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Advances in Production Management Systems

The Path to Intelligent, Collaborative and Sustainable Manufacturing

IFIP WG 5.7 International Conference, APMS 2017
Hamburg, Germany, September 3–7, 2017
Proceedings, Part II

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Preface

We live in exciting times. The technological revolution in information and communication technology has been going on for several decades already and there seemingly is no near end in sight. The possibilities for industrial companies are enormous, but so are the challenges.

The globalized economy has done its fair share in reducing extreme poverty levels. The United Nations report that the target of reducing extreme poverty by half was met five years ahead of the 2015 deadline: more than 1 billion people have been lifted out of extreme poverty since 1990.

The environmental burden humankind puts onto our planet is becoming bigger and bigger, threatening eco-systems and our own well-being in the future. Industrial companies are affecting, and affected by, all three environments. In fact they contribute significantly both to poverty relief by employing hundreds of millions of people but also to the ecological challenges we are confronted with by exploiting natural reserves and by their emissions to the environment.

Thus, the question of how to find the path to intelligent, collaborative and sustainable manufacturing is of eminent importance.

We invited experts, academics, researchers, and industrial practitioners from around the world to the Advances in Production Management Systems Conference 2017 in Hamburg, Germany, to contribute with ideas, concepts and theories. A large international panel of experts reviewed all the papers and selected the best to be presented and to be included in these conference proceedings.

In this collection of papers, the authors share their perspectives as well as their concepts and solutions for the challenges industrial companies are confronted with and the great opportunities new technologies, collaboration and the developments described above offer.

The chapters are organized in two parts

– Smart Manufacturing (Volume 1)
– Collaborative and Sustainable Manufacturing (Volume 2)

We hope that our readers will discover valuable new ideas and insights.

The conference was supported by the International Federation of Information Processing and was organized by the IFIP Working Group 5.7 on Advances in Production Management Systems.

We would like to thank all contributors for their research and for their willingness to share ideas and results. We are also indebted to the members of the IFIP Working Group 5.7 for their support in the review of the papers.

September 2017

Hermann Lödding
Ralph Riedel
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A System Maturity Model for Supply Chain Management

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Abstract. A supply chain system is a chain of processes from the initial raw materials to the ultimate consumption of the finished product linking across supplier-user companies. Huge investment is needed to build supply chain business systems. The goals and objectives must be revised repeatedly in accordance with its growth. A methodology is needed to support system management through its system life cycle. This paper proposes a novel system maturity model for supply chain management, SCMM (Supply Chain Maturity Model).

Keywords: Supply chain management · Capability Maturity Model
System maturity model · Information system management

1 Introduction

A supply chain system is a chain of processes from initial raw materials to ultimate consumption of the finished product linking across supplier-user companies. It provides functions within and outside a company that enable the value chain to make products and provide services to the customers.

System development needs its goals and strategies to be clarified. In addition, these goals and objectives must be revised repeatedly in accordance with its growth. Continuous improvement is, needless to say, very important in every system management. However, a repetition of improvement alone often produces fruitless investment in system management. The concept of a qualitative, stratified framework is needed to manage system growths for supply chain system.

Enterprise evolves organization capability by using re-structuring and re-engineering. This principal is applied universally to every enterprise organization. Supply chain system is also the same as this. To correspond this primary rule, we need own process models considering organization maturity.

SCOR (Supply Chain Operations Reference) model is a process reference model that has been developed and endorsed by the SCC (Supply Chain Council) as the cross-industry standard diagnostic tool for supply chain management [1, 2]. SCOR enables users to address, improve, and communicate supply chain management practices within and between all interested parties. However the SCOR model only

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addresses the "optimized" process operations. It does not include a concept of "Maturity" of system that is essential to phase-based system development. SCOR model is, in a sense, description of the best status of processes in supply chains.

CMM (Capability Maturity Model) was created for the software industry as a model for judging the maturity of an organization's software processes and identifying the key practices that are required to increase the maturity of those processes. The CMM has become a de facto standard for assessing and improving software processes [3].

This paper proposes a novel model for supply chain system maturity: SCMM (Supply Chain Maturity Model). Several measurements will be discussed for system's maturity of supply chain systems. This model is an evolution model for supply chain system integration. Individual maturity level associates with supply chain management problems. First, this paper proposes the supply chain maturity model. Second, it clarifies that each maturity level responses to supply chain management problems. Finally, conclusions and perspectives of future researches are described.

2 Supply Chain Maturity Model: SCMM

This section proposes a maturity model for supply chain system. CMM (Capability Maturity Model) is, as previously described, a model for judging the maturity of an organization's software processes. It also identifies the key practices in those processes [1]. This paper has applied the system maturity levels to a generic supply chain system. The maturity levels are defined as five levels, such as "Initial", "Repeatable", "Defined", "Managed", and "Optimized". Furthermore, supply chain management problems have been contrasted with individual system maturity levels.

2.1 Management View

(1) Process view

SCOR model defines provides key process according as its process classification; such as PLAN, SOURCE. MAKE. DELIVER and RETURN. The details of these processes are, for examples, described in the SCOR process model.

(2) Resource view

Supply chain resources are classified as the following four categories; such as "physical", "human", "information", and "finance".

Physical resources are poured in the organization, where they occupy each specific position and space. Examples of physical resources are land, factory, office, equipment, machines, vessels, raw materials, products, semi-finished products, by-products, supply of goods, and rubbish, etc. All of these resources assert their original primacy, and it demonstrates its potential power according to the verbal and written instructions, human strength in the organization, and contributions to the organization's goal.

Human resource represents enterprise organizations and its members. Every person belongs to a particular sub-organization, and owns competence according as his/her missions. A person is basically an active resource that works based on his/her mission. However, his/her activity has often been controlled by another one. In this case, he/she or a particular group works virtually as a passive resource. Performance of this resource depends on his/her authority, knowledge, skills, and availability of other resources; however, knowledge and skills are too hard to be measured. Accordingly, it is too difficult to measure this resource quantitatively without using simplified measure such as human-months.

Information resource includes raw data (first-hand information), meta-data, data models, ontology, and hardware systems, including both fore- and back-end systems. Many of modern enterprises own data as digitalized forms, so these data form can be automatically transformed to another one. Almost information resource is passive resource except highly intelligential software. This resource is transferable to attributes of other type resource. Information resource is generally classified into three groups, such as "Infrastructure", "System enabler", and "Application".

Financial resources include assets, cash, deposits, operating funds, and investment capital, and etc.

(3) Maturity view

Every organization evolves gradually by its growths and process improvements. Capability Maturity Model (CMM) is such a model as describing such organization growth processes (maturity). The objective of this model is to define details of business processes at each maturity stage. This model provides, however, maturity in software development organizations. Accordingly, it cannot be directly applied to supply chain organizations. However, the modeling framework would be applicable to describe maturity growth of supply chain systems.

2.2 Maturity Model

The maturity model represents organization maturity levels, which are composed of the following five stages (Fig. 1).

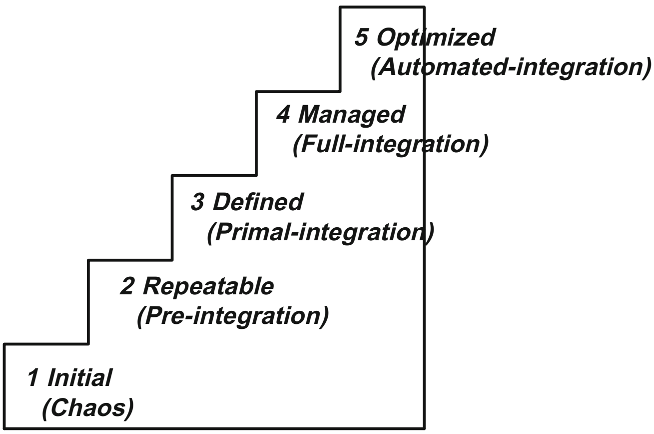

Fig. 1. Supply Chain Maturity Model

(1) Initial (Chaos): This is a pre-stage of process integrations of a firm. Almost all of business activities are operated in process-driven. Individual processes are “point solutions”. In this stage, business processes are reaction-based, and often depend on specific persons. Ad hoc decisions are often done based on the past successful experiments. Accordingly, the process quality is unstable. Resources are categorized such as “physical”, “human”, and “information”, however, the management is ad hoc and not systematic. Information systems mainly provide stand-alone applications. The data are transferred among processes and organizations, however it data exchange methods are often ad hoc. The most important item at this stage is “Vision building” for process, resource, and information management.
(2) Repeatable (Pre-integration): Business processes are stable but very limited visibility across the wider supply chain. The process definitions are primary documented, trained, and measured. The processes are partially supported by information system. Resources are mainly managed by category-dependent-way. Information system provides a set of stand-alone applications, and application-based data transformation. The common data transfer methods are provided in neither company-wide nor the chain-process-wide. Information system provides a set of stand-alone applications and Business process management and resource management are partially linked with the information systems. However, information system does not provide company-wide data connections. Companies should make detail investment plans to perform the robust information system infrastructure.
(3) Defined (Primal-integration): All of business process are fully documented, trained, and measured. And, individual process is fully supported by information systems. Resource data schemata are defined in enterprise’s data repository. Information systems provide well-defined and standardized data transformation among chain member companies. The plans for Information systems are linked with business process improvement activity plans. Investment to the information systems are proceeded toward full standardization of process input/output and information system enablers. The process definitions in SCOR model are corresponded to this maturity level.
(4) Managed (Full-integration): Business Process Management (BPM) is at full throttle, and it would proceed to quantitative process quality management and real-time monitoring and performance measurement. Every resource is managed by using resource ontology in process chains, and integrated information system would be synchronized with business process and resource management. It also provide services for consumers and customers.
(5) Optimized (Automated-integration): Level 5 is as much conceptual as it is factual. Business processes are fully formalized and authorized toward continuous improvement. Resources are managed including autonomous life-cycle management, and the information system provides full support of business process and resource management.

Investment policies would discussed toward the continuous improvement in process chains (Fig. 2).

Supply Chain Maturity		Supply Chain Growth			Decision on IS investment
		Business Process Mgmt	Resource Mgmt	Information System	
I	Initial	Ad-hoc decisions	Non systematic	Stand-alone applications	Vision building
II	Repeatable	Dependent on past success	Category-dependent	Primitive standards	Company-wide Infrastructure
III	Defined	Full documentation	Synchronized with IS	Well-defined standards	Standardization on BPM and IS
IV	Managed	Collaboration with partners	Resource Ontology	Synchronized with BPM	Virtual Enterprise
V	Optimized	Continuous improvement	Life-cycle Mgmt	Full-support to BPM & RM	Continuous improvement

Fig. 2. Supply Chain Maturity Model

3 Supply Chain Maturity Model with Business Management Problems

(1) Capacity planning problems: Capacity planning is to determine the amount of capacity required to produce in the future. This function includes establishing, measuring, and adjusting limits or levels of capacity. In general, this planning includes the process of determining in detail the amount of labor and machine resources required to accomplish the tasks of production. This group includes RSCP (Rough-cut Supply chain Capacity Planning) and SCRP (Supply chain Capacity Requirement Planning).

(2) Resource planning problems: Resource planning is capacity planning conducted at the business plan level. It is the process of establishing, measuring, and adjusting limits or levels of long-range capacity. Resource planning is normally based on long term production plans but may be driven by higher-level plans beyond the time horizon for the production plan, e.g., the business plan. It addresses those resources that take long periods of time to acquire. Resource planning decisions always require top management approval.

(3) Lead-time planning problems: Semantics of the term “Lead-time” is basically “the time between recognition of the need for an order and the receipt of goods”. The definition is often used in a logistics context. Individual components of lead-time can include order preparation time, queuing time, processing time, move or transportation time, and receiving and inspection time. This problem directly impacts the inventory planning problems through the Lead-time inventory, the inventory that is carried to cover demand during the lead-time.

(4) Production planning problems: There are two phases of production planning; the first phase is an aggregate production planning and the second phase is an operational production planning. An “Aggregate production plan” implies budgeted levels of finished products, inventory, production backlogs, and plans and changes in the work force to support the production strategy. Aggregate planning usually includes total sales, total production, targeted inventory, and targeted customer backlog on families of products. Operational production plan is a more detailed set of planned production targets that meet the goal of the higher level manufacturing output plan. It is based on an agreed-upon plan that comes from the aggregate (production) planning function. It is usually stated as a monthly rate for each product family (group of products, items, options, features, etc.).

(5) Supplier selection problems: One of the major issues, when a system planner designs a supply chain or a manager reviews performance of the existing supply chain is supplier selection problem. It is a significant decision as it affects the system performance for a long time. From supply chain performance viewpoint it affects all the primary problems discussed above.

(6) Outsource planning problems: Outsource planning is one of the very important problems for modern manufacturing enterprises. This is because maintaining expertise in all the technologies and processes required for manufacturing a product is almost impossible in single company. In addition to that, a proper outsourcing of process lets a company concentrate its resources on particular core processes, allowing the company to maintain its competitive position. Again, the outsourcing decisions impact all the primary problems discussed above and thus impact the supply chain performance.

(7) Operational strategy selection problems: This problem includes selecting the strategy to operate the supply chain. Suppose that the supply chain designer has solved the primary problems, has selected the best business partners as his/her suppliers and has decided the non-core processes to be outsourced, he/she still needs to decide how to control the flow of products through the supply chain. The problem examples are as follows:

- How to choose between PUSH, PULL, and Hybrid PUSH-PULL?
- How to choose the strategy such as STS, MTS, ATO, MTO, at each stage of the supply chain?

The problems in the above description are typical issues in supply chain management. Each problem would be discussed according as its maturity level. (1) (2) (3) would be discussed at comparatively low maturity levels (Level I Initial, Level II Repeatable), (4) (5) would be argued at middle maturity levels (Level III Defined), and (6) (7) would be considered at high maturity levels (Level IV Managed, Level V Optimized).

4 Supply Chain Management Problems and Investment Problems on Information Technologies

Information Technology (IT) is one of the most imperative concerns in today's enterprise business environment. This is because information systems are one of vital pivots in modern enterprise management. Building an effective investment policy in enterprise information systems is a critical matter.

Many discussions have been done on this matter since 1980's. Investment problems on Information systems are often discussed in the views of enterprise strategy building. (i.e. [5, 6]). Furthermore, these discussions include cost-effectiveness problems [7, 8], resource-based approaches [9, 10], company's competitiveness [11], and etc.

Enterprise information system is one of company resources and besides; it is also a management enabler for other resources. Further, the information systems' evolution is tightly coupled with a growth of the company. Making investment policies in enterprise information system should consider that capabilities of company organizations depend on its resources and its growth.

Figure 3 represents a rough sketch of SCMM. The lengthwise represents supply chain system maturity, meanwhile, the crosswise represents the extent of process integration. The boxes in the figure show system maturity levels, which are "Initial", "Repeatable", "Defined", "Managed", and "Optimized", respectively. For an example, "Level III Defined" is a stage that partner collaboration is possible, and systems are integrated in partially intra-enterprise and partially inter-enterprises.

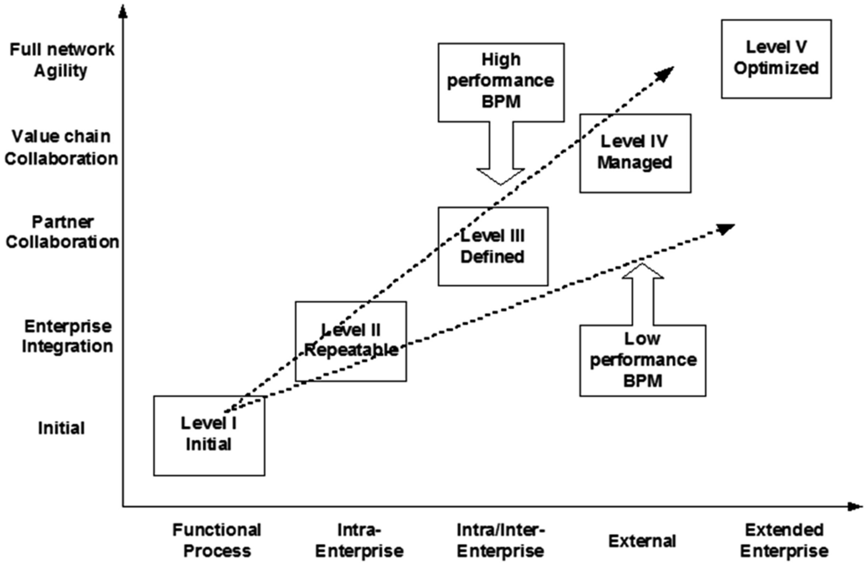

Fig. 3. Supply Chain Maturity Model with process integration

The dotted slope line represents trends of system evolution magnitude. System would mature rapidly if the Business Process Management (BPM) shows high performance; on the contrary, it would do in slow pace if BPM performance would be low.

5 Conclusion and Future Research

Managing supply chain is an execution of process life cycles such as system vision building, design, implementation, practice, and maintenance. A robust methodology for information system life-cycle management is needed [11]. This is a typical PDCA (Plan, Do, Check, and Action) cycle discussed in Total Quality management (TQM).

This paper proposed a novel maturity model for supply chain system (SCMM). The model proposed here, still stays at a primitive stage; however, it would be the first step to clarify supply chain system management considering systems' maturity. Our next step of this work will be detail specifications of the proposed model, and methodologies to use the SCMM for life-cycle management for supply chain systems.

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The Link Between Supply Chain Design Decision-Making and Supply Chain Complexity

An Embedded Case Study

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Abstract. This paper presents a conceptual model of the supply chain characteristics leading to supply chain complexity. This is combined with the change complexity of supply chain improvements, to reflect the complexity found in supply chain design decision-making when improving global supply chains. These two dimensions are used empirically, in the investigation of eight embedded cases of supply chain re-design, in a global OEM. Three contributions are made, improving the understanding of the link between supply chain design decision-making and supply chain complexity. First, the impact of different types of supply chain complexity on decision-making. Detail complexity leads to a higher need for resources for data collection and analysis, while dynamic complexity leads to challenges in predicting future performance. Second, the degree of change complexity is determining the potential supply chain complexity reduction. Third, a systematic bias resulting from low transparency on the marginal impact of increasing or decreasing supply chain complexity is proposed to lead to increasing supply chain complexity.

Keywords: Global supply chains · Supply chain design · Supply chain complexity

1 Introduction

Supply chain design decisions are characterised by complexity [1, 2], which is further complicated by the environment becoming increasingly turbulent [3]. For these reasons, the post assessment of supply chain design changes often reveals “hidden cost” and unexpected complexities, challenging the foundation of realized supply chain design changes [4]. In addition, high supply chain complexity is associated with negative performance impact [1]. Implying that companies must either continuously work towards reducing supply chain complexity, or equip themselves to cope within this new context. A step towards being able to do any of these two is to understand how supply chain design decisions are linked to supply chain complexity and vice versa. The objective of this paper is to conceptually model complexity related to supply chain design, and based on this conceptual model, empirically investigate the link with decision making.

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The paper is structured as follows. First, the parameters related to the complexity of the supply chain and supply chain design changes are proposed. Second, the two complexity dimensions are applied for eight embedded cases to explore the interplay between decision-making and complexity.

2 Conceptual Framework for Assessing Decision Complexity

2.1 Supply Chain Complexity

The parameters leading to supply chain complexity can be classified into detail and dynamic complexity. Detailed complexity is related to the number of variables which needs to be managed, while dynamic complexity is related to the dynamism, interdependence and causal ambiguity of the variables [5, 6]. In a supply chain context, these parameters have been decomposed into three areas, upstream complexity, internal manufacturing network complexity, and downstream complexity, mirroring a supply chain.

For the upstream supply chain, seven parameters driving complexity is suggested. First is the *number of suppliers*, which needs to be managed. This leads to detail complexity as the number suppliers is linked with the needed resources for managing these [6]. The *delivery lead time* and *delivery reliability* (timing and quantity) are the second and third parameter, respectively. A long delivery lead time requires the supply chain to plan details on a longer horizon, increasing the detail complexity. In addition, the reliability of these deliveries is a driver for dynamic complexity, as uncertainties need to be managed [6]. The fourth parameter is the *raw material price uncertainty*, fluctuating prices creates dynamic complexity which need to be managed to avoid loss of competitiveness from price arbitrage [7]. The fifth parameter is *upstream capacity constraints*, as the focal company has to manage its bottlenecks throughout the supply chain to avoid shortages or high inventory levels. Therefore, the number of bottlenecks is a driver for detail complexity [8]. The sixth parameter is the *governance mode of the supply chain.* Five governance modes; market, modular, relational, captive and lead firm are used [9]. These five represent a gradual increase in supply chain complexity, related to detail complexity. With the argument that a fully integrated supply chain will have more details to manage than one which is primarily driven by arm's length relationships (market). The seventh and last parameter is the *extent of global sourcing*, which leads to detail and dynamic complexity as volatility of exchange rates, tariffs, transport costs all impact the competitiveness of the supply chain [3].

Building on extant literature six parameters are expected to have an impact on internal manufacturing network complexity. The first parameter is the *depth and width of the bill-of-material (BOM)*, which lead to detail complexity, as more items need to be managed [6]. The second parameter is the *type of manufacturing process*; here a continuum from one-off customized products to a repetitive flow of similar products can be identified [7]. The further towards the one-off customized products, the higher the complexity, as multiple new items needs to be managed, leading to high detail complexity [6]. The third parameter is *internal capacity constraints*; here, the number of bottlenecks found in the manufacturing networks adds to the detailed complexity, as bottlenecks needs to be managed for planning purposes [7]. The fourth parameter is related to the *stability of the production schedule*, which if low causes dynamic complexity [7], as it creates a production environment which has to account for the unreliability of the production plan. The fifth parameter is related to the network aspect, namely the *extent of global production*. For global operations, supply chain complexity will be high, due to detail complexity from the numerous production locations and dynamic complexity from product allocation decisions, local labor agreements, tariffs, and trade agreements, which change over time [3] as well as interdependencies in planning, physical goods and information flows. The sixth and last parameter is *the maturity of the product design and processes*. If the product design is mature, fewer changes will occur, hence reducing the dynamic complexity. If the processes are mature, the uncertainty associated with the execution and planning of process activities is reduced, limiting dynamic complexity.

The downstream supply chain is divided into five parameters leading to complexity. The first being *demand variability* [6], here a high demand variability leads to high dynamic complexity, as it becomes complex to orchestrate the internal manufacturing network and upstream supply chain [8]. The second parameter is the *number of sales customers*, which is a driver for detail complexity, as the number drives the need for management efforts [6]. The third parameter is the *heterogeneity of the customer needs*, which lead to both detail and dynamic complexity as low heterogeneity both means more unique requirements to manage, as well as variability in the required deliveries [6]. The fourth parameter is the *length of the product life cycle*, a long product life cycle results in low complexity, while a short life cycle results in high complexity through a frequent change of products, as well as additional details needs to be managed as new and old products co-exists [6]. The *extent of global sale* is the fifth and last parameter. Similarly to the extent of global production, this leads to detail and dynamic complexity, as tariffs, exchange rates, transport costs all have an influence on the network [3].

In addition to these, the *level of interdependence* is a key driver of complexity across the entire supply network. If a supply network is primarily defined by pooled interdependence, a shift in supplier is likely to be simple. While if the interdependence is sequential or even reciprocal, the decision in the supply network is interconnected, and a change in one area might infer changes in multiple interconnected areas [10].

2.2 Supply Chain Change Complexity

Change to the supply chain design inherently contributes to the complexity faced by decision-makers. Changes to the supply chain reflect decision within upstream-, internal manufacturing network-, and downstream changes, similar to source, make and deliver in the SCOR framework.

Upstream changes to the sourcing setup can be simple, such as finding a new supplier in an already known location, or more complex if it is in an unknown offshore location. Of the highest complexity is changing ownership of the production of a component (either outsourcing or insourcing).

For *internal manufacturing network changes*, four possibilities for change are suggested. At the simplest, changes can be made to the production network by shifting to production in a known location of close proximity (onshore insourcing). Outsourcing production to a known location of close proximity (onshore outsourcing) or internally owned production in an offshore location (captive offshoring) represent higher levels of change complexity. The most complex change is to outsource production to an unknown offshore location (offshore outsourcing) [2].

For *downstream changes*, distribution channels and the setup of warehouses are relevant dimensions. Here, a change can be a new distribution channel in a known location as the simplest, more complex if it is in a new location, while a change of ownership of the distribution channel is seen as the most complex. Changes can occur in multiple dimensions simultaneously, making the resulting change complexity higher.

2.3 Complexity Framework

Combining the two dimension, then supply chain complexity and change complexity represents two areas of complexity; the complexity of the entity being changed, and the complexity of the proposed changes, as illustrated in Fig. 1.

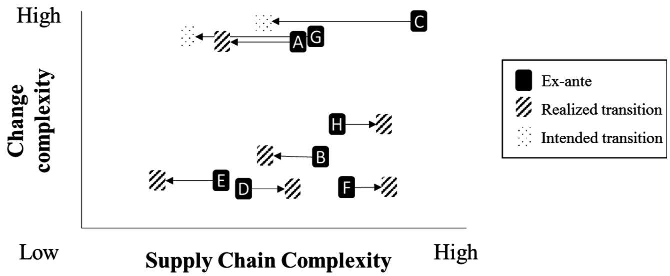

Fig. 1. Case mapping: intended and realized transition.

3 Method

The paper builds on an explorative case study to investigate how supply chain design decisions are linked to supply chain complexity. The case study approach is ideal for in-depth investigation of how supply chain design decisions are influenced by and influences supply chain complexity [11]. To be able to both generalize findings and achieve in-depth understanding [12], an embedded case study approach is chosen. Here, the focus is on eight different supply chain improvement projects undertaken in a global industry leading OEM. The cases have been chosen to investigate a mix of high and low supply chain- and change complexity.

Each case has been followed in their total duration from ideation to implementation decision, and if applicable, implementation. Thus, the duration of the cases ranged from three months to three years. The longitudinal data enabled an investigation of both the ex-ante intended outcome and the ex-post achieved outcome, as well as rich data on the impact of decision-making, change complexity and supply chain complexity. To ensure an unbiased understanding of the relationship with complexity in supply chain design decision-making cases, both cases which did and did not implement the proposed changes, were investigated. For each case, the researchers together with involved supply chain managers mapped the supply chain complexity and the area of change complexity, by scoring each dimension based on perceptual measures. The supply chain complexity was mapped for the subset of the OEM's supply chain relevant for the supply chain design project. Further, the objective for each supply chain design project was mapped, together with the decision process and outcome. Results from the eight cases of redesigning the supply chain are summarized in Table 1.

Table 1. Overview of supply chain design cases.

Case	Supply chain change complexity	Stated objective	Decision process	Realized outcome
A	Outsourcing of internally produced composite product. Utilizing suppliers of the shelf-available technology	– Cost reduction – Improve technical control – Complexity reduction	**Implemented.** Decision based on direct cost savings	Upstream-, internal manufacturing network- and downstream complexity reduced
B	Outsourcing of wire production. Divesting of production equipment	– Cost reduction – Avoid investments in production equipment – Reduce complexity in factory and upstream supply chain	**Implemented.** Decision based on direct cost savings	Internal manufacturing complexity reduced from outsourcing
C	Outsourcing of assembly and design of auxiliary module	– Complexity reduction – Utilizing supplier development capabilities	**Not implemented.** Decision based on direct cost comparison	Not implemented
D	Introduction of second source	– Cost reduction – Increased supply network reliability	**Implemented.** Decision based on cost reduction and increased network reliability	Increased planning complexity from operating with two suppliers
E	Outsourcing of machining activity	– Cost reduction – Complexity reduction from simplifying supply base and internal manufacturing setup	**Implemented.** Decision based on direct cost savings	Upstream and internal manufacturing network complexity reduced from outsourcing
F	Offshoring of controller module	– Cost reduction	**Implemented.** Decision based on direct cost savings	Increase in detail complexity from managing additional Chinese supply base and assembly location

(*continued*)

Table 1. (*continued*)

Case	Supply chain change complexity	Stated objective	Decision process	Realized outcome
G	Shift to kit-delivery of brake-system and outsourcing of design	– Cost reduction – Complexity reduction from utilizing suppliers of the shelf concepts	**Not implemented.** Decision based on direct cost comparison	Not implemented
H	Offshore and outsourcing of module assembly	– Cost reduction from establishing production close to emerging markets	**Implemented.** Decision based on direct cost savings	Increased planning complexity from managing inbound supply chain for outsourcing partner

Further, for each case, the impact of the supply chain design change on the supply chain complexity was mapped. For cases where the design change was implemented, the impact was mapped. For those cases, where it was decided not to implement the proposed changes, the impact of the intended changes to supply chain complexity was predicted based on the impact to the dimensions of upstream, internal manufacturing network, and downstream complexity. This enabled a mapping of the realized or intended transition for each case based on aggregate measures of supply chain complexity and change complexity as shown in Fig. 1.

4 Case Discussion

4.1 The Impact of Change Complexity and Supply Chain Complexity

High supply chain complexity was associated with significant resources spent on estimating the impact of the proposed decisions. This is ascribed to the complex interactions and unclear causality due to complex interdependencies (Case F, G and H). Thereby supporting that supply chain complexity lead to negative consequences in the form of additional resources required for managing and improving the supply chain [1]. An higher level of supply chain complexity is, thus, associated with higher resource requirements for justifying a decision. In addition, it was found that detail complexity was associated with a higher need for collecting, preparing and analyzing more of the same data (Case B and F), while dynamic complexity was associated with difficulty in problem understanding, and predicting impact across multiple tiers (Case A, C and G). Change complexity was associated with resources required for developing and validating the new supply chain design, such as transport solutions, logistics processes, production processes, and even adjusting product requirements and designs. The extent of change to existing design variables required the focal company to allocate resources with technical competence and strong functional understanding (Case A, C and G). The cases further suggest a significant interaction between change complexity and decision complexity. When change complexity was high, it increased decision-making complexity by expanding the number of design solutions, which needed to be evaluated, each with different impacts and causality (Case C and G).

4.2 Supply Chain Redesign to Reduce Complexity

The objective of reducing supply chain complexity was highlighted in a number of redesign projects (Case A, B, C, E and G). In general, these were experiencing medium or high level of supply chain complexity, suggesting that redesign initiatives were a response to increasing levels of supply chain complexity. Further, the higher the change complexity, the higher was the intended or realized reduction in complexity. Hence, working with multiple dimensions simultaneously, enables a larger potential for reducing supply chain complexity (Case A, G, and C). For instance in case A, where a combination of outsourcing production processes and utilizing suppliers' of-the-shelf technology, significantly reduced supply chain complexity. This was achieved by reducing number of items and suppliers maintained, eliminating internal capacity bottlenecks, adding access to global production locations and distribution capabilities, and shifting to market relations. Contrary, initiatives relying on changes within a single dimension provided smaller complexity reduction potentials (Case B and E).

4.3 Impact of Decision-Making on Supply Chain Complexity

Trade-offs between supply chain complexity and strategic benefits [6] was a visible part of the decision-making considered in the majority of the cases. During scoping and discussion of project initiatives, reduction of complexity was central together with alternative performance improvements, such as cost reduction. However, during decision-making meetings, primary attention was focused on what could be quantified with immediate impact on the OEM's profit/loss statement and validated by finance. Which meant that financial assessments did not account for the added complexity imposed on the supply chain, since the marginal impact of this could not be quantified using standard cost accounting principles. This leads to the proposition that increasing supply chain complexity, rests on the limited visibility of the marginal impact of supply chain complexity during managerial decision-making. Several mechanisms and case findings explain and support this. First, different levels of transparency and confidence in outcome are prevailing when discussing supply chain complexity in a trade-off with other strategic benefits. For instance, a ten percent price reduction from utilizing an offshore supplier is more tangible than the detrimental performance impact of longer and unstable lead-times. All cases revealed this discrepancy in transparency, suggesting supply chain complexity is prone to increase unless carefully considered during decision-making. Initiatives aimed at reducing supply chain complexity are not justified based on the benefits stemming from that reduction, due to low transparency on the marginal performance impact from reducing supply chain complexity (Case C and G). Rather, such initiatives are subject to the complexity reduction being supplemented by more tangible performance improvements (Case A, B and E), such as direct cost reductions. Second, initiatives seeking to improve aspect of the supply chain, typically factor inputs such as labor or material costs, are not adequately penalized for increases in supply chain complexity (Case D, F and H). This leads to a systematic increase in complexity, while the ability of decision-makers to reduce complexity is constrained.

5 Conclusion

By exploring the combined roles of supply chain complexity and change complexity, advances are made to the understanding of complexity and its impact on supply chain design decision-making. First, by presenting and testing a method for assessing supply chain complexity and change complexity, it enables an understanding of the role of complexity on supply chain design decision-making. Second, the findings document the negative effects of high supply chain complexity, through reduced decision speed and potential erroneous decision-making. In particular, the paper shows how high levels of detail complexity can be associated with the amount of data required for decision-making, meanwhile, dynamic complexity relates to the difficulty of estimating causality. In addition, the cases help explain why increasing supply chain complexity constitutes an increasing managerial challenge. It is revealed that the utilization of direct costing principles for decision-making constitutes a systematic bias underestimating or neglecting the consequences of supply chain complexity, propelling companies towards increased supply chain complexity. For practice this highlights the risk of a singular focus in supply chain design decision-making. Especially, as transforming away from high supply chain complexity becomes increasingly difficult as complexity increase.

As the study builds on an embedded case study, further research should seek to replicate and further substantiate the mechanism with which supply chain complexity is dependent on decision-making practice. In addition, research should seek to link the nature of supply chain complexity, upstream, internal, or downstream, with the aspects of change complexity. Another research proposal would be to improve the understanding of mechanisms mitigating the negative consequences of supply chain complexity in decision-making.

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Reframing the Outsourcing Process

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Abstract. Multiple functions and stakeholders from the buyer and the supplier are involved and affected, either directly or indirectly, by the outsourcing process and the way it is managed. These can all assign different meaning to the evaluations and decisions made during the process, which in turn may strongly influence its success. To avoid distrust and suboptimal solutions, managers need to take into consideration different stakeholders' opinions when making key outsourcing decisions. However, capturing these opinions is cumbersome, and may slow down the outsourcing process significantly. This paper proposes a segmentation approach to rationalize the inclusion of different stakeholders' opinions in outsourcing decision-making. More specifically, Bolman and Deal's four leadership frames are used to consider multiple opinions regarding a production transfer between a Norwegian manufacturer of advanced hydro-acoustic sensor systems and one of its strategic suppliers. The paper shows how a multi-frame model may bring new understanding to key outsourcing decisions, and ensure that multiple stakeholders' opinions are considered throughout the process.

Keywords: Outsourcing · Production transfer · Multi-frame perspective · Collaborative manufacturing

1 Introduction

Multiple functions from both the buyer (the company that outsources) and the supplier (the new producer or service provider) are directly involved at different times during an outsourcing process. In addition, various other stakeholders are affected, either directly or indirectly, by the process and the way it is managed. These can all assign different meaning to the evaluations and decisions made during the process, which in turn may strongly influence the success of both the outsourcing process and future business. For example, outsourcing a successful product may make perfect sense for the senior management, due to its potential cost savings; however, for the product manager it may be seen as a lack of trust, which may influence his motivation to continue working for the company. To avoid distrust and suboptimal solutions, companies need to avoid "one size fits all" approaches, and take into consideration different stakeholders' opinions when making key decisions and communicating with stakeholders during the outsourcing process. However, capturing the multitude of opinions is cumbersome, and may slow down the outsourcing process significantly.

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An often-used approach to handle heterogeneity efficiently is to group things (e.g. people, products) with similar characteristics into segments that are expected to exhibit similar behavior, and handle the segments separately instead of using one mass-approach. Seminal examples of such segmentation include market segmentation [1] and group technology [2]. We believe that the same logic can be applied in outsourcing. More specifically, we argue that key decisions in the outsourcing process may be assessed in light of the expected opinions of various stakeholder segments. Hence, the purpose of this paper is to show how multiple perspectives may bring new understanding to outsourcing decisions, and ensure that multiple stakeholders' opinions are considered efficiently throughout the process. While there are abundant ways of segmenting stakeholders, the four leadership frames by Bolman and Deal [3] are taken as a starting point, as they are widely recognized as a tool that improves understanding and promotes versatility in organizations. This framework has been used in numerous settings, from education [4] to sports [5]. However, to the best of our knowledge, it has not previously been applied to outsourcing processes. In this research, it is used to consider multiple opinions regarding a production transfer between a Norwegian manufacturer of advanced hydroacoustic sensor systems and one of its strategic suppliers.

The remainder of the paper is structured as follows. First, some theoretical background on outsourcing of production and the four frames by Bolman and Deal [3] are presented. Thereafter, the reframing case study is described. This includes research methodology, as well as empirical findings and discussions. Finally, the paper is concluded, with major contributions, limitations and suggestions for further research.

2 Theoretical Background

2.1 Outsourcing of Production

The transfer of activities to other supply chains actors is generally denoted outsourcing or offshoring, depending on the ownership structure (internal or external) and target location (domestic or foreign) of the transfer [6]. Outsourcing refers to a transfer of certain responsibilities across organizational borders, whereas offshoring indicates that the responsibility is transferred to a subsidiary or supplier in a foreign location. Outsourcing has numerous stated benefits (e.g. lower factor costs, access to new materials, distribution channels and technologies and focus on core competences) which have made it a very popular strategy in many industries [7, 8]. However, it involves considerable risk and may lead to increased costs and loss of business if it is not carried out in a systematic manner [7, 9].

Several frameworks [e.g. 10–13] outline different phases of the production outsourcing process. Broadly speaking, it comprises four phases: (1) Outsourcing decision; (2) supplier selection; (3) production transfer, and; (4) steady state. In the *outsourcing decision* phase, the company should decide its outsourcing policy [13]. This includes an assessment of outsourcing benefits, risks and motivators (cost, strategy, and politics), to decide whether it should continue considering possible outsourcing candidates. Thereafter, the company may proceed to the outsourcing candidate selection stage, where it identifies, evaluates and selects possible candidates (functions, products or processes) for outsourcing [13]. In the second phase, *supplier selection*, the company carries out initial supplier qualification (if it does not keep a record of prequalified suppliers), before agreeing on measurement criteria, obtaining relevant information, making a selection and negotiating legal arrangements [12, 14]. Several of the criteria for supplier selection will depend on the geographical location of the supplier. The third phase, *production transfer*, concerns the actual relocation of manufacturing of products or components between two production facilities. It consists of three distinct stages: Transfer preparation; physical transfer, and; production start-up [10]. The final phase is the *steady state*. Here, the supplier has reached a full-scale and stable production, at targeted levels of cost and quality [10].

Each of the phases and stages in the outsourcing process entails numerous decisions. Gunasekaran et al. [15] review outsourcing decisions and relevant performance measures and metrics in pre- (i.e., outsourcing decision and supplier selection), during- (i.e. production transfer) and post-outsourcing (i.e. steady state) stages. They distinguish between strategic and tactical decisions that are either financial or non-financial. Many of these are tangible and relatively easy to set goals for, anticipate and measure performance of, such as transaction costs, IT infrastructure, service performance, etc. These decisions are often made with the support of, e.g., multi-criteria decision techniques or optimization. However, a large number of decisions are classified as intangible. These may be harder to make using similar tools. Examples include degree of collaboration, teamwork, motivation of employees on the shop floor, etc. These are multifaceted decisions that require careful yet efficient consideration of different stakeholders' opinions.

2.2 Four Leadership Frames

Bolman and Deal [3] have identified four distinct frames people view their world through, namely (1) Structural, (2) Human Resources (HR), (3) Political and (4) Symbolic. Each frame comes with a range of concepts, values and metaphors that distinguish it from the others. For instance, the four frames' metaphors for organizations are (1) factory or machine, (2) family, (3) jungle and (4) carnival, temple or theatre, respectively. The frames' conception of organizational processes are illustrated in Table 1.

While no one uses only one frame to interpret their world, people often show a preference for one or two frames. Therefore, to improve understanding and promote versatility, the frames can function as mental maps for reading and negotiating different territories – such as outsourcing decisions. For instance, a Structurally oriented management team may consider an outsourcing process as a simple realignment of roles and responsibilities to fit core competences and the business environment. By using the four frames actively, the team can comprehend other implications of the process, such as its impact on the workforce (HR), the redistribution of power between the buyer and supplier (Political) and the customers' perception of product quality when operations are carried out by a contract manufacturer (Symbolic). These may all influence the course and outcome of the process, and as such, it can improve decision-making. Further, it can aid the team in foreseeing and complying proactively with the needs and demands of stakeholders that show preference for different frames.

Table 1. Organizational processes in light of the four-frame model [adapted from 3]

	(1) Structural	(2) HR	(3) Political	(4) Symbolic
Strategic planning	Strategies to set objectives and coordinate resources	Gatherings to promote participation	Arenas to air conflicts and realign power	Ritual to signal responsibility, produce symbols, negotiate meanings
Decision making	Rational sequence to produce right decision	Open process to produce commitment	Opportunity to gain or exercise power	Ritual to confirm values and provide opportunities for bonding
Reorganizing	Realign roles and responsibilities to fit tasks and environment	Maintain balance between human needs and formal roles	Redistribute power and form new coalitions	Maintain image of accountability and responsiveness, negotiate new social order
Evaluating	Way to distribute rewards or penalties and control performance	Process for helping individuals grow and improve	Opportunity to exercise power	Occasion to play roles in shared ritual
Goal setting	Keep organization headed in right direction	Keep people involved and communication open	Provide opportunity for individuals and groups to share interests	Develop symbols and shared values
Communication	Transmit facts and information	Exchange information, needs, and feelings	Influence or manipulate others	Tell stories
Motivation	Economic incentives	Growth and self-actualization	Coercion, manipulation, seduction	Symbols and celebrations

3 Case Study: Reframing the Outsourcing Process

3.1 Research Method

In this research, we explore how the four-frame model by Bolman and Deal [3] can be used to comprehend multiple opinions in outsourcing processes, by studying a product transfer between a Norwegian manufacturer of advanced hydroacoustic sensor systems and one of its strategic suppliers. No behavior was manipulated in the actual process, making a case study approach appropriate [16].

Empirical data has been collected through a series of joint workshops with the buyer's Supply Chain management team and the supplier's senior management, as part of a collaborative management development activity. In the workshops, selected parts of the outsourcing process were discussed with respect to the four-frame model. In addition to the workshops, the management teams did a self-assessment exercise to explore how their basic mindsets compare to the four-frame model, bearing in mind that people usually show a preference for one or two of the frames. More specifically, for a set of organizational processes (including Table 1), every participant would distribute ten points over the different frames' description of the process. More points were awarded to the frames with which the participant agreed the most. The aggregated distributions over the frames (Structural, Human Resources, Political, and Symbolic) were 37%; 34%; 13%; 16% and 44%; 38%; 8%; 10% for the buyer and supplier, respectively.

