patients. Looking at the accident site and emergency site separately, the frequency of registering timestamps for monitoring the three performance measures is different. The emergency site has higher registration frequency for *"triage begins*", *"nurse begins",* and *"informing patients about expected waiting time"*, which are 41 %, 84 %, and 95 %, respectively. For accident site, the registration frequencies are 13 %, 66 %, and 75 %, respectively.

Investigating the order of the timestamps indicates that some timestamps are registered right after each other (within 1 min time period). The timestamps for *"informing about expected time"* and *"triage begins"* are in 84 % of the time registered within the same minute. The *"nurse begins"* is in 82 % of the cases registered at the same time as *"triage begins"*, whereas they finish in 67 % of the cases at the same time. Looking at the flow of accident site and emergency site separately, the tendencies of timestamp order are corresponding to the overall view of A&E.

4.2 Fulfillment of Performance Target

Looking at the timestamp data, A&E North fulfills two performance targets out of three. The second performance target - first contact with health professional staff to be within an hour from arrival, is achieved in 92 % of the cases. The third performance target - the patients should be informed of the expected waiting time, is achieved in 93 % of the cases. However, the first performance measure is not fulfilled as the target

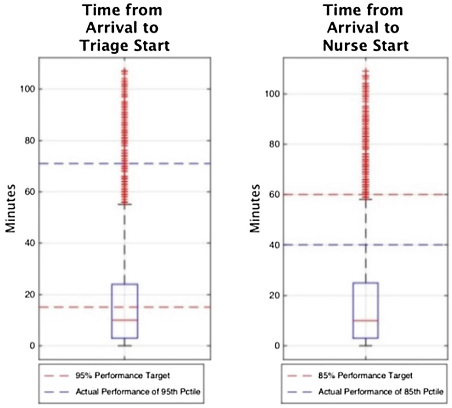

Fig. 2. Boxplots of the time interval from arrival to triage begins and to first contact with health professional begins, respectively.

of 95 % of the cases is within 56 min. Hence, 69 % of the cases are within 15 min. Figure 2 shows the boxplots for the first and second performance measures and targets.

4.3 Comparing Performance Measures at the Accident and the Emergency Sites

Looking at the time intervals reflecting the performance measures, Table 1, where it can be observed that based on Mann-Whitney test each of them is significantly different between the accident and emergency site. In addition, both times at the accident site are greater than the times at the emergency site. *AS* and *ES* are abbreviation for accident site and emergency site, respectively.

Table 1. Time intervals reflecting performance measures

		n	Mean ± SD	Median	IQR	Z	Sig
Arrival-triage begins	AS	324	25.7±21.2	19	8–40	−11.5	p<0.001
	ES	3496	13.7±16.6	7	3–18		
Arrival-nurse begins	AS	325	32.5±28.0	24	9.8–50	−11.8	p<0.001
	ES	3510	16.4±20.9	8	3–21		

Table 2 summarizes the results of the Mann-Whitney tests conducted to compare separately the process lead times of triage, nurse, and doctor, as well as length of stay between accident site and emergency sites. The triage and nurse process times are significantly longer at the accident site. On the contrary, the doctor time and the length of stay at A&E are significantly longer at the emergency site.

Table 2. Time intervals for triage, nurse and doctor processes, and time of stay

		n	Mean ± SD	Median	IQR	Z	Sig
Triage begins-triage ends	AS	662	51.0±45.7	38.5	13–81	−7.3	p<0.001
	ES	3871	33.4±30.6	24	14–42		
Nurse begins-nurse ends	AS	3681	74.4±62.7	56	26–1.8	−21.6	p<0.001
	ES	7834	51.6±53.0	31	17–65		
Doctor begins-doctor ends	AS	3866	52.0±59.1	29	14–69	44.7	p<0.001
	ES	7420	101.9±77.4	82	53–127		
Arrival-departs	AS	5841	124.7±80.5	109	63–166	37.0	p<0.001
	ES	5278	188.3±98.9	171	116–244		

5 Discussion and Conclusion

This section discusses the challenges that happen in practice when setting joint targets as well as performance measure that focus only on part of a patient flow. One of the challenges relates to inconsistent registration of the timestamps. This inconsistency is especially large at the triage process, and when looking at the accident site. It is important to investigate what are the causes of these differences in registration as well as their effect on the statistical significance of the conclusions.