3.2 The Outsourcing Process

The studied outsourcing process was the first production transfer from the buyer to the supplier. The outsourced product consists of a sensor (core technology produced by the buyer), casing, and electronics. The sensor and electronics are soldered together and molded into the casing, before the product is tested. All products are sold in high volumes to a sole customer that replaces products frequently, which creates a yearly demand for the product. For several years, the buyer purchased the casing and electronics from two other suppliers and assembled the products itself. However, some years ago, it approached the supplier with an invitation to tender for the product's assembly operation. Today the supplier gets the sensors from the buyer, and casing and electronics from two other suppliers, and carries out the assembly and associated product testing. The buyer still carries out spot checks, ships the finished products, and maintains communication with the end customer. The outsourcing process is briefly described in Table 2. Below, some selected elements of the process are discussed to illustrate possible use of the leadership frames, as was done in workshops with the management teams.

Table 2. The outsourcing process

Phase	Main activities
Outsourcing policy	The buyer's overall decision to outsource was mainly driven by a combination of cost and strategy. The company felt a need to reduce cost, and at the same reduce its high volume production activities, as "it aims to be a 'technology company', rather than manufacturing company"

(*continued*)

Table 2. (*continued*)

Phase	Main activities
Outsourcing candidate selection	The buyer quickly arrived at the selected outsourcing candidate, as the product had significantly higher volume and lower margins than the other products offered by the company. This required higher efficiency and manufacturing-/industrialization competence than the buyer possessed
Supplier selection	The supplier was prequalified and used to deliver electronics for the product. Today, the renowned contract manufacturer is classified as a strategic supplier by the buyer
Transfer preparation	There was no kick-off meeting signaling the start of the outsourcing process, and a transfer plan and risk assessment had not been prepared and conducted before the transfer. The supplier participated in value stream mapping at the buyer, and sent three operators to learn the current production process. The buyer's original suppliers of housings and electronics were transferred to the supplier
Physical transfer	Initially, it was decided that all test equipment would be moved from the buyer to the supplier. When the buyer's product team found this out, they realized that they would not be able to run spot-checks, thereby losing control over the end quality. The buyer therefore copied its test equipment and transferred the copy to the supplier
Prod. start-up and steady state	The contractual agreement between the buyer and supplier stated that the supplier would gradually lower the unit cost as production progressed. However, several of the supplier's process improvement suggestions were rejected without a clear justification

Supplier Selection. As pointed out in Table 2, the supplier was prequalified by the buyer, as it used to deliver electronics components for the product. Therefore, the supplier selection process mainly concerned contractual agreements between the buyer and the supplier. In the workshops, the management teams agreed that the Structural frame had been prominent in this phase. There was strong emphasis on transmitting facts and information, and formalizing conditions regarding e.g. forecasting, call-offs and delivery agreements. Several functions at the buyer (e.g. product team, purchasing and quality) were involved in the formulation of the contract's terms, to ensure conformance of end customer expectations. At the same time, both the buyer and supplier agreed that they were humble and a bit careful with each other during this phase, as they wanted to show respect and did not want to ruin their existing relationship. As such, they implicitly also had the HR frame in mind when initiating the transfer, by maintaining a balance between their relationship and formal roles. When challenged to view the phase from the Political and Symbolic perspectives, especially the buyer felt that they should have considered Political aspects more when establishing the relationship. They felt that by exercising power more, higher goals could have been set and reached, which would ultimately benefit both the buyer and supplier. The supplier, on the other hand, saw that it is important to be aware of and exercise its own power in such a constellation, and be humble but not submissive, as the parties may miss out on early opportunities for improvements due to fear of the power distribution.

Start-Up and Steady State. When asked to evaluate the current situation (somewhere between the start-up and steady state), the parties felt that the Structural focus in the supplier selection phase had resulted in a well-functioning relationship, with deliveries going from the supplier to the buyer at the right time, in the right quantity, and with the right quality. However, as seen in Table 2, the contractual agreement between the buyer and supplier also stated that the supplier should gradually lower the unit cost as production progressed. In this respect, the supplier experienced that several of their process improvement suggestions were rejected without a clear justification. While these rejections Structurally made sense (the buyer was afraid of altering the product performance in any direction, because the end customer was familiar with how to interpret data from the existing product), the buyer underestimated the Symbolic effect they had on stakeholders at the supplier, which experienced frustration and distrust over a lack of explanation. At the same time, the supplier did not communicate this explicitly to the buyer, due to little exerted power and the HR frame that was implicitly in play, as mentioned in the supplier selection phase above. During the research, the supplier got an explanation of why their suggestions were not taken into consideration. This was immediately understood and accepted. By looking at it from the Symbolic perspective, a lot of frustration could have been avoided if this had been communicated earlier. When the parties discussed this issue, they saw that the Symbolic and HR perspectives could be used more frequently. Especially the buyer acknowledged that they could use multiple frames to turn everyone's attention to achievement of objectives and, in collaboration with the supplier, acclaim good experiences and learn from bad ones.

Further Practice. Using the four frames generally made the parties realize that the outsourcing process could have run smoother if key issues had been discussed more proactively, in a way that captured more perspectives. As can be seen from the management teams' self-assessment, both teams show an overweight of Structural and HR traits. At the same time, they experience that many of their subordinates and stakeholders have other traits, and that these need to be taken into consideration during the outsourcing process. The parties saw that they could both exert their power to a larger degree (Political), but at the same time they need to be aware of how such actions may be interpreted through the other perspectives – especially the Symbolic frame. As mentioned in Table 2, there was no kick-off meeting to signal the start of the outsourcing process. While such a meeting could have a strong Symbolic effect in terms of signaling responsibility, it could also serve as an arena to promote participation (HR), align power (Political), and set objectives and coordinate resources (Structural) – thereby answering to different needs and opinions. To make amends for the lack of a kick-off, following the workshops the buyer sent key personnel to the supplier, to inform all employees about how the outsourced product is important to both the buyer and the end customer. Further, the buyer has categorized the supplier as one of six strategic suppliers. These are both strong symbols of their collaborative relationship, as is the collaborative management development activity that has been discussed in this paper.

4 Conclusion

This research has shown how the multi-frame model brought new understanding to some of the key decisions that were made during the outsourcing process between a Norwegian manufacturer of advanced hydroacoustic sensor systems and one of its strategic suppliers. When introduced to the model, the case companies themselves concluded that their relation was almost purely Structurally grounded, through e.g. contracts and terms of delivery. Throughout the workshops, the companies saw that the Symbolic and HR frames could increase stakeholders' feeling of ownership to the process, and that both companies could benefit from having a conscious attitude to power exertion, as described by the Political frame. As such, the managerial implications of utilizing such a framework to reframe 'traditional' outsourcing processes are evident.

There are, however, some limitations with the study. A single case study approach essentially limits the generalizability of the results. Further, only one segmentation model has been tested, on a limited part of an outsourcing process approaching completion. Moreover, the self-assessment done by the management teams showed an overweight of Structural and HR traits at both the buyer and supplier. While these arguably are 'typical' traits in, at least, Scandinavian manufacturing companies, the applicability and/or need for reframing may be less in other parts of the world or in companies with more heterogeneous composition of people. Finally, the study does not suggest which frames are best applied at different stages of the outsourcing process, and what is the best way of applying them. Further research should include more empirical testing to improve the generalizability of the findings. This could include multiple case studies in a range of industries and countries, with a diversity in products and services, using the same and other segmentation models on all phases of the outsourcing process.

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A Production Transfer Risk Assessment Framework

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Abstract. Many companies transfer production between them as part of relocation processes such as offshoring and outsourcing. Such production transfers (PT) are often associated with the risk of not achieving the expected performance results. Thus, many scholars and practitioners have acknowledged the importance of a thorough PT planning, based on risk management principles. One major principle is the assessment of PT risk in early stages of the process, in order to identify risk factors, analyze potential risk scenarios generated by the factors, implement risk-mitigation actions and improve PT performance. While several scholars have recommended conducting assessments early in the transfer process, which through the risk management lens, can be regarded as variants of risk assessment, there has not been published any recent review of the extant research on the risk assessment early in the PT process. Thereby, the main objectives of this paper are to identify and classify potential risk factors in the extant research, propose an assessment tool and test its utility on a longitudinal PT case. The paper also provides suggestions of how to apply the proposed tool to evaluate the requirements for resource intensive activities between the PT parties.

Keywords: Production relocation · Supply chain risk management · Performance management · Offshoring · Outsourcing

1 Introduction

Many companies carry out production transfers (PTs) as part of relocation processes such as offshoring or outsourcing [1]. In line with [2], a PT can be defined as the relocation of the manufacturing of products and components between a *sender* (original manufacturer) and a *receiver*. Further, it can be divided into three main phases: (i) *'PT preparation'*, (ii) the *'PT execution'* mainly consisting of the physical transfer of production equipment and inventories, and (iii) the production *'start-up'* at receiver. A PT is usually considered successful if a stable production is achieved at the expected performance objectives (e.g., cost and yield), in the start-up [3, 4]. The PT can be

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regarded as the final stage in a production relocation process, being usually preceded by the decision whether to relocate production or not, and the selection of suitable sourcing items, locations and suppliers [5]. All the new risk factors introduced when transferring the production to a new production environment (e.g. a new workforce, production equipment and sub-suppliers) contribute to an increased risk level. For PTs, the *'risk factors'* can be defined as tangible and intangible elements which have the intrinsic potential to give rise to supply-disruptions [6]. Although they are a common phenomenon, PTs tend to take much longer time than companies anticipate [7]. Further, they do not always meet the expected performance objectives, and can even lead to losses (e.g. financial or intellectual property (IP) losses) [8]. Thus, many scholars and practitioners have acknowledged the importance of thorough PT planning and control, based on risk management principles (e.g. [3, 9]). Two central risk management goals are the risk assessment and the risk mitigation process. For PTs, the assessment consists of the following activities: the identification of risk factors, potential supply-disruptions (e.g. a machine breakdown) generated by these factors and their effect on performance; an analysis to understand risk scenarios and estimate the level of risk, and an evaluation of whether risk-mitigation actions should be implemented or not [10]. Several scholars [e.g. 9, 11, 12] have recommended conducting assessments in the early stages of the PT process that, through the risk management lens, can be regarded as variants of risk assessment. Such assessments indicate potential sources of disruptions in the material and information flow (i.e. risk factors), and can aid in identifying risk-mitigation actions that should be included in the PT action plan. Nevertheless, to the authors' knowledge, there has not been published any recent review of the extant research on the risk assessment early in the PT process. Thus, the research problem this paper addresses is *'What are the risk factors during PTs?'* and the main objectives are to identify and classify potential PT risk factors in the extant research, and, thereby, propose a risk assessment tool. Moreover, the utility of the proposed tool is tested on a PT case.

Research Methodology

The research process has been conducted in two steps. First, we have carried out a literature review of peer-reviewed journal articles, dissertations, and best practices within the topics of *production-, knowledge-*, and *technology-transfer*, as well as about *manufacturing relocations and start-up, supplier assessment and audit*, and key *risk management* publications. The aim of the review was to identify potential PT risk factors. When synthesizing these factors into the proposed assessment tool, the most comprehensive frameworks found [9, 11, 12] were taken as a starting point. Second, a case study is used to test the utility of the tool. The case is the PT of electronics from a Norwegian company to a subsidiary in Spain. Rich empirical data has been collected during a period of 12 months. The case method was adopted because it allows the identification of PT risk factors during a real PT case and with a relatively full understanding of the nature and complexity of the PT process [13]. The sender had conducted PTs several times before, including to the receiver. Yet, they were experiencing a series of challenges during PTs. This made the selected PT an interesting case to study and get a better understanding of how to identify areas where risk-mitigation actions could be implemented in order to improve supply performance. Further, the PT project owner and the sender's PT Quality & Risk manager applied the tool to the case, 6 months after the PT decision. Both had rich experience from similar PTs. A semi-structured interview was conducted with the informants, who jointly analyzed and ranked the impact of the risk factors on the overall risk level during the case. Responses were cross-referenced with documentation and extensive field notes.

2 Potential Risk Factors During Production Transfers

Supplier qualification assessments are widespread in the scientific literature. Grant and Gregory [11], pioneers of the PT literature, argue that the PT success would not be only influenced by factors dependent on receiver but also by those inherent in the type of production transferred, and best controlled by sender. Thereby, based on [11], we have established the two first categories of literature findings: *'potential risk factors related to the transfer object'* and *'to the receiver'* respectively (see framework in Table 1). These factors have been further divided into five and nine areas respectively. The Risk factors related to the receiver can be encountered in the widespread supplier qualification assessments. Although these factors do not necessarily affect the selection of the receiver, they might still contribute to an increase in the PT risk level, and should therefore not be overseen. Moreover, WHO [9] recommends visiting the receiver early in the transfer process, in order to assess the new production environment at a more detailed level, and shed light on the capability gaps between the receiver and the sender. Thus, the 'production environment' area was added, and several factors in this area can be also encountered in Lean audits (i.e. R35, R36, R37 in Table 1).

Next, according to [3, 12] the PT outcome will be also influenced by the physical distance and the relationships within the supply chain. Thus, a third category was added to our classification, *'factors related to supplier relations'*. Finally, based on the widely used Kraljic model [14], the *'factors related to the profit impact'* a sourcing activity has, should be always considered along with the risk factors. According to [14], these factors stand out and have a moderating impact on the risk level. If the risk level is high, it is worth making high investments in the sourcing, provided the profit impact is also high. The 4 categories of risk factors are presented in Table 1. The factors have been divided into 18 distinctive areas. [9, 11, 12] were taken as a starting point for the framework.

Table 1. Framework for production transfer risk assessment

I. Risk factors related to the transfer object	
1. Novelty **R1.** Degree of experience sender and receiver have with transferring production between them [15, 16] **R2.** Sender's and receiver's individual experience with similar production [15, 16] **R3.** The similarity of the transfer object produced by receiver to the object produced by sender [15] **R4.** The similarity of the transfer object produced by receiver to other production at receiver (e.g. if receiver's equipment can be used) [16] **R5.** Production site's maturity (e.g. greenfield or brownfield) [17] ***2. Complexity*** **R6.** Degree of internal and external modularity (e.g. the object is part of a larger system) [15, 18] **R7.** Amount of elements, configurations and functions the object has (e.g. BOM complexity) [15, 18]	**R8.** The size of the product tolerances [16] **R9.** Availability of raw materials [14] **R10.** The extent to which the manufacture of products is complete prior to customer order [16] **R11.** Customer demand- and volume-certainty [16] **R12.** Facility to protect IP [11] ***3. Tacitness*** **R13**.The facility to codify (document) the tacit knowledge about the object [11, 15] **R14.** The transfer object's maturity (e.g. with well-defined processes) [11, 15] **R15.** The relevance of the documentation (e.g. updated and representative) [11, 15] ***4. Adaptability*** **R16.** Facility to find alternatives when adapting the production process to receiver's environment [11] **R17.** Facility to pilot and test the adaptations at sender prior to transfer execution phase [11]
R18. Sender's capability and willingness to make adaptations [11] ***5. Flexibility*** **R19.** The possibility to reserve resources at sender	for necessary tasks during transfer execution and start-up at receiver [16, 19] **R20**. The possibility to plan the transfer as a gradual transfer, volumes being only gradually decreased as outputs at receiver are increased [16, 19]
II. Risk factors related to the receiver	
6. Sub-suppliers **R21.** The quality, cost, flexibility, service level, reliability and proximity of local and international sub-suppliers [8, 11] ***7. Transfer market*** **R22.** The appropriateness of receiver's market for the transferred production (e.g. if product redesign is needed to satisfy demand) [11] ***8. Infrastructure*** **R23.** The appropriateness of the quality, cost and availability of local utilities [11] **R24.** The appropriateness of the space and format of buildings [11]	**R30.** The level of governmental stability [14] ***13. Labor force*** **R31.** Employee's productivity, educational level, language homogeneity and turnover [11] ***14. Culture*** **R32.** The closeness between job positions (e.g. manager-operator) **R33.** Individuals' willingness to assume responsibility and the appropriateness of receiver's approach to problem solving and quality perception [11] ***15. Production environment*** **R34.** Production and packaging rooms, the testing, production and packaging equipment, inventory control mechanisms,

(*continued*)

Table 1. (*continued*)

R25. The appropriateness of tele-communications, road, rail, shipping and airfreight infrastructure [8, 11] ***9. Legal requirements*** **R26.** The appropriateness of import duties [8, 11] **R27.** The appropriateness of quotas, labor law, government emission regulations, planning permission regulations, approval and license requirements, and other legal demands [11] ***10. Financing*** **R28.** The appropriateness of the cost of capital, land, inventory, and the foreign exchange requirement [11] ***11. Geographical environment*** **R29.** The appropriateness of the local temperature range, humidity level, air quality [11] and of geo-risk (e.g. if area is prone to natural disasters) [14] **12**. ***Sociopolitical environment***	documentation, the absence of banned substances, waste management [9] and other HSE aspects [20] **R35.** Layout and material flow; efficiency of space usage; levels of inventory and work-in-progress; quick changeover; installation and maintenance protocols; planning and control, value chain information sharing and other data systems (e.g. level of integration between systems); order management; quality management (e.g. TQM); Visual management [9, 20] **R36.** Workers' technical capabilities (e.g., to adapt the production process to own environment and the use of leading technology); organizational practices (e.g., customer focus, housekeeping) [11, 20] **R37.** Level of teamwork and worker empowerment and flexibility [20]
III. Risk factors related to supplier relations	
16. Distance **R38.** Physical proximity between related processes (e.g. the development and manufacturing units) after transfer execution [3, 16] **R39.** The relationship closeness between sender and receiver [3, 16] **R40.** The relationship closeness within the value chain (e.g. receiver has close sub-suppliers that deliver high quality items) [20]	**R41.** The similarity of transfer parties' perception of their relation [21] ***17. Power balance*** **R42.** Sender's and receiver's negotiating power [14] ***18. Motivation*** **R43.** Employees' motivation for transfer, at both locations (e.g. high when no lay-offs) [16]
IV. Risk factors related to profit impact	
R44. The size of the sourced volume compared to sender's and receiver's other products [14, 16] **R45.** The proportion of sender's total sourcing cost the sourced items stand for [14]	**R46.** The positive impact of the sourced items on quality and business growth [14]

Table 2. Risk factors in the case (1-low/2-medium/3-high contribution to increased risk)

Related to the Receiver	**Sub-suppliers:** The sub-suppliers' performance is evaluated as moderate. In addition, during one workshop, Receiver's personnel identifies a certain risk that sub-suppliers could unexpectedly stop their supply and thereby, it is decided to establish a long-term partnership with critical vendors and have available secondary sub-suppliers for standard items.	2
	Transfer market: The transfer parties benefited of a good and stable customer demand in Spain, without having to change the products.	1
	Infrastructure: The infrastructure at the Spanish receiver is evaluated as very good.	1
	Legal requirements: Sender realized during Preparations, that it would be more expensive to sell products Made in Spain to countries where EU had less favorable trade agreements than Norway. Nonetheless, Euro was more stable than the currency at their Chinese subsidiary and it was more advantageous to purchase from sub-suppliers within EU. Further, during one analysis early in the preparations phase, personnel with experience from previous transfers stressed the need to ensure comprehensive documentation for the transferred equipment and inventory, in order to avoid being stopped at the customs office, so several actions were implemented to reduce this risk.	2
	Financing: The cost of capital and land are evaluated as high, whereas the cost of inventory and the foreign exchange requirement are moderately appropriate.	3
	Geographical environment: The temperatures, humidity, air quality and geo-risk at the Spanish site are evaluated as moderately appropriate for electronics production.	2
	Sociopolitical environment: The area benefits of high governmental stability.	1
	Labor force: Workers' productivity and educational level at Receivers are evaluated as high and respectively moderate. Receiver's area was known for its material technology expertise and the labor force turnover was low. Yet, the workers' English skills were modest and this could be especially challenging during videoconferences.	2
	Culture: Workers are willing to assume responsibility and have an appropriate quality perception and problem solving approach. The relational closeness between job positions is moderate.	1
	Production environment: Receiver possessed the ISO 9001: 2008 certification within Quality management and achieved a good score when Sender conducted a Lean audit at their premises. Moreover, they were very receptive to new technologies and best practices. Nonetheless, when Sender's representatives visited them two months after kick-off, both parties realized how important it was to implement Sender's quality management systems and procedures in the new supply chain (for Change control, FIFO, tracing parts, the reception of sourced items, and for correct storage). In addition, they agreed on and took the first actions to implement Sender's ERP production module at Receiver. Receiver's personnel had to travel several times to Norway for training and the process required a trial period at Receiver, which could prolong the start-up and delay the steady state.	2
R. to Supplier Relations	**Distance:** Sender and Receiver were part of the same corporation, yet the supply agreement they had was a buyer-supplier contract similar to the ones Sender had with external suppliers. This generated certain confusion among personnel. Sometimes, Sender's workers were hesitant to share information, whereas Receiver's workers expected more openness. The physical distances between the development and manufacturing of the core technology and the molding material were small, since the processes were collocated at Sender and respectively, Receiver. Yet, the fact that the two sites were located far from each other posed some characteristic challenges to their collaboration (e.g. if they will have to adapt technology to the Spanish market).	3
	Power balance: The competition between Receiver and other 'receivers' that Sender could have selected is moderate, and the same applies for Sender and their competitors.	2
	Motivation: Some of Sender's employees were afraid to lose their jobs in the future.	2
R. to Profit	**Profit impact:** The product volume is rather low, compared to Sender's other products. The products require a high amount of manual labor and are one of Sender's most price sensitive. Thus, Sender hopes to decrease the costs in the future due to the cheaper workforce (1/3 the cost at Sender) and to improve the products' robustness due to the new molding material. The outbound logistics could also decrease due to higher market proximity, but the inbound logistics could increase as long as Sender's original Norwegian suppliers are used.	2

(*continued*)

Table 2. (*continued*)

Related to the Transfer Object	**Novelty:** Sender had transferred production several times before, but Receiver had initially only carried out sale and service operations for Sender and did not have much production experience. However, they had successfully undertaken production from Sender before (the assembly of a simple component), and they had been having a good collaboration for 20 years. Moreover, Receiver had employed a researcher with a PhD in material technology who was developing a new molding material, a process that could delay the transfer. Most of the machines had to be purchased and there were certain distinctions between this equipment and the original one at Sender. In addition, Receiver had bought these expensive machines too early (more than one year before start-up). Finally, because of increasing production activities, Receiver also had to buy a facility to move to before start-up, and its layout had to be changed. The constructors they contracted for the 1st part of the building project submitted a too costly offer for 2nd part, and the process of contracting new ones delayed the start-up with weeks.	3
	Complexity: The transferred object consisted of three product groups; each with three relatively simple products that were not part of Sender's other products. However, their production required many machines and tools that had to be either purchased or transferred from Sender. The demand was relatively certain; there was a good market for these products in Spain. Further, since it was rather difficult to protect the IP, Sender did not grant Receiver access to the document handling system, and little documentation had been transferred before Sender's representatives visited Receiver and saw that the material development process was promising. Because of the scarce information and Receiver's rush to start the production, the new layout at the purchased facility deviated from what the production required, and had to be modified after Sender's visit. Moreover, during one analysis conducted short time after kick-off, Sender's employees identified a certain risk of IP loss during the transport of the acoustic technology to Receiver, but actions were soon implemented to ensure that only qualified logistics suppliers are used.	3
	Tacitness: The transferred products were mature, but the documentation was not completely updated and a certain amount of tacit knowledge could not be codified. Thus, Receiver's operators had to travel several times than expected to Sender for hands-on and face-to-face training provided by Sender's operator and engineers. This could increase the transfer time.	2
	Adaptability: The production could not be changed and adapted to Receiver's environment.	3
	Flexibility: Receiver was seeking a rather high transfer pace, because of the unutilized expensive equipment they had bought. Nonetheless, during the preparations phase, it became increasingly clear that a gradual transfer was necessary. To cope with the uncertainty, Sender decided to continue producing for a couple of months, until Receiver achieved a stable production. Moreover, since one of the reasons for the transfer was to release resources for innovation (Sender's core competency), the amount of resources Sender was willing to invest in the transfer was moderate. Yet, Sender assigned significant resources to travel to Spain and assist Receiver during transfer execution and start-up.	

3 Case Description and Analysis

The case we have studied is a PT of one acoustic sensor product family from the domestic production site of a major Norwegian corporate group (*Sender*) to a financially autonomous subsidiary in Spain (*Receiver*). The production was offshored in order to get better access to the developed customer market and to the material technology expertise at Receiver, as well as to reduce labor cost and delivery time. Sender was transferring all the production activities to Receiver, apart from the acoustic technology, which contained a high IP level. Thus, Receiver was required to assemble the acoustic technology into housings from vendors, and mold, assemble, test and deliver final products. The PT decision was taken in spring 16', the Preparations started in September and the Start-up is estimated to start in June 17'. Further empirical findings are presented in Table 2. As explained in Sect. 1, the Project owner and Sender's Quality & risk manager for the PT analyzed and ranked the risk factors according to their contribution to increased PT risk level; the assessment was conducted 6 months after the PT decision. In the table, we have only displayed an average of all the factors' rankings in each area. Risk-mitigation actions could be implemented for the risk factors (or areas) in descending priority i.e., first for factors with 3-high contribution to increased risk, etc.

4 Discussion and Conclusion

In the previous section, we applied a conceptual framework developed from literature on a PT case. The framework was able to capture all the risk factors that had arisen during the PT process, suggesting its usefulness as a simple checklist for identifying and evaluating risk factors. When performing the assessment together with the Project owner and Sender's Quality & Risk manager, it was revealed that Sender and Receiver had identified some of the risk factors during the PT, and implemented actions for those on the way. For instance, as presented in Table 2, during one analysis early in the preparations phase, personnel who had been retained at the customs office for more than one day because of incomplete documentation stressed the need to validate the transportation documentation for equipment and inventory before transfer. Thereby, several actions were taken to avoid this scenario again. However, the PT parties had also encountered a series of unexpected events during the PT, which might negatively affect the performance results. For instance, a long time after the initial PT decision, Sender realized that there would be less favorable trade agreements when selling Made-in-Spain products to major customers overseas, compared to Made-in-Norway. The Receiver purchasing capital-intensive equipment more than one year prior to actual use is another example. If the PT parties had conducted the risk assessment early in the process, they could have implemented actions and avoided some of the pitfalls encountered. Moreover, we propose that the suggested assessment tool could be applied on several occasions, such as when the transfer object is selected (especially the 'factors related to transfer object'), when the location and receiver are selected ('factors related to receiver'), and when the PT plan is created (the entire list). A team with experienced members from key disciplines could jointly analyze possible unwanted events generated by each risk factor and rank them. Risk-mitigation actions should be considered for the factors in descending priority i.e., first for factors with high scores, etc. As [10, 14] recommend, a cost-benefit evaluation should be conducted before choosing the actions. Thus, if the risk level is high, it is worth making high investments in e.g. expensive training, provided the profit impact is also high. Here one should also consider that it is recommended to rather prevent performance deviations than to correct them [16].

To conclude, we argue that the theoretical contribution of this study is the development of a conceptual framework based on a range of factors identified in literature, which seen through the risk management lens can be regarded as potential common risk factors in PTs. Moreover, the framework has been tested on a PT case together with experienced managers. Although a single case impedes the generalizability of the framework to other companies and industries, the empirical data is thoroughly collected during a period of 1 year, and it is reasonable to expect that part of the findings are applicable to other electronics producers and offshoring cases. Nonetheless, several types of PT cases should be studied and the PT risk assessment framework could be validated through a survey. In this paper, the empirical data indicates that a structured assessment of risk factors during the early stages of PTs can aid practitioners in mitigating the PT risk, and thereby improve future performance.

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Design of Hybrid Multimodal Logistic Hub Network with Postponement Strategy

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Abstract. This paper suggests a method allowing to design a hybrid logistic hub network in the context of mass customization, postponement being performed in hubs having industrial capabilities in addition to logistic ones. We propose a two-stage mathematical mixed integer linear programming model for: (1) logistic hub network design (2) postponement location in the designed network. The suggested model manages characteristics not yet taken into account simultaneously in the literature: hierarchical logistic structure, postponement strategy, multi-commodity, multi-packaging of goods (raw materials or components vs. final products), multi-period planning. The solutions are compared through service level and logistic costs.

Keywords: Hybrid logistic hub · Postponement · Mass customization · Service level · Hierarchical logistic structure · Multi-period · Multi-commodity

1 Introduction

The implementation of networks of logistic hubs usually allows to decrease transportation costs and delivery delays in comparison with direct source/destination transportation [1]. Within logistic hubs, material flows coming from different origins are sorted, consolidated according to their destination then transported using unimodal or multimodal transport. Two families of hubs can be distinguished: pure logistic hubs, providing standard logistic services (warehousing, inventory management, packaging, labeling, orders preparation or cross-docking, sorting and transport/distribution) and combined logistic/industrial hubs, offering high added-value services on logistics (such as co-packing) and/or industrial functionalities allowing the final customization of the product.

Late customization of products (often called "postponement") was considered for many years by some industries such as computers, printers, medical products and fertilizers [2]. Pushing this logic to its limits, multinational firms now attempt to customize their products within their distribution centers, like Hewlett-Packard producing DeskJet printers in its factory in Singapore and customizing them for the European and Asian markets within its European distribution center near Stuttgart. In that new context, this paper aims at defining the optimal design of a network of logistic

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hubs with postponement strategy integration, in a context of mass customization. The distribution network has four levels: production plants, regional logistic hubs, sub-regional logistic hubs, and urban/rural distribution centers. The network processes goods with possibly different packaging (raw materials/components and finished products). The main originality of this study is that the joint location of logistic hub and postponement units was rarely addressed in the literature on supply chain network design. This original concept challenges the classical production-distribution model where a clear distinction is made between production and distribution networks [3].

2 State of the Art

The hub network design problem, also known as the distribution network design problem, was intensively studied in the literature on global distribution networks [1, 4]. An analysis of this literature is summarized in Fig. 1.

Paper				Proposal	Melo and stefan (2006)	Rodríguez et al (2007)	Gelareh et al (2010)	Contreras et al (2011)	Alumur et al (2012_a)	Alumur et al (2012_b)	Albareda et al (2012)	Rieck et al (2014)	Alibeyg et al (2015)	Gelareh et al (2015)
Hub network structure	Single level					×	×	×	×		×	×	×	×
	Multiple levels			×	×					×				
Hub Features	Hub capacity	Uncapacitated hub		×			×	×	×	×	×	×	×	×
		Fixed			×	×						×		
		Extensible	Based on known capacity		×									
			To be determined											
	Hub services	Logistical hubs		×	×	×	×	×		×	×	×	×	×
		Industrial hubs		×										
Allocation strategy	Static (S)/ Dynamic (D)			S	D	S	S	S	S	S	S	S	S	D
	Single (S)/Multiple (M)			M/S		S	S	S	S	S	S		M	M
Transport Organization	Means of transportation	Transport Mode	Uni-modal			×	×	×			×	×	×	
			Multi-modal	×					×	×				
		Type of fleet of vehicles	Homogenous	×		×		×		×		×		
			Heterogenous											
		Vehicles capacity	Uncapacitated			×		×	×	×	×			
			Determined	×								×		
			To be determined											
	Transport packaging	Identical containers		×										
		Heterogeneous containers												
	Commodity information	Unitype												
		Multi-commodity		×										
	Service level	Time		×		×	×		×	×				
		Distance		×		×								

Fig. 1. Logistic hub network review analysis

Few authors consider a multi-level network [4], while no paper addresses the integration of industrial services. Origin and destination nodes might be either allocated to a unique hub or to multiple ones: [5] considers multiple allocation of clients to located hubs while [6] studies multiple allocation of plants and customers to intermediate hubs. Service level can be addressed through the definition of a maximum distance between distribution center and market zone [7] or through a delivery delay [8, 9]. Many papers assume that demand is deterministic, which is seldom true. Multiple commodity, allowing to consider products using different transportation means, is only considered by few researchers (cf. Fig. 1).

To our best knowledge, no paper considers a physical transformation of goods while transiting a hub (from bulk material to packs or pallets for instance). [10] states that one of the main characteristics of supply chain network design models is their multi-period nature. Many studies have analyzed the advantages and disadvantages of various postponement strategies [11–13]. However, quantitative models for postponement implementation decisions are scarce: [14] considers decisions on where to implement assembly and packaging functions in a distribution network while [15] addresses the problem of facility location-allocation (plants, warehouses) considering commonality and postponement strategies in the logistic network.

This quick analysis of the literature shows that no study gathers yet all the characteristics we have chosen to address in order to answer to present real problems, summarized by the "Proposal" column in Fig. 1.

3 Problem Formulation

The problem is to determine simultaneously the location of the logistic hubs and of the postponement services, while minimizing the total logistics costs. Postponement units will have as inputs raw materials and components coming from international plants, based on their specialization and logistic costs, and will provide bagged/assembled products in response to the requirements of the market zones. These requirements may differ in terms of packaging preferences and required response time. We assume that postponement units hold sufficient component inventories for meeting the customer deterministic demands. The capacities (processing and storage) will be determined a posteriori (through simulation) by considering the expected levels of service. Market zones are allocated to a unique hub based on logistic costs.

In this problem, the interdependence of the decisions makes it difficult to instantiate all the decision variables simultaneously: the location of postponement units will impact the management of the logistic flow, as they constitute decoupling points. On the other hand, their location depends on the location of the logistic hubs and of the allocated demand (volume, response time and product preferences). For addressing this problem, we have chosen as a first approach to decouple the initial problem in two sub problems: definition of the logistic network, then location of the postponements facilities, even if the network structure may in theory be set into question by the positioning of the postponement units. Each sub-problem will be modeled by a deterministic mixed integer linear programming models (cf. Sects. 3.1 and 3.2).

3.1 First Sub-problem: Logistic Hub Location Problem

Within this sub-problem we have to decide: (1) The location of hub h among potential locations H using the z_h binary variable (2) The allocation of the origin and destination nodes to the located hubs, using transport mode m represented by the $y^{m}_{o,d}$ binary variable defined only if a modal link between node "o" and "d" exists (Link (o, d, m) = 1) and (3) The flow routing within the network $x^{m,k,t}_{o,d}$ i.e. the amount of final product k originated from plant p and transported from node "o" to node "d" using vehicle mode m and under packaging n at period t. The generated solution must provide the max benefit considering the initial investment to open hubs, the total transportation costs including customs, the external handling cost with seaport terminal or rail terminals and the internal handling cost within opened hubs (Eq. 1):

$$Min(\text{Cost}) = \sum_{h\in H} co_h \times Am \times z_h + \sum_{m\in M,t\in T,o\in O,d\in D} (ct_m + cd^{m}_{o,d}) \times NV^{m,t}_{o,d} + \sum_{\substack{m\in M,n\in N,t\in T,\\ k\in K_p,o\in O,h\in H,\\ d\in D|o\neq h\neq d}} cm^{m}_{h} \times (NV^{m,t}_{o,h} + NV^{m,t}_{h,d}) + cm^{n}\_\text{int}_h \times (x^{m,k,t,n}_{o,h} + x^{m,k,t,n}_{h,d}) \times f^{n} \quad (1)$$

Subject to:

$$\sum_{m\in M,h\in H} y^{m}_{h,z} = z_h \,\forall h \in H \wedge z \in Dz \wedge Link(h,z,m) = 1 \quad (2)$$

$$\sum_{m\in M,h_1\in H} y^{m}_{h_1,h_2} = z_{h_2} \,\forall h_2 \in H \wedge Link(h_1,h_2,m) = 1 \quad (3)$$

$$\sum_{m\in M,h_1\in H} y^{m}_{h_1,h_2} = z_{h_2} \,\forall h_2 \in H \wedge Link(h_1,h_2,m) = 1 \quad (4)$$

$$y^{1}_{p,h} + y^{2}_{p,h} \leq 2 \times z_h \,\forall h \in H_1 \wedge \ \text{p} \in P \wedge m \in \{1,2\} \wedge Link(p,h,m) = 1 \quad (5)$$

$$y^{m}_{h_1,h_2} \leq z_{h1} \quad \forall m \in \{2,3\} \wedge h_1, \text{h}_2 \in H \wedge \text{Link}(h_1, \text{h}_2, \text{m}) = 1 \wedge \text{Dist}(\text{h}_1, \text{h}_2, \text{m}) \leq \text{D(m)} \quad (6)$$

$$y^{m}_{h_1,h_2} \leq z_{h2} \quad \forall m \in \{2,3\} \wedge h_1, \text{h}_2 \in H \wedge \text{Link}(h_1, \text{h}_2, \text{m}) = 1 \wedge \text{Dist}(\text{h}_1, \text{h}_2, \text{m}) \leq \text{D(m)} \quad (7)$$

$$y^{3}_{h,z} \leq z_h \quad \forall h \in H \wedge z \in Dz \wedge \text{Link}(h,z,3) = 1 \wedge \text{Dist(h,z,3)} \leq \text{D(3)} \quad (8)$$

$$x^{1,k,n,t,p}_{p,h_1} \leq BigM \times z_h \quad \forall h \in H1 \wedge \ \text{p} \in P_k \wedge k \in Kp \wedge t \in T \quad (9)$$

$$x^{m,k,t,p}_{h_1,h_2} \leq BigM \times z_{h_1} \quad \forall t \in T \wedge m \in \{2,3\} \wedge k \in K_p \wedge h_1 \in H \wedge Dist(h_1,h_2,m) \leq D(m) \quad (10)$$

$$x_{h,z}^{3,k,t,p} \leq BigM \times z_h \quad \forall t \in T \wedge \mathrm{h} \in H \wedge z \in Dz \wedge k \in K_p \wedge Dist(h,z,3) \leq D(3) \tag{11}$$

$$\sum_{p \in P_k} x_{o,d}^{m,k,n,t,p} \leq BigM \times y_{o,d}^{m}$$
$$\forall \mathrm{m} \in \mathrm{M} \wedge \mathrm{n} \in \mathrm{N} \wedge \mathrm{t} \in \mathrm{T} \wedge \ \mathrm{k} \in \mathrm{K}_p \wedge \mathrm{o} \in O \wedge \mathrm{d} \in D \wedge Link(o,d,m) = 1 \tag{12}$$

$$y_{o,d}^{m} \leq \sum_{p \in P_k} x_{o,d}^{m,k,n,t,p}$$
$$\forall \mathrm{m} \in \mathrm{M} \wedge n \in N \wedge \mathrm{t} \in \mathrm{T} \wedge \mathrm{k} \in \mathrm{K}_p \wedge \mathrm{o} \in O \wedge \mathrm{d} \in D \wedge Link(o,d,m) = 1 \tag{13}$$

$$\sum_{\substack{m \in M, \\ p \in P_k}} x_{p,h}^{m,k,n,t,p} = \sum_{m \in M, z \in Dz, h' \in H} x_{h,z}^{m,k,n,t+\Delta(p,h)+\theta,p} + x_{h,h'}^{m,k,n,t+\Delta(p,h)+\theta,p}$$
$$\forall k \in K \wedge \mathrm{h} \in H \wedge t \in T \tag{14}$$

$$\sum_{\substack{h_1 \in H, \\ m \in M}} x_{h_1,h_2}^{m,k,n,t,p} = \sum_{z \in Dz, m \in M} x_{h_2,z}^{m,k,n,t+\Delta(h_1,h_2)+\theta,p} \forall k \in K_p \wedge t \in T \wedge \mathrm{h}_2 \in H \tag{15}$$

$$\sum_{m \in M, h \in H} x_{h,d}^{m,k,t} = \mathrm{D}_z^{k,t} \times \mathrm{y}_{h,d}^{m} \quad \forall k \in K_p \wedge t \in T \wedge d \in D \tag{16}$$

$$NV_{o,d}^{m,t} \geq \sum_{k \in K_p} \frac{x_{o,d}^{m,k,t}}{CT_m \times f^n} \forall t \in T \wedge o \in O \wedge d \in D \wedge m \in M \wedge n \in N \tag{17}$$

Constraints (2, 3, 4) express the single allocation of nodes to hubs. Constraints (5, 6, 7, 8) control the allocation mode to physical links. Outgoing hub flows exist only if the hub is active (9, 10, 11) and require that this modal link should be already activated (12, 13). Constraints (14, 15) ensure flow conservation at each period of time where Δ (o, h) +θ is the sum of the transports to h and transit time within h. Outgoing flows toward distribution centers must be equal to their respective demand (16). Equation (17) computes the number of modal vehicles within the network where $\mathrm{CT_m}$ is the capacity of a vehicle.