The setup of performance measures and the targets does not take into account the actual process setup. In the case, the performance measures “arrival to triage begins” and “arrival to the first contact with health professional staff” indicate that there are two different processes to be measured. However, looking at the actual patient flow, the triage and the initial contact at A&E North are provided by the same nurse, which will be responsible for the care of this particular patient during the stay at A&E. Looking at the order of timestamps, it appears that in 84 % of the cases, the timestamps for triage begins and nurse begins are registered at the same point of time. This may indicate that the process of triage and start of treatment are overlapping. In the case that they do not overlap, and could be seen as separate processes, it may indicate that the nurse might not be the same providing the triage. From A&E perspective, these performance measures do not contribute to getting an insight of how well they perform as they measure the same activity. From a Region perspective, they do not provide a reliable overview of the actual performance. The “arrival to first contact with a health professional staff” measure has a longer target (1 h) but it actually measures same as the other performance measure which has a target of 15 min. It can be questioned whether the intention of the modified performance target is to show a better target result rather than providing relevant information about the performance minutes. Thus, there is a need for a clear guideline of the data collection methods and the purpose of each performance target.

The findings regarding the length of time intervals corresponding to the performance measures in Table 1 suggest that performance targets should be differentiated between accident site and emergency site. Looking at the lead times for triage and nurse processes in Table 2 we could see that the process times of these activities may affect the waiting times prior to those processes. For example, the process time of triage at accident site being longer than the process time of triage at emergency site (Table 2) may indicate why the patients at accident site wait longer for triage start than the patients at emergency site (Table 1). Thus, it is suggested to also measure process lead time of triage, nurse and doctor as well as the total length of stay. In addition, the targets of performance measure should be differentiated between the two sites. This will provide valuable insight from A&E perspective of the performance and create a foundation for examining possible trigger for any changes in performance systematically. Another challenge in the registration of timestamps is that some activities are not covered in the registrations such as bloodtests, radiology imaging diagnostic etc. These registrations of the treatment process are important in the patient flow, even though they are not provided by the A&E staff, as these affect the performance of the department.

Looking at a health care quality in total, performance measures of how fast A&E can provide a treatment is not enough. The quality of service and treatment need to be considered when evaluating the performance and improvement. Thus, it is necessary that the further studies focus on how to design a performance measurement system that balances different performance measures and create the right environment and behavior that will help the A&E to fulfill performance target. These studies need to take into consideration the context and the organization structure.

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Business Process Simulation for the Design of Sustainable Product Service Systems (PSS)

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Abstract. Nowadays, a lot of manufacturing companies are shifting their value proposition from a product-centric perspective to sustainable Product-Service-Systems (PSS). This transition allows companies to improve the customization of their offer and to contribute to the reduction of material flow and consumption; nonetheless, it poses some new challenges in terms of mindset and organization. In particular, the analysis of the literature about PSS shows that there is still a gap concerning the evaluation and the monitoring of new or reengineered PSS provision processes using business process simulation. Few examples of simulation in PSS field can be found, and multidimensional models considering customer perspective and environmental sustainability beyond the economic driver are not yet available. Thus, the purpose of this paper is to compare different simulation paradigms and to define the most suitable to support the engineering phase of a sustainable, customer-oriented PSS. Two possible alternatives were identified and discussed through a test-case.

Keywords: PSS · Customer · Sustainability · Simulation · Hybrid modelling

1 Introduction

Facing the difficult economic juncture, an increasing number of companies has been enlarging its value proposition starting to provide services in addition to their products, moving from a product-centric perspective towards the provision of sustainable Product-Service Systems (PSSs). This is contributing, from one side, to increase their revenues and customer satisfaction and, from the other side, to a dematerialization of their offering [1]. In particular, different are the advantages and the benefits achieved with the introduction of a PSS: (i) differentiation from competitors, (ii) customers lock-in and (iii) competitors lock-out thank to the provision and selling of a unique solution [2]. Nevertheless, the shift to the PSS paradigm also poses some critical challenges to companies, as they are required to review the entire organization [2]. Furthermore, failing to manage this mindset shift can lead to limited payoffs and