3.2 Second Sub-problem: Postponement Location Problem

Given a set of located hubs Hl $\{\mathrm{h} \in \mathrm{H}/\check{\mathrm{z}}\mathrm{h} = 1\} \cup \mathrm{Dz}$ and a set of active links $\mathrm{L} = \{(\mathrm{o},\mathrm{d},\mathrm{m});\ \mathrm{o} \in \mathrm{O}, \mathrm{d} \in \mathrm{D}, \mathrm{m} \in \mathrm{M}/\hat{\mathrm{y}}_{\mathrm{o,d}}^{\mathrm{m}} = 1\}$, we have to select the suitable location of postponement units in the designed distribution network. Location can be either on regional hubs, sub-regional ones or on local distribution centers, in order to minimize the total logistic costs (Eq. 18) where $\mathrm{b_h^e}$ is a binary variable equal to 1 if the postponement unit is located on hub h at echelon e, while Bin (H, e) is a Boolean value equal to 1 if hub h is located at level e.

$$Min(\mathrm{Cos}\,t\_postp) = \sum_{h \in Hl, e \in E} co_h \times Am \times b_h^e$$
$$+ [\sum_{m \in M, t \in T, o \in O, d \in D} (ct_m^1 + cd_{o,d}^m + cm_m^1) \times NBV_{o,d}^{m,t} + \sum_{m \in M, t \in T, k \in K_b, o \in O, d \in D} cm_m^1\_\mathrm{int} \times x_{o,d}^{m,k,t}]$$
$$+ [\sum_{m \in M, t \in T, o \in O, d \in D} (ct_m^2 + cd_{o,d}^m + cm_m^2) \times NCV_{o,d}^{m,t} + \sum_{\substack{m \in M, t \in T, k \in K_c, \\ o \in O, d \in D, p \in Pk}} cm_m^2\_\mathrm{int} \times \bar{x}_{p,o,d}^{m,k,n,t}] \tag{18}$$

Subject to:

$$\sum_{e \in E} b_h^e = \widehat{z}_h \quad \forall \mathrm{h} \in H \wedge Bin(H, e) = 1 \tag{19}$$

$$\sum_{m \in M, p \in P_k} \mathrm{x}_{h_1,h_3}^{m,k,t} \leq \mathrm{BigM} \times \bar{y}_{h_1,h_2}^m \times \mathrm{b}_{h_3}^3 \quad \forall t \in T \wedge k \in K_b \wedge h_1, h_3 \in Hl \tag{20}$$

$$\sum_{m \in M, p \in P_k} \mathrm{x}_{h_1,h_2}^{m,k,t} \leq \mathrm{BigM} \times \bar{y}_{h_1,h_2}^m \times (\mathrm{b}_{h_2}^2 + \mathrm{b}_{h_3}^3) \quad \forall \mathrm{t} \in \mathrm{T} \wedge \mathrm{k} \in \mathrm{K}_b \wedge h_1, h_2, h_3 \in Hl \tag{21}$$

$$\sum_{m \in M} x_{h_2,z}^{m,k,t} = \sum_{\substack{m \in M, k' \in K_c, \\ p \in P_k}} \widehat{y}_{h_2,z}^m \times \bar{x}_{p,h_2,z}^{m,n,k',t+\Delta(h_2,z)+\theta} \times Conv(n) \times Cs(k, k') \times b_z^3$$
$$/\forall t \in T, h_2 \in Hl, z \in Dz, k \in K_b \tag{22}$$

$$\sum_{m \in M} x_{h_1,h_2}^{m,k,t} = \sum_{\substack{m, m' \in M, \\ k' \in K_c, \\ p \in P_k, z \in Dz}} \widehat{y}_{h_1,h_2}^m \times \widehat{y}_{h_2,z}^{m'} \times \bar{x}_{p,h_2,z}^{m',n,k',t+\Delta(h_1,h_2)+\theta} \times Conv(n) \times Cs(k, k') \times (1 - b_{h_1}^1)$$
$$/\forall t \in T, h_1, h_2 \in Hl, k \in K_b \tag{23}$$

$$\sum_{m \in M} x_{h_1,z}^{m,k,t} = \sum_{\substack{m \in M, k' \in K_c, \\ p \in P_k, z \in Dz}} \widehat{y}_{h_1,z}^m \times \bar{x}_{p,h_1,z}^{m,n,k',t+\Delta(h_1,h_2)+\theta} \times Conv(n) \times Cs(k, k') \times (1 - b_{h_1}^1)$$
$$/\forall t \in T, h_1, h_2 \in Hl, k \in K_b \tag{24}$$

$$NBV_{o,d}^{m,t} \geq \sum_{k \in K_b, p \in P_k} \frac{x_{p,o,d}^{m,k,t}}{CT_m^1} \times NV_m; \quad \forall t \in T \wedge m \in M \wedge h \in Hl \wedge h_3 \in Dz \tag{25}$$

$$NCV_{h,h_3}^{m,t} \geq \sum_{e \in E} b_h^e \times [\sum_{k \in K_c, p \in P_k, n \in N} \frac{\bar{x}_{p,h,h_3}^{m,k,n,t}}{CT_m^2 \times f^n}] / \forall t \in T \wedge m \in M \wedge h \in Hl \wedge h_3 \in Dz \tag{26}$$

$$NCV^{m,t}_{h_2,h_3} \geq (b^1_{h_1} + b^2_{h_2}) \times [\sum_{\substack{k \in K_c, \\ p \in P_{k,} n \in Pg}} \frac{\bar{x}^{m,n,k,t}_{p,h_2,h_3}}{CT^2_m \times f^n}] / \forall t \in T \wedge m \in M \wedge h_1, h_2 \in Hl \wedge h_3 \in \mathrm{Dz} \quad (27)$$

Constraint (19) translates that a postponement activity can only be located on activated hubs, at only one level. "Continuous flows" $x^{m,k,t}_{o,h}$ exist only if postponement units are located before that hub if a modal link is activated (20, 21). (22, 23, 24) express a flow balance at each period and on each hub and computes the ingoing discrete flows to each hub depending on location of postponement units. Conv(n) is the conversion ratio from unit of packaging product under n commodity to a continuous unit (tons for example) and Cs(k, k') is the amount of component k needed to produce a unit of product k'. (25, 26, 27) assess the number of bulk and container vehicles within the network.

4 Illustrative Study

This case study aims to illustrate the application of the proposed models. It concerns the location of blending units within East Africa for specific industries involving hybrid (discrete-continuous) flows, like the fertilizer industry. Three production zones located in Morocco, Ethiopia and Nigeria and considered. Five Regional hubs are defined: Kenya-Angola-Tanzania-Djibouti, so that ten sub-regional hubs: Nairobi-Kisumu-Dodoma-Arusha-Tabora-Kuito-Tete-Lichinga-Kigali. The considered data are summarized in Tables 1 and 2. The demand (aggregated on one year) varies for each zone. We assume that shipment is done every month and that all the market zones require the same service level. Distances and traveling times are extracted from Google Maps. The problem was solved using the Xpress-IVE solver tools. The results of models 1 and 2 are summarized in Tables 3 and 4.

Table 1. List of transport cost parameter

Parameter	Discrete flow	Continuous flow
Transport capacity-sea	50 palette	30000 tons
Transport capacity-rail	40 palette	25000 tons
Transport capacity-road	40 palette	25000 tons
Rail unit transport cost	0.06/train/km	0.04/Train/km
Road unit transport cost	3.75$/truck/km	2$/truck/km

Table 2. List of other cost parameters

Cost	Regional hub	Sub-regional hub
Hub location cost ($/year)	5760000	2880000
Blending location	30000	30000
Intern handling (bulk)	15$/tons	35$/tons
Extern handling (rail)	100$/train	120$/train
Intern handling (discrete)	5$/palette	10$/palette
Extern handling (rail) (discrete)	40$/train	50$/train

Table 3. Results of sub-model 1

Located hub	Plant	Sub-hub	% DC
Kenya	Morocco Ethiopia	Kisumu-Lichingua	25%
Mozambique	Morocco	Tete	10%
Angola	Nigeria	luau	10%
Tanzania	Morocco Ethiopia	Kuito-Kigali	10%

Total logistic cost	216 M$
Sea Transport	9.52 M$
Rail Transport	8.75 M$
Road Transport	21.97 M$
Intern handling	109.45 M$
Extern handling	26890.5 $
Location	66.3 M$

Table 4. Results of sub-model 2

Blending location	Kenya-Mozambique-Angola-Tanzania
Level	1

Total logistic cost	157 M$
Total bulk costs	47.1 M$
Total discrete costs	109.9 M$

The location of the blending within the distribution network is the result of a comparison between investments and operational costs linked to postponement and to the transportation of bulk and packed materials. Especially, it requires to compare the profit generated by several small blending units, close to the final customers, and the one of larger units, located earlier in the network but requiring more time to adapt their production to the final demand. In real cases, good sense is not sufficient to figure out this decision problem. Our model helps the decision maker to assess quantitatively each possible solution.

5 Conclusion and Research Perspectives

In the context of mass customization, postponement activities may provide an answer to fulfill customized orders, increase customer responsiveness and increase service level. However, the literature combining design of logistic hub networks and implementation of postponement facilities is scarce and usually assumes that the location of the distribution centers is already known. In order to address the problem, we have developed and tested a two-phase deterministic mathematical programming model where, as a first step, we design incapacitated discrete logistic hub, then allocate postponement services on some hubs. In our future work, this model will be coupled with a discrete event simulation model in order to take into consideration uncertainties on the demand and on the availability of the resources. Simulation will also allow to assess postponement capacities and to refine logistic costs, these results being re-injected in the mathematical model as new constraints.

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Collaborative Process Planning on Route Market Platform

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Abstract. In order for a group of manufacturing SMEs to become competitive as a team, each of them should have its own strength and the strength must be united into an appealing process plan suitable for the specification of every manufacturing order. Since the detailed knowledge on the capability of each SME is owned only by the SME itself and often difficult to be disclosed to public, it is a big challenge how to properly incorporate the strength into the process plan without a single planner who knows the details of the capabilities of all SMEs. This paper calls this task as collaborative process planning, and proposes how to refine and utilize the platform of *Route Market*, which was originally developed by the authors for geographical route recommendation service, for the task.

Keywords: Collaborative design · Collective intelligence · Networked SMEs · Process planning · Prediction markets

1 Introduction

There are usually several possible processing routes for manufacturing a specific part, and which to choose among them is an important decision for a manufacturer, since it affects the production costs, lead-time, and quality of the part. The task of making this decision is called process planning. Most process planning problems are mathematically captured as a problem of selecting a suitable path in a network of candidate process elements. For example, D'Souza (2006) discusses how to obtain such a network for 2.5D pocket machining process. If only a single objective function needs to be considered for each path and the function is additive in terms of the arcs, the problem becomes a well-known shortest path problem and can be solved through a suitable algorithm such as Dijkstra's algorithm. Otherwise, the problem becomes a more cumbersome combinatorial optimization problem, and it is often handled through a meta-heuristic approach. For example, Awadh et al. (1995) and Ahmed et al. (2010) applied genetic algorithms to such a process planning problem. Whereas, Li et al. (2008) employed

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genetic programming, and Wang et al. (2015) utilized ant colony optimization, respectively.

Thus, if the topology of the network connecting possible process elements and the attributes of each element relevant to the objective function(s) are known to a planner, what remains to be done by the planner is to solve the resultant optimization problem. However, when a group of manufacturing SMEs try to respond to various manufacturing orders competitively as a team, a different challenge emerges. To attain this goal, the strength of each SME should be united into an appealing process plan suitable for the specification of each manufacturing order. However, since the detailed knowledge on the capability of each SME is owned only by the SME itself and often difficult to be disclosed to public, this should be accomplished without a single planner who knows the details of the capabilities of all SMEs. This paper calls this challenging task as collaborative process planning, and proposes an approach to the problem utilizing *Route Market* as the platform.

Route Market is a geographical route recommendation service proposed by the authors (Beppu et al. 2016). This service collects information on the topology of the road network and relevant conditions of any part of the network from crowds in an incentive-compatible way using the mechanism of prediction markets, and provides several suitable routes to the one raised a query about the route. What this service carries out is to choose suitable paths in an network utilizing the collective knowledge of the crowds. When replacing the road network with the network of process elements and crowds with SMEs, it becomes apparent that this task is isomorphic to collaborative process planning. In the remainder, collaborative process planning problem is formally described first, and then how *Route Market* can be modified and used as a solution platform for the problem is disscussed.

2 Collaborative Process Planning Problem

We consider a situation where a group of manufacturing SMEs try to win or received a manufacturing order of a part, and need to design a suitable process plan for it collaboratively as a team. The manufacturing order can be captured as a transformation of a given raw material into a specified finished part. The transformation can be made through applying several process elements to the material one by one, such as milling, drilling, polishing, etc., and there are many optional sequences of process elements, i.e. process plans, for the part. The SMEs have different capabilities in processing the part. For example, one may be good at drilling a long narrow hole into a stainless steel block in a high speed. These capabilities should be united appropriately into the plan. However, the details of the capability of each SME is private information of the SME.

When the SMEs' capabilities are known, all applicable process elements and executable process plans by them can be represented by a directed graph.

$$G = (V, A) \tag{1}$$

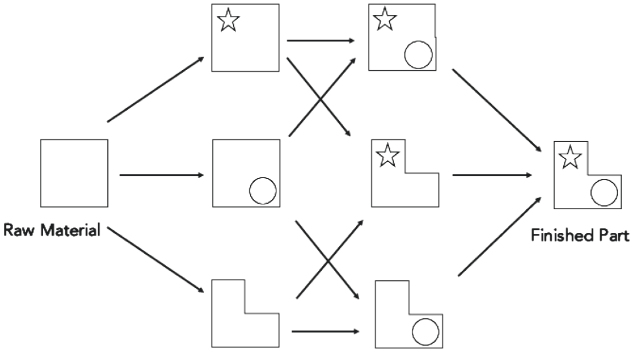

Fig. 1. Example: process element network

This is a network like Fig. 1, for example. In this network, a node $v \in V$ indicates the shape of a work (in progress), and each arc $a \in A$ indicates a process element. Especially, the start node v_S represents the raw material and the end node v_E corresponds to the finished part. Any path from v_S to v_E is a processing route and is denoted by p, and the set of all feasible processing routes is represented by Ω. A processing route $p \in \Omega$ is an ordered set of process elements a (process elements included in the processing route p).

The entity placed the manufacturing order expects that the part can be manufactured in a low production costs, a short processing lead-time, and a high quality (in terms of the tolerance, surface roughness, dimensional error, shape error, etc.). If the costs for carrying out the process element a is denoted by $c(a)$, the whole production costs of the processing route p can be defined by the following equation.

$$c_P(p) = \sum_{a \in p} c(a) \tag{2}$$

Similarly, if how long it takes to carry out the process element a is denoted by $t(a)$, the whole processing lead-time of the processing route p can be calculated as

$$t_P(p) = \sum_{a \in p} t(a) \tag{3}$$

Further, we denote the quality characteristics, such as those described above, which can be evaluated after executing the process element a as $q(a)$, and express the overall production quality obtained through a processing route p by a set $q_P(p)$ as follows.

$$q_P(p) = \{q(a) | a \in p\} \tag{4}$$

Then, how the orderer prefers a processing route p can be evaluated by a multi-attribute utility function

$$F(c_P(p), t_P(p), q_P(p)) \tag{5}$$

and the process planning problem can be captured as a problem of selecting a processing route p that maximizes $F(c_P(p), t_P(p), q_P(p))$.

In the situation we consider in this paper, where a group of SMEs need to deal with this problem collaboratively, each SME may have its own special manufacturing capability, such as drilling a long narrow hole into a stainless steel block in a high speed. Further, the details of such capability is basically private information of the SME, and hence it is difficult to exhaustively capture the possible process elements as well as to properly evaluate their cost, lead-time and quality without collecting relevant private information from the SMEs.

This means that, if we denote the process element network constructed based only on common knowledge by G_0, it is not sufficient to find an optimal path p in G_0 in terms of the objective function $F(c_P(p), t_P(p), q_P(p))$. It is also important to refine the network G_0 into $G_1, G_2, G_3, \ldots$ by incorporating relevant private information of the SMEs little by little. Thus, the collaborative process planning problem considered in this paper can be modeled as a problem of refining the process element network G_n and find an suitable path p in it in terms of $F(c_P(p), t_P(p), q_P(p))$ through interactions among the SMEs. In general, the more informative the final network G_n is, the more preferable the output processing route will be.

3 Route Market for Collaborative Process Planning

The original *Route Market* is refined so that it can be used as a platform for collaborative process planning. The refined *Route Market* system links an orderer who poses a manufacturing order of a part and a group of manufacturing SEMs who undertake the processing of the part as a team, and presents some recommended processing routes to the orderer based on the information collected from the SMEs. First, the orderer provides technical specifications of the manufacturing order, that is, detailed descriptions of the raw material v_S and the finished part v_E. Then, the SMEs can clearly understand that the process of transforming v_S into v_E should be designed. The orderer is also expected to present information on its preference, that is, how to balance the production costs, processing lead-times, production quality, etc.

Then, a baseline process element network G_0 is constructed based on common knowledge and shown to SMEs. The SEMs are expected to (re-)evaluate candidate process elements and processing routes in the network according to their own technical capabilities and engineering knowledge. They are also invited to provide a reason behind the evaluation. In addition, they can refine the network by adding some new process elements to it. The system summarizes the reasons and evaluations provided by the SEMs, and indicates several highly-evaluated processing routes. At the end, those recommended routes are shown to the orderer with the reasons supporting them collected from the SMEs. Then, the orderer selects one that best meets its preference among the presented processing routes.

This system uses the mechanism of prediction markets for motivating the SMEs to evaluate candidate paths and provide relevant information. Prediction markets are the market of a prediction security whose worth depends on the unknown realized value of a certain random variable of interest, and thus the market price of the security provides a dynamic forecast of the random variable reflecting the collective knowledge of the traders. This approach can be applied not only to forecasting problems but also to decision-making problems (Chen and Pennock 2010; Plott 2000).

The prediction market used in the proposed system is designed according to the authors' earlier work (Mizuyama 2012; Mizuyama et al. 2013). The prediction market utilizes two types of prediction securities. One is a winner-take-all security for each path $p \in \Omega$, to which a fixed amount payoff will be given if and only if p is chosen by the orderer and the orderer confirms that the path was satisfactory. Hereafter, this is called path security p. The other is a security corresponding to each arc $a \in A$, to which a fixed amount payoff will be given if and only if is included in the chosen path. Hereafter, this is called arc security a.

Path securities are useful for the system to compare different candidate routes. We can regard the price of p as the evaluation of the corresponding processing route. However, it is not straightforward for the SMEs to directly trade them, especially when they are familiar with only a specific type of process elements. Thus, the proposed system lets the SMEs trade arc securities instead of path securities, and relate the two security types by treating each arc security a as a bundle of path securities $p(a \in p)$.

3.1 How to Refine Network Topology

In order to refine the topology of the process element network, the SMEs are allowed to add new arcs to the network. For example, when a certain SEM owns an advanced processing technology and the technology makes it possible to translate a work in progress corresponding to a node in the network into a shape specified by another node but the nodes are not connected with an arc, they can be connected with a new arc, as shown in Fig. 2. How to maintain the consistency among the securities when an arc is added is discussed in (Mizuyama 2012).

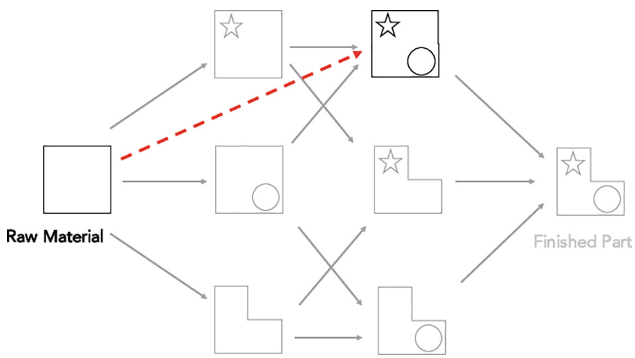

Fig. 2. Example: adding an arc

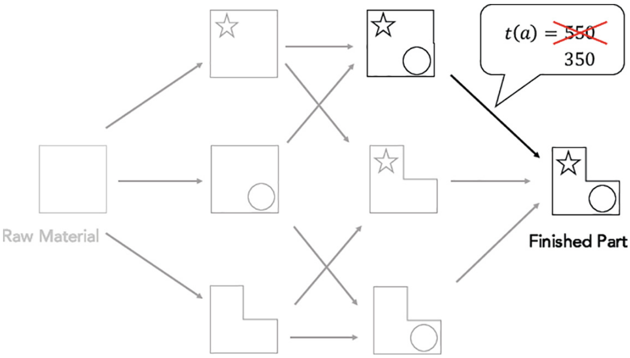

Fig. 3. Example: providing comments

3.2 Comment Function

In the proposed system, the SMEs are also supposed to contribute information about the arcs. They can provide each arc with information related to the processing lead-time, production costs and quality, as shown in Fig. 3. The provided information on the arcs contained in each recommended path is shown to the orderer, when the market is closed.

3.3 Market Maker

To preserve smoothness in transactions, the prediction market in the proposed system utilizes an automated market maker. The most widely-used market maker algorithm for a prediction market is LMSR (Hanson 2003; Hanson 2007), but, if it is to be used as is, it cannot handle topological changes of the network. Thus, LMSR was extended, so that it can be used in the proposed system (Mizuyama 2012). A specific algorithm for this extended LMSR is described below.

The candidate process elements derived by common knowledge comprises the initial network G_0, and it is updated as $G_1, G_2, G_3, \dots$ by adding arcs one by one. We denote the set of processing routes included in the process element networks as $\Omega_0, \Omega_1, \Omega_2, \Omega_3, \dots$. It is noted here that deleting arcs is not necessary. If a certain arc is regarded to be useless, $F(c_P(p), t_P(p), q_P(p))$ will be decreased for all p $(a \in p)$. Thus, we can assume tnat $\Omega_0 \subseteq \Omega_1 \subseteq \Omega_2 \subseteq \Omega_3, \dots$ holds.

Let's denote the current process element network by G_i and the set of all new process elements which can be added to it as O_i. Then, by treating O_i as a single unknown route, the definition of the processing route set Ω can be modified as follows.

$$\Omega = \Omega_i \cup O_i \tag{6}$$

Assuming that there are K SMEs and letting q_{kp} be the number of path security p possessed by SME k, the total number of path securities p is given by the following equation.

$$Q_p = \sum_{k=1}^{K} q_{kp} \tag{7}$$

Then, the cost function for trading is defined by the following equation,

$$C(\boldsymbol{Q}) = b \cdot \log \left[\sum_{p \in \Omega} s_p \cdot \exp(\frac{Q_p}{b}) \right] \tag{8}$$

where Q_{O_i} for unknown path O_i is always 0. Then, the probability of p becoming the best process route s_p is equally initialized to $s_p = \frac{1}{|\Omega_0|+1}$, when there is no prior information. The value of parameter b is adjusted according to the size of the prediction market.

When a SME buys and sells Δq of path securities, the SME pays the following amount

$$C(\boldsymbol{Q} + \boldsymbol{\Delta q}) - C(\boldsymbol{Q}) \tag{9}$$

The price expression of the path security p is as follows.

$$price_p = \frac{s_p \cdot \exp(\frac{Q_p}{b})}{\sum_{p' \in \Omega} s_{p'} \cdot \exp(\frac{Q_{p'}}{b})} \tag{10}$$

We next consider the case when the network topology is changed from G_i to G_{i+1}. In this case, the set of newly added routes $\Delta\Omega_i = \Omega_{i+1} - \Omega_i$ is regarded to be taken out from the unknown route set O_i. Therefore, the total sales number and prior probability of the processing route $p \in \Delta\Omega_i$ are set as follows.

$$Q_p = 0 \tag{11}$$

$$s_p = \frac{s_{O_i}}{|\Delta\Omega_i| + 1} \tag{12}$$

However, the arc securities corresponding to an existing arc a included in the network G_i are already sold and it may be the case that $Q_a \neq 0$ $(\exists a \in p)$ holds at this point. This causes inconsistency. Therefore, we let the market maker keep the difference, so that $Q_p = 0$ holds.

4 Conclusions

This paper first formulates collaborative process planning problem which is faced by a networked manufacturing SMEs. Process planning is modeled as a problem of selecting a suitable path in a network representing the possible process elements and their sequences. However, none has the whole picture of the network, but the SMEs only know different aspects of it. Under the circumstances, the challenge is not simply solving an optimization problem, but also contains the phase of formulating what problem to solve, or what network to deal with. Next, the paper refines *Route Market*, which is originally developed for geographical route recommendation service, so that it can be used as a platform for collaborative process planning and describes how it works. Future research directions include testing it in a practical case.

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Continuous vs Step Change Production Process Improvement as Enablers for Product Redesign and New Market Opportunities

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Abstract. Firms competing in global markets have to rapidly improve and innovate their products, processes, value chains and business models. Innovations can originate from a multitude of sources, where market needs and technology push are about the most common. However, company internal efforts towards incremental improvements of production processes can sum up to achieve breakthrough product innovations. This study focuses on the dynamic between process and product development, and bring about new knowledge on how systematic improvements of technological and organizational aspects related to manufacturing affects product innovation. We hypothesize that in global and mature markets and dispersed value chains the effect of mutual understanding and close collaboration between process- and product development can lead to breakthrough innovations at least as fast as by focusing on step change and disruptive process innovations. To explore this hypothesis we have conducted a case study, exploring two companies according to what we categorize as; the continuous improvement approach and the disruptive approach. Findings demonstrate that neither of the approaches necessarily respond to the ever-increasing requirement to reduce time-to-market, but a set of barriers and enablers that together with contextual issues, supports step changes on products and processes.

Keywords: Exploration · Exploitation · Product redesign

1 Introduction

Increasing pressure to develop products of higher quality, with added functionality, at a lower cost, and in shorter time frames unquestionably brings about some dichotomies. The examples of high quality vs. low cost, less resources and time vs. higher performance, and increased robustness vs. lower weight all illustrate well known contradictions which become more and more important to balance and optimize. Only companies that can manage such conflicting objectives and in an adaptive manner consistently and timely bring new and innovative products to the market will be regarded as long-term partners. Advances in information and communication technology, cross functional

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teams, overlapping processes, platform and module thinking, standardization of processes, and project management techniques have in various ways been introduced to keep up the pace of the product development process. However, implementations of such attempts have in many cases been only partial successful, suffering from lack of involvement and coordination. In this regard, Utterback [1] claimed that the main challenge is to develop the ability to innovate products, processes, and the organization, seeing them dependent of each other as a whole. This paper aims at investigate how company maturity affects the relation between process- and product development and how this relation support levels of innovation.

2 Theory

A brief description of capabilities seen from three main approaches to product development are; the strategic viewpoint of Ansoff [2] and Porter [3, 4] which identifies product development as an instrument to achieve superior market positions, the firm level (see Prahalad and Hamel [5] and Wernerfelt [6]) which identifies resource utilization as a driving force behind successful product development and competitive advantage, and a third stream of literature, with contributors like Nelson and Winter [7] and Utterback [1], concluding that technological and organizational progress is driven by mechanisms of variation, selection, and retention.

Many firms will not see any dichotomies in these approaches; rather they will see them as a complementary mix of necessary focal areas at any given time. Another way to perceive these approaches is viewing the market-based perspective as rather static and outside-in focused, the resource-based as inside-out focused, whereas the evolutionary aspect adds dynamics to the whole. History shows that humans continuously have tried to polarise theories describing how we can improve the environment we are part of. Studies of society back in the 1950s sought to distinguish between the nature of social order and equilibrium on the one side and change and conflict on the other [8]. This order and conflict debate has been partly moderated, or as Burrell and Morgan (1979) put it; “outnumbered by order theorists”. They also try to moderate the notion “order vs conflict” into the respectively terms regulation vs radical change. Theorists of the latter domain are concerned about finding explanations and drivers behind those justifying structural conflicts, contradictions, modes of domination, deprivation and radical changes, whereas followers of the regulation approach support the status quo, social order, consensus, social integration and system satisfaction. Transforming this philosophical and social theoretical distinctions into the domains of socio-technical studies and manufacturing management, we can argue that the following dimensions represent fundamentals and component characteristics of the regulation vs radical change perspective: Continuous improvement vs Innovation [9], Kaizen vs Kaikaku (process innovation) [10], Exploitation vs Exploration [11], Lean vs Radical innovation (step change) [12], and Stability vs Disruptive innovation [13].

Incremental innovation is characterized by a firm’s current abilities to conduct small changes to its technological trajectory [14]. To achieve a continuous stream of such changes in a structured and strategic way initiatives such as lean production, Six Sigma and TQM have been extensively introduced in manufacturing organizations.

The baseline for incremental innovation is standardized operational routines, in order to decrease variation and to discover performance gaps as opportunities for improvement. What these process management tools all have in common is that they seek to build capabilities for continuously and incremental innovations in operations [15]. A variant of incremental innovation is Continuous improvement, which is defined as “a systematic effort to seek out and apply new ways of doing work i.e. actively and repeatedly making process improvements” [16]. The main difference between these two approaches is that incremental innovation to some extent requires support from different organizational functions to be realized – whilst continuous improvement is something that can be initiated and realized at operational team level.

On the other hand, radical innovation is characterized by fundamentally changing the technological trajectory in an organization, and is often associated with searching and exploration, experimentation, risk and a break with the existing stock of knowledge. Hence, going in that direction requires exploratory efforts toward creating new competence and knowledge [14]. The goal of such an effort is mainly to develop new products/services that fulfils unspoken needs and wants in existing as well as new and emergent markets. This stream of literature is relatively sparse in having examples from process technology development and manufacturing industry in general, but Aylen describes such innovative activities with regards to new plants and the scrapping of old technology [17]. Traditional product development may have ingredients of radical innovation, at least in the fuzzy front where variants and alternatives are valuable input to a more structured process aiming at improve the properties and performance of a physical product [18]. Implications from such a process may be reengineering or modification of the manufacturing process.

Proponents of process management and incremental and continuous innovation argue that such a focus lead to organizational benefits as increased yields, less rework and waste, cost reductions and faster delivery times [16]. However, studies have shown that following a strategy entirely promoting incremental changes may over time suffer subsequent financial losses. One explanation for being trapped into such a situation is that by removing variation-increasing activities it also removes an organization`s ability to adapt outside its established technological trajectories [14]. By following a pure exploration strategy, the risk may aggregate to levels of threating the business so it may survive to reap the benefits of the investments [19].

A metaphor of ambidexterity has been coined by researchers to describe the ability of an organization to maintain dual attention on exploration and exploitation activities in order to survive and excel the present and secure the future. Managing this duality is a challenge as organizational structure, culture, activities, time span and activities all are elements of different nature, or contradictory at times, depending on degree of exploration and exploitation. However increasingly dynamic business environments forces organizations to pay attention to, and to balance both [20]. In its essence, the unknown have to be discovered or explored, and the known have to be exploited, to generate profit for the organization. Exploration involves activities such as search, variation, risk taking, experimentation, discovery, and innovation – and exploitation involves activities such as refinement, efficiency, selection, implementation, and execution [11]. There are many elements dividing these two trajectories, indeed one important distinction is that exploration is said to rely on double-loop learning while exploitation involves single-loop learning [21].

In 1994 Utterback proposed that process and product innovation is interlinked, but could be differentiated into stages [1]. Thus an organization can balance the continuity and change in time, having long periods of consolidation combined with short periods of discontinuous change [22]. However, degree of organizational adaptation may be hampered by such an approach and it adds complexity to organizational structure and flexibility. Burgelman supposed a dynamic and autonomous strategy process to overcome the issue of flexibility and to solve the concept of organizational ambidexterity [23]. Similar thoughts are evident in discussions on static versus dynamic efficiency and leverage versus stretch [5]. The main conclusion from this discourse is that successful firms are engaged in two types of strategic activities, both for product and process development, which have different resource needs and outcomes.

3 Method

A case study is one of several ways of doing social science and understanding complex social phenomena, used in many situations to contribute to our knowledge of groups, organizations and related phenomena within a real life context [24]. Aase studies have become a very powerful research method, often dealing with a growing magnitude of changes over lesser and lesser time [25]. When conducting case studies construct validity it is important; to attain data that describes the phenomenon we are studying and that data can be separated from other phenomenon data [26]. External validity concerns how much can be generalized beyond the case itself. It is generally believed that multiple cases have a higher external validity than single cases.

This study includes two Norwegian case companies that we as researchers have followed in more than 5 years prior to writing this article. Our basis for empirical findings is observations, formal and unformal meetings, interviews and documents made available to us. The empirical data were categorized according to a model of the firms, see Fig. 1.

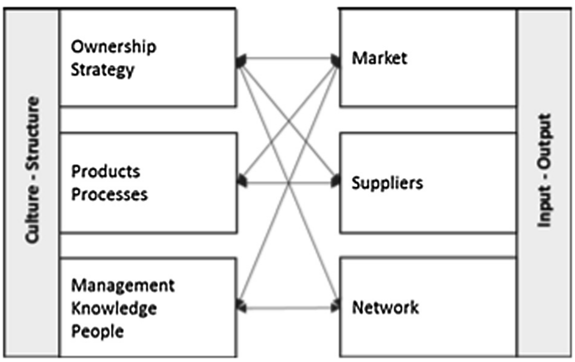

Fig. 1. Method for case studies. Intern factors in the left side, external factors on the right side.

The model include internal and external factors. The internal factors are ownership, strategy, products and processes, management, knowledge and people, whereas external factors embrace market, suppliers and network. These factors are highlighted in the findings section below.

4 Results

4.1 Case Description

Case A is a subsidiary of a multinational company developing and producing components and systems for utility vehicles. The company as a whole employs more than 10.000 employees and had in 2016 a revenue of about one billion USD across 30 production facilities globally. The case unit has about 240 employees.

Case B is a company which was established 8–9 years ago based on an idea of producing complex light weight parts by an innovative additive manufacturing process. The case company has today about 60 employees; all directed towards research and development activities to unleash the technology potential. The revenue stream is so far in the level of 1.5 million USD.

4.2 Findings

Case A is a supplier for the commercial vehicle market globally and is producing **multi-material parts** that must fulfill high demands on quality and safety. The production volume can be categorized as **mass production**, but the number of product variants are increasing so the production system is challenged by the flexibility criteria. Production is fully automated and the factory is designed to run unmanned for periods of time. Further, ambitions are to reduce cycle times and to produce according to zero defect manufacturing principles, where quality at an even larger extent has to be built into the product and the process to achieve in-line and real time quality control. These processes need to be interlinked through an automated component handling system, and each separate process needs to be reconfigurable to a new product variant within the timeframe of one cycle due to required flexibility and volume.

An interesting feature is that the case company in order to be an attractive and challenging workplace, has kicked-off a programme aiming at enabling **operators**, maintenance personnel and technicians to design and build next generation machines and equipment. The reasoning behind such a programme is that these resources have the best knowledge about existing capabilities and requirements, hence being able to convert these experiences into building robust machines producing zero defects. This new and integrative way of working aims to combine both technology utilisation and attractive work content, in line with the Industry 4.0 concept. Moreover, the company stresses high intellectual property on both products and processes. The manager has a long-term vision for the combined development efforts in the company. The approach for reaching the vision is sequentially working on very restricted, but critical technical tasks with regard to product and process, that combined will results in step changes to the product and might open new market opportunities. The company is **organized** as a relatively integrated product, process and production unit, but where support functions as product development, quality, and performance are reporting into a global matrix structure.

The main **strategy** for the subsidiary, among many others in the company, is to produce as cost effective, with outstanding quality, as possible to attract new and existing customers as well as internal positive attention towards receiving new investments and products to produce. The **market** is stable in the western world and growing in Asia, but the case company aims at taking a greater share of the existing market because their products support light-weight criteria in global environmental regulations. **Network** is important to the company, especially related to extend R&D efforts. Numerous R&D projects with external research institutes and universities have been carried out to improve products and processes combined. Additionally, the company representatives are nurturing direct and close relations to external experts; frequently receiving feedback on ideas and securing state of art knowledge. Collaboration with suppliers is also present, especially for developing critical tooling parts.

Case B is a company founded on an idea of producing **complex light-weight parts** by an innovative **additive manufacturing process**. Considerably research and development has been directed towards generating new knowledge about the specific and patented manufacturing process the last five years in order to scale up production to reach customer tact time. The new process aims at save time, cost and material usage throughout the extended value chain, and that rapidly and seamlessly can be configured to a broad portfolio of new products for different market applications. specially the transport sector and particularly the aerospace industry will benefit from successfully bringing this technology to an accepted readiness level. The market outlook views opportunities for a growing number of component variants, which needs to be met by flexibility in manufacturing and a set-up for frequent product introductions. Much effort is placed to industrialize the processes into a stable and repetitive production system. There are no or little room for launching product errors as a newcomer to a relatively conservative market for critical and structural components for use in for instance the aerospace industry. Thus, developing, utilizing and combining enabling technologies to create a zero defect manufacturing system is of crucial importance for a manufacturer of high-value, high-performance, and custom designed parts.

The knowledge base of the company is very strong in terms of formal education and experience, where a great number of the employees have a PhD or master degree. Extensive frontloading is to be found in the company, where near 60 employees are working on particular tasks as preparation for a product sales. The researchers and developers are **organized** into functional departments responsible for different parts of the value chain, where they have outlined a strategy for building an integrated value chain from raw material to finished products. From the relative short lifetime of the company and the ambitious goal, a more entrepreneurial or flexible organization might be expected.

The **market** demand for products from this process is expected to grow by 6% per year in the years to come, especially due to the high strength/weight ratio of the material. Developing a strong **supplier** base is not high on the agenda at the moment. The **network** is currently external R&D resources involved in improving material properties, critical processes, and manufacturing efficiency.

5 Discussions and Conclusion

The first case company seeks innovation by summing up a number of continuous improvements and sequentially efforts of incremental innovation. These improvements are often combined product and process innovations, but each incremental step can occur in timely manner indicating that the time for realizing a breakthrough innovation in the market takes time. Company structure, core competence focus, performance, incitement systems and a considerably market maturity underpins that major innovations has to follow an incremental path. This is in line with Tushman, claiming that the focus on variation reduction and search for incremental improvements in routines, will lead to increased incremental innovation, exploiting existing capabilities [27]. The second case demonstrates that bringing a technology from a low to acceptable technology readiness level, at the same time as it intends to substitute a functioning and well-proven technology, is time and resource consuming. The capital needed is considerable and number of risk factors brings about an organization that focuses strongly on R&D. For case B the outcome of the innovation process is intended to be breakthrough, still the process is very structured and contradictory to theories telling that such innovation journeys should take on a more explorative approach. Christensen and Overdorf argue that having the right resources in the early years of an organization is of the greatest importance, but when the organization matures capabilities shift more towards processes and values [28]. Thus, even though having the right resources a mature organization can have processes and values so powerful that it almost does not matter which people are assigned to which project. Analysing the innovation approach, whether continuous improvement or disruptive, based on an internal and external factor model demonstrates that neither of the approaches necessarily respond to the ever increasing requirement to reduce time-to-market in mature markets. This model can be supportive in defining contextual issues, barriers and enablers for innovation and guidelines for enabling the organization for bringing new products to the market in an ever-faster phase.

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Cluster Competitiveness Analysis: A Brazilian Case

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Abstract. The objective of this study was to compare the factors related to the development stage and the level of competitiveness of the furniture cluster located in the northwestern region of Paraná/Brazil. For the development of the research, descriptive approaches with quantitative and qualitative procedures were used. As a data collection instrument, a cross-sectional survey was applied with 20 companies in the sector. The data were interpreted from a statistical analysis using the average of the relative frequencies. The results indicated that the competitiveness index is unfavorable and the cluster is in initial stage, pointing out fragility, mainly in the item government policies.

Keywords: Cluster · Competitiveness factors · Cluster ranking

1 Introduction

Organizations need competitiveness to manage their businesses, in face of the turbulence imposed by the globalized economic environment [1]. In addition, companies are seeking to adjust to the new competitiveness standards, to the impact of technologies on competitiveness, to cultural influences and to different interfering factors in the organizations routines [2, 3].

The management of local productive arrangements (LPA), through collective actions between the companies, whether they are suppliers of goods or services, is an impressible strategy to obtain competitive advantages in the local markets, contributing considerably to the increase of companies' profitability and growth [1, 4, 5]. However, the analysis of competitiveness in productive agglomerations is based on human capital, governance, logistics infrastructure, collective efficiency, productive cooperation, technological innovation, quality, productivity, government policies and training programs.

The aim of this study is comparing factors related to the development stages and the level of competitiveness in the Northwestern Paraná furniture cluster. For this, a survey was applied to the companies belonging to the sector under study, considering the internal and external factors involved in the competitiveness context, for the analysis of

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the level of maturity of the cluster. It is inferred that the analysis of the proposed factors allows determining the capacity of the companies in the sector, aiming at the development of competitive advantages and strategies that are feasible for the growth and development of the local and regional economy.

2 Literature Review

2.1 Competitive Clusters

The formation of regional clusters and local productive systems are strategies of geographic concentrations of companies and institutions interconnected in a particular field, involving suppliers, machines, services and infrastructure, to provide conditions of competitiveness [1, 4].

Clusters promote competition and co-operation among firms to engage and retain customers [1, 6]. Cooperation is carried out vertically, involving related companies and local institutions. Basically, the arrangements affect the competitiveness in three levels: increase of the productivity of the companies, direction and pace of the innovations and stimulation of the formation of new businesses [1, 7].

Clusters can be classified according to the stage of development, offering subsidies for the development of related public policies [7, 8].

The stages specified in Fig. 1 below show that in the initial stage called pre-cluster, firms and industries are independent existing a regional concentration of the same productive chain; and at the emergent stage, the cluster is at the beginning of the development process, anticipating a possible overrun of the embryonic stage, with the government acting for the regional industry with the consequent action of incentive policies. The expanding cluster increases the links between companies by promoting the growth of collective actions between them. At this stage, local actors actively participate in support mechanisms to attract potential domestic and international competitors to the cluster. In the last stage, understood as a mature cluster, there is a phase of maturity in the institutional, commercial, industrial, environmental and local sphere with solid mechanisms of information sharing, inter-company cooperation and diffusion of innovation and knowledge [7, 8].

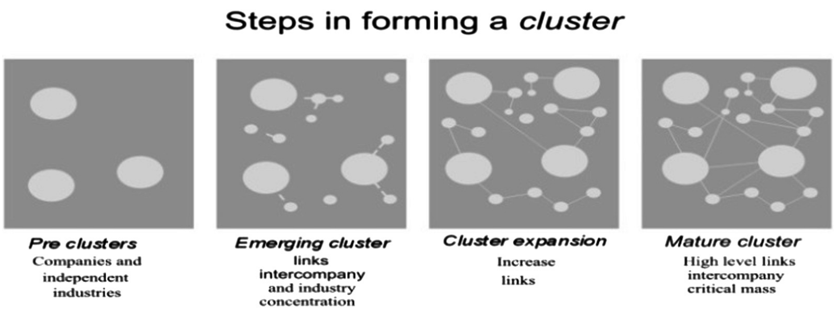

Fig. 1. Cluster classification.

The arrangements favor cooperation, solidarity and reciprocity, with the presence of local institutions to understand and sustain the systems. Some conditions are relevant to the development of arrangements such as the significant number of firms and agents, specialization in a specific productive activity, as well as the existence of skilled local labor and correlated activities [7, 9, 10].

2.2 Competitiveness Factors Among Cluster Operating Systems

Following, is presented factors of analysis related to the competitiveness of an agglomeration, which serves as a reference for a possible assessment of this study.

Human Capital. Organizations with dynamic environments are constantly changing to develop and empower people, aiming to obtain better results in the activities developed, with investments in education, incorporation of centers and even universities to offer training and development of people [10, 11].

Governance. This concept is linked to the idea of development management that consists of a set of mechanisms of administration of a social system and organized actions, with the intention of guaranteeing security, prosperity, coherence, order and continuity of the system itself [12]. Therefore, governance advocates viable forms of administration to meet the aspirations of most of the people (actors) involved, leading to healthy management of business development [7, 12]. This concept is linked to the idea of development management.

Logistic Infrastructure. This expression aims to analyze the set of facilities (factories and storage points) and means of transportation used by the supply chain of the productive arrangement to achieve objectives. The logistic factor is a key element in supply chain considerations and in the movement of products and materials to organizations [13]. This way, the more strategic the cluster is in relation to its location, the better its competitiveness in the market will be.

Collective Efficiency. The collective actions in networks, associations, agglomerations imply opportunities and risks. They exist in a group of different agents, connected to each other, for distinct reasons, which may be financial, technological, cultural, among others [14]. In a competitive scenario which is complex and unpredictable, small and medium-size businesses may find difficulty to achieve their goals. Collective initiatives contribute to overcome such difficulties [15].

Intercompany Cooperation. This system of cooperation is based on a set of independent small businesses, organized in a local and/or regional basis. These individual companies use local institutions, integrating relationships, competition and cooperation [16, 17]. Sharing a value activity, results in a significant cost advantage, presenting an important fraction of assets or operating costs.

Technologic Innovation. The management of technology uses administration techniques in order to maximize the technological potential as a support tool for the organization, contributing to cost reduction, improvement in the development of products and reducing lead times for innovations [7, 18]. When it comes to clusters, this element is necessary for a competitive activity, considering that over time the technological of companies tends to become outdated, anachronistic and obsolete [7].

Quality. Quality in the production process is determined and perceived by the customer, being decisive at the moment of purchase. Quality control is essential to ensure product reliability, compliance, durability and aesthetics [12, 13].

Productivity. Productivity is crucial in the company competitiveness to measure the efficiency of an operational system, in relation to its products and goods used in the production. Productivity efficiency is developed when there is collaboration among employees, making the values of the company be verified in all its hierarchy levels, making productivity a collective goal [13].

Government Institutions (Support Policies). Interaction and cooperation among companies is overriding for the development, promoting collective actions and information sharing, knowledge and infrastructure. External support institutions belonging to the cluster involve public institutions (local, regional and federal), entities, fomentation agencies, support institutions and associations representing the company in the several branches of the chain [5, 19].

Training Programs. Such programs contribute to show the strategic profile of the company to all its staff, integrating and stimulating differences and promoting quality in the operations. The maintenance and development of staff are the pillars of sustainability of any organization. Considering that the companies need to have as goals a good strategic plan and investments in programs which aim at a great operational climate and the guarantee of financial return [20].

3 Methodology

This study was applied in the furniture sector of the region of Umuarama, located in the south of Brazil. The approach was descriptive, with quantitative and qualitative procedures, using the survey, aiming to contribute to the knowledge of a particular area of interest, through the collection of data/information about individuals or the environment.

In the data collection phase, 20 structured questionnaires were applied to the managers of the companies belonging to the agglomeration studied, in the second semester of 2016, containing closed questions using Likert scale of five points, to analyze the competitiveness factors and the development stage of the furniture cluster.

The relative frequency average was used as statistical tool. Let $f(i)$ be the relative frequency over the competitiveness level of the cluster under study, covering a range [0, 100%] over real numbers. Let X_{Fr} be measured on a semantic scale, then the average of the relative frequencies (X_{Fr}) can be calculated with the aid of Eq. 1 below:

$$X_{Fr} = \frac{1}{n.k} \cdot \sum\nolimits_{i=n}^{n} i. \sum\nolimits_{j=1}^{k} f_j(i) \quad (1)$$

where $i = -2, -1, 0, 1, 2, \ldots, n$; $n \in \mathbb{Z}$, is the weight attributed to the level of competitiveness on the semantic scale, where zero is the equilibrium (origin) and $f(i)$ is the relative frequency on the level i and k is the number of variables with $j = 1, 2, \ldots, k$, under these conditions, $X_{Fr} \in [-100\%, 100\%]$ in the real numbers.

To better understand the results obtained in the statistical analysis, a scale divided into eight intervals was constructed to measure competitiveness, as shown in Fig. 2.

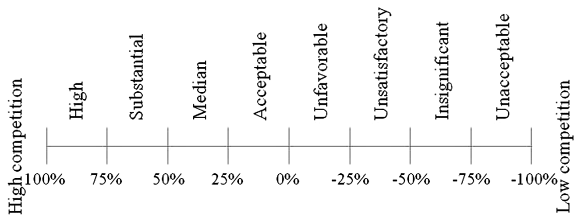

Fig. 2. Low and high competitiveness scale.

4 Results and Discussion

In the area of furniture, the Paraná currently has three local productive arrangements, in the north, northwest and southwest. This survey focused on the furniture sector of the northwest region, on competitive factors. Out of the companies interviewed, 47% are in the upholstery furniture sector; 39% represent the mattresses business; and 14% are part of the tailored furniture.

This sector is representative in the local economy. The wood and furniture industries represent 19% of the region's commercial establishments, directly creating one thousand three hundred and forty-nine jobs. The levels of satisfaction, in relation to competitiveness factors, have been measured and tabulated, in percentage, according to Table 1 below.

Table 1. Analyzis of competitiveness factors (in percentage).

Question	Competitiveness Assessment / Competitiveness Analysis	Awful (-2)	Bad (-1)	Regular (0)	Good (+1)	Excellent (+2)
Q_1	Human Capital	5.0	20.0	45.0	15.0	15.0
Q_2	Governance	35.0	15.0	30.0	15.0	5.0
Q_3	Logistic Infrastructure	5.0	10.0	10.0	45.0	30.0
Q_4	Collective Efficiency	55.0	15.0	10.0	20.0	0.0
Q_5	Production Cooperation	60.0	10.0	10.0	15.0	5.0
Q_6	Technological Innovation	10.0	15.0	50.0	20.0	5.0
Q_7	Quality	0.0	0.0	40.0	20.0	40.0
Q_8	Productivity	0.0	5.0	45.0	25.0	25.0
Q_9	Adequate Government Policies	70.0	0.0	20.0	10.0	0.0
Q_{10}	Training Programs	50.0	30.0	10.0	5.0	5.0
TOTAL		290	120	270	190	130

Assigning weight in a weighted way (appalling −2, bad −1, average 0, good +1, excellent +2) according to the results obtained, on the internal side Fig. 3 shows the low competitiveness; and on the external side aspects of high competitiveness.

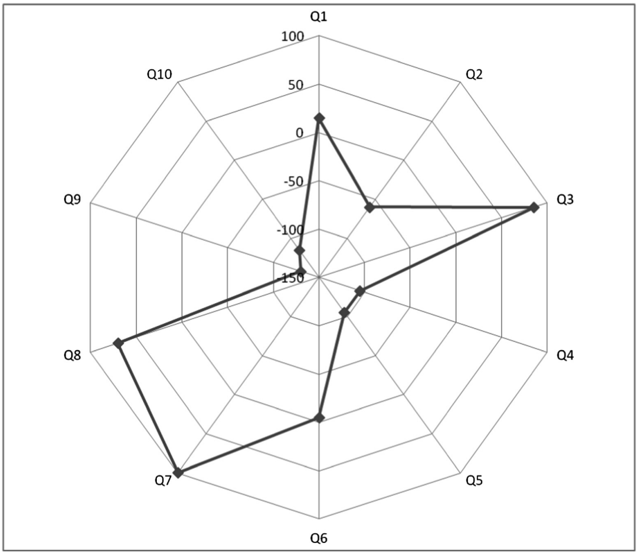

Fig. 3. Graphic representation of relative frequency.

According to the image above, the results show positive and negative answers, in relation to the competitiveness elements. Among the positive items are logistic infrastructure (Q3) and quality (Q7). Among the negative items are government policies (Q9) and training programs (Q10).

The logistic infrastructure has as a sum of good and excellent results in 75% of the answers, indicating that it is a highly competitive element. This item is related to the physical distribution of products, both internal and external, storage, and layout of work tools within the company.

The quality aspect was the excellence of 40% of its responses, and represents one of the elements invested by entrepreneurs in the region as a competitive advantage; another 40% assessed quality as average, evidencing the discrepancy between the priorities of the companies.

In government policies, 70% of the answers were assessed as appalling, representing the worst result in the survey. External influence is a factor which makes competitiveness hard.

As for training programs developed in the cluster, 50% of the interviewed assessed this item as appalling. It was found that cluster managers do not invest in the development and training of their staff, which may lead to demotivation.

In general, the relative frequency average was carried on according to Eq. 2, and the results obtained are shown in Fig. 4.

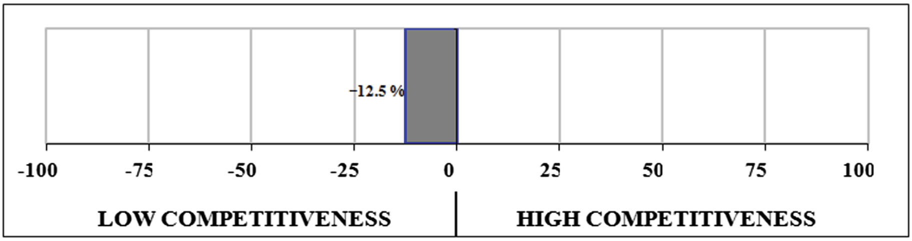

Fig. 4. Average relative frequency result.

$$Mf_r = \frac{(-2).(290.0) + (-1).(120.0) + (0).(270.0) + (+1).(190.0) + (+2).(130.0)}{2.10} = -12.5\% \quad (2)$$

An assessment conducted with the cluster managers on competitiveness, related to the above-mentioned items, resulted in –12.5%, obtained by the relative frequency average. It was concluded that it is an unfavorable result, according to the scale used to assess the Relative Frequencies Average. In such analysis, it can be inferred that the answers of managers tend to be more negative, rather than positive.

5 Conclusion

The competitive analysis in the furniture sector, in relation to companies from the cluster, contributes to the obtaining of a view closer to reality about the strengths and weaknesses of the local productive arrangement, aiming at the possibility of collective actions directed to furniture companies.

This study showed that the stage of development of the furniture cluster in Umuarama, Paraná/Brazil is still embryonic. The analysis of competitive elements showed an unfavorable percentage.

Such analysis requires actions for the development and growth of the local economy. In this way, the importance of the study of corporate networks is noticeable, since new forms of governance in productive arrangements are frequent nowadays, as a way of expanding and generating competitive advantages for the companies participating in the local arrangements.

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Goal Programming for Supply Chain Optimization with Insufficient Capacity

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Abstract. This article presents three different approaches to modeling and solving the classic transportation-location problem including the traditional cost-minimization mixed integer linear program. It is shown that modeling these problems as a profit maximization mixed integer program instead allows for the relaxation of a set of constraints. An alternative multi-objective optimization model using goal programming is also presented. A representative model of the fluid milk supply chain in the U.S. is developed to demonstrate the scenarios and solutions achieved by the three different models to conclude that the multi-objective model is a robust approach to solve these optimization problems even when there is only a single explicit objective.

Keywords: Goal programming · Multi-criteria optimization · Relaxed constraints

1 Introduction

A standard transportation-location problem is defined as shipping goods from origins with fixed capacities to destinations with defined demand requirement. The objective is to select source nodes to open and distribute the goods to destinations subject to capacity and demand constraints minimizing the total cost [1]. Key assumptions are that there is only one kind of good being shipped from the origins to the destinations and that the unit transportation cost does not depend on the volume shipped.

These problems are traditionally modeled as an overall cost minimization mixed integer linear program. However, this approach fails to return a feasible solution when the assumption that "capacity equals or exceeds demand" is not met, which is a fairly common scenario in real life scenarios. One alternative approach is to model the problem as a maximize profit instead of minimize cost, thereby eliminating the necessity to define "capacity equals or exceeds demand" as a hard constraint. Although this mitigates the limitation of the cost minimization model, it does not provide the flexibility to the decision maker to define a minimum requirement at some or all of the demand points. This condition can be incorporated by defining a "*supply greater than or equal demand multiplied by fill rate*" constraint, where fill rate is specified by the decision maker. The profit maximization model fails to return a feasible solution when there is not enough capacity in the system to fulfil this constraint across all the demand points.

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We are interested in modeling this problem in such a way that a best possible solution is returned when there is not enough capacity to fulfil the demand, enabling decision makers to make the most of the situation. This way, they can schedule the shipments or inventory as optimized by the model and arrange for back ordering to fulfil the demand in the remaining nodes at a later point of time. To achieve this, the transportation-location problem can be modeled as a multi-objective optimization model with maximizing fill rate at the demand nodes and minimizing overall system cost.

The following sections present a review of the literature of interest and relevant to this work, the mathematical formulation of the different models described above and an illustrative case study of the fluid milk supply chain in U.S. demonstrating the performance of these models.

2 Literature Review

Perl and Daskin [2] define and solve a transportation problem simultaneous as a facility location and vehicle routing problem. A mixed-integer programming formulation was developed to minimize the system cost and also a heuristic was presented to solve this large and complex problem which decomposes the original program into three sub problems.

Hillier and Lieberman [3] present algorithms for linear programming with multiple objectives. Goal programming is defined as "an approach to establish a specific numeric goal for each of the objectives, formulate an objective function for each objective, and then seek a solution that minimizes the (weighted) sum of deviations of these objective functions from their respective goals". If the different objectives are of same importance, it is a non-preemptive goal program and if there is a priority order for the objectives, it is a preemptive goal program.

Maas et al. [4] present a mixed-integer program that captures the operational options that facility managers have to meet demands in excess of capacity for short periods of time. This study empirically demonstrates the operational flexibility available with managers in reality which is not captured in the traditional facility location problems because of the use of hard capacity constraints.

Nicholson et al. [5] present an analysis of localization policies with the case of diary supply chain in the northeastern states of USA. A baseline scenario was defined with the objective is to minimize the cost of the entire system and two scenarios with additional constraints placed on shipments between sources and destinations and then evaluated on multiple criteria like food miles, supply chain costs, and greenhouse emissions. Milk demand is stated as being seasonal and two typical months of a year were considered–March (supply exceeds demand) and September (demand exceeds supply).

3 Formulation

In this section, we present the mathematical formulation of the three different models discussed. The followings are the model parameters.

$I - \text{Set of source locations}$
$J - \text{Set of destinations or demand points}$
$f_i - \text{fixed cost of locating a facility at candidate site } i \in I$
$k_i - \text{capacity of warehouse at site } i \in \mathrm{I}$
$c_{ij} - \text{cost of shipping one unit from site } i \text{ to node } j \in J$
$d_j - \text{demand requirement at each destination } j \in J$
$h_j - \text{fill rate requires at each destination } j \in J$
$p - \text{unit selling price of product}$

The decision variables common to all three models are the following.

$x_{ij} - \text{volume shipped from warehouse } (i) \text{ to destination } (j)$

$$B_i = \begin{cases} 1 & \text{if source location } i \text{ is chosen to open}, \\ 0 & \text{otherwise.} \end{cases}$$

The capacity constraint remains the same for all different models and is defined as

$$\sum\nolimits_j x_{ij} \le k_i \times B_i, \quad \forall i \in I \tag{1}$$

3.1 Cost Minimization Problem (CMP)

The CMP solves for the decision variables x_{ij} and B_i by minimizing the overall cost of the system, formulated in (2) subject to (1) and the demand constraint defined in (3).

$$\text{Min} \sum\nolimits_i f_i B_i + \sum\nolimits_i \sum\nolimits_j x_{ij} c_{ij} \tag{2}$$

$$\sum\nolimits_i x_{ij} = d_j, \ \forall j \in J \tag{3}$$

3.2 Profit Maximization Problem (PMP)

The PMP solves for the decision variables by maximizing the overall profit othe system, and the objective function is defined in (4).

$$\text{Max} - \sum\nolimits_i f_i B_i + \sum\nolimits_i \sum\nolimits_j x_{ij}(p - c_{ij}) \tag{4}$$

The capacity constraint remains the same as in (1) but the demand constraint (2) is modified as in (5). An additional constraint (6) can be imposed if a minimum fill rate is required at each demand point.

$$\sum\nolimits_i x_{ij} \le d_j, \ \forall j \in J, \tag{5}$$

$$\sum\nolimits_i x_{ij} \geq h_j d_j,\ \forall j \in J \tag{6}$$

3.3 Multi Criteria Problem (MCP)

A new set of decision variables is introduced in this model. Fill rate h_j for each demand point j, defined as the fraction of demand to be supplied at each destination j such that

$$0 \leq h_j \leq 1,\ \forall j \in J \tag{7}$$

The two objectives of this model are to maximize the fill rate across the system and to minimize the overall cost, which can be mathematically expressed as

$$Max \sum\nolimits_j h_j, \tag{8}$$

$$Min \sum\nolimits_i f_i B_i + \sum\nolimits_i \sum\nolimits_j x_{ij} c_{ij} \tag{9}$$

Subject to (1), (7) and a modified demand constraint defined in (10).

$$\sum\nolimits_i x_{ij} = h_j d_j,\ \forall j \in J \tag{10}$$

This problem can be modelled to be solved as a linear program introducing auxiliary slack variables U, E and target values for the different objectives.

$$h_j + U_j^1 - E_j^1 = T_j^1\ \forall j \in J, \tag{11}$$

$$\sum\nolimits_i f_i B_i + \sum\nolimits_i \sum\nolimits_j x_{ij} c_{ij} + U^2 - E^2 = T^2, \tag{12}$$

$$U_j^1, E_j^1, U^2, E^2, T_j^1, T^2 \geq 0 \tag{13}$$

The final objective function for MCP is defined in (14), where M is an arbitrarily large number, and subject to constraints (1), (7), (10), (11), (12), and (13).

$$Min\ M \sum\nolimits_j U_j + E \tag{14}$$

4 Illustration and Results

A mathematical model of the fluid milk supply network in the U.S. was developed with the geographic centers of each mainland state excluding Washington D.C. as the candidate locations for the sources. Three scenarios were developed, differing on the system capacity (SC) available to satisfy the overall demand (OD). These scenarios are

Table 1. Definition of scenarios for benchmarking

Scenario	SC/OD	FR
Scenario 1	1.7	1
Scenario 2	0.75	1
Scenario 3	0.75	0.8

differentiated by the ratio SC/OD and any minimum fill rate (FR) condition specified (h_i in (6) and T_j^1 in (11)) at each destination and are listed in Table 1.

4.1 Demand and Supply Data

The warehouse capacities were sized proportionally to the fluid milk produced in that particular state as obtained from USDA [6–8]. The annual milk production data from USDA was scaled to the time horizon to obtain the supply capacity of each warehouse and fixed costs of opening such warehouses have been estimated proportionally.

We model the demand points as the U.S. Zip codes and use a dataset acquired from the marketing company, Nielsen, via the James M. Kilts Center for Marketing at the University of Chicago, Booth School of Business [9] to calibrate our demand. The Nielsen Homescan Consumer Panel dataset contains six years of longitudinal panel data of consumer products. The data files were consolidated and segregated so as to obtain parameters in accordance with the purpose of our analysis. This extracted data was combined with the population distribution in zip code tabulation areas from the U. S. Census Bureau [10] to calibrate the demand in two different time periods of the year, when demand exceeds supply and when there is sufficient capacity to meet demand.

Longitudinal and latitudinal parameters were attributed to the zip codes to compute the distance matrix for the network using the formula presented in (15), where *lat1, lat2, lon1* and *lon2* are the latitudes and longitudes of the two points respectively and R ~ 3,963 miles [11] is the equatorial radius of the Earth returning distance between two zip codes as flown by a crow in miles [12]. It is assumed that all shipments are done in regular sized, fully loaded refrigerated trucks for which an average rate/mile is computed, taking into account fuel charges and refrigeration costs. Using a conversion factor, the distance in miles and capacity of each truck, the shipping rate per each unit can be computed using simple arithmetic [13, 14].

$$\cos^{-1}[\sin(lat1)\sin(lat2) + \cos(lat1)\cos(lat2)\cos(lon2 - lon1)] * R \qquad (15)$$

4.2 Benchmarking Results

All three models of a simplified version of the problem were formulated and solved in two software packages – Lindo Systems' LINGO [15] and IBM's ILOG CPLEX [16] on a Windows 10 machine with Intel Core i7-2670QM CPU @ 2.20 GHz and 8 GB of memory. This version considers only the transportation part of the original problem with all the source locations open, thereby making it a pure linear program and

Table 2. Results achieved by the three models under different scenarios

Scenario	Model	Result
Scenario 1	CMP	Global optimal
	PMP	Global optimal
	MCP	Global optimal
Scenario 2	CMP	Infeasible
	PMP	Best feasible
	MCP	Best feasible
Scenario 3	CMP	Infeasible
	PMP	Infeasible
	MCP	Best feasible

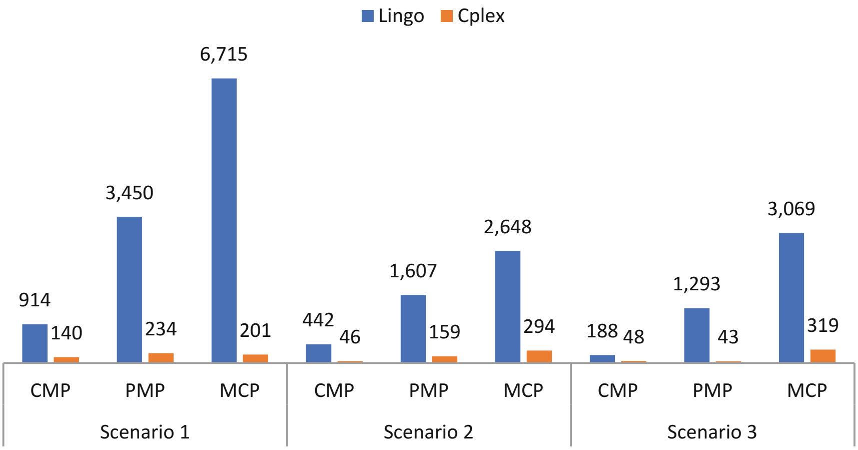

Fig. 1. Solving times in seconds for Lingo and CPLEX under different scenarios

reducing the solving times. Both the software packages returned identical solutions in all three scenarios as can be seen in Table 2 and their performance is benchmarked for solving time in Fig. 1. CPLEX, being considerably faster was chosen to solve the complete MILP under different scenarios.

All three models return a global optimal solution in Scenario 1 as expected. The PMP yields the same solution as CMP even with (2) modified to (4) because each additional unit of demand supplied contributes to an increase in profits and hence, the model has an inherent incentive to satisfy as much of the demand as possible. This property enables the PMP to return a best feasible solution in Scenario 2 when the overall demand is greater than the system capacity while CMP reaches infeasibility. Best feasible can described as satisfying the most profitable portion of the demand, given the system capacity. As for the MCP, first the fill rates for the demand nodes are decided depending on the system capacity and then, the shipping schedules are optimized for minimal cost. In Scenario 1, all nodes are given a fill rate 1 and in Scenario 2, the nodes with least cost to fulfill demand are allotted a fill rate 1. This adds up to the least expensive demand to fulfill within the system capacity. The solutions returned by PMP and MCP in Scenario 2 are identical and termed best feasible because all the constraints have not been satisfied completely, but have been satisfied to the best capabilities of the system.

In Scenario 3, we simulate a situation where the decision makers want to maintain a minimum fill rate h_j at each of the demand nodes, which is done by introducing (6) with $h_i = 0.8$ into the PMP and changing the T_j^1 to 0.8 in the MCP. The PMP reaches infeasibility because constraint set (6) cannot be satisfied at all the nodes. The number of nodes supplied by the MCP is more in Scenario 3 than Scenario 2 as the overall capacity is the same but each node is now being filled up to 80% only.

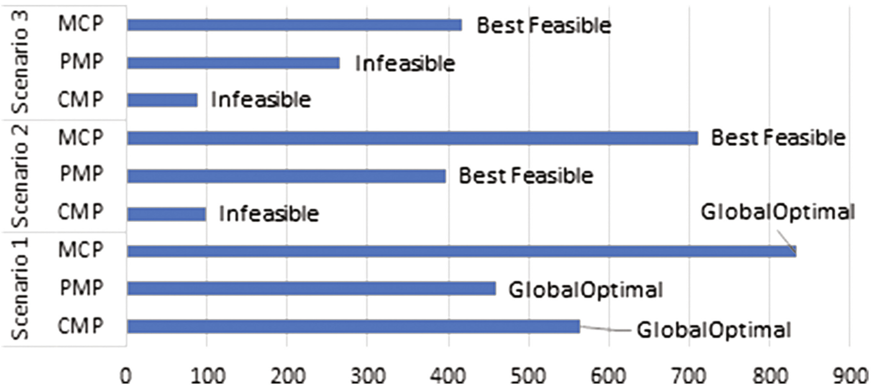

Fig. 2. Solving times in seconds in CPLEX for complete MILP

Identical results were returned when the complete MILP problem was run on CPLEX, but with longer solving times than the pure LP problem. These times can be seen in Fig. 2 and there is an increase in solving times of CMP and PMP to MCP as expected, because of the introduction of a new set of decision variables.

5 Conclusions

Modeling the classic transportation-facility problem as a multi-objective optimization problem with maximizing fill rate at demand points and minimizing overall system cost proved to be a versatile and flexible approach. The model achieved the objective of returning the best feasible solution to decision makers as can be seen in the results of the illustrative example. While the PMP performed better than the CMP in solving the MILP problem, it could not offer the level of constraint flexibility the MCP could.

The problem size in MCP is larger due to introduction of new variables - one heuristic could be to check for the system feasibility and then choose between the PMP or MCP models to find the shipping schedules. As the demand and transportation matrices are sparse matrices, with numerous 0 entries, the solving times can be reduced by using heuristic algorithms to traverse through these matrices. Further studies could be conducted on the effect of the target values defined in MCP on the solution quality, defining the second objective in MCP as a profit maximization, or how the solutions differ when the priorities of the two objectives are switched.

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Production Management in Food Supply Chains

Neural Network System to Forecast the Soybean Exportation on Brazilian Port of Santos

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Abstract. Agricultural products are an important part of the Brazilian economy. In soybean production, the country is the second largest producer with 114.0 million tons in the 2016/2017 harvest. Mato Grosso state is the largest Brazilian producer with 30.5 million tons and the port of Santos is mainly requested by being the largest port in Latin America. However, the poor infrastructure of the transport road causes bottlenecks when dispatching soybean through the major ports. Artificial Neural Networks (ANN) are used worldwide in logistics; therefore, we propose to design, train and simulate an ANN on MatLab© software to forecast the demand of soybean produced in Mato Grosso and exported through the port of Santos. The value of 9.0 million tons was predicted for 2017 as an increase of about 26.5% compared with the 2016 movement of 7.1 million tons. In addition, it was noticed that 5.9 million tons were moved only in the first five months (Jan–May) of transactions in 2017.

Keywords: Artificial intelligence · Intelligent systems · Artificial neural network · Soybean · Logistics

1 Introduction

The expected global production of soybean in the 2016/2017 harvest was 351.3 million tons [1]. Brazil is the second largest producer of soybean with 114.0 million tons. A major Brazilian producer is the Mato Grosso state located in the midwest of the country with 30.5 million tons [2]. Despite these numbers, Brazil's challenge is drained this production that generally use the port of Santos, and it is in average about two thousand kilometers away.

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In a competitive world, companies need excellence in logistics management and some factors are essential to their success such as cost cutting, meeting clients' requirements, fast delivery and high service quality [3]. In this context, among several logistics activities, one of them is distinguished because it corresponds to 60% of the logistics costs, transport, which has a direct influence on client satisfaction [4]. In Brazil, for instance, the main model used for cargo traffic is road transport with 1.7 million kilometers of roads [5].

Research done by a non-governmental Brazilian organization, the National Confederation of Transport - CNT [6] analyzed approximately 103 thousand kilometers of roads and observed that 58.2% have shown some sort of problem in their general status (flooring, signaling and geometry of the ground). This problem has been increased in the past few years with the increment of transportation volume and the cargo capacity of vehicles. Additionally, the CNT study [6] showed that only the damages on flooring generates an average increase of 24.9% in the cost of transport and it is estimated at R$ 2.3 billion (around of 755 million US dollars in March 2017) losses to the transporters because of over 700 million liters of diesel wasted in 2016. Finally, research also indicated that in order to adjust the Brazilian road network, it would be necessary to spend R$ 292.5 billion (around of 94.7 billion US dollars in March 2017). It is worth mentioning that in 2015 only R$ 9.3 billion (around of 3.1 billion US dollars in March 2017) had been authorized.

At the same time, while road transportation raises many issues railroad transportation is neglected in the country. Even though it is considered the largest one in Latin America with an approximate territorial extension of 28 thousand kilometers, it is still very small compared with developed countries [5].

The influence of transport infrastructure on the Brazilian economy is huge because, historically, the country is moved by agricultural production and many products are produced far from ports.

The Brazilian port system has a fundamental importance in commerce. In 2016, the ports in Brazil moved 998 million tons; considering the 37 public ports, the port of Santos is the highlight moving 113.8 million tons in its commercial operations [7]. The structure of docking complex in Santos contributes to the position of the largest port in Latin America [8]. With a building area of 7.8 million m^2, the port of Santos was the one that received the most ships in 2016, about 13 ships per day [7]. This port has an area of primary influence that includes the states of Mato Grosso, Mato Grosso do Sul, Goias, Minas Gerais and São Paulo. Together, they represent 67% of the Gross National Product and 56% of the Brazilian Commerce Balance [7].

Port of Santos has been in great demand and consequently it can suffer bottlenecks in its operations. Besides that, deficiencies related to the Brazilian road transport infrastructure and the lack of investments in the sector stimulates the research for solutions that do not depend on government's initiative.

Thus, the use of intelligent systems appear as an important tool to optimize the use of transportation networks. Intelligent Systems are used in optimization solutions and logistics processes worldwide and the most used techniques are Genetic Algorithms, Fuzzy Logic and ANN. These systems are part of the research in Artificial Intelligence (A.I) and have been mainly used in pattern recognition and demand prediction especially in non-linear problems [3].

The objective of this work is to build, train and simulate an ANN able to forecast the soybean exportation demand (metric tons) from Mato Grosso in the port of Santos. This system can help policy-making improve forecasts and consequently, establish a priority for the investments in this soybean traffic route.

2 Methodology

This paper uses ANN knowledge to predict Brazilian Soybean exportation by the Santos Port.

2.1 ANN

Intelligent systems such as ANN are able to solve problems uniquely and "creatively". They have been intended to emulate human behavior in making decisions through the learning processes. In addition, they are fault-tolerant because they can extract useful results from an incomplete data set. ANNs should be designed to solve dynamic problems and are not suitable for classical problems. They are trained from situations that have already happened (historical data) and the main approaches are to solve problems related to pattern recognition and prediction of future values according to past occurrences [9–11]. The computational logic of an ANN is similar to human neural networks, in other words, it consists of several computational units known as connected neurons. Each neuron (Fig. 1) is associated with specific weights (intensity and signal of the connection) in several input values. The neurons are activated in function of inferences and propagate the signal to others until the last units [9–11].

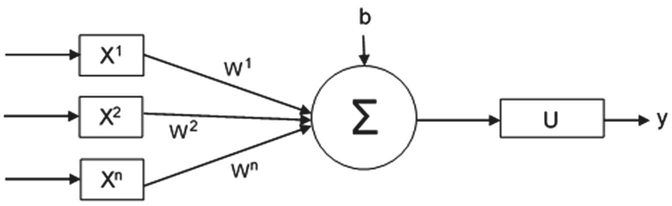

Fig. 1. Artificial neuron. Adapted from: [12]

2.2 Sample

The data were collected on Information Systems of Foreign Trade (ALICE WEB). This system is based on the information extracted from the Foreign Trade Integrated System (SISCOMEX) and is maintained by the Ministry of Industry, Foreign Trade and Services. It divulges the Brazilian Statistics of export - import transactions [13].

A database query was performed using the following filter:

1. Posição (position) - SH 4 dígitos: 1201 - Soja, mesmo triturada (Soybeans, whether or not broken); 2. UF: 52 - Mato Grosso (state); 3. Porto: 4117 - Santos - SP (port); 4. Via (way): 1 Marítima; 5. Período (period): 1997–2016 (yearly production).

The system generated a spreadsheet in MS Excel, which was easily imported into an array in the Matlab software. In this study, the soybean exportation data analysis is presented in metric tons and links the Mato Grosso state production with the port of Santos in the last 16 years (2001–2016). The first years of the series (1997, 1998, 1999 and 2000) were used for delays and were not plotted.

2.3 Computacional Tool

To build, train and simulate an ANN we used the software Matlab©R2016b and its neural network toolbox. This toolbox provides a graphic interface and allows the creation of a time series application. A Non-linear Autoregressive (NAR) solution was adopted because it is an excellent solution for a unique data set, without external interferences [14]. The ANN considered 80% of data for training, 5% for validation, and 15% for testing the network. In each section, data were selected randomly. According to Mirabdolazimi and Shafabakhsh [15] "Determination of proper structure, education algorithm, transmission functions and number of neurons in hidden layers are among the most important factors in the designing process of neural networks". The network was generated and trained in an open loop form with 50 neurons and four delays. The training algorithm used was the Bayesian regularization that provides the best output for a small data set and noises (Fig. 2) [14].

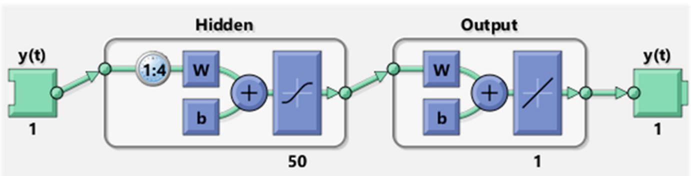

Fig. 2. Neural network. MatLab©R2016b

After training, a closed loop form simulation was done; according to [14] "this function replaces the feedback input with a direct connection from the output layer creating a multi step prediction. A Step Ahead form simulation was done too; according to [14] the new network returns the same outputs as the original network plus one step ahead. These algorithms were provided by the Matlab software.

3 Results and Discussion

The training reached the best value for minimum errors after 152 interactions and 6 seconds of processing in order to minimize the mistakes between the data (target) and the feedback. Also an estimated linear regression with the correlation between the variables was performed (Fig. 3).

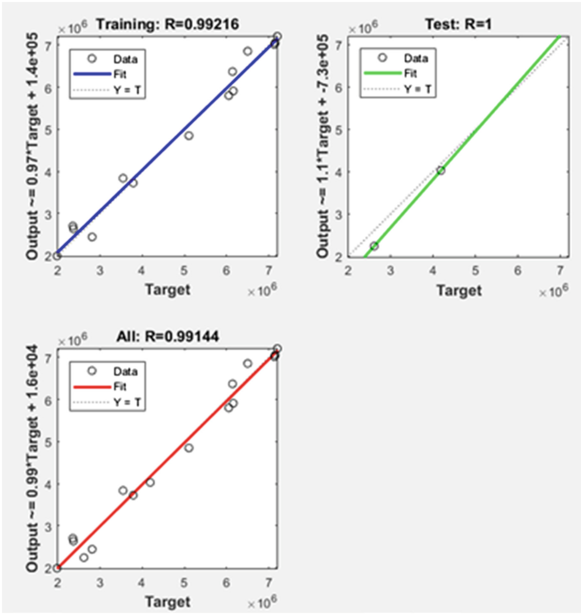

Fig. 3. Regression and correlation. MatLab©R2016b

The results shows that both training and test surpass the minimum value of correlation (0.9), which means that the model is positively correlated with soybean data analysis. The next step was to plotted a time series using the data according to Fig. 4.

This is the original series that represents the cargo traffic of the soybean exportation from Mato Grosso to the Port of Santos in a period of 16 years (2001–2016). According to Laboissiere et al. [12] the analysis of time series is referred to as a sequence of data specified at regular time intervals during a period. Consequently, the time series analysis is used to determine structures and patterns in historical data and develop a model that predicts their behavior. They are normally treated by means of regression models. The error represents the difference between the data (target) and the feedback generated by the neural network. The time is represented by the x- axis and the y- axis represents the amount in tons. It is noticeable that the movement in tons has increased over the years. Another interesting observation is that there was a significant increase

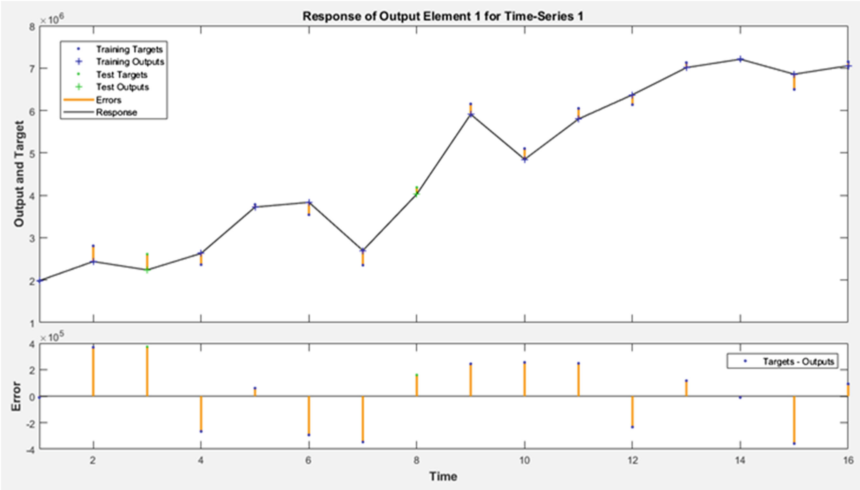

Fig. 4. Original time series. MatLab©R2016b

in demand after 2007. Although these tendencies exist, the series showed some aleatory data which is interesting to analyze with ANN that deal with non-linear problems. Afterwards we used the data to plot a time series in closed loop form (Multi Step Prediction) as shown in Fig. 5.

The multi step prediction was performed each year of the series based on previous years. The first four years that were not plotted served as a delay for the 2001 forecast. The other years were predicted on the basis of all the years

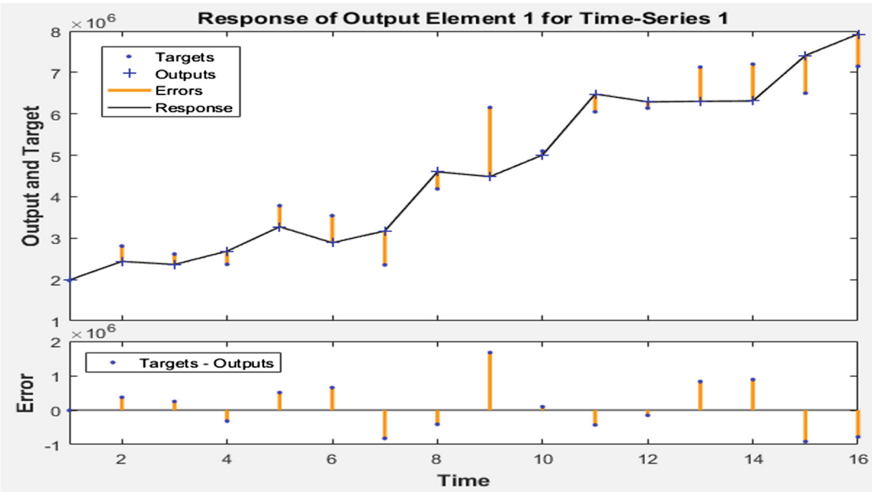

Fig. 5. Multi step prediction. MatLab©R2016b

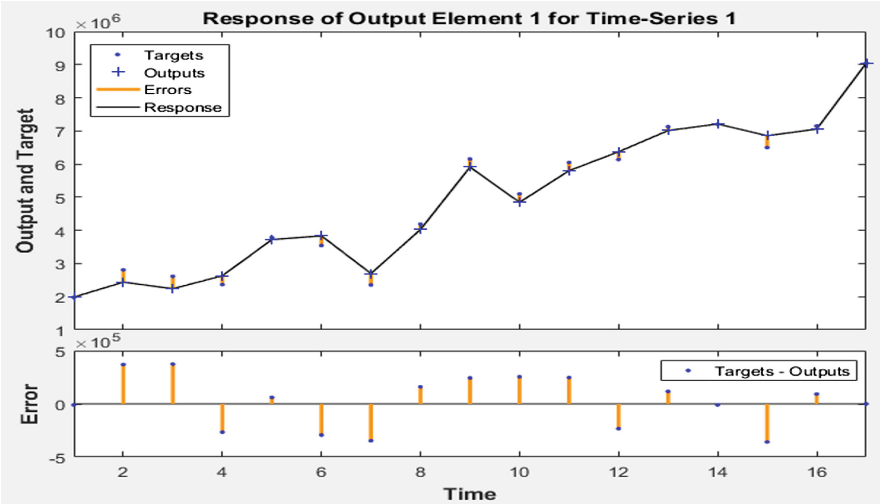

Fig. 6. Step ahead prediction. MatLab©R2016b

prior to the analysis. This type of simulation is interesting to determine the real capacity of the network to make predictions, since it is possible to perceive the actual data (target) and the predicted data (output). The difference is the error in the forecast. The calculated mean error was 12.57%. Finally, we used the algorithm provided by Matlab software to generate a time series step ahead as shown in Fig. 6.

This time series represents the feedback of the data which allows to inferred demand prediction in 2017 for the port of Santos. The value of 9.0 million tons was predicted for 2017 as an increase of about 26.5% compared with the 2016 movement of 7.1 million tons. Considering the mean error of 12.57% in making predictions, demand is expected to vary between 7.9 and 10.1 million tons. A database query was performed on ALICEWEB on Jun/2017 and it was noticed that 5.9 million tons were moved only in the first five months (Jan–May) of transactions in 2017, meaning an increasing demand and the alignment of the model proposed to make predictions.

4 Conclusions and Outlook

Brazil is the second largest producer of soybean in the world and the state of Mato Grosso is responsible for over a third of the country's production. The largest part of soybean from this state is dispatched to the main port of Latin America, the port of Santos. However, the trade in Brazil faces issues in dispatching the production to the port of Santos by road transport. This system is the most widely used in Brazil and presents poor logistics infrastructure. Besides that, bottlenecks can occur in the port due to delays in operations. Therefore, this work quested to use an ANN algorithm that simulates human behavior to generate a time series that represents the movement of soybean coming from Mato Grosso to the port of Santos in the last 16 years. It was verified that the cargo traffic has been increasing year after year practically uninterrupted. The errors between the data inserted in the system and the feedback of the network is related to the technology that simulates the human knowledge for making decisions, therefore being dynamic and subject to learning. Furthermore, in future research we intend to use a larger data set in the time series and compare with the performing training results.

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Business Games Based on Simulation and Decision-Making in Logistics Processes

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Abstract. The use of business games can help users to find solutions to complex management problems, to develop critical and strategic thinking skills, and to prepare professionals for the labor market. Business games as an active learning method has been widely debated, and there is a continuing interest in how students learn when they are stimulated. The goal of this research is to analyze the application of business games as an effective teaching methodology and decision-making in logistics processes in business administration undergraduate courses. The business game ENTERSIM was built with software and cloud computing. As the results, the student's testimonies showed some deficiencies in the instructions given and in the activity application's time. However, students emphasized the wish to carry out again activities that involve business games for bringing theory to practice. Students recognized the contribution of the business game to improve learning about operations, problem-solving, and decision-making.

Keywords: Business games · Active methodologies · Logistics processes

1 Introduction

Business games can improve student learning and prepare them for the labor market to create environmental experiences to offer them an opportunity to learn how to do it [3, 6]. Business games aim to collaborate in the teaching-learning process when the proposed environment is risk-free, offers realism and allows responses with immediate feedback.

The relationships between supply, plant and distribution processes by activities of storage, transport, movement and distribution of logistics products can be considered complex and involve strategic, tactical and operational levels. Besides, the complexity of these relations can raise results in the organizational performance. In this way,

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decisions made in the logistic processes must be integrated and systematized to reduce costs or to make tradeoffs [1].

According to authors [7], some issues can be discussed about the use of business games as an effective teaching methodology to improve decision-making for training in management processes. What the criteria of success with the use of business games and the relationships of business games with other teaching methodologies are the author's questions.

This research paper intends to implement a business game based on simulation, with the incorporation of challenges with goals for the performance indicators and decision model to define the sequence of decisions related to organizational levels. Lastly, the main purpose is to analyze the application of business games as an effective teaching methodology and decision-making in logistics processes in business administration courses.

2 Decision-Making in Logistics Processes in Business Games Based on Simulation

The search for answers to what are the criteria of success with the use of business games and the relations with other subjects in the teaching of business administration have been significant challenges to be overcome [7]. To authors [6], the goal is to create an instructional program that incorporates resources and features of the game. The reactions and judgments of the participants are caught during the game, and at the end, it must have the commitment to validate if the learning objectives have been achieved.