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unsuitable revenues, thus originating the so-called "service paradox" [3]. This is the reason why Service Engineering (SE) [4], a relatively new research field, has been developed to adapt existing engineering know-how to services. It is not a completely mature discipline, and a common standard to deal with PSS and services is still missing [5]. Within this context, many authors [6–8] defined possible design methodologies for PSS but none of the existing provide suggestions to (i) manage the dynamics involved in a PSS (e.g. customer interaction or participation in the provision process; moving human resources and high variability in customer behaviour), (ii) monitor and implement a PSS, and iii) manage the customer and company co-creation process. Therefore, considering these issues, the main goal of the paper is to answer to the following research questions (RQ):

1. What are the main KPIs of a PSS delivery process that should be evaluated to guarantee high customer value and to make it sustainable in the long term?
2. How do simulation paradigms (DES - Discrete Event Simulation, SD System Dynamics, ABM - Agent-Based Modelling, and Hybrid Modelling) allow gathering and managing the dynamics involved in a PSS?
3. How is it possible to integrate the environmental sustainability and customer satisfaction performances into a PSS simulated process?

On this basis, this study is based on the following four steps:

1. Identification of the main KPIs that should be monitored in a PSS delivery process;
2. Literature analysis of the state of the art in simulation modelling for sustainable PSS;
3. Identification of the existing simulation paradigms allowing sustainable PSS delivery process measurement;
4. Adoption and comparison of the simulation paradigms identified in a test-case.

The remaining part of the paper is structured as follows: Sect. 2 describes the main KPIs to be considered in a PSS. Section 3 presents a brief literature review about simulation and environmental sustainability in PSS, whereas Sect. 4 provides an overview of the test case together with considerations about the two different approaches. Section 5 presents the conclusions and possible further development directions.

2 Identification of the Main KPIs to Be Monitored in a PSS

Literature analysis provides a useful overview to define the main performance that should be evaluated in a PSS delivery process. In particular, the co-creation process between the customer and the company is a leading concept to understand how the value is created in a PSS. Adopting the *Service-Dominant logic*, the roles of producers and consumers are not distinct, meaning that value is always co-created, jointly and reciprocally, in interactions among providers and beneficiaries through the integration of resources and application of competences [9]. From this point of view, both the customer (in terms of satisfaction) and the company (in terms of profitability and efficiency) perspectives might be taken into account. Moreover, one of the main elements emerged from the literature review is that, among the main advantages of a PSS, sustainability is becoming more and more relevant [10]. For this reason, it has been taken into account as well in our study.

To summarize and answer the RQ1, we consequently defined three main dimensions for the evaluation of a PSS delivery process: (i) process efficiency, (ii) customers' satisfaction, and (iii) environmental sustainability.

To measure and monitor these dimensions, we tried to adapt and translate existing product-based knowledge into the service field. Among the existing tools largely used in traditional manufacturing industry to tackle the dynamics and to monitor the process, simulation is the most well-known, but its application to the PSS field is still largely unexplored [11]. In particular since "the interaction of people with processes and technology results in an infinite number of possible scenarios and outcomes that are not possible to predict and evaluate using widely popular static process modelling methods" [12], simulation has been selected. In this paper we will define simulation as "the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system" [13].

3 State of the Art About Simulation Modelling for Sustainable PSS Delivery Process

Concerning the adoption of simulation in the SE context, we have been looking for examples of simulation frameworks including both customers' involvement in the PSS delivery process and the environmental advantages carried out by the introduction of a PSS offering. No framework seems to provide a broad perspective considering these two dimensions as part of everyday business, but some studies actually deal with one or the other.

There are three main simulation paradigms widely used to model manufacturing systems: Discrete Event Simulation (DES), System Dynamics (SD) and Agent-Based Modelling (ABM). SD can easily represent flows and cause-effect relations in a system at a strategic level, starting from the consideration that the behavior of a system is strongly dependent on its structure. DES is process-centric and focuses more on the tactical/operational dimension level; it is, based on entity flows, resource sharing and sequences of activities. On the other hand, ABM is more effective in the modelling of individuals' behavior, through a bottom-up approach in which agents have their own rules and become active elements of the model [14]. All of them cannot be immediately adopted into the PSS field and literature highlights that the underpinning reasons must be sought in some key features of a PSS that are difficult to simulate, such as the presence of human beings whose behavior cannot be easily translated into an equation [15], the difficulty to define specific set of resources to allocate to service activities [16] and the still undefined concept of PSS productivity [17]. Nevertheless, there are few examples of the adoption of simulation modelling paradigms for both the assessment of (i) PSS sustainability and (ii) PSS customer and company's performance.