The some authors [6] consider the results pointed out by students in business games based on simulation for the learning process: interest, pleasure, involvement, confidence, behavior, feedback and debriefing (Table 1). The authors conclude that a business game based on simulation should be fun, interesting and engaging, and beyond learning, it should be considered as entertainment that builds trust and spontaneous participation of the student. When well designed, a game can facilitate the learning of specific concepts and skills by solving problems with decision-making.

Business games based on simulation have been used in the classroom to support in the teaching and learning process since the 1950s [5]. The use of business games as a pedagogical support tool to modernize classes and the implementation of information technologies has improved the process of disseminating simultaneous results with immediate feedback.

According to authors [8], the use of simulation can contribute to strategic and tactical decisions to improve financial performance. In [2] introduced a scheme that incorporates a production system with the view of a decision model through the GRAI grid that aims to provide a generic description of a production system, focusing on the control of point of view. The control of a production system will be represented from a global perspective, at the decision center level.

The Development of the GRAI grid modeling started from a theoretical basis. At the conceptual level, the model is composed of three systems: the physical system, the decision system and the information system (Fig. 1).

Table 1. Determinant factors for learning with business games

Factor	Characteristics
Relevance	The business game must be more interesting than the traditional teaching strategies with the possibility of offering a real simulated environment bringing theory to practice
Pleasure	Business games must be fun and enjoyable, combining challenge, learning, and retention of knowledge
Task involvement	The involvement in the learning process results in a better retention of information and use of knowledge
Confidence	Games can provide a training environment where users can perform tasks without facing the consequences of a failure in the real world
Behavior	Committed participants who spend more time on tasks have sustainable behavior and involvement. They work hard, return to the game spontaneously and achieve better levels of concentration
Feedback	The feedback on the performance that participants are getting in the game is essential to evaluate the progress, motivate, keep them playing, and spend more effort to persist on the proposed task
Debriefing	The discussion and analysis of events happened during the game can produce corrective actions by verifying mistakes and successes, and it is a significant relation between experiences of game and learning

Note: Adapted from [6].

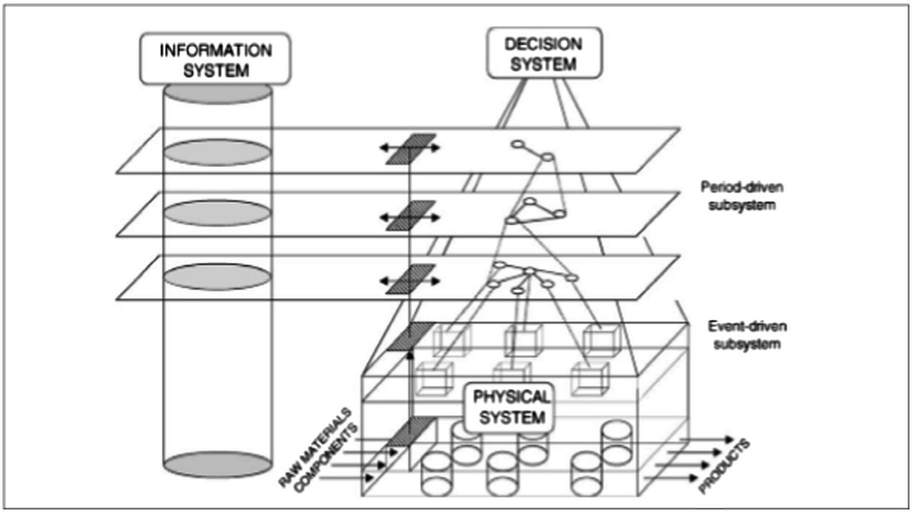

Fig. 1. The GRAI model. Source: [2].

In this research, the information system used is the business games based on simulation. Besides, it was used the grid diagram to build the menu of options for students to operationalize their decisions at the strategic, tactical and operational levels.

The simulation of the results from the decision-making process to help students in the learning process or the training of professionals for the labor market can occur through the application of business games. Therefore, a system based on a decision model can be used to facilitate the visualization and organization of the decision-making process. However, some authors point out that the existing relations, both operational and informational, between the hierarchical levels can raise difficulties in the decision-making process. In this scenario of complexity, decisions must be made in a systematic and integrated way.

The logistics processes of supply, plant, and distribution are logistics costs generators through physical operations of packing, transport, storage and handling between the factories and the values inherent to the chain functioning such as maintaining inventory, information technology, taxation and failures [4]. Furthermore, logistics costs tradeoffs are compensatory tradeoffs between costs and the level of service provided to the customer and interfere with the company's economic and financial performance [9]. Likewise, according to [1], professionals know that logistics costs tradeoffs do exist, but they do not clearly have the idea that the total cost is determined by them.

Regarding the implementation of the organization for the decision-making process in the ENTERSIM business game (Table 2), the GRAI grid Methodology was used according to the studies developed by [2].

Table 2. Logistic decision proposed for the business game based on simulation.

Logistic process	Decision	Description
Inbound	Selection of suppliers	The student can choose three suppliers to buy raw material
	Modal of transport	The student must select a modal (road, rail, air or sea) to carry the raw material
	Lot for acquisition of raw material	The quantities (lots) offered by the selected suppliers and stocks of raw material can be checked
Plant	Plant location	The student must choose the location of the factory plant among the 27 capitals of Brazilian states. The revenue from the chosen capital will be ignored to calculate the indicators
	Manufacturing planning	The student can define the product in each production unit on the business day
Outbound	Freight	The student can choose CIF or FOB for delivery.
	Modal transport	The student must select a modal (road, rail, air or sea) to transport the finished goods
	Revenue of orders	The student will define the day of delivery and control the finished goods inventory
Inventory	Raw material inventory	The student can check raw material inventory
	Finished goods inventory	The student can check finished goods inventory

Source: the authors (2017).

The values for the indicators were calculated using the values for the costs involved in logistics processes, expenses, stock inventory, and gross revenue. Table 3 shows the performance indicators classified by the logistic process, a key factor, and attribute. The authors [10] state that the use of a simulated environment, without risk and losses in decision-making, can contribute to analyzing events and their impacts influence on organizational performance.

Table 3. Performance of indicators at the business game

Logistic process	Key-factor	Attribute	Indicator	Measure
Inbound	Factory	Efficiency	Raw material level	%
	Inventory	Efficiency	Raw material efficiency	%
	Transport	Cost	Inbound cost	% of income
		Cost	Raw material cost	% of income
		Responsiveness	Delivery time	days
Plant	Factory	Cost	Rental cost	% of income
Outbound		Efficiency	Finished goods level	%
		Cost	Internal cost	% of income
	Inventory	Efficiency	Finished goods efficiency	%
	Transport	Cost	Outbound cost	% of income
		Responsiveness	Delivery time	days
		Efficiency	Orders	orders

Source: the authors (2017).

The scenario chosen for the application of the business game was the simulation of an environment of a textile industry from the point of view of the analysis and the influence of logistics costs based on the processes of supply, plant and distribution. The use of simulation, optimization and decision models in business games serves to assist students in the teaching and learning process for decision-making. The complexity of costs and tradeoffs in logistics processes create performance indicators that will be used as a basis for training new managers.

3 Methodology

The research was carried out in three steps: structure, application, and analysis of the data to evaluate the relationship between aspects of active teaching methods and student performance in the application of a business game based on simulation at a decision-making scenario in logistics process. The first step, the structure one, was related to the literature review on active learning, business games based on simulation, logistics costs, and decision-making in logistic processes. Besides, with this information, activities for the field research involving the use of business games, the research instruments for the data collection and sampling were designed.

Regarding the second step, the research application, it was subdivided as follows: to enable students participating in the game and register the personal characteristics; to train students for taking part in the game through instruction in order to perform basic operations in the business game; to apply inventories to measure learning styles; to apply the research instrument about the learning facilitating factor; to apply the research instrument for validating the learning environment quality; and to apply the business game based on simulation. Furthermore, the third step was to analyze the gathered data.

The application was carried out at UNIDAVI at 2 undergraduate courses: business administration (with 95 students) and international trade (with 27 students). The application process totalized 122 samples for data analysis.

Moreover, when accessing the business game, the student could access the decision-making options in logistics processes such as plant location, manufacturing planning, selection of suppliers, modal transport, a lot of raw material acquisition, freight and revenue of orders. The business game presented the performance indicators in the logistics processes of inbound, plant and outbound classified by cost, efficiency, and responsiveness. The student can verify the impact on performance indicators in each decision made in the logistics processes.

Furthermore, from the collected variables and definition of constructs data were validated. The performance of the student in the business game did not present significant differences in the perception of the learning facilitating factors, excepting for the aspects related to the classroom environment. Regarding the learning environment quality, there was no significant difference between the evaluated factors.

After analyzing the results, it was necessary to investigate some points that presented the best and the worst results in the participants' responses. The points that needed to be investigated were: the learning facilitating, in the dimensions of teaching strategy and reflection in action; and also on the quality of information in the instrument that evaluated the learning environment. Therefore, for this process were selected business administration students with better and worse outcomes at the business game, a total of fifteen students. Considering the invited students, eight accepted to participate in another data collection through individual questions and personal testimonies about the experiment they had participated.

About this step, an interview script was designed to gather students' testimony on the issues that presented the most relevance to improving understanding in a subjective way. The script had the following questions: (1) Would you use a business game again? Was the time for the activity appropriate? (2) Did the business game contribute to your learning? Did the business game associate theory with practice? (3) Regarding the instructions provided, do you think they can be improved? (4) Did the business game provide information to improve your knowledge about a company's operation or problem-solving? (5) Did the business game help in discussing problems and solving conflicts in the group? (6) Can the business game improve my knowledge about decision-making?

4 Data Analysis

The quality of the virtual environment for learning in the business game presented a better result in the indicators of satisfaction about the perception of the student on perceived utility. Likewise, the quality of information indicated a significant difference when related to performance. The ease-of-use factor showed below-average performance and the variable about "interacting with business games did not require much intellectual effort" had a discordance index of 14%. This indicator reflects the complexity involved in choosing the scenario for designing the business game based on decision-making in logistics processes.

Considering the variable "to help integrate learning in several areas", it obtained good indicators. Then the variable "helps to know the activities related to the professional practice" was well evaluated in this research and did not obtain good indicators in the previous researches. Additionally, this result may consider that the ENTERSIM business game associates theory to practice regarding students' perceptions about the labor market. The factors evaluated in this study about the learning facilitators presented agreement indexes between 35% and 64% in all variables.

Concerning the students' voluntary testimony, it can be observed that all of them would participate again in activities with business games. However, the time available to perform the activity was divergent among students, with a tendency to affirm that the application time was not enough. "Yes, I would, but the time was not sufficient. As the software is broad and involves some processes it takes time", reported A5. Disagreeing with this statement, A8 reports that "I would play whenever available and the time was enough for me."

There was a strong demonstration of the students about the contribution to the learning process since it connects the theory to the practice. The responses show that everyone agrees, but A6 points out that there were many doubts during the process, and A7 states: "With more time, I could make enjoy it better." Therefore, in the opinion of the students, the business game can help in the decision-making process. However, they emphasized that it just happens with a clear understanding of the operation and routines contained in the activity.

Regarding company's operations and problem-solving, there was agreement and consciousness of some respondents that decisions might influence the indicators more than others: "any details can lead to great impacts" reports A8. Likewise, in the group discussions, A6 mentioned that he preferred to play individually. Except for A2 and A3, the others reported that there were discussions in the group; there is information about disagreement and consensus in the group. Considering the contribution of the game to learning in the decision-making process, all students agreed with the relevance of this methodology. Although, A6 and A7 report that only with the clear understanding of the entire decision-making process the business game contributes to the apprenticeship.

5 Final Remarks

Business games have been used as a teaching strategy in universities for decades. Since the beginning, the discussion about the use this active learning methodology, impacts and contribution in teaching business administration has raised studies that demonstrate the importance of the evolution of business games adapting itself to the innovations of information and communication technologies.

Furthermore, for most students that participated on the voluntary testimony, instructions can be improved. Group discussions and conflict resolution did not obtain defined patterns, and it was observed that each group had its behavior. Although the gathered results highlighted some difficulties and suggestions for improvements: in general, the application of the game contributed to the learning process; and it was also considered a teaching strategy that contributes to the development of reasoning in decision-making, problem-solving, as well it brings theory to practice. The students' statements validate the results presented previously by [6].

In conclusion, the ways in which business games have been used on updated technological platforms have allowed changes on the interaction development as well as about the immediate feedback on decision-making results. Lastly, these aspects motivate students to participate more actively in the learning process and to interact with educational tools. All of this is possible due to the Internet and cloud computing associated to friendly interfaces together with the independence of geographical location and time zones.

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Managing Enterprise Resource System (ERP) and Balanced Scorecard (BSC) in Food Industry in Brazil - Food and Beverage Products: A Multiple Case Study

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Abstract. This study aims to verify, analyze, and describe the importance of managing the Enterprise Resource Planning-ERP information system and the Balanced Scorecard-BSC strategic management system in the food industry in Brazil. The synergies, benefits, problems, and difficulties between them that can influence the implementation of the strategy in the organization to improve the results are analyzed. The present study focuses on the relationship between ERP and BSC, as well as the particularities of each that can influence the efficient management of the organization. The study was based on a multiple case study in five food industries located in Brazil. The theoretical framework was based on topics related to production and operations, strategy, organizational systems, integrated management system (ERP), strategic management system (BSC) and performance indicators. The conclusion of this study highlights the importance of each of these systems, as well as the synergies, benefits, problems, and difficulties among them in the execution of the strategy in organizations.

Keywords: Strategy · Systems · Information technology · ERP · BSC

1 Introduction

The Brazilian food industry (food and beverage products) has faced decades of problems with high tax burden, high raw material costs, high logistical costs and fierce market competition. With this, Brazil loses its competitive power about the quality and prices practiced by other countries [1].

According to the Brazilian Food Industry Association (ABIA) [1] the food industry, which includes the production of food and beverage products, represented in 2016 the amount corresponding to 12% of the Brazilian GDP. The results could be better if the strategy planned by the companies could be translated into actions and performance indicators that could involve a larger number of employees [1].

Amongst the main challenges for the food and beverage industry that require extensive attention and continuous process improvement, it is possible to mention:

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stock control and storage, product's distribution, quality control and compliance with specific standards. Given the sector's challenges, it is worth emphasizing that the use of an integrated information system (ERP) and a strategic management system (BSC) is a fundamental tool for strategic, tactical and operational management [2]. According to [11], for the BSC use in the Strategic Management System to be effective, it needs to be integrated with an ERP - Information Management System.

Constant monitoring of competitive pressures over the years has prompted a series of investigations, not only in the area of integrated information systems but also in the strategic management systems segment of organizations [3]. It is interesting to note that according to [1], 96% the food industries have been working with ERP and BSC systems for more than ten years in getting their business.

This study aimed to analyze the ERP system and the BSC system in the food industry for identifying:

- Whether there is integration between ERP and BSC and the benefits that the ERP offers to the BSC;
- The problems and difficulties of the ERP to meet the BSC; and
- The consequences for the organization of the problems and challenges generated by the ERP to meet the BSC.

2 Literature Review

A synthesis of the theory to the support of the study is provided, with the presentation of a brief history of management of production systems and operations, strategy, organizational systems, integrated management systems – ERP's, performance indicators and BSC - strategic management system.

The topics were analyzed as the theoretical basis for the understanding of each of the theories, the relations between them and for the purpose of the research that is to verify the alignment (synergies/difficulties) between the BSC and ERP in the execution of the strategy in the organizations.

The authors of the BSC - strategy management system [10] conceptualize strategy as the choice of market segments and customers that business units intend to serve [4].

The Information Technology (IT) is considered as one of the corporate resources that support strategy at all levels of the organization, giving elements to the business in gaining competitive advantage [5]. The importance of IT grows at all levels of decision-making, IT improves the communication, integration, and exchange of information among all areas of the organization, enabling at all levels knowledge and operationalization of the strategy defined by the organization [6]. The quality of every decision depends greatly on the quality of information and synergies among the systems deployed in the organization [7]. The evolution of management information systems has brought advances in production planning and control systems, with significant cost reductions and improved quality and customer satisfaction [8].

The choice of an ERP affects the stakeholders or social groups that participated in the market. ERP is the choice to determinate a critical point to ensure the obtaining of transparent and reliable information that supports the strategy and decision making in the organization. It is necessary for the information systems strategy to reflect the company's strategy [9]. In the case of organizations, the indicators enable the unfolding of the business goals in the organizational structure, ensuring that improvements achieved in each unit will contribute to the overall purposes of the organization [10]. The indicators help the organization to direct its efforts towards the strategy and test the organization's progress [4].

The acceptance and worldwide growth of the use of the BSC methodology are due to the IT areas, which automated the method, thus allowing its application with greater practicality [11]. The BSC methodology is based on four perspectives on the organization's vision and strategy: Financial Perspective, Customer Perspective, Internal Processes Perspective and Innovation and Learning Perspective [12]. The benefits considered by scholars and researchers in the implementation of the Kaplan and Norton model are in the alignment of outcome indicators with trend indicators. Those are related to consideration of different interest groups, such as in the analysis and execution of the strategy; the strategy communication; it is focused on actions, and being a flexible management and monitoring tool for strategic planning.

3 Materials and Methods

3.1 The Research

A preliminary bibliographical survey was carried out to identify the main questions regarding the ERP system (functions, benefits, comments, and statements) and the BSC system (functions, purposes, benefits, and limitations) in current literature. Afterward, 12 pilot companies were visited to identify which companies were willing to participate in the survey. With the support of these companies, there were chosen the main questions that should be included in the questionnaire to satisfy the research objective. The questionnaire had 15 questions, and it was applied to the manager of the financial area, controlling, logistics, production, information technology, human resources, administration, sales and after sales.

The research was carried out in five food industries based in Brazil with the objective of verifying and analyzing the existence of synergies and difficulties between the BSC (Balanced Scorecard) strategic management systems and the ERP (Enterprise Resource Planning), in the execution of the organization's strategy.

3.2 The Case Study

Due to the empirical research, we choose the case study method to describe and analyze the integration and synergy between BSC and ERP [13]. In a research conducted using the case study method, dual-dimensions should be considered [14]:

- The number of cases that make up the study; and
- The focus attributed to the unit under analysis.

Table 1. Characteristics of food industries (food and beverage products) researched in Brazil.

Industries	1	2	3	4	5
Established (year)	1970	2009	1905	1963	1921
Source of capital	Brazil and Netherlands	Brazil	Holanda	Brazil	Switzerland
Branch	Foods/Beverage	Foods/Beverage	Foods	Foods	Foods
Products	Foods/Beverage	Foods/Beverage	Foods	Foods	Foods
Revenues in Brazil (year 2016)	US$ 1.4 bi	US$ 16.1 bi	US$ 16.5 bi	US$ 2.2 bi	US$ 1.8 bi
Employees (2016)	ca. 5,200	ca. 105,733	ca. 17,000	ca. 6,421	ca. 21,642
Domestic market	In all Brazil	In all Brazil	In all Brazil	In all Brazil	In all Brazil
International market	Europe/USA/ Asia/Africa	Europe/USA/ Asia/Africa	Europe/USA/ Asia/Africa	Europe/USA/ Asia/Africa	Europe/USA Asia/Africa

Source: Research Data.

The purpose of the use of multiple cases is to enable the comparison between the ERP system and the BSC system in different companies that use these two management systems. Table 1 presents the characteristics of the food industries researched.

4 Discussion of the Case Study - Results

Analyzing the answers of the interviewees, it was possible to state that:

- The main synergies between the BSC and the ERP are in the planning, calculation, monitoring, and dissemination of performance indices together with the speed, quality and reliability of the information;
- Synergy and integration between ERP and BSC brought improvements in production and operations processes, productivity gains, cost savings, improved product and service quality, increased market share and profitability;
- The benefits generated by the integration and synergy between the BSC and the ERP refer to the monitoring and control of the objectives and goals of the industry, timely correction in the decision-making process, the reports made available at any time and improvements in the processes of cost rationalization;
- The difficulty in integrating BSC with ERP is one that could at first be considered predictable: the ERP was not prepared to meet all the needs of the BSC; consequently, there was a need for adjustments and improvements with the generation of additional, unplanned costs.

The problems in integration and difficulties between BSC and ERP systems observed in all industries surveyed were:

- The areas that presented the greatest difficulties in this regard were the areas of logistics, production, and sales, while in the financial, accounting and controlling areas, the integration of the BSC was normal;
- However, the greatest difficulty common to all the industries surveyed was the lack of understanding of those involved in the proposal that the BSC system intended to take the organization's strategy to the knowledge and participation of all. The training factor was considered the most vulnerable point in the process and was later used on a larger scale to raise awareness and minimize resistance to change.

5 Final Remarks

The use of information management systems (ERP) and strategic management (BSC) becomes a significant competitive advantage for the food industries in Brazil, so it is possible to understand why 96% of the food industries use ERP and BSC in the management of their businesses.

The multiple-case study method discussed in this study showed that the ERP and the BSC, as well as the synergies between them, meet the needs of the management and execution of the strategy in these organizations. Both ERP and BSC systems, integrated, bring benefits in stock control and storage of the raw material and the finished product, avoiding perishable products spoil and cause damages. Both ERP and BSC integrated through synergies, contribute to the control of quality management that is determinant in the food industries, through defined processes and parameterized for each batch produced. These systems make it possible to manage the quality of products purchased and finished, issue reports of non-conformity, batch domain and mainly product traceability.

ERP and BSC, individually, and primarily by their synergies facilitate compliance with the legal standards that certify the release of consumption for the product. These systems issue technical reports, printing of nutritional labels with details of product specification and its components to meet specific legal standards. It is observed that when there are synergies, integration between the ERP and the BSC these companies become more competitive and more profitable.

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Brazilian Corn Exports: An Analysis of Cargo Flow in Santos and Paranagua Port

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Abstract. The world's population is projected to increase to 9 billion till 2050, increasing feed demand. Corn is one of the most important grains in food supply chains (FSC), and growers have an essential role. This article aims to investigate the flow of Brazilian corn among origin, main ports, and international markets to address a panorama of corn production in Brazil. With this objective, we collected data from the Brazilian Ministry of Industry and Foreign Trade, and we analyzed this data using Social Network Analysis (SNA) tools. The results showed that corn exports in Brazil use two main ports, with Santos being the most important one.

Keywords: Logistics · Corn production · Exports · International market

1 Introduction

It is forecasted that the world trade of corn will reach newer heights, boosted by a stronger demand for feed. Currently, the United States and China are the main growers, but Brazil has been considered a new frontier and occupies the third place [1]. Despite the important role of China in production, over the last five years, around 83% of export was associated with the US, Brazil, Argentina, and Ukraine. This distinctly indicates a huge internal market in China and the potential business opportunities for producers in the US and Brazil.

The United Nations expects the world population to increase to 9,725 billion by 2050 [2]; this implies a challenge for the global leaders to raise food production and at the same time to preserve the environment and local market production. In this manner, Brazil appears to be a major player in commodity production to feed the world. In case of corn, for instance, projections show an increase in

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Brazilian exports of 52.4% until 2026. In numbers, the country is expected to reach 46.3 million metric tonnes (mt) per year [3].

Although Brazil has high productivity and a high quantity of available land, the flow of commodities export depends on few routes and ports that entail logistics bottlenecks. For example, Reis et al. [2] argue that poor logistics of Brazilian infrastructure increases the inland freight of soybean in comparison with the US by 146%. Moreover, Galvão et al. [4,5] showed that Brazilian ports cargo flow grew significantly, around 42% from 2001 to 2011, reaching 886 million (mt) in 2011; this was mainly solid bulk cargo.

Regarding Brazilian ports, Santos (Sao Paulo) and Paranagua (Parana) are the major corn exporters with 66.5 million (mt) between 2012 and 2016. The corn flow concentration creates logistics bottlenecks such as extensive truck lines to unload cargo and low static storage capacity. Rodrigues [6] affirms that logistics management adopts a systematic cost approach based on parameters such as cost, time, and service quality level. Therefore, analyzing the flow of corn production is very important for developing a plan to improve the logistics infrastructure of major corridors.

This article aims to analyze the Brazilian corn routes and exports for understanding the current scenario and for providing knowledge to develop future plans for improving logistics operation. Thus, we address the flows of corn among the six main growers of the country to two main ports of Brazil and to the international market.

2 Brazilian Ports

Brazil has a continental dimension with an extensive coastline; for this reason, sea shipping is relevant to the social and economic development of the country [4]. Brazilian port sector is divided into two categories: first, the port sector that is composed of 37 seaports, managed by the federal government; the second category that is composed of 122 inland port facilities management by the Ministry of Transport [7].

The cargo flow in Brazil's seaports, in 2016, was 998,068 million (mt), where the main international traffic was dry bulk of upto 628,700 million (mt); liquid bulk of upto 218,000 with million (mt); general cargo of upto 51,300 million (t); and containers of up to 100,100 million (mt) [9].

2.1 Santos Port

Santos is Brazil's larger port. In 2006, it represented around 28.5% of the balance of trade of the country. Its operations reached 113.8 million (mt) [10]. This suggests the great relevance of Santos Port among the 37 Brazilian ports. Nowadays, it is the main port of the country with 4,520 ships being docked in 2016. Furthermore, this port is considered as being one of the biggest ports in Latin America in terms of container flow in 2015 [11].

Accessibility is the main factor that attracts cargo to the Santos Port. The port has a link with the main roadways. Moreover, it is connected to Tiete-Paraná inland waterways by railway that facilitates a large-scale movement of commodities.

In addition, the areas dependent on Santos Port represents 67% of Brazilian GDP including states such as Sao Paulo, Minas Gerais, Mato Grosso, Mato Grosso do Sul, and Goias e o Distrito Federal. These states are responsible for 56% of Brazilian balance of trade [10].

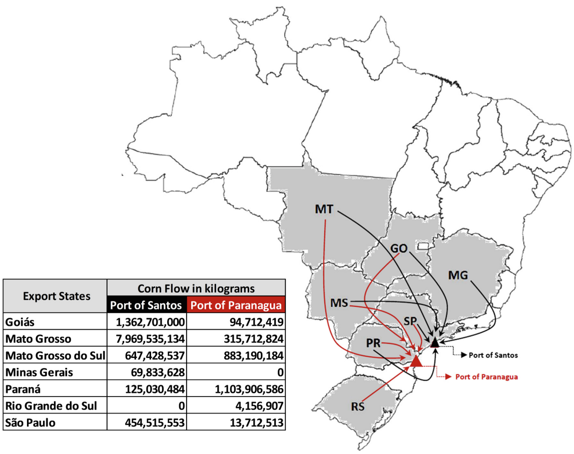
2.2 Paranagua Port

According to the Administration of Paranagua Port and Antonina - APPA [12], the Paranagua Port has 3,581 meters of wharfs and 23 berths. It is among the five main Brazilian ports in relation to the flow of goods. The port in 2016 moved 45,045 million (mt), and it has the capacity to receive 1,909 vessels. The three main cargo were as follows: containers (8,231 million (mt)), fertilizers (8,227 million (mt)), and soybean (7,950 million (mt)) [9].

Additionally, the Paranagua port's balance of trade was around 7.6%, immediately after Santos, which, as mentioned earlier, lead the ranking with a striking difference of 28.5% [10].

3 Methodology

For understanding the flow of Brazil's corn exports and the role of Santos Port (Sao Paulo state), we conducted an exploratory research and comparison between the Santos Port and the major Brazilian port competitor, Paranagua. The Fig. 1 displays the location of these ports and the main origin routes.



Export States	Corn Flow in kilograms	
	Port of Santos	Port of Paranagua
Goiás	1,362,701,000	94,712,419
Mato Grosso	7,969,535,134	315,712,824
Mato Grosso do Sul	647,428,537	883,190,184
Minas Gerais	69,833,628	0
Paraná	125,030,484	1,103,906,586
Rio Grande do Sul	0	4,156,907
São Paulo	454,515,553	13,712,513

Fig. 1. Main corn corridors 2016

Santos and Paranagua were chosen because they represent around 50% of volume exported by the country. To perform this study we follow the following three steps:

First: Data Collection. Data were collected from the Brazilian Ministry of Industry and Foreign Trade, using the Foreign Trade Information Analysis System (ALICEWEB). The Aliceweb provided us information regarding the volume of corn exported by grower states such as Goias, Parana, Sao Paulo, Minas Gerais, Mato Grosso do Sul, Rio Grande do Sul, and Mato Grosso.
Second: Database Procedure. We selected ten major destinations for Brazil's corn as per the state of origin. This allowed us to observe 38 relations among players. The data were organized considering the state of origin, the port of origin, and the country of destination. The relationships were created considering the corn flow of growers to the ports and them to countries.
Third: Analysis. Using the Social Network Analysis (SNA) tools, Ucinet 6.0 and Netdraw plotted the graphs of the corn networks considering exports flow using Santos Port, Paranagua Port, and both of them together. This helped us to create a flow map regarding the corridors of exportations and also to analyze corn traffic.

4 Results

Santos and Paranagua ports are established as major corridors for corn exports in Brazil. Both moved around 66.5 million (mt) between 2012 and 2016 (Fig. 2). Together, Santos and Paranagua Ports deal with 81.48% and 18.52% of Brazil's corn respectively.

The origin of cargo flow can be observed in Mato Grosso, Mato Grosso do Sul, Goias, Parana, Minas Gerais, and Sao Paulo e Rio Grande do Sul. As mentioned earlier in the methodology section, the volume of corn among these states and

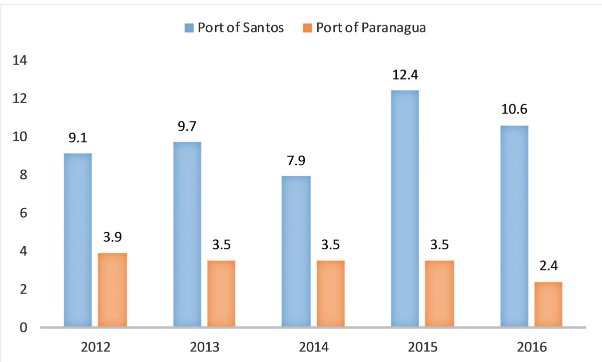


Fig. 2. Cargo flow in million of metric tonnes to Santos and Paranagua ports (Source: Adapted of [13]).

Ports of Santos and Paranagua are organized in Microsoft Excel and are entered in the Ucinet 6.0 software. Using the module Netdraw was possible to provide that networks to infer some analysis presented in the next subsections.

4.1 International Traffic Considering Both Ports

The Fig. 3 depict the corn flow considering the network as a whole, including all the states, ports, and destination. Herein, we gather the countries of destination in the continents to facilitate visualization.

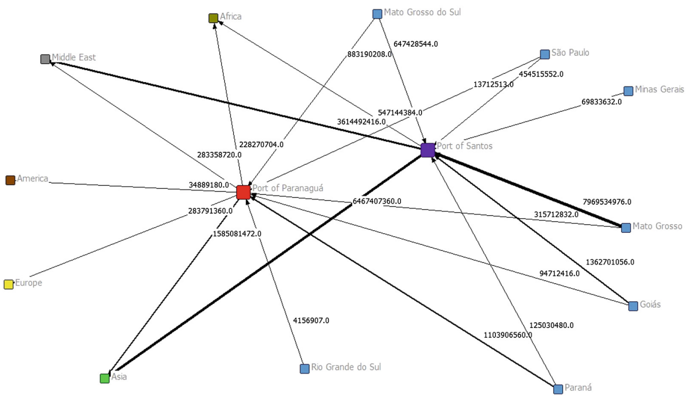


Fig. 3. Corn flow among Brazilian States, Ports of Santos and Paranagua, and continents of destination

As can be seen in Fig. 3, Mato Grosso is the main grower with 8,285 million (mt) flowing to Santos and Paranagua. The distance that needs to be covered to reach both ports is almost the same, but the Santos route, especially the railroad service, is more developed than the Paranagua route. As a result, this is directly responsible for the highest cargo flow to Santos.

On the other hand, Mato Grosso do Sul represents the second volume of corn to be exported, with 1,530 million (mt) distributed equitably between both ports. The geographical position of the state with a dependence of roadway transportation allows Mato Grosso do Sul to use the ports indistinctly. They are located at the same distance of about 1,100 km.

The destination of Brazilian corn as per continent was also analyzed. Our results indicate the following percentages: Asia (61.73%), Middle-East (29,88%), Africa (5,94%), Europe (2,18%), and America (0,27%). Vietnam boosted the flow in Asia, while the Middle-East distinctly depended on import of agricultural products, both constituting the most important markets of Brazil.

4.2 Santos

The Fig. 4 depicts the corn flow considering the network of Santos Port.

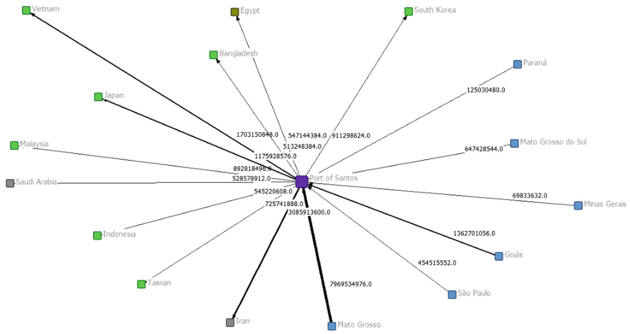


Fig. 4. Corn flow by Santos corridor

Santos moved 10,629 million (mt) of corn in 2016. The main exporters via Santos were Mato Grosso (74.98%), followed by Goias (12.82%), Mato Grosso do Sul (6.09%), São Paulo (4.28%), Parana (1.18%), and Minas Gerais (0.66%). It is possible to note that despite 60.85% of the volume being exported to the Asian continent (Taiwan, Indonesia, Japan, Vietnam, South Korea, and Bangladesh), Iran and Middle-East were highlighted within 29.03% of the volume of corn exported by Santos.

4.3 Paranagua

The Fig. 5 depicts the corn flow considering the network of Paranagua Port.

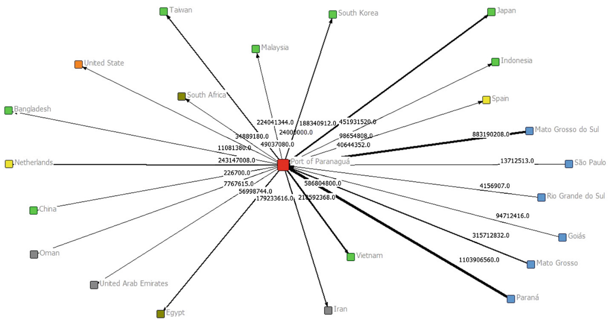


Fig. 5. Corn flow by Paranagua corridor

Based on Fig. 5, it is noticeable that Paranagua, in 2016, exported 2,415 million (mt). The state of Parana (45.70%) lead the export, followed by Mato Grosso do Sul (36.57%) and Mato Grosso (13,07%). Among the 16 main buyers highlighted were Vietnam (24.29%) and Japan (18.71%). Other states represent 57.0% of imports. In relation to continents, the most important were Asia

(65.62%), followed by Europe (11.75%), Middle-East (11.73%), Africa (9.45%), and America (1.44%).

5 Discussion

We found that Santos Port is the major corridor that exports Brazilian corn production with a cargo volume that is almost three times more than that of Paranagua. Santos is undoubtedly the biggest port of Latin America, and it has the largest infrastructure associated with the main Brazilian corridors of commodities exports.

However, despite the advancement of the Port Modernization Act (8630, of 1993) and the new regulatory framework of the port sector (12.815, of 2013) that have the objective of providing more agility and modernizing the sector, reducing the costs of transactions [4,5], port infrastructure and the quality of services remain issues that affect the agricultural production of the country [14]. According to data by the World Economic Forum pertaining to the Brazilian port infrastructure, compared with the main exporters of corn and soybeans, Brazil was the 122nd position among 144 evaluated countries [14].

Our current findings expand previous work regarding the Brazilian agribusiness sector and logistics infrastructure; this allows the identification of the corn flow to the main international markets of Brazil using quantitative data.

In spite of this article being an exploratory analysis, it permits the identification of a pathway for future studies to improve the bulk of cargo flow. The results showed that Santos and Paranagua are the main routes of corn exports and constitute a logistics operations bottleneck for the international traffic of this important feed. This is especially true for Santos because it is the major exporter of commodities and many other products. It is also Brazil's main access to the international market.

Some authors such as Marlow and Casaca [15], Vieira et al. [16] and the Brazilian National Transport Confederation [14] identified many issues that make exporting difficult; further, they provided the following aspects and opportunities to improve Santos Port: (i) *Maritime access:* Lack of dredging and overthrow of access channels and docking berths making access of large ships difficult; (ii) *Territorial Access:* Traffic jam and limited availability of railroads; (iii) *Low productivity:* Obsolete equipment and lack of availability of equipment and facilities; *Burocracy:* Greater agility in cargo clearance at ports, mooring, single window paperless port to boost delivery of documents; *Information flow:* Multiple systems to manage the operations, loss-making media channel, hindering the customer response time.

6 Conclusions and Outlook

The objective of this study was to describe the logistical corn flow of exports; moreover, it was possible to conclude that the Midwestern region was the main corn export region of Brazil. Additionally, it was noticeable that the flow of grain to the international market is concentrated in Santos and Paranaguá. It was also found that Asia is the main destination for exports of corn, followed by the Middle East. However, Iran is the largest purchaser of Brazilian corn followed by Vietnam.

Finally, the concentration of two routes generates logistics bottlenecks in both ports creating a traffic jam, low static capacity, and overuse of the port capacity. Thus, the subsequent studies will concentrate on simulating the capacity of Santos and Paranagua Ports to lead with commodities exports and opportunities to improve Brazilian logistics infrastructure.

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Inventory Allocation of Perishables: Guidelines

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Abstract. The purpose of this study is to investigate and propose guidelines for how to allocate perishables to improve the balance of freshness and availability in retail stores. Specifically, it is investigated how a single warehouse can make the allocation decision to stores with and without access to remaining shelf life information of the products in the stores. Contrary to complex decisions models, this study aim to develop simple guidelines that can be applied manually or easily integrated into existing decision support systems.

Keywords: Inventory allocation · Food supply chain · Perishables · Information sharing · Remaining shelf life

1 Introduction

Food supply chains separates itself from other supply chains and necessitates special logistical requirements due its characteristics of perishability of products, high demands on quality, and tractability requirements [1, 2]. Particularly, for products with a shelf life less than 30 days – known as perishables [3, 4] – where the quality of the products deteriorate over time, questions the applicability of non-perishable supply chain practices in food supply chains [5, 6].

In retail supply chains, stores in a particular geographical region may be supplied from a central warehouse or a smaller distribution centre. Inventory allocation policies consider how to distribute products among the requesting stores from the warehouse in case of shortage – also known as rationing policies [7, 8]. For perishables, this decision is further complicated as the products to allocate may have different remaining shelf life. Even if the warehouse has more stock on hand than what is requested from the stores (no rationing required) the products still needs to be allocated among the stores to reduce the risk of outdating. Consequently, it has been stated that for perishables the *age* of the allocated products may be as important as the *amount* allocated [9].

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Rationing policies consider how to distribute the *amount* of products from the warehouse typically based on information about expected demand, inventory position, or safety stock levels at the stores [7]. The different *age* groups of products at the warehouse can be expressed by the remaining shelf life (RSL_W) of those products. To decide which stores that should receive products with the longest RSL_W the remaining shelf life of the products currently at the stores (RSL_S) appear useful and will be investigated. Hereby, a more even distribution of freshness across the supply chain may be obtained.

The literature on allocation of perishables in distribution systems is limited [10] and is often presented as comprehensive decision models [11, 12]. It has been noticed that advanced models and decision support systems faces some barriers of implementation (e.g. the underlying model is too complex and not understood nor trusted [13]). Subsequently, there is a need to investigate more real world settings of perishables [14].

In this study, we investigate and propose simple guidelines for how practitioners can allocate the amount and the age of perishables. As the allocation of the products is made at the warehouse, we assume access to RSL_W at all times. However, depending on the level of shared information the warehouse might not have access to the RSL_S. Thus, we investigate and propose guidelines for the following scenarios:

(1a) The warehouse has not access to RSL_S and no shortage at the warehouse
(1b) The warehouse has not access to RSL_S and shortage at the warehouse
(2a) The warehouse has access to RSL_S and no shortage at the warehouse
(2b) The warehouse has access to RSL_S and shortage at the warehouse.

The remainder of this paper is organized as follows: first, we present the relevant literature about rationing and inventory allocation of perishables. Afterwards, we restrict our attention to the development of the guidelines. Section four discusses the implications and applicability of the guidelines.

2 Background

For non-perishables the optimal control of divergent distribution systems follows the order-up-to policy under the balanced stock assumption [9]. The balanced stock assumption assumes that the inventory position across all downstream stocking points are balanced or at least negligible unbalanced, making it possible to consider a divergent system as a serial system [15]. For divergent systems typical rationing policies includes: *Fair Share* allocation which strives to obtain an even probability of stock-out at each downstream stocking point [7]. *Priority* allocation which ranks and allocate the amount available based on the importance of each customer. *Consistent Appropriate Share* allocation where downstream stocking points with higher safety stock receives a bigger ratio from the warehouse [7].

No equivalent optimal control mechanism exists for perishables in divergent systems due to the complexity created by the different ages of the products [9]. Divergent systems are of special interest as these reflects the common situation of food supply chains. Yet, the contributions for controlling perishables are limited in these systems [10]. Two main classes of policies can be identified: (1) rotation policies, where the remaining inventory from downstream stocking points is returned to the warehouse at the end of each period, and (2) retention policies where the downstream stocking points keeps all remaining inventory until sold or outdated [16]. As it is most common to apply the retention policy in food supply chains we restrict our attention to these.

Traditionally, the allocation decisions for perishables have been simplified to reduce complexity [9]. For instance assuming zero lead time [17] or infinite supply to the stores [10]. Also, in the policy by Prastacos [16] the only products of interest are products that outdate at the end of the next period, or in other words, only products with one day left of shelf life. Because it is assumed that the warehouse has a constant flow of products to the stores, the warehouse will never keep products with a remaining shelf life of one day. Hereof it follows that what the warehouse allocates to the stores do not influence outdating in the end of next period (the products that outdates are already in the stores), and the problem is reduced to minimize the risk of shortage.

To minimize shortage and outdating a common observation appear to have been found in literature: (1) the number of products soon-to-outdate should be distributed evenly and relatively to demand (for each location), and (2) the total amount allocated should equalize the probability of stock-out at each location [10, 16].

3 Development of Guidelines

If the RSL_S are unbalanced among downstream stocking points it might not be sufficient to *just* focus on the soon-to-outdate products at the warehouse, and allocate them relatively to demand as suggested above. Three practical obstacles highlights this. Firstly, that allocation procedure do not consider how to allocate products which are not classified as "soon-to-outdate" and how this affect the freshness at the stores. Secondly, in food supply chain products are often shipped in multiplies of batch sizes [3], and the allocation sizes might end up being different from the number of batches – meaning the soon-to-outdate products cannot be evenly distributed. Thirdly, from the perspective of the pick-and-pack process it is more efficient if e.g. three batches from the same pallet (same RSL_W) is collected to one order instead of three batches from three different pallets.

Similar to literature about simple replenishment policies of perishables (see e.g. [4, 18], we aim to develop simple allocation policies for perishables which acts as guidelines to ensure its applicability. These guidelines should consider and accommodate the obstacles highlighted above.

The following section presents the guidelines if RSL_S information from the stores are not available to the warehouse, and the second section presents the guidelines if we assume RSL_S is available. All guidelines assumes there is access to RSL_W at all times. Some general notation is outlined below:

B: Batch size (order multiplier between the store and the warehouse)
Q_i: Order quantity (in batches) from store *i*
I_i: Current inventory level at store *i* (in SKUs)
I_0: Current inventory level at warehouse (in batches)
L_i: Lead time for store *i*

R_i: Days till next review at store *i*
A_i: Amount of “old” products at store *i* whit a RSL_S less than or equal to R + L
WA_i: Weighted average RSL_S of A_i at store *i*.

3.1 Allocation of Perishables Without RSL_S Information

Inventory Greater than Demand
Rationing among stores are not necessary when the warehouse holds more inventory on hand than what is totally requested from the stores. This reduces the problem to how to allocate the different ages groups from the warehouse. To counteract the obstacles of batches and how to distribute different RSL_W to the requesting stores, we propose to rank stores according to expected sales until next delivery – stores with the highest expected sales receive the oldest products from the warehouse to increase the chance of selling these products before they outdate. The expected sales until next delivery (L_i + R_i) includes the order (Q_i) plus the current inventory level at the store (I_i), mathematically we formulate this ranking as:

$$Rank_1 = \frac{BQ_i + I_i}{L_i + R_i} \tag{1}$$

As an example, assume store A has 20 products currently on inventory (I_i) and ordered (Q_i) additionally 2 batches of 10 products, while store B has 40 products on inventory and also ordered additionally 2 batches. With both stores having a review and lead time (L_i + R_i) of totally 2 days, store A would obtain a $Rank_1$ score on (2 * 10 + 20)/2 = 20 and store B (2 * 10 + 40)/2 = 30. In this case store B should receive the oldest RSL_W as a higher sales is expected here compared to store A.

Inventory Less than Demand
If the warehouse holds less inventory than what is totally requested from the stores, rationing among the requesting stores are necessary. Thus, it is necessary to allocate the available amount and the different age groups from the warehouse. We propose a three-step procedure following the logic from the fair share allocation rule to calculate the amount to allocate.

Step 1 - Calculate the average supply chain wide service level:
Assuming a perfect balanced distribution of available products among the stores, we calculate the ratio between available products (ΣI_i + I_0) in the chain and the total demand across (ΣBQ_i + ΣI_i) the whole chain – giving an indication of the best case service level. Again, demand is considered as the sum of orders and current inventory levels from the stores.

$$SLA1_{SC} = \frac{\sum I_i + BI_0}{\sum BQ_i + \sum I_i}; \text{for all } i \tag{2}$$

Similar, for each store the current service level can be calculated:

$$SL1_i = \frac{I_i}{I_i + BQ_i} \tag{3}$$

Continuing the example from above, and with 3 batches available at the warehouse (I_0) it can be calculated that $SLA1_{SC}$ is (40 + 20 + 10 * 3)/(10 * 2 + 10 * 2 + 20 + 40) = 90%. $SL1_A$ equals 20/(20 + 10 * 2) = 50% and $SL1_B$ 40/(40 + 10 * 2) = 66.67%.

Step 2 - Calculate the possible supply chain wide service level:
Stores which has a current service level ($SL1_i$) larger than average supply chain wide service level ($SLA1_{SC}$) is "overstocked", and should ideally receive negative quantities in order to distribute their surplus among "understocked" locations [7, 16]. However, as these types of transshipments is very uncommon food supply chains, we propose to exclude the overstocked locations and only distribute the available products from the warehouse to understocked locations by calculating a new supply chain wide service level:

$$SLP1_{SC} = \frac{\sum I_i + BI_0}{\sum BQ_i + \sum I_i}; \text{for all } i \text{ where: } SL1_i < SLA1_{SC} \tag{4}$$

From the example, as both $SL1_A$ and $SL1_B$ is less than $SLA1_{SC}$ both stores are understocked and $SLP1_{SC}$ will in this case be equal to $SLA1_{SC}$.

Step 3 – Calculate allocation quantities:
$SLP1_{sc}$ specifies the service level at each store after allocation, thus the allocation quantity can easily be determined by subtracting the current inventory level (I_i):

$$QA1_i = \frac{(I_i + BQ_i)SLP_{SC} - I_i}{B}; \text{for all } i \text{ where: } SL1_i < SLA1_{SC} \tag{5}$$

$QA1_A$ would equal ((20 + 10 * 2) * 90% − 20)/10 = 1.6 and $QA1_B$ = 1.4. Hence, store A would receive 2 batches and store B 1 batch. Lastly, the stores are again ranked following $Rank_1$ to allocate RSL_W. Stores B will have the highest score and receives the oldest products.

3.2 Allocation of Perishables with RSL_S Information

Inventory Greater than Demand

As in Sect. 3.1 when inventory is greater than demand the issue is reduced to how to allocate the different age groups from the warehouse to the requesting stores. With access to RSL_S information both the number of products soon-to-outdate (A) and the weighted average remaining shelf life of that amount (WA) can be calculated and used to improve the allocation. To compensate for either a high amount of products (A) or a low RSL_S (WA) for improving the allocation the ratio between those two are calculated:

$$RA_i = \frac{A_i}{WA_i}; \text{for all } i \tag{6}$$

This ratio may be used as a measure for comparing stores against each other – a smaller ratio indicates a smaller risk of products outdating. E.g. assume store A has 4 products soon-to-outdate with a weighted average RSL_S of 2 days (RA_i = 4/2 = 2) compared to the bigger risk at store B with 15 products with a weighted average RSL_S of 2 days (RA_i = 15/2 = 7.5).

However, this risk should be considered in relation to the expected sales of the two stores. As previously, stores with higher expected sales are expected to have a higher chance of selling products before the expire and should receive the oldest products from the warehouse. The risk of products outdating (RA_i) is compared to the expected sales:

$$Rank_2 = \frac{RA_i}{BQ_i + I_i} \tag{7}$$

Store A equals 2/(2 * 10 + 20) = 0.05 on $Rank_2$ while store B ranks with 7.5/(10 * 2 + 40) = 0.125 meaning that, proportionally to demand, store B has a higher risk that the products already in the store will outdate. Thus, store A (with the lowest $Rank_2$ value) receive the oldest product and store B receive the newest. Hereby, a more even distribution of freshness will be obtained across the chain.

Inventory Less than Demand

In case of shortage at the warehouse a similar procedure is followed as without RSL_S information - the difference is stores, which either has many products soon-to-outdate (A) or little RSL_S left (*WA*) which gets more weight relative to other stores. We use the *RA* ratio to make this comparison. A high value indicates that the store risks some products to outdate, thus it can be considered as an "extra demand" to be covered by the store. We adjust the steps and formula 2–5 accordingly:

Step 1 - Calculate the average supply chain wide service level:

$$SLA2_{SC} = \frac{\sum I_i + BI_0}{\sum BQ_i + \sum I_i + \sum RA_i}; \text{for all } i \tag{8}$$

$$SL2_i = \frac{I_i}{I_i + BQ_i + RA_i} \tag{9}$$

Assuming 3 batches on the warehouse, $SLA2_{SC}$ can be calculated to (20 + 40 + 10 * 3)/(10 * 2 + 10 * 2 + 20 + 40 + 2 + 7.5) = 82.2%, $SL2_A$ to 20/(20 + 10 * 2 + 2) = 47.6% and $SL2_B$ to 59.2%.

Step 2 - Calculate the possible supply chain wide service level:

$$SLP2_{SC} = \frac{\sum I_i + BI_0}{\sum BQ_i + \sum I_i + \sum RA_i};\ \text{for all } i \text{ where: } SL2_i < SLA2_{SC} \quad (10)$$

As both $SL2_A$ and $SL2_B$ is less than $SLA2_{SC}$ both stores are understocked and $SLP2_{SC}$ will in this case be equal to $SLA2_{SC}$.

Step 3 – Calculate allocation quantities:

$$QA2_i = \frac{(I_i + BQ_i + RA_i)SLP2_{SC} - I_i}{B};\ \text{for all } i \text{ where: } SL2_i < SLA2_{SC} \quad (11)$$

$QA2_A$ would equal ((20 + 10 * 2 + 2) * 82.2% − 20)/10 = 1.45 and $QA2_B$ = 1.55. Hence, store A would receive 1 batches and store B 2 batches. Lastly, the stores are again ranked according to $Rank_2$. Stores A will have the lowest score and will receive the oldest products.

4 Conclusions

This study adds to the limited literature about allocation of perishables [10] by proposing guidelines for how practitioners can allocate perishables to improve the balance of freshness and availability in stores. Two main areas of concern is discussed in this section. Firstly, what is the implications[1] of applying guidelines like these in practice? Secondly, how widespread is the applicability and the ease of implementation?

The guidelines strive to balance the risk of shortage and outdating evenly across all downstream stocking points while accommodating practical obstacles like batch sizing and the efficiency of pick-and-pack process. $Rank_1$ is applied when there is no access to RSL_S information, and strives to ensure smaller stores with less sales receive products with the highest RSL. Often smaller stores only have deliveries few times a week, thus it is essential that the products they receive last as long as possible. On the contrary, bigger stores with higher sales will receive the less fresh products. The chances of a consumer willing to accept a lower RSL might be higher in these stores as they generally has more consumers through the store during the day. $Rank_2$ can be applied when the warehouse has access to the RSL_S information. It basically follows the same reasoning about fresher products to smaller stores. But, here the allocation (amount and RSL) are dynamically adjusted according to the RSL_S. Hereby, larger stores do not necessarily always get the products with lowest RSL.

Even though the guidelines can be considered applicable to most food supply chains, there is risk that some stores perceive themselves as having a lower priority if they continuously receive products with lower RSL than other stores. This should be

[1] The guidelines will be tested through discrete event simulation to estimate the impact on freshness, waste, and available. The results will be presented at the APMS conference in Hamburg 2017 and will be available upon request, but is omitted in the paper due to space limitation.

considered, especially if the stores are independently owned or franchising of a larger retail concept. The benefits should be distributed to ensure those stores that may take a big risk of receiving products with low RSL also receive a corresponding reward. On the other hand, stores that are fully owned by the same retailer may prefer guidelines as these proposed in this study to improve the balance of freshness and availability across all its stores.

Lastly, it should be noticed, that using guidelines like these do not guarantee an optimum balance of freshness and availability and could be considered as a limitation – however, they provide an easier reasoning for the employees who has to apply them. As future research the guidelines should be tested either through simulation experiments or case implementation to quantify the impact on freshness and availability.

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Challenges and Opportunities in 'Last Mile' Logistics for On-Line Food Retail

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Abstract. Conventional approaches to logistics for food retail continue to be challenged by the rapid growth of on-line food retail. At the same time, '*last mile*' logistics optimization for on-line retail also face challenges as changing consumer expectations, habits and purchasing patterns intersect with the increasing density of urban environments. Numerous considerations are already in play around servicing of last mile logistics for on-line food retail including whether it is home delivery or pick-up; delivery is attended or not; and, whether the service is managed in-house or out-sourced to third party providers. Selecting the appropriate distribution and delivery channel is challenging with choices intimately related to the variety and price of products offered for sale (premium or discount) as well as the delivery times promoted to prospective customers. Beyond these pragmatic considerations, are also changing consumer expectations and preferences, innovations in new technology, provenance & traceability, seasonality and emerging reverse logistics issues linked to 'green' carbon miles considerations. This paper systematically explores these issues emerging in online food retail logistics.

1 Introduction

On-line retail has expanded very rapidly during the last decade. In many Western countries, the on-line retail market-share of conventional retailing has grown to be between 5–10% of the total market. In on-line food retail according to *Food Processing* [1] while traditional grocery stores in US increased their turnover by 0.3% in 2014, eCommerce retailers increased their turnover by 13.5%. Traditional grocery stores still have the majority of sales with a turnover of US$547 billion in 2014 in contrast to US $24 billion for e-commerce initiatives. According to *Food Processing* [1] there will be fewer traditional grocery stores in the future, and many will be engage in as much Internet order fulfillment in terms of "click-and-collect" as browsing-the-aisles retail.

Companies can be fully, partially or not engaged in e-commerce. Firms that are entirely based on e-commerce are also often described as virtual (or 'pure-play')

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organisations. Click-and-mortar (or click-and-brick) means that organisations are partially engaged in electronic commerce but operate a physical store as well. Brick-and-mortar companies are not engaged in e-commerce at all [1]. In a response to the rapidly developing e-commerce market, many physical retailers started to use the internet as an extra channel to sell their products [2]. Moreover, a lot of pure-play on-line retailers are opening physical shops or collaborating with traditional retailers [3]. They are engaged in what is commonly referred to as 'multi-channel retail" that not only includes physical stores, but also other channels, including on-line stores and a range of different types of delivery options for end-customers [4]. Perhaps unsurprisingly, with the growing pervasiveness of mobile internet connectivity and increasing competition in the retail marketplace, most retailers are diversifying into these multi-channel forms of retail.

This multi-channel strategy attracts three segments of customers. The on-line channel attracts the type of customer that prefers to view product descriptions on-line and save travel and purchasing time. The physical store captures the loyal clients that prefer to shop in a store rather than on-line. While the availability of both channels has stimulated the emergence of a third segment of consumers that opt to use different channels at different times and thereby display multi-channel purchasing behaviors [5].

Newswire [6] conducted a small survey among 1250 consumers comparing physical and on-line retailers. For perishable goods, 67% of consumers surveyed indicated that physical shops outperform on-line retail, while only 5% indicated the reverse. In relation to product variety 38% of consumers surveyed favour physical shops, while 22% indicated favouring the reverse. These survey results highlight some of the issues emerging with the rapid growth of on-line retail including changing shopping habits, challenges in servicing variety and higher requirements for quality and trust.

In supermarkets there are many fresh food departments including bakery, butcher and grocery where perishability and personal preference are significant factors. For example, grocery items such as vegetables and fruits belong in the 'see/touch/smell' category. Consumers want to check that for example, the apples they pick have no bruises and/or if a melon feels firm. Consumers want to personally choose their own fruits and vegetables and pick and choose their bread and meat purchases. Clearly buying on-line creates a risk that the product received may not meet the expectations of the consumer. Furthermore, many consumers attach significant value to the 'shopping experience' that involves being helped by expert personnel during the purchase of fresh products. Another challenge to overcome is the lack of instant fulfilment with on-line shopping. New technology such as streaming media, that provide real-time visual information of these type of products, and chat possibilities with store employees may mitigate some aspects of this lack of instant fulfillment and contribute to a further increase in on-line shopping, although it is likely to be only one factor amongst many for consumers when opting to purchase on-line.

Another important challenge for on-line food retailers is developing a convenient and user friendly on-line environment where consumers can buy groceries quickly and easily. Following Babin et al., there are at least two types of on-line shopping behaviors exhibited by either 'utilitarian shoppers' or 'hedonic shoppers'. Utilitarian shoppers perceive shopping as work, they want to do it fast and have it done quickly and easily. Hedonic shoppers strive for fun and entertainment in shopping (Babin et al. 1994). As a result on-line retail needs to be able to service both types of shopping behaviors in its on-line retail environments i.e. It has to support convenient and quick-to-use, as well as pleasant and enjoyable shopping experiences. To-date, the most innovative approaches to address these challenges has been the use of virtual reality and/or augmented reality to enhance interaction in on-line shopping environment in response to on-line consumer behaviors and preferences Although it appears probable that choices about investment in these types of on-line experiences may be contingent on the volume of hedonic shoppers as opposed to utilitarian shoppers engaged through the on-line retail environment.

2 The Last Mile

Around 1950, about 50% of the European population was living in cities. Nowadays, this is more than 70% and according to the United Nations, this will rise to slightly over 80% by 2050 [7]. For logistics, cities are a challenging area. As a result of the high population in cities, demand for goods and services is high as is the density of buildings and the complexity of the public and private infrastructure [8]. Another source of the complexity of the urban environment rises from the great number of firms operating and delivering their products and services in a dense area with limited integration or coordination between them [9].

The last-mile refers to the last part of the physical goods delivery process. It contains the upstream logistic activities necessary for the delivery from the last transit point to the final destination of the retail chain. The urban last-mile in logistics and distribution systems is responsible for as much as 75% of the total supply chain costs [10]. For both retailers and manufacturers, the last-mile is becoming both more complex and of more strategic importance both from cost and sustainability perspectives.

In on-line food retail Fernie and Sparks [11] describe the challenges as follows: “They must typically pick an order comprising 60–80 items across three temperature regimes from a total range of 10–25,000 products within 12–24 h for delivery to customers within 1–2 h time-slots”.

Inventory Management

Two major organizational models for inventory management that can be identified are: (1) store-picking and (2) warehouse-picking and drop-shipping. With store-picking the consumer places an order on-line and the information is sent to the nearest (or designated) store and an employee picks the ordered product from the shelves. This strategy is only operable in the case of a click-and-mortar retailer. Warehouse-picking has warehouses dedicated to internet orders. The internet orders are packaged in the warehouses and shipped out to the consumers. This form of inventory management necessitates investment in warehouses and lead times can be long, because of the single, centralized, warehouse [12].

Delivery Options

To support maintenance of customer loyalty, trust and satisfaction, after-sales and support services are key issues with physical delivery (and returns) have a critical role. The last mile is the critical part of the delivery of Internet orders of consumers.

Generally, it is considered the most important part of the order fulfilment process [13]. This is especially so, given the remarks above about consumer satisfaction, trust and loyalty that are mainly instantiated during the last part of the delivery process. Last mile delivery can take place in two ways, through home delivery and through pick-up points. Both strategies have their own challenges (Fig. 1).

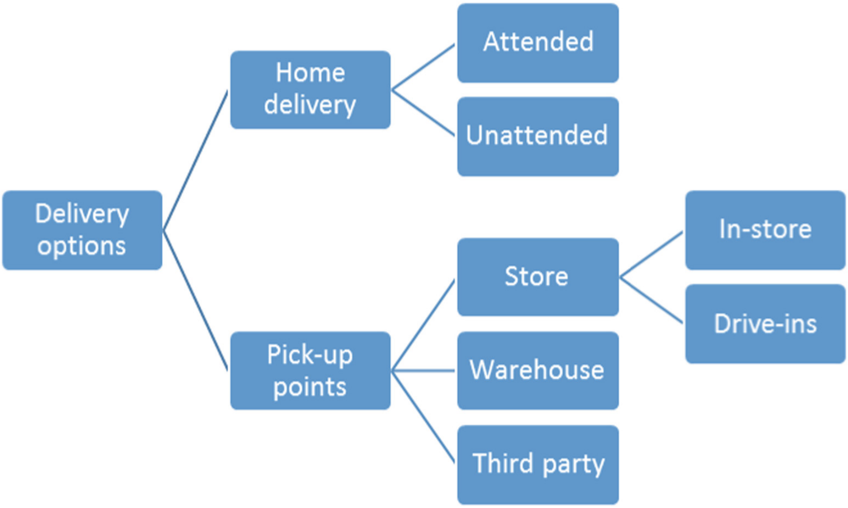

Fig. 1. On-line delivery options [19]

In the case of home delivery, the delivery time slot is very important if the order is directly delivered to the consumer (attended home delivery). Other options are putting the order in a box nearby the consumer's home and leaving the consumer to pick it up, or by leaving the box of goods at the consumer's house (unattended home delivery). It is evident that the costs increase with the more choice available to the consumer when selecting the home delivery time window. This is primarily because with smaller time windows the delivery truck needs to drive back and forth in the service area to meet the promised delivery times. The average number of orders per route will be lower with a smaller delivery time window. Other typical challenges of home delivery include the order comprising different items requiring different temperature regimes; the extra costs (for consumers and/or retailers/logistics providers) from the provision of facilities like a cool box at the consumer's premise in case of unattended delivery, and the management of delivery time slots in case of attended delivery. Periodic home deliveries of (unspecified) products such vegetables or fish. may enable retailers to balance their sales and supply better than the retailers based on ad-hoc sales. But consideration also has to be given to reverse logistics (returns) of products that do not meet customer expectations or alternative sales responses such as discounts or rewards for future orders when deliveries do not meet consumer expectations.

Pick-up points have developed as an alternative to home delivery. Pick-up points are locations to collect items ordered on-line. The most frequent type of pick-up point is the parcel service point, a staffed point that can be found in supermarkets and stores. Alternatively, unstaffed pick-up points exist, as for instance via secure lockers. Delivering at a pick-up point may give the consumer more flexibility. Once delivered, the consumer can collect the product whenever suits them. In the Netherlands, the number of pick-up points has increased from 900 in 2006, to about 2500 in 2013.

The use of pick-up points is often free of charge, or cheaper than the delivery fee. This may make the option to collect the order at a pick-up point more attractive for consumers. For businesses, delivering to a pick-up point is often cheaper than home delivery, because orders can be consolidated [14]. On-line retailers as well as third-party logistics operate pick-up points in the Netherlands. Bol.com, for instance, cooperates with Albert Heijn and offers pick-up points in their supermarkets [15]. DHL, a 3PL provider, deploys more than 1300 pick-up points in different stores in the Netherlands (DHL, n.d.). Ultimately, the balance that will emerge between home delivery and pick-up points is intimately related to how changing consumer expectations, habits and purchasing patterns intersect with the increasing density of urban environments. The experiences in the Netherlands may not be easily transferable to other urban contexts.

3 Logistics Challenges of Online Retail

We distinguish the following key business challenges.

Process Design in Multi-channel Solutions
The fulfilment of on-line orders differs from the traditional channel. This is particularly challenging for a brick and click retailers. In the on-line channel, packages tend to be small for single-orders. Delivery to a physical store, mostly includes larger packages, containing multiple identical products [3]. Firms need to decide which processes to separate for both channels, providing the optimal processing for each, and what processes to combine, to find a compromise between efficiency and costs.

Assortments and Cost Effectiveness in Pure Play Solutions
The challenge of using the pure-play method is to acquire enough sales to get at least break-even. To be cost-effective, dedicated picking centres must handle a large throughput. In the early stage of on-line grocery retailing, when the sales volumes are still low, it is costly to offer an extensive range of products. An on-line grocer can choose to offer a limited range of products, but this will make it more difficult to lure consumers from traditional grocery shopping. Another problem using the pure-play method is that dedicated picking centres encounter difficulties with the disposal of excess stocks of short shelf-life products.

Order Picking
With the growth of the B2C, the amount of small lot-size and dynamic arrival of customer orders has increased tremendously, making order picking and delivery with short lead times more important [16]. To make this possible, flexible and timely

warehousing is needed. However, the great number of small orders and irregular items makes this more complex. Warehouses need to lower the processing times, while offering great service [16].

Technology Challenges
The growing trend of using wireless devices, such as laptops, tablets and mobile phones, for electronic transactions, is also known as m-commerce or mobile e-commerce. With the wide-spread use of this mobile technology, customers are able to shop wherever they are and whenever they want, through an electronic commerce platform [17]. Regarding delivery technologies, large players like amazon.com are investigating the use of drones for grocery deliveries.

Returns
The growth of E-commerce has led to a new problem: the large volume of customer returns. This problem is especially present in product categories where the 'touch and feel' element is important to determine if a product is suitable, for instance the clothing category or fresh food products. The relevant attributes for consumer decision making for such products are difficult to communicate on-line. Janakiraman et al. [18] discuss different ways of return policies and conclude that time, scope and exchange policies are most suitable to reduce returns. Return policies will receive increasing attention while our production and waste economy makes its change to a "circular" economy.

4 Discussion and Conclusion

A large number of issues related on on-line retail has been discussed with a main focus on channels and (last mile) deliveries. The elements are summarized in Fig. 2.

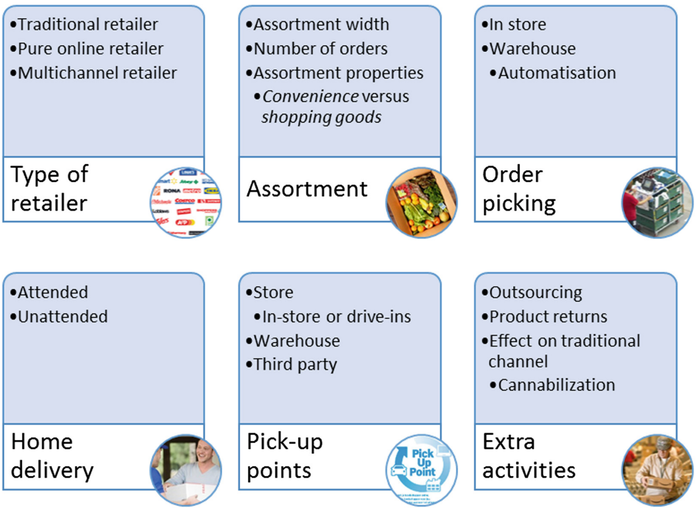

Fig. 2. Overview of logistics aspects of on-line retail

With the physical retailers move towards multi-channel and on-line sales the on-line retail is expected to grow even faster in the coming years. Some of the major challenges being the last mile of delivery and product returns whereas some of the options may be to enable innovative information systems and a higher degree of customization.

Innovative information systems may include consolidation of individual orders enabling different functions in the supply/demand chain from order to delivery. Customization has, alongside quality and price, been the main competitive advantages in manufacturing over the last 30 years. In a retail perspective this may involve customized packing of fruit and vegetables or supply of ingredients for full meals customized for special needs (diet, intolerance etc.).

To level the resources in the warehouse a detailed analysis of POS data could be used to identify the position of the customer order decoupling point and thereby enabling prepacking combinations of products that are likely to be sold.

Finally, many companies will consider outsourcing of functions to new players in the supply chain. Indeed, transaction costs in on-line retailing can be exceptionally high. Outsourcing to specialized (logistics) service providers may bring down these transaction costs [2]. In this regards, web-only retailers will outsource to a bigger extent than multi-channel retailers [2]. Apart from outsourcing of picking and delivery and return management, also functions like customer management and web ordering could be functions to be outsourced to specific service providers, making these into "infomediaries". This would be in line with general developments in outsourcing where 3PL providers develop into 4PL providers offering a wider range of logistics and management services to their customers.

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Replenishment Planning of Fresh Meat Products: Case Study from a Danish Wholesaler

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Abstract. Replenishment planning of meat products with short shelf life is studied through a Danish wholesaler case-study. Main findings are that timeliness and frequency of information sharing adapted to demand dynamics can derive higher service level, and, that increased collaboration, regardless of integration, is important to obtain higher service levels. This study suggests uniform planning for both normal and campaign demand to enhance service level and profit for the normal demand.

Keywords: Collaboration · Integration · Replenishment planning · Fresh meat · Perishable

1 Introduction

Today, consumers have increasing power and requirements to the highly competitive grocery sector [1], demanding low price, at the same time with high availability, quality (i.e. freshness of products) and variety of products [2]. This has led to increasing collaboration across the supply chain, differentiated demand planning (campaign versus normal sale) [3] and emerging of replenishment programs [4], overcoming e.g. the lack of visibility of downstream sales, plans and inventory levels through distributing responsibility of planning according to competences and capabilities [5–10]. Albeit benefits of the collaborative programs (such as Efficient Consumer Response (ECR) and Collaborative Planning, Forecasting and Replenishment (CPFR)) are well documented, Mena et al. [11] find only few instances of these initiatives being used in practice.

Therefore, it is relevant to investigate how the replenishment is conducted in practice and what is the effect of it on the service level. The purpose of this study is to investigate if the differentiated planning approach as described in theory for different contexts (i.e. normal and campaign sale) applies for fresh meat products with shelf life less than 14 days. This is studied with one of Denmark's biggest wholesalers supplying

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the second largest and fastest growing discount retail chain in Denmark, which has not implemented a specific replenishment program. Moreover, the collaboration and information sharing (i.e. replenishment program) required to ensure downstream requirements for availability is studied. By comparing the wholesaler's approach against existing replenishment programs, it is possible to identify how collaboration and integration plays role on the replenishment performance. Focus is on meat products with shelf life up to 14 days. The following presents the theoretical background for collaboration, integration and structure of existing replenishment programs. Next, the methodology is presented followed by presentation of the case study, the analysis, discussion and conclusion.

2 Theoretical Framework

Replenishment programs can be categorized as either non-collaborative traditional replenishment (TR) or collaborative automated replenishment programs (ARP). Whereas TR is a one-time replenishment, ARP can be executed through different concepts like, efficient replenishment (ER), continuous replenishment program (CRP), vendor-managed and -owned inventory (VMI and VOI), collaborative buyer-managed forecasting (CBMF) and collaborative planning, forecasting and replenishment planning (CPFR). A literature study on TR and ARP programs is conducted and their main characteristics across a number of parameters are shown in Table 1. In general literature differs between the different replenishment programs through level of collaboration and integration with supply chain stages, and the (quantitative and/or qualitative) information shared [12, 13].

The (external) integration is the configuration-oriented structuring and connection of processes and data to better facilitate the flow and availability of information, products and services between supply chain stages [16–18], hence how to share. The programs range from no integration, connecting through paper, call, fax or email (i.e. TR), to electronic data interchange (EDI) (i.e. ER, CRP and VMI/VOI) to internet-based integration (i.e. CBMF and CPFR). (External) collaboration is the relational and informational cooperation for working across organisational boundaries and sharing resources (information, people and technology) resulting in competitive advantage [16–18], hence what and how much to share. TR entails very low collaboration, low information sharing, and decentralized forecasting and inventory management. ARP enables collaborating supply chain stages, enhancing service provided to downstream stages, by sharing "information in advance and work together to develop realistic, informed and detailed estimates that can be used to guide business operations" [8]. Depending on the ARP program, information sharing is from merely placed order to extensive sharing of e.g. point-of-sales, inventory levels and strategies [6, 19], allowing replenishments based on actual sales, resulting in higher product availability at lower costs [5]. During time, ARP has moved towards more information sharing proportionally between supply chain stages with only VMI/VOI deviating (greater buyer sharing) [6, 14]. The programs are either supplier (i.e. VMI/VOI), buyer (i.e. TR and ER) or equally dominated (i.e. CRP), or, distinct collaborative (i.e. CBMF and CPFR). The evolvement of programs have focused from single-transaction

Table 1. Collaboration and context characteristics of replenishment programs

Parameters	TR	ER	CRP	VMI/VOI	CBMF	CPFR
Information sharing level (col)	Very low	Low	Medium	Medium	High	Very high
Information shared (col)	Placed order	Placed order	Incoming order, sales forecast, inventory level, promotions, upcoming campaigns, performance metrics, delivery schedules…		… historical consumption patterns, market-product intelligence…	… long-term goals and plans
Demand-input (col)	Hist. orders	POS	POS	POS	POS	POS
Developer of forecast (col)	W	W	W	S	W/S[1]	W & S
Replenishment responsible (col)	W	W	W (/S[2])	S	S	W & S
Order dispatcher (col)	W	W	W	S	S	S
Collaborative planning (col)	No	No	(Yes)[3]	No	Yes	Yes
Planning time-horizon (col)	Short	Short	Medium	Short	Medium	Long
Relationship-term (col)	Short	Medium	Medium	Long	Long	Long
Demand pattern (con)	Any	Any	Stable	Stable	Stable with exception	Less stable[4]
Product type (con)	All types	All types	All types	Standard	Intro and seasonal	Critical

Col = collaboration/con = context, W = wholesaler/S = supplier, [1]best capable, [2]different between authors, see e.g. Verheijen [14], Reyes and Bhutta [15], [3]combined with ECR, [4]CPFR is more tolerant to instability than VMI.

relationship (i.e. TR) to medium (<12 months) to long-term (>12 months) relationship. For planning, CPFR is long-term (>12 months), CRP and CBMF medium-term (6–12 months) and the remaining primarily short-term programs (<6 months). The programs relate to different contexts, e.g. VMI for standard products stable demand, CPFR for critical products with less stable demand (compared to VMI) and CBMF for introduction of and seasonal products with exceptions demand [10].

3 Methodology

This study presents an empirical case-study research, following Flynn's six-stage framework for explorative case study [20], about fresh meat products' replenishment planning and the level of collaboration and information sharing to ensure downstream availability. Since both context and delivery performance are important in this case, studying the phenomenon in depth in natural context allows rich insight and good understanding of existing experiences [21, 22]. To provide a generalizable view of replenishment planning, focus is on four different types of meat products at on one of the biggest and fastest growing retail chains in Denmark and its 16 different first tier suppliers. Due to commercial confidentiality, the company is called ABC throughout this article, and, data is indexed per mean values or stated in percentage. To strengthen validity of the study, four types of meat products with short shelf life are in focus, beef, pork, chicken and fish. Information and data for understanding the different replenishment processes was gathered through semi-structured interviews with product manager and purchasers, evolving from standardized questions. Quantitative data for the whole year 2016 about ordered and delivered amounts has been extracted from the company's enterprise resource planning (ERP) system, for all shops on daily level per SKU with shelf life of two weeks or less. In total, 46,356 unique data points (ordered and delivered quantities) are identified, categorized as either normal or campaign sale, for meat type, with service level to shops as performance indicator.

4 Case Study

ABC is part of Scandinavia's biggest player within grocery and service trading. A centralized warehouse supplies the almost 300 discount shops in Denmark, receiving products either on Mondays, Wednesdays and Fridays (MWF-shops), or, Tuesdays, Thursdays and Saturdays (TTS-shops). ABC's overall goal is to be Scandinavia' most value-driven company and uses service level as primary performance indicator. In 2016, ABC supplied 201 different SKUs (53 beef, 45 chicken, 70 pork and 33 fish) from 16 suppliers (five for beef, two for chicken, seven for pork and two for fish). All products have the same lead-time from order dispatch to delivery, down to 36 h.

For meat products, ABC uses a so-called "transit"-flow where products are ordered in exact amounts with no stock keeping, six days per week. The replenishment and planning cycles are presented in Fig. 1 at a time continuum, where activities above the timeline are for assortment sale and below the timeline for campaign sale.

For assortment products, shops send orders via computer or handheld order-terminal to ABC's ERP-system via EDI at latest 18:00 two days before expected delivery. From 18:00 to 19:00, ABC sums up and aggregates all shop-orders into orders for each supplier. Shortly after 19:00, ABC sends orders to suppliers manually via mail or automatically via EDI (vast amount) depending on the supplier's IT-system. For products on campaign, shops send a primary order four weeks in advance and ABC

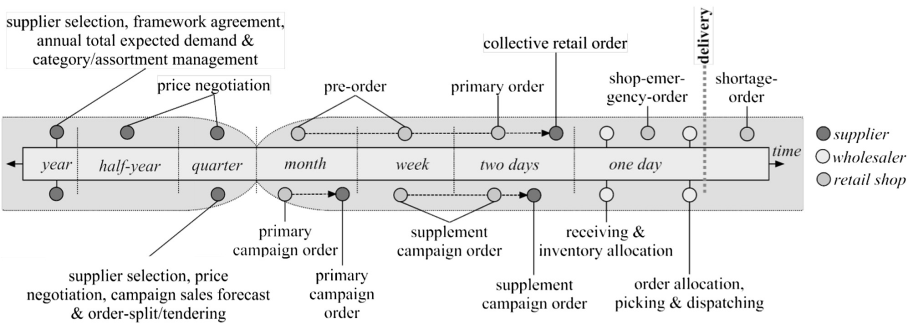

Fig. 1. Time continuum for replenishment planning activities

forwards these to supplier as totals similarly four weeks in advance. If a shop has orders too few or too many products on its primary order, it has the option of dispatching supplementing orders or reducing existing order, up until two days before delivery. The day after placing the orders, between 06:00 and 15:00 (down to 11 h after order dispatch), the products arrive to ABC. After registering and reporting all incoming deliveries to the warehouse management system (WMS), information is transferred to the ERP-system. If a shop has not send an order the day before in due time, ABC may accept the order as an emergency order, depending on the reason (e.g. IT breakdown) and if the supplier can deliver the additional amount(s). In extreme cases, if supplier cannot deliver, ABC reduces other large shop-orders selectively by a few to accommodate the emergency order. Shop-orders are transferred from ERP-system to the WMS, ready for picking, from around 16:00. Received and delayed (same-day) incoming quantities are allocated to the individual shop-orders. Between 20:00 and 04:00 the next day, products are picked and packed, and dispatched from ABC to the shops from around 02:00 until around 07:00 in the morning.

ABC negotiates price for assortment products, with suppliers every three to six months. If there are several potential suppliers for a product, ABC may choose a different supplier with lower price, and, same or higher quality and delivery degree. For campaign-products, to assure competitive pricing, ABC sends demand forecast to suppliers via a tendering-like process, approximately three months prior to campaign start. Depending on price, quality and delivery degree, and if a single supplier can supply total expected demand, a single/several supplier(s) is/are chosen. If several, ABC splits the orders according to capacity available at each supplier. At annual meetings, typically in November and early December, ABC and suppliers agree upon a framework agreement (logistics terms, payment terms etc.), and ABC informs suppliers about total expected sales for upcoming year and category/assortment changes.

ABC has limited integration with suppliers (only EDI for some) and the collaboration is higher for campaign sale than for normal sale. Whereas ABC expects suppliers to supply normal demand without any further notice, ABC shares campaign demand forecasts and shop-orders, respectively three months and four weeks in advance. This, to notify the supplier about upcoming deviating demand behaviour, allowing him to plan and source raw materials accordingly. Interviews with procurement departments further highlighted that shops typically order 20–25% below actual demand when sending orders months in advance – but suppliers know this (from historical order data and behaviour) and adjust their internal plans accordingly.

ABC integrates with shops through EDI in order receiving, and does not collaborate any further when planning, leaving shops with individual responsibility in planning. If ordered too many products, shops may change the primary order up until normal deadline for order-dispatch (18:00 two days before delivery). However, changes allowed are smaller and smaller the closer to deadline. If supplementing orders exceed supplier' capacity, the available amount of raw materials to produce ordered product-quantities is split between the two upcoming deliveries to ABC (i.e. MWF- and TTS-shops), allowing all shops to receive products.

5 Analysis

5.1 Comparing Normal and Campaign Demand and Service Levels

The quantitative investigation showed that ABC during 2016 faced a demand of more than 5.5 million boxes of meat products with shelf life less than 14 days (beef/pork/chicken/fish). Upper part of Table 2 provides statistical information about the demand throughout the year for each meat-type, where *N* is number of days with a demand (campaign or normal) during the year. Values are indexed against mean demand for each meat types' demand type (hence, all have a mean value of 100). For 50% of the observations (IQR), campaign demand deviates up to 3.7 times more across an up to 3.5 times broader range than normal demand. In terms of demand distributions' peaking behaviour (i.e. kurtosis), campaign demand is very leptokurtic, and normal demand is comparable almost mesokurtic (even platykurtic for fish) with a more flat and "random" demand pattern. Looking at skewness, campaign demand has a higher frequency of less-than-mean as opposed to normal demand's more symmetrical distribution with tendency of higher frequency of above-mean demand. Campaign demand is characterized by few large and many small campaigns, normal demand is characterised by few small and many large demand observations. Lower part of Table 2 summarizes service levels for product and demand types. The analysis showed a mean delivery degree for all meat products of 97.99%. The service level for campaign deliveries is characterized by being more negatively skewed and more frequently closer to 100% than for normal deliveries. Oppositely the demand behaviour, service level for normal deliveries fluctuates more and over broader range. Service level for 75% of campaign deliveries are above 99.2% (beef), 99.7% (pork and chicken) and 98.5% (fish) – all with leptokurtic distribution around 99.9% (beef, 99.8%). 75% of normal deliveries' service levels are 6.4% (beef), 0.5% (pork), 4.9% (chicken) and 2.6% (fish) lower than for campaign. Figure 2 illustrates campaign versus normal demand service levels (circles are campaign sale and triangles normal), showing that campaign deliveries, regardless order size, generally have higher service levels than normal, with only fish products having a more scattered relation.

5.2 Replenishment Planning

ABC uses aspects from different replenishment programs, depending on whether the planning regards normal or campaign demand. ABC' approach for normal demand is similar to those of low collaboration (e.g. TR and ER). There is no distinctive collaboration and integration with suppliers, sharing only orders through mail or EDI and planning is individual, based on historical orders. For campaign demand, ABC' approach is more like those of higher collaboration (e.g. CBMF and CPFR) in that of close collaboration and sharing of forecasted demand, incoming orders, upcoming campaigns and medium to long-term plans – yet with no distinctive integration. Since ABC acts as facilitator for the shops by negotiating price, adjusting assortment to shops' requirements and balancing the converging-diverging product flow, ABC has no distinct decision-making in order dispatching and replenishment planning in shops.

Table 2. Group-indexed demand and service levels of meat products, year 2016

		N	Mean ± SD	Median	IQR	Kurtosis	Skewness
Demand							
Beef	C	*310*	100 ± 84.791	80.510	49.341–126.836	14.455	2.963
	N	*312*	100 ± 24.567	103.159	82.346–116.596	0.354	−0.431
Pork	C	*309*	100 ± 77.241	80.192	51.403–131.288	10.518	2.549
	N	*312*	100 ± 21.049	100.141	88.452–111.334	3.215	−0.266
Chicken	C	*304*	100 ± 65.339	89.945	48.961–128.301	2.859	1.433
	N	*312*	100 ± 28.302	99.111	81.914–118.459	0.344	0.002
Fish	C	*297*	100 ± 113.162	71.387	34.425–117.625	27.229	4.140
	N	*312*	100 ± 40.590	106.716	66.212–133.564	−0.986	−0.198
Service level							
Beef	C	310	0.983 ± 0.048	0.998	0.992–1.000	39.556	−5.531
	N	312	0.956 ± 0.045	0.973	0.928–0.995	0.195	−1.004
Pork	C	309	0.994 ± 0.019	0.999	0.997–1.000	29.189	−5.145
	N	312	0.992 ± 0.017	0.998	0.992–0.999	31.859	−4.765
Chicken	C	304	0.994 ± 0.024	0.999	0.997–1.000	80.260	−8.297
	N	312	0.966 ± 0.050	0.990	0.948–0.999	6.578	−2.272
Fish	C	297	0.934 ± 0.173	0.999	0.985–1.000	11.552	−3.356
	N	312	0.962 ± 0.069	0.996	0.959–0.999	9.464	−2.819

C = campaign sales, N = normal sales

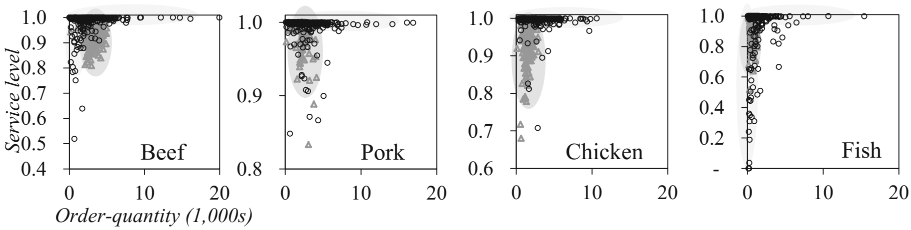

Fig. 2. Campaign and normal service levels versus order size for meat products

ABC merely aggregates and forwards incoming orders to suppliers. Based upon the differences in replenishment planning and performed service levels for respectively normal and campaign demand, it is desirable to share more information and collaborate closer for normal demand, to create higher service levels for normal demand.