Regarding the evaluation of sustainability, there are two noteworthy examples. Lee et al. [18] show the application of SD to a PSS whereas [19] try to put together economic, social and environmental sustainability through a decision support system based on ABM.

Considering the company and the customer performance perspectives, there are only few studies. One of them is focused on the possible application of life cycle simulation to PSS [20] and another is an application of SD to the analysis of the impact of PSS in a manufacturing company [21]. Moreover, we found a single application of DES in services, specifically focused on efficiency in social services [22]. Only one approach has been specifically developed to analyze the performance of a PSS [23]. In addition, some interesting applications of ABM to PSS development focusing on customer's satisfaction have been found [14, 24].

Next to the three "pure" simulation paradigms presented, hybrid modelling grew out of the need to combine the advantages of two or more of these approaches, integrating in one model specific features from the different techniques. This allows attaining a higher flexibility and working at different levels of abstraction, exploiting at the same time the strengths of each method [25]. For these reasons, the opportunity to use a hybrid model has been considered as a possible way to better deal with the complexity and the dynamics of a PSS.

As a first conclusion, we can state that some attempts to evaluate sustainability or customer satisfaction in a PSS through a simulation approach already exist, meaning that simulation can help to gather the dynamics of a PSS. This provides an answer to RQ2, but still leaves a gap in the performance analysis because none of them considers all the three KPIs identified from a multidimensional perspective. On this base, to answer RQ3 we choose to analyze the system through two modelling solutions: a DES model, focusing more on the delivery process and activities of which the PSS is made up and a hybrid model, taking advantage of the specific features of both DES-ABM, in which customers are modelled through the ABM approach. This gives more centrality to their interaction with the PSS provider.

4 Test Case

In order to better evaluate the potentiality of the identified approaches, we applied DES and ABM to a real case from the automotive sector where the service market can be four or five times larger than the market for products, and where nowadays there is a strong commitment to environmental sustainability. We decided to use a truck standard maintenance process as a test case, due to the extensive experience of some of the authors in that area. The process works as follows: first, the customer arrives at the workshop with his truck and is received by a receptionist. Then, the workshop foreman performs an initial diagnosis, provides a general quotation for the estimated services, and schedules the intervention. At its turn, the truck is exposed to three different maintenance activities and, if no additional problems arise, it is checked out and brought back to customer. If, instead, unplanned problems arise, or the final check does not show a proper condition, another maintenance activity is carried out. As in reality, there are two types of customers: (i) customer with a single truck and (ii) customers with a truck fleet. Of course, at the scheduling, the customer with a fleet available would bear better a long waiting time than the customer with only one truck that may eventually decide to leave the system before being serviced. For the sake of simplicity, at this point of the analysis the truck utilization of both the two customers would not be considered. As hinted before, the automotive sector is characterized by high pressure from the environmental point of view. In relation to a maintenance process, there are different elements that can be taken into account; however, for the case presented in this study, only the use of refurbished spare parts has been considered: that is, the customer has the possibility to choose between new or refurbished spare parts both for the scheduled maintenance and for the unplanned problems solving phase.

All the data related to the number of maintenance requests, the activities duration, the customer willingness to wait, the number of utilized spare parts and the resources employed have been taken from the company database and direct observations. Data related to sustainability have been inferred from literature (e.g., the percentage related to the adoption of refurbished spare parts [26]).

For what concerns the measurement of the main KPIs, we decided to use *resources utilization coefficients* (workers and work spaces) to give a proxy for the economic efficiency, while the *total waiting time*, the *total service time* and the *percentage of customers leaving the system before being served* (they do not want to wait too much time in queue) help to understand what is the service level perceived by the customer. Finally, the environmental gain due to the customer's choice of buying refurbished spare parts is modelled through the indicator of *CO2 avoided emissions*. In this case, a general reference value has been gathered from a study about remanufactured diesel engines [27], not considering the variety of spare parts that can be substituted in a truck maintenance process. This approximation can be justified observing that the focus of the analysis is not the real case, but the application of the simulation to evaluate KPIs in a PSS.