6 Discussion and Conclusion

One of the main findings is that information sharing timeliness and frequency adapted to the demand dynamics can derive higher service level from supplier to ABC to the shops (given the transit flow), thus greater revenue. For ABC, simply sharing demand data in advance for all demand types may lead to (perfectly) 100% service levels, giving an estimated revenue growth of 2.6% (more than USD 2.75 million) plus additional increase due to the constant availability. The literature suggests that a company' performance is relatively influenced by level of collaboration, and further enhanced by the level of integration [18] due to the suggested information sharing frequencies. For TR and ARP programs, level of integration is relative to the level of collaboration (TR versus ER/CRP/VMI/VOI versus CBMF/CPFR). This is justified by the appropriateness of the programs relative to the context, e.g. CPFR and CBMF for campaign sale. However, two interlinked factors evident in the case study suggest that only collaboration is important to obtain high service levels, regardless context, and that integration does not play any role. This can be explained by two interlinked factors. First factor is the three-stage supply chain (supplier, wholesaler and shops), opposite to ARP programs mainly two-stages. By including three stages, the wholesaler's consolidating function allows reducing the need for integration. Albeit the main-reason for integration is to increase efficiency by better facilitating the flow and availability of information, (particularly) when having several downstream entities, case study suggests that the consolidating role of wholesaler makes the need of integration less, since the downstream flow of information is combined and unified into one upstream flow. Second factor is wholesaler' role as a transit point, where products are not stored for longer time. Meat products are, due to the rapid degradation, moved through the supply chain fast and produced down to 36 h before delivery, following the make-to-order principle, delaying the production decoupling point.

This research has focused on major common meat types in grocery business, and more research is needed for other types to establish the level of validity in using non-integrated and uniform planning. The meat types in focus are with constant demand throughout the year, and other meat types may be influenced by e.g. seasonality or only sold for a certain period during the year. Also, this research has focused on discount shops which are heavily influenced by low price, availability, large amounts sold during campaign and high frequency of campaigns. Additional research is needed for other store-types such as convenience stores and hypermarkets with different characteristics (e.g. different campaign frequency and/or price level).

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Differentiated Demand and Supply Chain Planning of Fresh Meat Products: Linking to Animals' Lifetime

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Abstract. Demand and supply chain planning of meat products with short shelf life is studied in a Danish wholesaler case. Main findings are that the lifetime of animals influences information sharing in planning, and differentiating planning according to demand characteristics influence supply chain negatively. This study suggests lifetime-dependent differentiation in timeliness and frequency in sharing of information to enhance supply chain effectiveness and efficiency.

Keywords: Differentiation · Animal lifetime · Fresh meat · Demand planning

1 Introduction

Due to meat products' short shelf life, the risk of waste from expired products, due to poor planning and derived stock building, is large [1]. Meat products have a time-dependent scarcity, as their raw materials (i.e. animals) have different time between birth and slaughtering/catching. Since fresh meat products are unfit for storing, and high availability influences consumer loyalty [2], efficient, effective and differentiated demand and supply chain planning is paramount. In particular for wholesalers, linking shops with upstream supply chain by consolidating and balancing the converging and diverging demand and supply flow.

Current planning frameworks tends to focus on information sharing between the producer and customer [3], and, internal planning at product group level [4–6], differentiated through forecasting-, production strategy- and/or inventory management-oriented segmentation [7] (e.g. order characteristics (lead-time, shelf life, temperature etc.) and demand characteristics (seasonality, fluctuation, frequency etc.) [7–11]). This influences wholesaler' effectiveness and efficiency inappropriately. Since wholesaler has no control of producing the products [11], the products have short time from order dispatch to order arrival and are unsuitable for storing, and, the raw materials have large differences in growth time, there are the different requirements to timeliness and frequency of information sharing. The second largest discount retail chain in Denmark

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and its wholesaler operates with hundreds of different meat products, segmented only per demand characteristics. It is thus relevant to investigate how demand and supply chain planning could differentiate and what is its effect on information sharing and frequency. By comparing wholesaler's planning approach against different raw materials' lifetime, it is possible to identify how demand and supply chain planning should include the differentiating aspects. Focus is on fresh meat products with up to 14 days shelf life. The following presents this study' framework about animal lifetime and demand planning time-horizon, then methodology, case study, analysis, discussion and conclusion.

2 Theoretical Background

Demand and supply chain planning aims to predict the future demand and supply, and respond upon this by sharing information and initiating different upstream activities accordingly and timely, to effectively and efficiently meet demand instantly when occurring [11, 12]. Particularly for meat products, understanding demand and sharing information timely is needed due to the bullwhip effect [13] and constant degradation.

A key factor for improving supply chain operations is improving forecasting [14], which in turn creates a cost-effective supply chain [15]. For this purpose, products are usually grouped according to demand characteristics (e.g. steady, seasonal and promotional) with different efforts needed in forecasting and levels of supply chain collaboration [14]. The accuracy of forecasting is affected by time-horizon to forecast. The shorter time-horizon, the greater accuracy and reliability, hence, the lower risk and errors [8]. However, fresh meat products are influenced by scarcity after a certain point in time (i.e. when time to produce raw materials for slaughtering exceeds the forecast horizon). Hence, demand planning must be closely related with supply planning, since raw materials are living animals with different growth time. Table 1 shows the time it takes to grow different animals ready for slaughtering/catching, according to Danish Agriculture and Food Council. Clearly, the different meat types differ, from growth time of around one month for chickens to more than 24 months for beef, to catching fish according to size (influenced by nature and climate).

Table 1. Age and size of animals ready for slaughtering and catching

Beef	Pork	Chicken	Fish
<10 months (veal)	≈5–6 months (90–105 kilos)	≈40 days	>40–60* cm (salmon)
10–24 months (young cattle)			>25–27* cm (flounder)
>24 months (cow-beef)			>30–35* cm (cod)

**Depends on catching area (e.g. North Sea, Baltic Sea, Kattegat) and sea (salt- or freshwater)*

Combined with the shelf life, fresh meat products' total lead-time differs largely from other food products. The total lead-time (growth, production and shelf life) of meat products, compared against a different food product, canned food, is illustrated in Fig. 1. Canned food has relatively short growth time and long shelf life and may thus be handled (more or less strictly) in terms of inventory level and capital costs, due to the derived suitability for make-to-stock planning. Oppositely, fresh food has short shelf life with large growth time (animals' lifetime) and cannot be stored for more than few days (i.e. no stock building), meaning it must be handled in terms of risk of waste from poor planning, making it suitable for make-to-order planning.

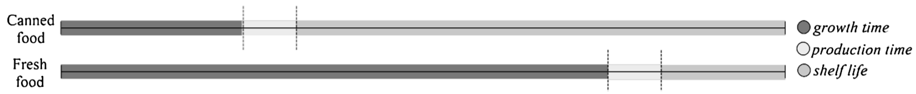

Fig. 1. Complete lifetime of different product groups

3 Methodology

This paper follows the explorative and empirical case study research approach of Flynn's six-stage design framework [16]. After investigating the current level of collaboration and differentiation in demand and supply chain planning, the purpose is to propose a differentiated planning approach that includes the raw materials' growth time. The ultimate goal of the approach is to meet consumers' requirements for availability. Since the product type and context is of particular importance in this case, studying in-depth in natural context enhances the insight and understanding of experiences [17, 18]. Four different meat types from 16 different suppliers, supplied by one of the largest wholesalers in Demark, are in focus in order to provide a generalizable view of differentiation in demand planning. Due to reasons of commercial confidentiality, the company' identity will not be revealed and called ABC throughout this article. This study uses information obtained through semi-structured interview with product manager and purchaser evolving from standardized questions about demand planning. The study focuses on products with less than 14 days shelf life for beef (veal/young cattle/cow), pork, chicken and fish.

4 Case Study

ABC (part of Scandinavia's biggest company within grocery and service trading) uses a centralized warehouse to supply the Danish market (almost 300 shops). ABC's overall goal is to be "the most value-driven company in Scandinavia", and they measure performance mainly through service level. In 2016, ABC sourced 53 beef products from five suppliers, 45 chicken products from two suppliers, 70 pork products from seven suppliers and 33 fish products from two suppliers, with down to 36 h from order dispatch at shop to delivery. ABC uses a so-called "transit"-flow where products are ordered six days per week, in exact amounts, with no stock keeping. Depending on whether the shops order normal (i.e. assortment) or campaign products, ABC receives shops' orders at latest 18:00 two days or four weeks before delivery, respectively. ABC aggregates and sums up all incoming orders, and forwards these to respective suppliers. Shops are allowed to add additional supplementing orders or change existing orders down to two days before delivery. At the end of the year, ABC shares information with suppliers about total expected sales for upcoming year (including expected growth and expanding) as well as category/assortment changes. For campaigns, forecasted demand is sent to suppliers around three months before campaign start through a tendering-like process. If several suppliers are chosen to deliver the products, ABC splits the demand according to available capacity at supplier's site, price, quality level and delivery degree. No further demand information is shared, and the suppliers use historical incoming orders from ABC in their internal demand planning. Figure 2 shows ABC' planning cycles and information sharing, with activities for normal sale shown above the timeline and for campaign sale, below the timeline.

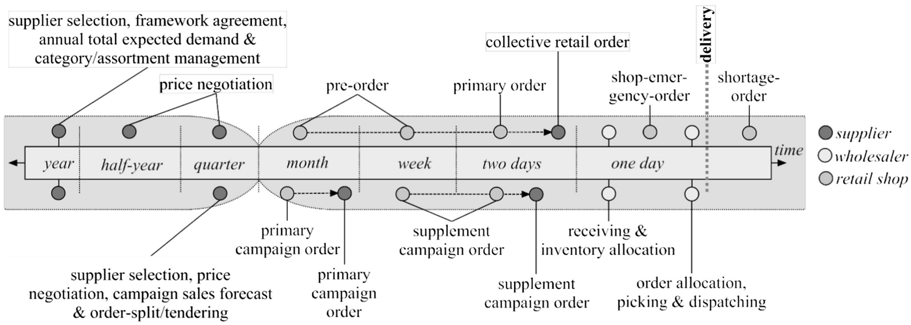

Fig. 2. Time continuum for planning activities

5 Analysis

At overall level, ABC shares expected total annual demand (i.e. campaign and normal) for the upcoming year in November/early December. At lower level, the sharing differs, depending on whether it is campaign or normal demand. Campaign demand forecast and real orders are shared respectively three months and four weeks in advance for all products, allowing suppliers time to source raw materials needed (due to the larger demand). For normal demand, ABC expects suppliers to meet demand with two days' notice and does not share any information. The different meat types' lifetime characteristics influence the supply chain performance. Figure 3 shows timelines for each meat type with months back in time from the order dispatch, indicating the different times of information sharing between ABC and suppliers – relative to animals' life time and when they are given birth. The yellow area indicates the time it takes to raise animals until slaughtering back in time, while the blue area represents the time-window available for giving birth to the animals in order to have the animals ready for slaughtering and order dispatch.

Cleary there is inconsistency between ABC' uniform approach in information sharing with the suppliers and the time it takes to raise animals. For chickens campaign forecast is shared almost two months before they are born, which increases the noise in

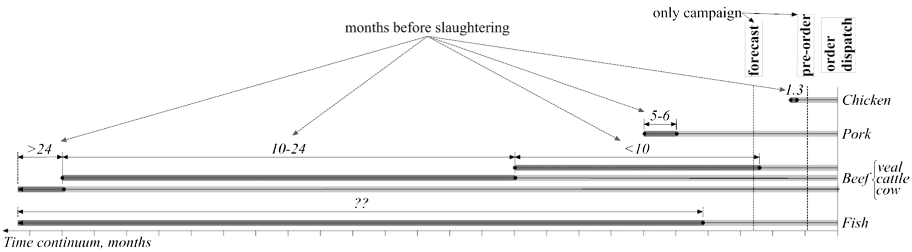

Fig. 3. Time continuum for planning of meat products versus lifetime of animals, in months

the supply chain due to premature information sharing and increases the forecasts errors due to untimely sharing of forecast. Instead, demand information should be shared at the time where the chickens need to be born, i.e. 40 days before order dispatch, meaning down to 42.5 days before order arrival in shops (when including the 36 h from order dispatch in shop until arrival of order). This principle of lifetime dependent timely sharing of forecast also applies for other fresh meat types. For pork, beef and fish, the current approach means that forecast is shared months/years after animals are born creating a latent scarcity in availability of raw materials, deriving increased risk of not being able to source raw materials. This also means that upstream stages initiate production of animals according to isolated forecast, not driven by demand, meaning guess based forecasting with increased errors. In particular, fish are caught (and slaughtered) according to size and are heavily influenced by nature and climate, requiring forecasting longer time in advance to avoid unavailability. Hence, all meat types, but chicken, require relatively high level of collaboration and information sharing, i.e. timely demand planning. Figure 4 shows the animals available as raw material upstream in the supply chain (farmer stage) in relation to their lifetime planning window for slaughtering (after which they become unfit for use).

In Fig. 4, Y-axis is available amount of raw materials for production (i.e. living animals) at a given time, and x-axis indicating the time. The light grey areas are amounts available within time-slack during which the animal's lifetime is acceptable for production, black areas are amounts available when lifetime exceeds upper limit (i.e. animals are too old for production) and dark grey areas are amounts when animals are too old, but suitable for different type of product. From the figure, chicken and pork face the chance of being too old and not fit for production (creating waste) with few days or one-month time-slack, respectively, which enhances the need for accuracy in demand planning. Fish only corresponds to a minimum size when caught and "the-bigger-the-merrier"-principle applies (i.e. bigger fish means more products per fish thus greater revenue). Opposite to all meat types, beef animals face a stepwise requirement: if animals are too old for one category (i.e. veal/cattle) they can be used for different product type (i.e. cattle/cow), and when reaching "cow"-step "the-bigger-the-merrier"-principle applies.

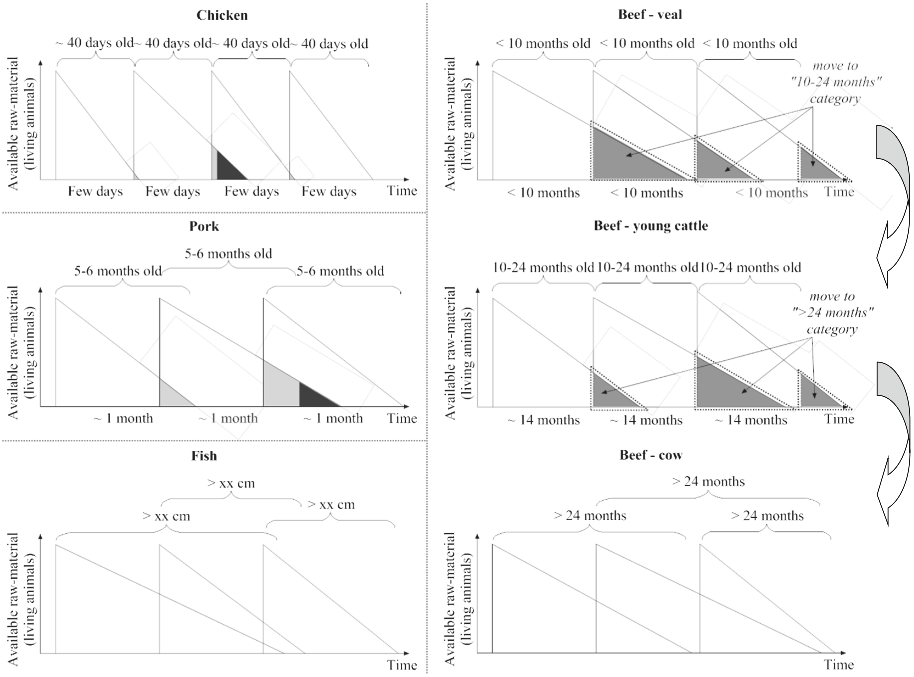

Fig. 4. Time continuum for planning of animals and their lifetime window

6 Discussion and Conclusion

One of the main findings is that sharing demand information relatively to the time it takes to raise the animals ready for slaughtering/catching (i.e. animals' lifetime) can allow upstream supply chain to be better prepared for the demand behavior. In turn, this may not only reduce forecast errors from untimely forecast sharing, which influences the service levels from supplier to ABC to the shops positively and derives higher revenue, it also reduce undesirable noise in the supply chain from premature demand information. Thus, sharing information timely align the upstream production and birth of animals to the real demand behavior. As a consolidator in the supply chain, the wholesaler must be able to interpret and plan to expected level of demand [2], "to be more proactive to anticipated demand and more reactive to unanticipated demand" [12]. From the theoretical framework, the longer time horizon to forecast the greater level of forecast error, meaning that forecasting and demand information sharing should be as timely as possible. By taking into consideration the total time of the product, in particular the animals' lifetime and production time, it is possible to derive the timely point in time, at which forecast should be shared and point in time actual order should be dispatched. That is, just prior to the animals' birth.

In order to ensure the overall efficient and effective demand and supply chain planning and thus encompass the different planning-steps at each supply chain stage (production planning, master production schedule, material requirements planning, capacity planning etc.) – and the time-horizon-related forecast errors, information should be shared with certain time-intervals throughout time, relative to the animals' lifetime. Figure 5 illustrates demand forecasts' error-distributions and their adjustment of mean and median values relatively to the forecasts' time-horizon (the short time-horizon, the smaller error), hence also the risk of over - and undersupply of resources. The dark grey area presents the chance of undersupply and stock out is greater than 100% service level (i.e. forecast X−n, X−2 and X). Light grey area shows the chance of oversupply and full delivery is greatest (i.e. forecast X−3 and X−1). Thus, depending on the individual animal' lifetime (i.e. meat-type), demand forecast(s) should be shared differently through time – i.e. either several (for beef), few times (for pork) or a single time (for chicken). Hence, sharing demand information relatively to animals' lifetime also means later information sharing for chicken products.

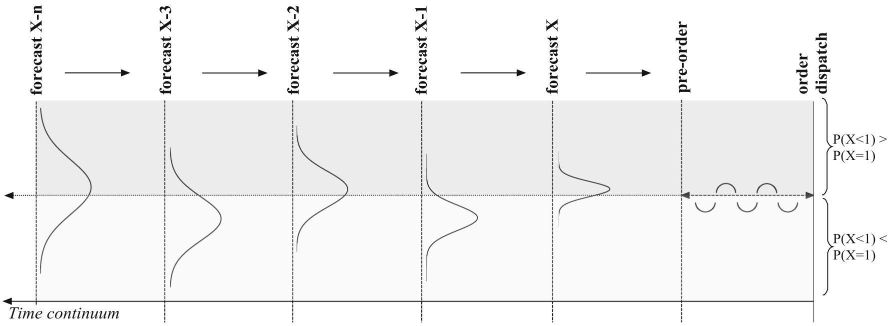

Fig. 5. Forecasting error distribution through time

In Fig. 6, ABC' current versus suggested point of forecast is shown. Since chickens require 40 days before ready for slaughtering, the postponement of demand sharing (from three months to around 40 days) will reduce errors in estimation and noise in the supply chain. Moreover, this will also reduce the chance of oversupply, and hence the chance of having chickens too old causing waste. For the other meat products, the

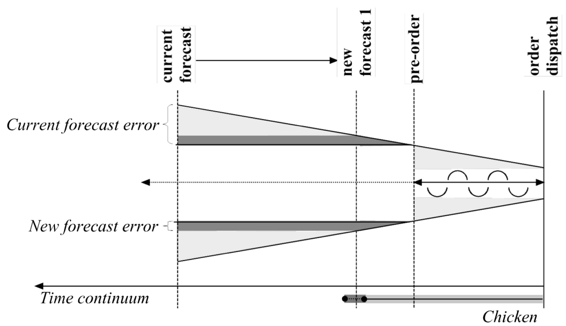

Fig. 6. Reduction in forecasting error for chicken products

differentiation is similarly influenced by animals' lifetime. Pork meat requires five to six months to become ready for slaughtering and demand forecast should be shared from around six months before order dispatch and on regular interval up until pre-order. Beef meat type is a stepwise product (veal/cattle/cow) and less sensitive to overestimation. If having too many raw materials (i.e. animals), they can be moved into different category – and when reaching "cow"-category, they follow "the-more-the-merrier"-principle. Fish type follows the "the-more-the-merrier"-principle, and is per se only sensitive to under-estimation since overestimation means greater value (keeping fish alive means bigger fish, hence more products from a single fish), in turn reducing the sensitivity in demand planning. Alike pork, demand information about beef and fish should similarly be shared on regular interval prior to order dispatch. From theoretical framework, the interval depends on different factors outside the scope of this paper, hereunder demand fluctuations and demand type.

This research has focused on differentiation for four major products groups in a single case study, and additional research is needed in terms of more product groups, more case companies and testing of suggested approach, to increase level of validity. Other meat-types are seasonal and/or only sold for limited time during a year, which may have influence (products in this study have constant demand throughout year). Also, research should be made in reduction of relative waste amount from having too large amount of products in shops, in regards to differentiated pricing of products when getting closer to expiration date [19] and its influence on demand behavior.

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Scheduling Fresh Food Production Networks

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Abstract. To cope with the high labour costs of developed countries, and volatile market companies aim for flexible machines, that work in parallel in facilities that are dispersed geographically. This paper draws on an example from the food production industry, and investigates how production volumes should be allocated in a heterogeneous network of facilities with parallel machines. Apart from capacity costs, we entertain holding and backlog costs, which are significant due to the undesirability of storing perishable food products at the production facilities. Assuming that a weekly production schedule has been made for the network, we use an interior-point algorithm to optimize the production allocation. Our model takes into account three dimensions: the product, the facility, and the production line. For a network of three facilities, five production lines, and eight products, the optimisation procedure provides a cost reduction potential of 6.9% compared to the historical costs. Notably, the savings are realized by producing closer to the delivery date, as the inventory costs of fresh food products outweigh the savings of early production on more efficient equipment. Our contribution is threefold: First, the development of the optimisation procedure, second, the validation of the procedure against historical data, and third, evidence that fresh-food production should be responsive to demand and produce close to the delivery date, due to high inventory holding costs in comparison to the cost of capacity.

Keywords: Multi-purpose plants · Flexible capacity · Production allocation

1 Introduction

A major challenge for producers in high-cost countries is the efficient allocation of labour and the associated payroll costs. In addition to that dealing with volatile market makes companies to stay closer to the market, and therefore distribute production facilities geographically. Typical ways to manage these two problems include the use of parallel machines over network, and there after automation, production levelling, and multi-skilled labour. However, these do not guarantee low total costs unless an appropriate schedule is set for the network [1]. Setting an appropriate schedule for a network is a complicated task that gets more complex when the network is heterogeneous. That is when production facilities are different from each other in terms of machining speed, required operators at each machine, labour cost, etc. This paper

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investigates how a heterogeneous network of flexible production lines can achieve a lower total production cost of production and inventory. In the presented case company, although machines work in parallel across network, the efficiency and labour requirements varies between machines, and the marginal cost of production is subject to step changes when additional machine operators are required. Our investigation reflects the processing and packing operation of a Norwegian producer of fresh-food products, and is limited to one cluster of eight products, produced by five packing lines in three facilities (See Fig. 1).

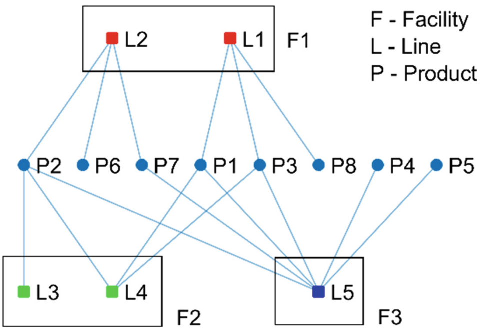


Fig. 1. One cluster of eight products, five lines, and three facilities.

The aim of this paper is to, first, develop an optimisation procedure, second, to validate the procedure against historical data from a case company, and third, evidently show that fresh-food production should be responsive to demand and produce close to the delivery date, due to high inventory holding costs in comparison to the cost of capacity.

2 Background

Operational planning relates to deciding how much to produce of each end product in a facility, commonly with a planning period of 1–2 weeks [2, 3]. In multi-site production planning, decision makers must look at the demand in several locations and make a rough capacity allocation (machines and workforce) before setting a detailed schedule. In other words, the disaggregation of a plan is not done only over time, but also over locations [4, 5].

Network planning is often done on an aggregated level, while lower level planning is left to the facilities [1, 6]. Other approaches for network production planning takes detailed scheduling decisions in the network level [4, 7, 8]. This paper follows the latter approach. We look at short term production scheduling problem for an intra firm production network with parallel machines that facilities have similar distance to customers (i.e. instead of having every facility allocated to specific orders, the customer orders are allocated over the network to minimize the cost of production and inventory).

The multi-location scheduling problem has been optimized as a single-objective problem [9], but single facilities have exploited multiobjective optimisation [10]. Elements like capacity (Labour, and machine), cost of labour (Over time and regular), inventory limits and service level requirement are repeated in majority of models, also represented in this study.

The model proposed in this paper reflects the situation of the case company (a fresh food producer), including a multi-site, multi-product, production environment with multi skilled, flexible workforce that has planning horizon of one week, with two staggered deliveries per week. Combining workforce and production schedule (allocation of orders to machines in each facility) in a multi-site parallel production network makes this study unique compare to other models in the literature. We benefit from studies that address vital elements of this model, such as staggered deliveries [11], flexible workforce [1], and parallel machine [12] in other contexts, and use it in production allocation across production network to reduce costs.

3 Problem Description

The case company is a food producer in Norway, having a substantial share of the market, hundreds of end products and a multitude of production facilities. Here we study a limited sample of eight products that are produced in three proximate plants (Fig. 1). Products have different degrees of perishability, from days to months, making stockholding. The products are distributed to serval delivery points.

Production takes place in response to customer orders, with shipments from all three sites due every Wednesday and Sunday morning. Between these days, inventory is accumulated every shift at each site, based on a weekly plan. The facilities are assumed to be geographically close, and any one may be used to satisfy demand. As each production plan covers two sequential shipments, we operate in a setting termed *staggered deliveries* [2].

By accounting for materials as a holding cost, and considering that line maintenance is done according to a fixed cycle independent of production, the marginal cost of production reduces to the cost of labour. This in turn, is affected by labour laws, as well as the physical characteristics of the operations, and the scheduling. Up to two shifts are worked per day, from Monday to Saturday. Located in Norway, the producer must pay workers for a full shift, regardless of production volume. This includes the weekend shifts on Saturdays, where the compensation is thirty percent higher than on weekdays (Table 2). While the staff is skilled to operate any line, the lines operate at different speeds, have different staffing requirements, and different product-mix capabilities (Table 1). Four dimensions must be taken into account when planning production: facilities, lines, products, and shifts, as shown in Table 3.

The required production volumes per product are given once per week, with due dates on Wednesday and Sunday. Production that commences too early receives a holding cost h per unit a day, while late orders are penalized with a backorder cost b per unit a day.

Table 1. Production resources and capacity

Product	Human resource								Production rate (unit/hour)								
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	
Facility 1	Line 1	3	-	3	-	-	-	-	3	2086	-	113	-	-	-	-	1353
	Line 2	-	3	-	-	-	3	3	-	-	241	-	-	-	1964	1780	-
Facility 2	Line 3	-	3	-	-	-	-	-	-	-	215	-	-	-	-	-	-
	Line 4	3	4	3	-	-	-	-	-	1896	202	106	-	-	-	-	-
Facility 3	Line 5	4	4	4	3	3	-	3	-	1773	210	144	98	1527	-	1353	-

Table 2. Production and inventory cost parameters

Cost type	Inventory		Labour	
	Holding cost	Backlog	Day 1 to day 5	Day 6
Value	1	3	250	300

Table 3. Nomenclature

Name		Description
Indices	L	Number of production lines (l = 1, …, L)
	P	Number of products (p = 1, …, P)
	F	Number of facilities in the network (f = 1, …, F)
	T	Shift, (t = 1, …, T)
Parameters	d_{pt}	Total network demand for product p in shift t
	i_{ft}	Inventory level of product p in shift t at facility f
	$c_{\boldsymbol{Bt}}$	Backlog cost per shift per unit of product p
	$c_{\boldsymbol{Hp}}$	Holding cost per shift per unit of product p
	$c_{\mathbf{W}t}$	Labour cost in shift t
	$C_{\boldsymbol{Ift}}$	Inventory cost of product p, at facility f, in shift t
	$C_{\boldsymbol{T}}$	Total inventory and labour cost in a week
	$C_{\mathbf{W}t}$	Total labour cost of the network in shift t
	m_{lft}	Operating time (hours) of line l at facility f in shift t
	r_{pft}	Production rate of product p at facility f in shift t
	M_{ft}	Total amount of line operating hours in shift t at f
	w_{lt}	Amount of labours needed to man line l in shift t
	W_f	Amount of labours needed at f in shift t
	h_{ft}	Number of hours in at facility f in shift t

The product-mix capability, staffing requirement, and capacity vary between the lines, but staff may be allocated to any line, and may transition freely to another line during a shift. Thus, for each facility, the number of workers required for an entire shift is given by the lines running at the busiest part of the shift. Therefore, we calculate the total production time in the shift, for all the active lines of one facility, to find out if the lines must operate in parallel, or if they can work sequentially.

$$M_f = \sum\nolimits_{l \in f} m_l. \tag{1}$$

As each facility in this case has at most two active lines, we have

$$W_f = \begin{cases} \max_{l \in f}(w_l), & M_f \leq 6, \\ \sum_{l \in f} w_l, & \text{otherwise.} \end{cases} \tag{2}$$

Here, the number 6 stands for the hours available per shift. The total labour cost is then accumulated over the whole production network for the shift,

$$C_{\boldsymbol{W}} = c_{\boldsymbol{W}t} \sum\nolimits_f W_f, \quad c_{\boldsymbol{W}t} \begin{cases} u_1 \leq t \leq u_2 \\ u_3 < t \end{cases} \tag{3}$$

where c_{wt} is the cost per worker in shift t (t suppressed). In this case a different cost is applied to the last shift. The inventory level for a given product and facility is given by the balance equation

$$i_{t+1} = i_t + r_t - d_t \tag{4}$$

Holding and backlog costs are applied per unit and shift

$$C_{\boldsymbol{I}} = c_{\boldsymbol{H}} \cdot \max(i_t, 0) + c_{\boldsymbol{B}} \cdot \max(-i_t, 0). \tag{5}$$

We then obtain the total cost for the week by summing inventory costs over shifts, products, and facilities and by summing labour cost by facilities and shifts:

$$C_{\boldsymbol{T}} = \sum\nolimits_{f,p,t} C_{\boldsymbol{Ift}} + C_{\boldsymbol{Wpt}}. \tag{6}$$

The cost function contains two main components: The cost of inventory, and the cost of labour. While other costs are associated with production, like maintenance and facility costs, they tend not to be influenced significantly by the schedule, and are therefore excluded from our analysis. When attempting to minimize (6), several constraints must be taken into account:

$$\sum\nolimits_{l=1}^{L} m_{lft} \leq h_{ft} \qquad \forall t, f \tag{7}$$

$$\sum\nolimits_{t=1}^{T} M_{ft} \leq \sum\nolimits_{t=1}^{T} \sum\nolimits_{p=1}^{P} r_{pft} m_{lft} \qquad \forall l, f \tag{8}$$

$$\sum\nolimits_{l=1}^{L} \sum\nolimits_{f=1}^{F} r_{pft}\, m_{lft} \leq d_{pt} \qquad \forall p, t \tag{9}$$

$$\sum\nolimits_{l=1}^{L} \sum\nolimits_{f=1}^{F} r_{pft}\, m_{lft} \leq SL_t d_{pt} \qquad \forall p, t \tag{10}$$

$$m_{lft}, r_{pft}, M_{ft}, h_{pt} \geq 0 \qquad \forall p, t, f, l$$

4 Experimental Results

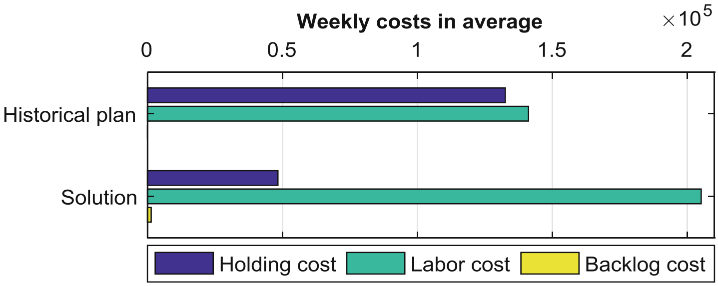
The delivery frequency is twice per week, i.e., on Wednesday and Saturday. Therefore, weekly demand is calculated from historical production as shown in Table 4. As the historical production plan data is at day level, we used one shift of 12 h per day in the model to make the historical data and the model output comparable. Table 5 reveals that the model output achieves a significantly lower cost (reduction by 6.9%), and that this follows from high production volumes on the day before a shipment is due. Figure 2 shows how this results in a higher labour cost, but a lower total cost through significant inventory savings.

Table 4. Demand from historical production (one week)

Case		Historical production						Demand					
Day		1	2	3	4	5	6	1	2	3	4	5	6
Products	1	18,306	12,024	-	-	-	-	-	-	30,330	-	-	-
	2	-	61	3,097	3,935	4,247	-	-	-	3,158	-	-	8,182
	3	1,162	1,268	228	-	-	-	-	-	2,658	-	-	-
	4	480	-	-	-	-	-	-	-	480	-	-	-
	5	5,400	-	-	-	-	-	-	-	5,400	-	-	-
	6	-	-	10,328	-	-	-	-	-	10,328	-	-	-
	7	-	-	-	22,928	-	-	-	-	-	-	-	22,928
	8	-	2,196	-	-	-	-	-	-	2,196	-	-	-

Table 5. Comparison between historical plan and solution (39 weeks)

Case	Historical						Solution					
Day	1	2	3	4	5	6	1	2	3	4	5	6
Volume	24,941	23,966	21,703	22,946	12,776	194	5,076	14,641	51,914	3,219	7,261	30,722
W_1	3.5	4.4	4.1	3.8	2.6	-	2.5	3.7	5.6	2.2	2.5	4.3
W_2	3.0	3.1	3.4	3.4	2.5	-	2.9	4.9	6.1	2.5	2.9	4.9
W_3	3.3	2.7	2.4	2.4	2.2	0.1	3.2	3.9	4.0	2.8	3.1	3.8
c_H	24,941	48,907	-	22,946	35,722	-	5,076	19,718	1,315	4,292	11,538	6,386
c_B	-	-	-	-	-	-	-	-	880	154	110	234
C_W	29,692	30,615	29,769	28,769	22,000	277	25,769	37,308	47,077	22,692	25,538	46,708
C_T	54,634	79,522	29,769	51,715	57,722	277	30,845	57,025	49,272	27,138	37,187	53,328



	Holding cost	Labour cost	Backlog cost	Total cost
Historical plan	132,516	141,122	0	273,639
Solution	48,325	205,092	1,378	254,795

Fig. 2. Average costs of historical plans and solutions (39 weeks)

5 Discussion

Historical production reveals a close balance between holding and labour cost, with no backlogs occurring at all. This reflects a conservative approach to production, which is done well in advance of delivery, using the most efficient equipment to force down labour cost. In contrast, the model solution accepts a much higher labour cost in exchange for an even greater reduction of holding costs. The reason for this is that the daily holding cost (2% of the sales price) is high enough to offset the gains made by producing on the most efficient machinery in advance of the deliveries occurring twice per week. Although labour costs are significant, they are overshadowed by the cost of maintaining perishable inventory. The results given by the scheduling procedure are consistent with the following principles:

1. Determine how much to be delivered on delivery days, and schedule production backwards
2. Produce as late as possible, unless production in previous periods results in savings greater than the additional holding cost.
3. There are integer effects associated with the labour employed in each facility. Use capacity from idle workers – even for operating slow machines.

Occasionally, the historical production figures have exceeded the capacity as indicated by the production rate of the packing lines. This suggests that actual capacity may be higher than indicated, and that further savings may follow if the company maintains accurate data on production rates and capacity.

6 Conclusion

We have shown that a procedure for scheduling by reallocating production be-tween facilities can reduce production costs by 6.9%. Although the producer is located in Scandinavia and therefore has high labour costs, the fresh-food products being prduced have such high unit holding costs that production should be made to coincide with shipments, even if this requires the use of slower packing machines. One particular benefit of the algorithm is that it efficiently allocates otherwise idle workers to produce – although they may be operating slow machines, the marginal labour cost of this production is zero.

There are a few limitations to be observed: First, the data quality of machine speeds underestimates capacity, which constrains the algorithm to produce a solution that could lead to higher savings if proper machine speeds were used. Second, the packing plants are assumed to be proximate, and we need not be concerned about delivery lead times, transhipment cost, delivery costs, or raw materials availability. Third, there are no notable setup times or costs. The algorithm could be more generally with the capability to handle setup time. We view these three limitations as opportunities for further research.

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Factory Planning

Case Studies of Participatory Design

Comparison of Methodologies in Factory Planning

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Abstract. Nowadays, user integration is focused at an early stage of the innovation process by using methods of open innovation, especially of participatory design. The methods LEGO® SERIOUS PLAY®, gamification with LEGO® MINDSTORMS® as well as interactive workshops are investigated successfully concerning their suitability. This evaluation relates to various objectives and applications by dint of three case studies relating to factory planning – merged technologies, digitalization and professional education. The comparison of the used methods shows the need of a context- and objective-related preselection of methodological approaches of participatory design to tap their full potentials.

Keywords: Open innovation · Participatory design · Prototyping · LEGO® SERIOUS PLAY® · LEGO® MINDSTORMS® · Factory planning · Merging technology · Digitalization · Education

1 Introduction and Motivation

The increasing significance of innovations [1] results either from the rising market demands [2] or the need to improve products and processes by consideration of new technologies and digital approaches [3, 4]. Innovations are only successful when the provided products and services sate the wants of the end users by gaining an additional value [5]. Hence, user-integrated innovation is a key competitive factor for the design of innovative products, services and processes [2] supporting the implementation of new technologies in a working factory and their consideration in the planning process. Hence, methods of open innovation – especially of participatory design – are investigated to identify their application fields in the context of factory planning and management.

Currently, there is a big variety of methods whose applications are not concerted with the innovation process. Different procedures should be selected by focusing the targeted objectives of the innovation process. Three case studies are used to represent the characteristics of different applications and demands for appropriate methods. LEGO® SERIOUS PLAY®, LEGO® MINDSTORMS® and an interactive workshop

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are investigated related to their suitability and conditions of use. The findings lead to the design process for dealing with new technologies by varying initial situations.

This article starts with a literature review referring to the disciplines of open innovation and describes the diversity of methods of participatory design with focus on process innovation. Product innovation will be neglected. Subsequently, three case studies represent the potentials of different methodological approaches in comparison.

2 Open Innovation

Innovations are the driver of the national economics [6] by generating new ideas as basis for the creation of new products, processes and services. The importance of a product innovation is its impact on the competitive strategy of the enterprise. Process innovations increase the economic efficiency of the production by improving business and production processes. New ideas for innovations result either from user or customer needs or from new production procedures and technologies [7]. Hence, it is necessary to study demands across the enterprise with open innovation approaches considering internal as well as external ideas in the development of innovative processes [8]. The phases of an innovation process are shown in Fig. 1.

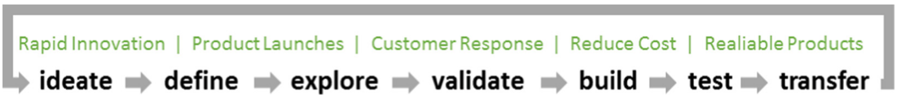

Fig. 1. Innovation circle (related to [9])

Participatory Design is a discipline of open innovation during the ideation phase of the innovation process and describes the involvement of different stakeholders in the design process to increase the degree of need satisfaction of the end users [10]. In the field of factory planning, it is necessary to integrate stakeholders directly representing their actual needs of functional and designing features. Hence, the methods of Participatory Design have to be investigated in detail. Muller and Kuhn [11] provide an overview of methodological approaches of Participatory Design related to their utilization point along the product life cycle and their stakeholder participation (shown in Fig. 2).

The diversity of methods in Participatory Design can be divided in five categories: gamification, prototyping, creativity techniques, dynagrams and image schemes.

Gamification is used to understand the context playfully [12]. Examples of methods are LEGO® SERIOUS PLAY® or scenario analysis. LEGO® SERIOUS PLAY® is an innovative hands-on and minds-on method based on metaphorical thinking to improve the understanding of processes. This is achieved by interpretation of alternatives and significances, and discussions in the group [13]. Scenario Analysis describes the investigation of future developments based either on varying ways to reach desired situations or on varying expectations of progressing [14]. LEGO®

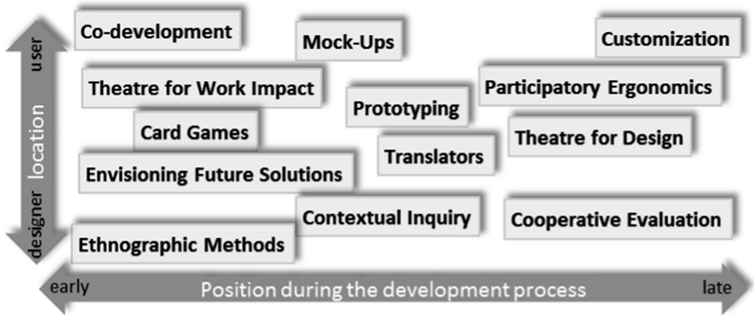

Fig. 2. Overview on methodological approaches of participatory design (related to [11])

MINDSTORMS® rebuilds the production structure in a scaled Lego model representing processes with the aid of programming, and technical components [15].

Prototyping describes the creation of the first of its manner with reduced demands related to design, function and quality compared with the end product/process to identify weaknesses. Prototypes are physical or virtual models of products or processes. Physical product prototypes are realized by rough or rapid prototyping, while virtual product prototypes are done by CAD modelling and drawing [16, 17]. A process prototype represents the main activities of a process considering their interdependencies. The level of detail is geared to the original process. Hence, the complexity increases [18]. Process prototypes can be implemented physically by using LEGO® MINDSTORMS® or Cardboard Engineering for example [15] and virtually by simulating. Simulation is the key method of systems dynamics used to investigate the characteristics of a social, economic, biological and ecological system. Such a system is defined by dynamic and temporary interdependencies between system components and their environment [19].