Two models have been built: a DES model built using Arena Rockwell simulation and a hybrid DES-ABM model built using Anylogic. Input data, not reported in this paper, were the same in both the two models. In Table 1, the results (mean values) of the simulation considering the three main dimensions identified are reported considering both DES and hybrid models. The total simulation time is equal to six months; the service company is open five days a week, eight hours per day. The results obtained are aligned with the as-is real data.

The test case performed represents just an initial step in defining an integrated PSS simulation approach. In this sense, the work performed helped to shed light on the possible use of business process simulation in assessing PSS performance, confirming that this tool can reveal useful to manage PSS dynamism. In this sense, both the two approaches suggested (DES and Hybrid model) provide an answer to RQ2 having an acceptable fit with reality. Moreover, both are capable to measure the three main areas of performance indicated. This last point, that answers RQ3, is demonstrated by the data shown in Table 1 with the results related to company, customers and sustainability dimensions. Results from the two approaches are almost similar, but there is a discrepancy in the percentage of customer leaving the system. This is caused by one of the main problems emerged in DES with Arena software that has some limitations in defining the schedule arrival of trucks. The initial distribution reveals less random than

Table 1. Results of simulations

Criteria	Parameter	DES	Hybrid model
	N° customers entering the system	597	611
	N° customers served	513	568
Economic efficiency	Mechanics utilization	44 %	44 %
	Workshop foreman utilization	33 %	35 %
	Receptionist utilization	39 %	40 %
	Work space utilization	95 %	89 %
Customer satisfaction	Service time	1,8(days)	1,4(days)
	Total waiting time per customer	1,5(days)	1,2(days)
	% of customers leaving the system	15.0 %	6.5 %
Environmental sustainability	Avoided CO_2 emissions	7.7 %	7.2 %

expected; for this reason, the number of truck waiting is higher and consequently a higher percentage of customer leaves the system. This reason also explains the difference in the service time (from 1.8 to 1.4 days).

The less random distribution indeed causes higher queues in the initial part of the process where the customer cannot decide to leave the queue. Finally, the negligible difference in the number of entities entering the system can be influenced as well by this problem. Apart from this clear difference in the two approaches, the work performed for this study also highlights some advantages of hybrid technique with respect to DES. In particular, the use of ABM to model customers' behavior and preferences creates a considerable advantage in terms of model definition and use. This method allows for the definition of copious rules that agents have to follow and in this way facilitates the creation of the DES part that describes the process. The pure DES approach indeed can describe the customer rule for the simple test case, but it required additional technical expedients and work. Due to space constraint, data and other simulations results have been omitted. However, they are available - with the exception of those subject to non-disclosure agreement - upon request to the corresponding author.

Further analysis can encompass the adoption of the two approaches to describe a more complex PSS process. Through this, the advantages of the hybrid simulation paradigm would become clearer. The use of the approaches in more complex scenarios can be also a good starting point for the analysis of additional drivers to measure the three main KPIs identified (e.g. costs as a driver for efficiency, a qualitative evaluation of customer service, material consumption, energy utilization and waste reduction to evaluate environmental sustainability).

5 Conclusions and Further Developments

The study presented in this paper illustrates a possible integrated simulation approach to evaluate a PSS from multiple perspectives. First, a literature analysis has been performed to define a set of integrated and effective metrics for PSSs. In this still open research area, we decide to consider three main performance dimensions: (i) customer satisfaction, (ii) economic efficiency and (iii) environmental sustainability (RQ1).

In the second stage, a literature analysis on simulation paradigms has been carried out showing that DES, ABM and SD have been rarely applied to design services and PSSs. The hybrid simulation paradigm is also still unexplored in PSS environment.

Two possible simulation approaches have been defined to test the different simulation approaches: the first one is based on DES paradigm, and the latter uses a hybrid model, which integrates advantages of DES and ABM paradigms. The two have been applied in a test case and evaluated through their ability to describe the customer and companies' complexity. The results show that both the models allowed the measurement of the performance of the three metrics defined (RQ2), but the hybrid model revealed more useful in defining PSS and customer interaction monitoring the three strategic perspectives (RQ3).

Further developments can regard the analysis of more complex test cases with the introduction of other variables and constraints, in order to investigate the potentialities of hybrid modelling for PSS more in depth.

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