Creativity techniques are well-known methodological approaches to gather ideas by open-minded and unlimited thinking. Typical methods are Mind Mapping, Morphological Box and Brainwriting [20].

Dynagrams are defined as interactive visualizations based on a diagram. They allow users to create, change and extend collaboratively products or processes. The analysis and investigation of scenarios, the yield of conclusions, the preparation of experiences as well as the evaluation and decision-making are enabled. Common dynagrams are the Roger Dynagram, the Sankey Diagram and the Confluence Diagram [21].

Image schemes are abstract representations of recurring dynamic patterns of interactions to structure people's view on the world. The basis are abstractions being more tangible than symbols but less realistic than pictures. They represent sensorimotor contours consisting of information which can be visual, haptic, kinesthetic or acoustical. Hence, image schemes are a metaphorical approach originating from linguistic contexts that is now extended into non-linguistic fields like cognitive psychology [22].

3 Methodological Investigation and Case Studies

All the different methods of Participatory Design are suitable for varying use cases in factory planning to tap their full potential. Hence, it was necessary to classify them on their objectives. Three main objectives of participatory design methods result from the knowledge basis of the single participants. (1) Acquisition of knowledge, i.e. participants don't know the technologies yet and get to know them by acquiring knowledge related to these new technologies. (2) Identification and analysis of potentials i.e. participants know the new technologies, but neither did they consider their implementation nor any analysis of potentials in their enterprises. (3) Prototypical realization i.e. participants develop a prototype for the identified application fields.

For these categories, based on design objectives, three case studies are investigated varying in their application fields and selected methods of participatory design. The suitability of these methods is analyzed by additional influences resulting from the innovation context and the integrated participants. After the workshop, the fit of the methods was assessed by analyzing the initial situation, while considering the quality of the results, too. The comparison of the methods is based on deduced criteria. The three used approaches – the interactive workshop, LEGO® SERIOUS PLAY® and LEGO® MINDSTORMS® – are evaluated and possible application fields are deduced.

3.1 Case Study 1: Merged Technologies to Produce Hybrid Components

The German Federal Cluster of Excellence MERGE studies the combination of different technologies like plastics injection molding and metal die casting to produce resource efficiently hybrid components for lightweight conveyor systems in a large-scale manner. Hence, factory planning deals with the upcoming challenge of space-concentration requiring optimization of logistics processes. A modified logistics concept and a logistics planning procedure have been created which bring up changing conditions.

A workshop (described in [23, 24]) was used to validate the new approaches and to offer a frame for educational contexts. It consists of two parts: (1) challenges of merged production processes and (2) knowledge transfer for dimensioning a load carrier.

In the first workshop part "challenges of merged production processes", the participants present, analyze and investigate synergy effects of merged production processes. This is based in the previous introduction of plastic injection molding and metal die casting. Subsequently, synergy effects of production and logistics processes can be identified and investigated. The results of this first part concentrate on technological aspects. The identified synergy effects are:

Material flows on a modular constructed tool as well as on several clamping units and robots for handling facilitates a faster change of cavities to deal with small production batches. Whereas, the transportation complexity decreases. The big differences of melting temperatures of metal and plastics can be reduced by using zinc alloy instead of aluminum alloy. Thereby, the energy demand decreases.

The second part "knowledge transfer for dimensioning a load carrier" is based on the definition of needs and attributes resulting from the chosen material which has to be conveyed. These needs and attributes include handling geometries, work flows, operations and premises of logistics. Afterwards, workshop participants design a load carrier and define its demands on transportation and material supply. They create different variants of load carriers with the aid of a load carrier morphology being evaluated by a cross-impact matrix and an efficiency analysis. One result is the identification of the best variant dimensioned afterwards related to technical or structural parameters, type and size in conjunction with the existing setting restrictions.

3.2 Case Study 2: Transfer of Digitalization Knowledge

The German promotion initiative "Mittelstand 4.0 – Agentur Prozesse" is focused on the digitalization of resource and process management. The main objective is the qualification of information multipliers who are enabled to assist SMEs as well as handicraft enterprises. Hereby, the LEGO® SERIOUS PLAY® method is used [25].

In this context, LEGO® SERIOUS PLAY® aims at the establishment of a shared comprehension of digitalization. A fictive enterprise builds the frame where each participant puts oneself in the position of a certain role. After a short theoretical introduction and warm up with Lego, each participant designs a future vision of the enterprise as most digitalized SME in the year 2020 from his point of view. They accentuate special features in comparison to the rival businesses. Concrete realization actions are carved out for the working area of his role in the enterprise. Additionally, possibilities to integrate users and colleagues into the digitalization of the processes are reflected. The resulting single models are presented to the other participants by storytelling.

Subsequently, a collective model is created in the group by combing the single models. It is important that every participant is represented in his role. The design has to be accepted by everyone and new ideas are also considered. Finally, this collective model is presented by one or more participants via storytelling. This presentation is filmed.

Additionally, the systems environment has to be analyzed to identify external influences considered as small single Lego models. Their relations to the main system and its components are rebuilt with their positions on the table. The participants are supposed to move around the table to be inspired by different perspectives on the system.

The analysis of potential future events with positive or negative effects follows. Therefore, the creativity technique approach of issue cards is used. The most important scenario has to be identified in a group discussion which will be investigated concerning its influences and consequences for the system. That's the finishing point to work with the Lego model.

Finally, each participant changes his role from the fictive enterprise to the multiplier role and all findings of the design process being relevant for the work of multipliers are collected. Possible recommended actions and starting points for digitalization are assembled creating the foundation for the support of centers of excellence and enterprises. The five most important approaches are highlighted.

3.3 Case Study 3: Professional Education in Factory Planning

The professorship factory planning and management at Chemnitz University of Technology offers several subjects to students for specialized knowledge transfer based on theoretical learning procedures which don't represent the actual key competence of interdisciplinary thinking and working with the entire factory. Therefore, the course "Methods of Systems Engineering" combines different disciplines and the students get the chance to connect abstract theoretical knowledge within a practical context.

In this practical context, a connection between an intermediate store and two machines for laser cutting has to be analyzed, optimized, planned and realized prototypically by minimizing the work in progress of semi-finished goods.

Students create a technical solution in a team under consideration of given and arising restrictions. This task improves the ability to solve problems in a creative and innovative procedures by using group synergies.

At the beginning, the students have to analyze different given process variants to select their favorite one by applying queuing theory. Additionally, the project has to be planned by focusing on team building with different competencies and planning the project organization, structuring of the context and defining demands.

In the execution phase, the main task is to generate a model of the entire production system with LEGO® MINDSTORMS®. The sub systems are solved step by step in different variants. Their tests and evaluations are done continuously to identify the favorite solution by using predefined criteria. Besides the model building tasks, the project has to be controlled related to the achievement of the objectives – time and progress. The procedure as well as the results are documented continuously.

4 Comparison of the Methods

The three case studies access different methodological approaches to integrate users in the innovation process. Case study 1 uses creativity techniques to collect ideas and acquire knowledge. In contrast, a combination of methods builds the basis for case study 2 where the open-minded idea generation is realized by LEGO® SERIOUS PLAY® and results are collected and prioritized by creativity techniques like storytelling. In case study 3, the participants are supposed to design a realistic prototype with LEGO® MINDSTORMS®.

The main differences of the used methodological approaches are identified in innovation need as well as the abstraction and design level.

The interactive workshop with creativity techniques is suitable for case study 1 to acquire knowledge because it serves as tool for further education regarding merged production processes, the new logistics concept and general methods of factory and logistics planning. The workshop is accepted as suitable tool for further education.

In case study 2, the participants with varying knowledge background aim at the creation of a shared understanding of digitalization and investigation of technological potentials. The basis is an open-minded team working progress achievable with LEGO® SERIOUS PLAY® which allows creative thinking and interpreting of common structures. During discussions and storytelling of the participants, everybody is able to share knowledge and experiences. Hence, LEGO® SERIOUS PLAY® supports successfully the open-minded innovation process whose results are prepared by additional using of creativity techniques.

In case study 3, students work in a creative but realistic way to design a prototype of a factory by using project management and synergies from team work. Idea generation refers to finding new realization approaches to solve problems during the modeling process. Technological possibilities are known. The realistic representation of a factory system supports the understanding of the theoretical knowledge from lectures. Students can integrate their own ideas into the model under consideration of restrictions. Hence, LEGO® MINDSTORMS® is an applicable method in the professional education.

More detailed characteristics of each designing process are shown in Table 1.

Table 1. Characteristics of the different case studies

	Criteria	Case study 1	Case study 2	Case study 3
Objectives	Innovation need	Knowledge acquisition	Shared understanding and potential analysis	Idea generation and prototypical realization
	Innovation level	New creation	New creation/ changing	New creation/ changing
	Planning level	Strategic	Strategic	Tactical
People	Knowledge basis	Homogeneous	Heterogeneous	Heterogeneous
	Professional background	Homogeneous	Homogeneous	Homogeneous
Method	Abstraction level	Realistic	Metaphoric	Realistic
	Design level	Traditional	Creative	Creative

All three case studies achieve the targeted objectives with the aid of the pre-selected methods of participatory design what their suitability affirm.

5 Summary

The significance of Participatory Design methods increases in the process innovation. Hence, three case studies were investigated in the application field of factory planning. Every case study has its own characteristics and demands towards user-integrated innovation processes improving the quality of the results. The affirmation of the suitability of the preselected user-integrated methods was successfully for all case studies. In summary, the interactive workshop with creativity techniques supports the acquisition of knowledge. In contrast, LEGO® SERIOUS PLAY® combined with creativity techniques is used to design innovative and open-minded ideas or solutions while getting a shared knowledge base in the team. Finally, prototyping improves the professional education at university because theoretical knowledge is transferred into a practical context. As conclusion, the results can be used as data base for the development of a systematical approach to select a suitable method of participatory design for different use cases. The systematical approach should be based on the consideration of targeted effects, characteristics of content and participants. Hence, a suitable approach of participatory design has to be selected to tap its full potential.

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A Robust Facility Layout Planning Method Considering Temporal Efficiency

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Abstract. Facility layout planning (FLP) is an important stage for optimal design of manufacturing systems. A major approach is to define an evaluation index based on distance and find a layout which minimizes it. Temporal efficiency is not considered in this stage but in later stages. The resultant temporal efficiency may not be optimal enough, since decision and optimization in those stages are performed under the fixed layout. For this reason, the authors have developed FLP methods considering temporal efficiency. Those methods provide the optimal layout plan for a fixed production scenario. However, production environments change dynamically in actual manufacturing, and the layout plan is no longer optimal after the changes. In this paper, the conventional method is enhanced considering robustness against the changes.

1 Introduction

In order to convert data of an artifact generated in product design into an entity and place it on the market as a product with high cost-performance, it is necessary to design a manufacturing system optimally. Facility layout planning (FLP) is an important stage for the design and has been a topic of discussion for a long time [1–3]. In research of FLP, evaluation indices based on distance such as total travel distance and total material handling cost are usually taken into consideration, and optimization based on them is performed by mathematical optimization (quadratic assignment problem [4] and mixed integer programming [5]) or metaheuristics (tabu search [6], simulated annealing [7], genetic algorithm [8,9], etc.). Those indices do not include temporal efficiency which is considered in the stage of production scheduling performed after completing the FLP stage. However, this may result in inadequate optimization from the point of view of the whole system. For example, optimization in terms of total travel distance may cause locating some facilities unnecessarily closer than they are required from the point of view of scheduling and other facilities which are required to be located as close as possible are located apart. For this reason, it is desirable to take temporal efficiency into account in FLP stage.

Consideration of temporal efficiency in FLP stage was discussed by some research groups [10–12]. Those researches dealt with allocation of facilities to

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pre-given sites, and detailed position and size of facilities were ignored. The authors proposed an integrated method for FLP and production scheduling in which the integrated planning problem was formulated as a mixed integer programming which minimizes makespan and includes detailed position and size of facilities as decision variables and constants [13]. However, transportation routes were not taken into consideration and transportation times for evaluating temporal efficiency were calculated roughly based on the Manhattan distance between facilities. In addition, loading/unloading points of facilities were not considered either. Therefore, the authors also proposed an FLP method considering these problems [14]. Due to difficulty of describing the shortest transportation route by linear equations/inequalities mathematically, genetic algorithm (GA) was taken for optimization of facility layout plan in which finding the optimal routes and makespan based on the routes was performed for each layout plan.

Those methods provide the optimal layout plan for a fixed production scenario. However, production environments change dynamically in actual manufacturing, and the layout plan is no longer optimal after the changes. An approach for solving this problem is to adopt the concept of robustness against the changes [15] and robust FLP based on enumerative method [16], branch-and-bound method [17], fuzzy theory [18], etc. has been discussed. In this paper, the FLP method considering temporal efficiency and routing is enhanced from the point of view of robustness.

2 Manufacturing System Taken into Consideration

This research deals with job-shop production with J kinds of jobs and F facilities. Job $j \in \{1, \ldots, J\}$ needs O_j operations. Operation $o \in \{1, \ldots, O_j\}$ of job j is processed by facility $f_{jo} \in \{1, \ldots, F\}$. Width and depth of facility f are w_f and d_f. Each facility has loading and unloading points. Those facilities are located in the production area which has a rectangular shape of width W and depth D.

3 Outline of FLP Considering Temporal Efficiency

This section provides an outline of the FLP method considering temporal efficiency where transportation routes and loading/unloading points of facilities are also considered [14]. Because it is impossible to describe the shortest transportation route by linear equations/inequalities mathematically and to formulate the problem of finding the optimal layout based on temporal efficiency as a mathematical optimization problem, optimization of facility layout plan is carried out iteratively by GA and routing and minimization of makespan are performed for each layout plan (Fig. 1). It is necessary to represent a layout plan as an individual in GA. For this purpose, the production area is divided up into a grid of squares with sides one meter and each cell has its ID number (Fig. 2). It is possible to represent a layout plan as an individual by defining the structure of chromosome as F pairs of two numbers, where the second number of the f-th

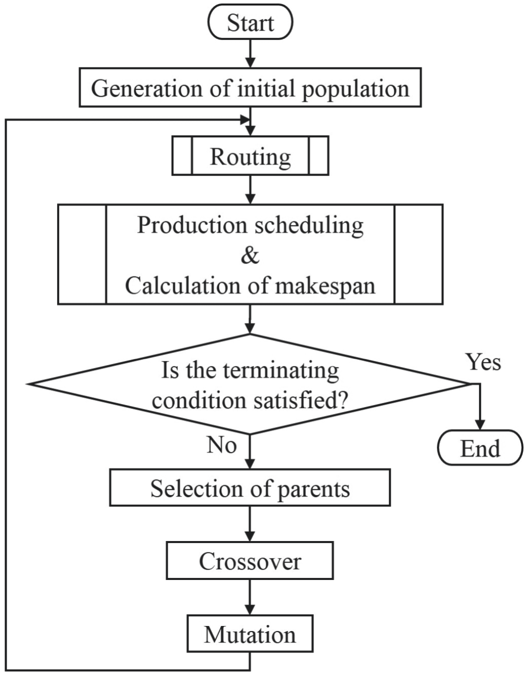

Fig. 1. Flowchart of FLP considering routing and temporal efficiency using GA [14].

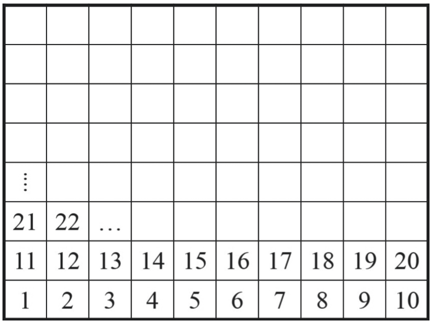

Fig. 2. Production area divided up into a grid of squares [14].

pair is the number of clockwise rotation by 90° and the first number is the ID number of the cell on which the upper left part of facility f (Fig. 3).

For a layout plan represented as stated above, the shortest route between two facilities can be obtained by using Dijkstra's method. Transportation time can be obtained by dividing the length of the route by the velocity of an automated guided vehicle (AGV).

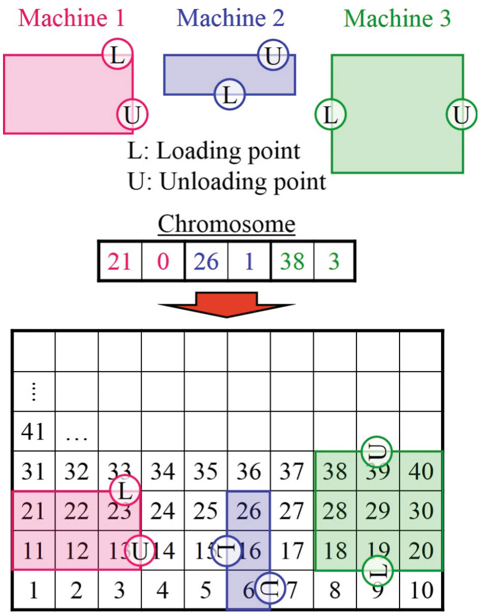

Fig. 3. Chromosome representation of a layout plan [14].

Production scheduling for a layout plan should be completed in a short time, since this process has to be performed many times. For this reason, mathematical optimization is not adopted but GA is utilized also for this process.

4 Robust FLP Method Considering Temporal Efficiency and Routing

This section describes enhancement of the conventional method for robust FLP. In the conventional method, makespan of the optimal schedule for the given production scenario was taken as a temporal index. To take various scenarios and obtain a robust layout, the following index is adopted:

$$\Sigma_{i=1}^{S} M_i P_i \tag{1}$$

where M_i stands for the makespan of the optimal schedule for the i-th one in the given set of production scenarios the cardinality of which is S, and P_i is the probability of the scenario. Because a production scenario is defined as a combination of the number of production of jobs in this research, P_i is given by

$$P_i = \Pi_{j=1}^{J} p_j^i, \tag{2}$$

where p_j^i is the probability of the number of production of the j-th kind of job specified by the i-th production scenario. By introducing this evaluation index, facility layout considering various production scenarios can be obtained.

Table 1. Dimensions of facilities. “N”, “E”, “S” and “W” stand for “North”, “East”, “South” and “West”, respectively.

Facility m	1	2	3	4	5	6	7
Width w_f [m]	2	3	4	3	5	4	2
Depth d_f [m]	2	2	2	3	4	3	2
Loading/Unloading	N/N	N/E	N/W	N/S	N/N	N/N	N/N

Table 2. Processing sequence m_{jo}.

Job j	Operation o						
	1	2	3	4	5	6	7
1	3	6	2	4	5	1	7
2	2	3	5	1	4	7	6
3	3	4	1	7	5	2	6
4	2	6	3	4	7	5	1
5	3	7	5	1	4	6	2

Table 3. Required processing time [min].

Job j	Operation o						
	1	2	3	4	5	6	7
1	5	3	2	7	6	4	5
2	3	6	5	8	4	3	3
3	4	4	3	5	2	1	4
4	6	5	4	3	8	5	6
5	2	3	4	3	1	4	2

Table 4. Parameters of GA.

Population size	300
Maximum # of alternation	200
Crossover probability	0.7
Mutation probability	0.03

This new index increases the required number of performing production scheduling by S times. It is unreasonable to perform scheduling using GA from the point of view of computational load. Therefore, in this method, scheduling is performed based on the simulation approach using a dispatching rule.

5 Numerical Example

The proposed method was applied to a simple example of $F = 7$, $J = 5$, $O_j = 7$, $W = D = 15$[m]. It was assumed that there were sufficient number of AGVs and the velocity of an AGV was given as 3[m/min]. Dimensions of the facilities were given as shown in Table 1, where “North” means that the loading/unloading point is located in the center of the north part of the facility without rotation. Processing sequence and required processing time were given as shown in Tables 2 and 3. Optimization of facility layout by GA was performed with the parameters shown in Table 4. The shortest processing time (SPT) rule was adopted as a dispatching rule for production scheduling.

The number of production of each kind of job was assumed to be 4, 5 or 6, and their probability were given as 0.3, 0.4 and 0.3, respectively. The number of production scenarios S was $3^5 = 243$. Figure 4 shows the facility layout obtained by the integrated method considering only one scenario (called as *standard scenario* in this paper) where the number of production is 5 for all kinds of job,

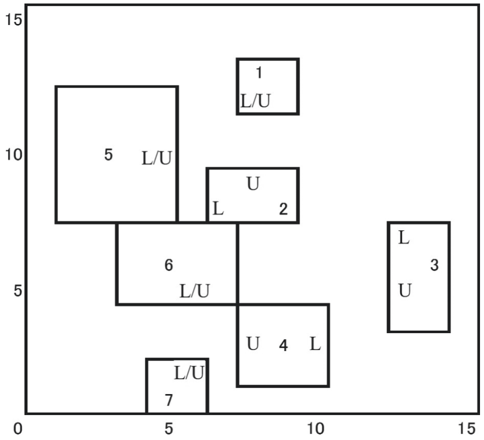

Fig. 4. Facility layout obtained by the integrated method considering only one production scenario.

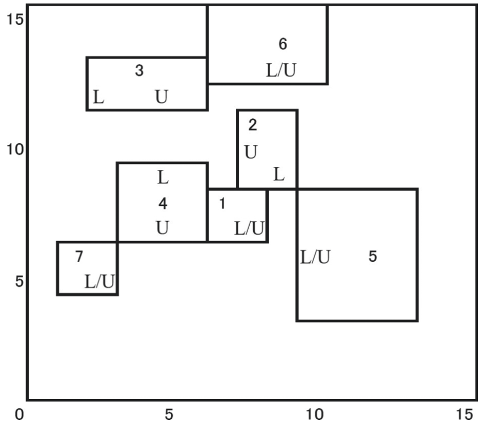

Fig. 5. Facility layout obtained by the integrated method considering various production scenarios.

and Fig. 5 shows the layout obtained by the proposed method considering all the scenarios (243 scenarios).

Table 5 shows the values of makespan calculated for the two layouts under the standard scenario, and Table 6 shows the values of the evaluation index (1) calculated for the two layouts considering all the scenarios, respectively. Figure 6 shows the values of makespan calculated for the two layouts under each of the scenarios. It can be confirmed that better makespan can be achieved with the layout obtained by the proposed method under many scenarios, in other words, the proposed method provides a robust layout.

Table 5. Makespan under the standard scenario.

Fig. 4	10299
Fig. 5	10799

Table 6. Value of evaluation index (1).

Fig. 4	11264
Fig. 5	10793

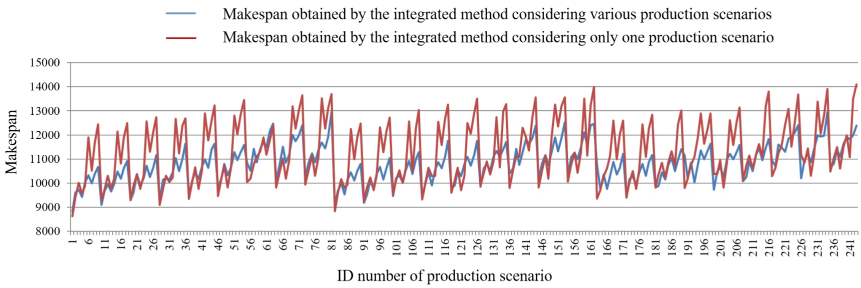

Fig. 6. Makespan for the obtained layouts on each production scenario.

6 Conclusion

In this paper, the conventional FLP method considering temporal efficiency and routing has been improved from the point of view of robustness. Sum of product of the probability of production scenario and makespan achieved under the scenario has been defined as an evaluation index for taking robustness into consideration. Simulation approach has been adopted for performing production scheduling in a reasonable time, since the new index causes drastic increase of computational load in production scheduling. The effectiveness of the proposed method was illustrated by a numerical example.

To make the proposed method practical, it is necessary to reduce computational load further. The sampling approach [19] would be effective for this problem, and this issue will be discussed in a future work.

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Approach for the Evaluation of Production Structures

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Abstract. Turbulent environment evoking intrinsic complexity of production systems dares in particular series production. As a result, sophisticated structures for production are inevitable to manage these challenges. Due to path dependency, stepwise optimization of production processes leads to pseudo-optimums. During factory operation, minor changes of the production program may result gradually in a suboptimal configuration of the production system. Production systems are forced to cope with these changes by adjusting their temporal and/or spatial structure. For the purpose of an adequate adaption, all options for adjustment should be considered. The evaluation of proper adaption requires suitable figures that assess the appropriateness of the production structure regarding the pending tasks and demands. This paper introduces an approach that enables a deduction of adequate measures. It aims at matching the temporal and spatial structure with the production program by revealing operational and strategic gaps.

Keywords: Production structure · Suitability of system's configuration · Structural adaption · Evaluation procedure

1 Introduction

Only a few analytical approaches exist evaluating the appropriateness of the production structure regarding pending customer demands [1]. Most planning approaches try to pre-determine a flexible system structure [2]. For this reason, we introduced the Structural Quality (SQ) that enables the assessment of the spatial and temporal structure [3]. In this paper, we illustrate an SQ-based approach and its application potential.

The arrangement of the elements of a production system (spatial reference) and the planned configuration of the relations a product undergoes to its production (time reference) is called structure [1]. As an essential (planning or design) activity for the configuration of production systems, structuring determines the implementation costs of the production processes. Based on the specific type and number of workstations (system's composition) and the relationship between them, a production structure defines the basic structure of a production system (system's setup) as well as its function (system's behavior) [4].

Spatial system configuration, reflected as the economic arrangement of workstations, is done by optimizing the layout on the basis of relevant design criteria, such as

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transport performance and the communication index. Thus, it is aimed at minimizing expenses when "using" the relations during operation [3, 5]. The system's behavior – processes and their interactions as temporal structure – is based on the system's pre-defined setup, and is influenced by the basic principle of the order processing's flow and sequence. Thus, it is aimed at maximizing the performance of resource elements [6].

The vector SQ as key figure enables verifying the suitability of the installed system structure and a specific production program in terms of a proper function of the production system. According to Chandler's insights into the interrelations between structure and strategy, the production task (expressed by the production program) is one of the main inputs to structural design within the framework of production structure planning [7, 8]. Theoretically, any change in the production program per se leads to a changed structure in terms of a modified spatial-temporal organization of the production system. On the contrary, industrial production processes require a long-term stable cost function. Therefore, long-term valid structures for production systems are typically sought in production management [9]. In practice, any established production structure is a transition between the function-oriented and the object-oriented type of structure [10]. Consequently, the definition of a structure is commonly a long-term decision of the general principle of structuring.

However, the underlying assumptions of such a defined structure are counteracted by the increasing individualization of customer requirements. Due to significant shifts in production program, there is increasing pressure to change an installed production structure. Beyond the limits of the equipment's flexibility [9], adaptations to the inherent system-related properties are necessary, i.e. a re-configuration of the system's composition, setup, and behavior. Companies do not use every change in the production program as an opportunity to adopt the installed production structure. Typically, more often rationalization measures are introduced, such as process-specific modification or integration of production steps. Finally, there are adapted structures in the form of case-specific operation solutions. This results in huge amount of different transitional structures.

SQ reveals the potential of an adaptation of the production structure. At this point, SQ facilitates an assessment of changing the spatial and temporal structure. Both in the planning phase as well as in the operation and optimization phase, suitability of production structures for the present production task can be evaluated. If the existing production structure is a planning construct, an anticipatory structure evaluation takes place, whereas structure is actively monitored during operation.

2 Holistic Evaluation Approach

2.1 Basic Process Model

Derived from control theory, we illustrate our re-configuration model as a block diagram of a closed-loop control system (Fig. 1). The object of observation is a production system with a planned or already installed production structure as described above. Typically, key performance indicators are recorded during system operation. Such

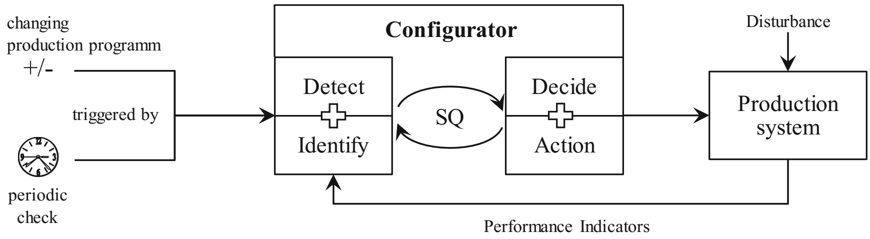

Fig. 1. Configuration procedure as closed-loop system.

performance indicators along with sufficient input variables are necessary for an overall re-configuration or adjustment of production structures. Starting point for such a re-configuration is a relevant change to the production program. Such changes affect variations in the type and quantity of the products to be manufactured in relation to the original design specifications of the production system.

In a multi-stage procedure, the SQ-based structure evaluation is performed in the configurator. Thus, necessary adaptation measures can be derived. Nevertheless, unlike the actual "control theory", such measures refer to the change of the control system, i.e. the present structure of the production system. Thus, the following integrated configuration procedure is based on human decisions. However, proper indicators and detailed analysis of the Structural Quality of the production system support the detection of changes and the adopting of appropriate measures.

2.2 Integrated Configuration Procedure

The configurator carries out a two-step evaluation and decision-making process. At first, changes of the production program are detected by a preliminary evaluation. Moreover, the amount of value alternation facilitates decisions about further steps. After this rough assessment, a detailed analysis is based on Structural Quality [3]. The more in-depth evaluation procedure enables an identification of significant shifts within the production program. Thereby planning and design activities are taken into account simultaneously. As a result, proper measurements in terms of structural adaptions are revealed. This allows the planner both, to evaluate the suitability of the current production structure and to identify adequate structural solutions in case the present production system is not sufficient regarding the pending tasks anymore. Thus, the integrated configuration procedure is an iterative evaluation and decision-making process.

During preliminary assessment, the planner gets first impressions about the effect of the changed production program on the already installed production structure. Thus, the planner can detect if there are certain alterations within the production program. If the limits defined by the planner in advance are adhered to, then no action is necessary. If the indicator values go beyond defined thresholds, then a detailed structure evaluation is carried out using SQ-determination. Based on this SQ-determination, the planner finally decides which specific changes have to be worked out. This refers to both, temporal and spatial aspects of the production structure.

The determination of the Structural Quality within the integrated configuration procedure is an event-driven process, triggered by a changing production program. In this case, the vector SQ serves as an important criterion for allowing the planner to weigh the need for changes in the production structure (cf. Fig. 1). Structural decisions are consequently long-term decisions regarding the general principle. For this reason, a periodic check of the functional structure also is recommended. Then, the configurator runs as a time-discrete application.

3 Key Figures for Evaluation of Production Structures

3.1 Spatial Structure

In order to evaluate the spatial structural component, an assessment of the relevant spatial layout is required. Basically, we focus on the complexity of material flow. Minimal "complexity of the material flow" is found within the purest form of a production line. Precisely one upstream and one downstream workstation without return flow characterize such a production line. However, maximum "complexity of the material flow" is found in a fully meshed job-shop structure. In order to assess the "complexity of the material flow", we use two indicators: The degree of linearity and the standardized degree of cooperation.

The latter determines the number of material flow relations existing between the workstations [11]. For the standardized degree of cooperation, the value 1 is defined as a threshold value: In the range $0 \leq \kappa \leq 1$, the working stations are directly connected to one another in a sequence. Thus, structure of such arrangements tends to be a linear. If more than one workstation is connected to more than two other workstations, the values' range is $\kappa > 1$. Such arrangement tends to be a job-shop structure. The degree of linearity takes into account the number of return flows in contrast to the prevalent sequence of operations.

A change in intensity and basic orientation of the relations imply the trend of a potential structural change. Minimum "complexity of the material flow" exists when the degree of linearity assumes the value of 1 and the standardized degree of cooperation has a value of 0.

3.2 Temporal Structure

The temporal structure considers the workflow, i.e. the logical and temporal linking of the partial tasks of production [11]. The sequence of relations between the system elements (workstations) expresses the temporal component of the processes running in the production system. Based on the intensities of the relations as dynamic variables, different temporal courses can be characterized.

Parameters of the system-related temporal structure are mean value and variance of material flow's intensity. These figures refer specifically to the (variable or constant) amplitude of the system load. The regularity of the intensity is determined by the load-oriented coefficient of variation. It provides reliable information on the variability of the load resulting from a changed product and/or quantity mix.

If the production system is fundamentally capable of dealing with the upcoming production program, order-induced average system load as estimated value of processing times characterizes the dynamics of load situation. It combines the mix of the production task and the intervals of the specific customer demands. If both aspects are differentiated, the workload for each order and the average time span between the respective customer orders result. However, the effect on the production system is only apparent when considered aggregated.

3.3 Functional Structure

The functional production structure is based on different product characteristics (demand profiles) and thus leads to a segmentation of the production in bestseller (quantity focus) and exotics (diversity focus) [11]. The distinction with regard to a product specification requires a certain diversity of the product range with divergent continuity and contrasting order volumes, i.e. the primary structuring takes place according to the type of production demand. Both the assessment of quantities as well as product changes are thus of central importance for evaluating the suitability of an existing or planned production structure.

The quantity index indicates the average number of products for each order. The average order volume combined with the corresponding coefficient of variation expresses the quantity mix of a production program. In contrast, the variance index represents the number of product variants of an organizational unit (product mix). In this case, nominally different types of orders can be combined into identical product families due to their process-related system load.

An increasing quantity index and a decreasing variation index indicate a concentration of the production program on a decreasing number of rather homogeneous products. Similarity is expressed particularly by a reduction of the coefficient of variation. On the contrary, the organizational unit tends to a broader and more heterogeneous product spectrum if the trends are reverse. By using these indicators, a decisive characterization of the production program is carried out which takes account of both the quantity and the product mix. Thus, a decision regarding the basis segmentation of the production system into organizational units is enabled.

4 Case Study

4.1 Indicator-Based Check of Production Structures

In the following, we will present an overview of the practical use of SQ by means of case study data, whereby the “Basic Process Model” forms the framework. In addition to the integrated SQ-assessment for the evaluation of the spatial and temporal aspects of production structures (event-driven process), the periodic check of the functional structure of a production system (time-discrete process) is also shown using the “Integrated Configuration Procedure”. According to the presented approach, the mode of operation of the configurator is described; both for the evaluation of the spatial and temporal structure components (event-driven mode) as well as the assessment of the functional structure of the given system (time-discrete mode).

The installed production structure is based on the former production program shown in Fig. 2 (top). Currently, a change in the production program is apparent, as shown in Fig. 2 (bottom). If this change is significant, the need for structural adaptation is analyzed in the following sections.

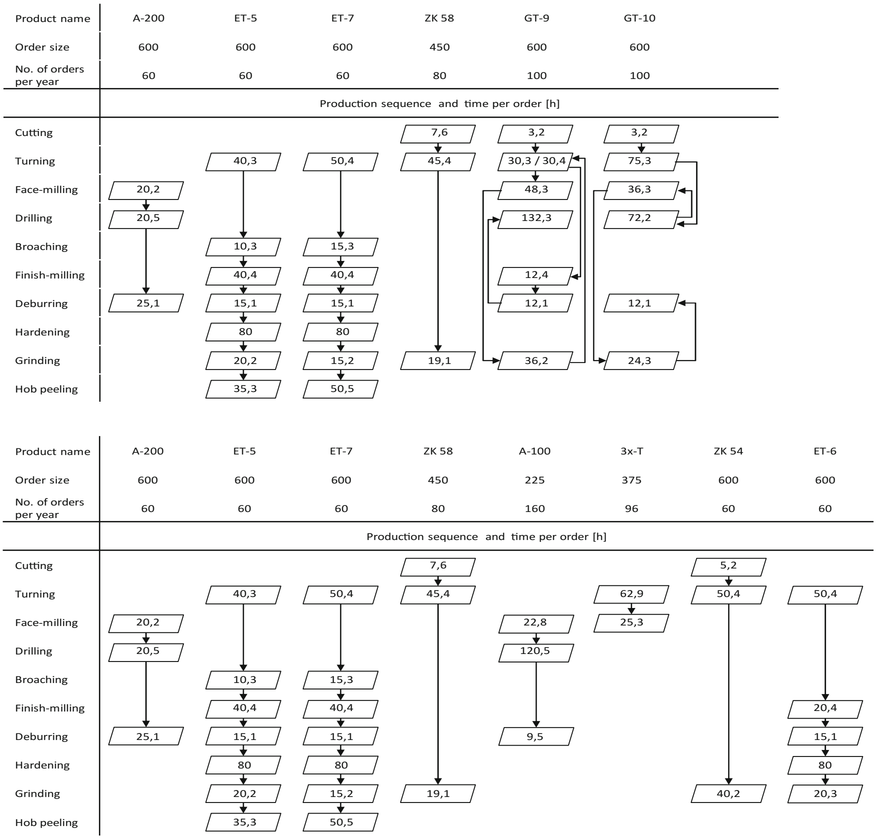

Fig. 2. Former production program (top) and actual production program (bottom).

Consequently, at first the preliminary assessment of relevant indicators is executed. The standardized degree of cooperation amounts 0.92 (previous: 1.29). The degree of linearity amounts 1 (previous: 0.85). Thus, after the change of the production program, a consistently forward-directed sequence of operations is present. With regard to the standardized degree of cooperation, a production line appears to be suitable. Thus, the complexity of material flow decreases. According to the change of the indicator values, the production structure gradually migrates from a job shop production towards a production line.

Indicators for the temporal aspect of the production structure show an ambiguous development. The mean workload remains approximately constant. Accordingly, the capacity of the production system and thus the system composition is still sufficient. In contrast, the coefficient of variation alters from 98 to 132%. Diversity of process times increases, which is indicative for a shift towards a job shop production. This contradicts the development of the other indicators.

With regard to the functional structure, quantity index increases and variation index decreases. In contrast to the coefficient of variation, the variation index compares the similarity of production processes and their workload for every workstation. Whereas the number of products grows, their homogeneity also enlarges. There are different groups of products with nearly the same production sequence (e.g. group 1: ET-5, ET-6, and ET-7; group 2: A-100 and A-200 etc.). This underpins in particular the change of the spatial indicators. However, a further in-depth analysis seems to be necessary.

4.2 Detailed Analysis of Production Structures

Finally, detailed structure evaluation determines spatial, temporal, and functional SQ. For a detailed SQ-assessment regarding material flow, we refer back to known (ideal-typical) arrangement algorithms for minimizing transport effort. For the purpose of a comparison of future and actual structure types, a visualization in form of scaled block-layouts is helpful. Transport effort decreases from 59,023 to 51,809 transport units per year. Subsequently, the ideal spatial arrangement was used as normalization value of 100% transport effort. Based on the previous production program that indicates a job shop production, spatial component of Structural Quality improves from 1.90 to 1.67. Additionally, a simulated shift from a job-shop structure to a production line reveals a potential improvement of about 13.9%.

Derived from three logistic performance indicators: throughput time, output rate and Work in Progress (WIP), the quality of Temporal Structure refers to the operation point of the production systems. To sum up, all figures decrease when retaining the current control strategy: Constant Work-in-Progress (CONWIP). Output rate declines from 338.3 h per SCD to 313.2 h per SCD, WIP decreases from an average workload of 5718.8 to 3437.5 h, and mean throughput time lowers from 17.28 to 11.27 days. The decrease of the output rate reveals a less effective system behavior, whereas the reduction of WIP and lead-time represents an improvement. However, the simulation-based assessment of operating points shows that the existing system composition is still capable to fulfill respective production tasks. Thus, the Temporal Quality improves from 2.71 to 1.43.

The evaluation of the functional structure emphasizes that a splitting of the existing organizational unit according to product families revealed seems to be promising. However, further segmentation of the organizational unit may require other structural solutions respectively. In this case, the integrated configuration procedure and in particular the SQ-determining is conducted iteratively until an adequate segmentation including suitable production structures is found.

5 Conclusion and Outlook

The integrated configuration procedure facilitates an easy detection of structural changes by indicators. These indicators reveal the amount and direction of change. If defined thresholds are exceeded, an in-depth analysis is conducted. This detailed analysis comprises an assessment of the suitability of current production structure by determining the Structural Quality vectors. During this procedure, planning and design alternatives are considered systematically. Thus, an iterative improvement of suitability is enabled. The evaluation of different structural variants is supported by simulation studies because only in this way dynamic behavior and performance of the altered production system become obvious.

The case study highlights the application of the multi-stage approach. If thresholds of indicators are exceeded or indicator's development shows an ambiguous trend, a detailed analysis of Structural Quality is inevitable. Assessment of functional structure indicates a different segmentation of the considered organizational unit. With regard to proper product families in terms of homogeneous processes and workload, at least three new organizational units are reasonable. Each of these units need an appropriate production structure. In this regard, further research is necessary to extent the iterative procedure.

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An Investigation on Implemented Actions to Improve Responsiveness in Manufacturing Firms

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Abstract. The unpredictability of market requirements is currently challenging manufacturing firms in addressing the need to be more and more responsive. To meet this need and to gain competitive advantage firms require reconfigurability. Literature provides much information on characteristics of reconfigurability, but generally restricting the focus on highly automated systems. In order to investigate on reconfigurability characteristics in a broader context, within this paper, three cases of plant reconfiguration were analysed and implemented actions were interpreted via the core characteristics of reconfigurability. Results allow fostering an extension of definitions of such core characteristics with respect to what stated by literature.

Keywords: Reconfiguration · Systemic approach · Modularity · Integrability · Convertibility

1 Introduction

Nowadays, manufacturing firms need to survive in the current context characterized by unpredictable and frequent market changes and the demand for products with shortened life cycles [1]. In this scenario, responsiveness is more and more a decisive competitive advantage [2]. Responsiveness is the speed at which a system can meet changing goals at an affordable cost, producing according to new requirements or technology changes [3, 4]. In the interest of being responsive, manufacturing firms need to develop the reconfigurability capability [2, 3, 5–9].

Reconfigurability is the ability to repeatedly change and/or rearrange the components of a system in a cost-effective way, to meet new environmental and technological changes [10]. Reconfigurability has been associated to Reconfigurable Manufacturing Systems (RMSs), often described by literature as highly automated systems. However, due to the actual evolving context, nowadays reconfigurability should be needed, in a broader way, not only referring to highly automated systems. For example, it could be the case of Small and Medium Enterprises (SMEs), producing customized and low-volume products, requiring manual assembly for final phases of the manufacturing process. The objective of this paper is to investigate on characteristics of reconfigurability at firm level through the exploratory and descriptive analysis of three cases.

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2 Literature Review on Core Characteristics of Reconfigurability

According to literature, reconfigurability is composed of six core characteristics: modularity, integrability, diagnosability, scalability, convertibility and customization [3, 4, 6, 7, 11, 12]. According to Bi et al. [13], "Modularity implies that both software and hardware elements are modularized. Scalability means the system is scalable in terms of the product volume. Integrability means the system and system components are designed for both ready integration and future introduction of new technology. Convertibility allows quick changeover between existing products and quick system adaptability for future products. Diagnosability is able to identify quickly the sources of quality and reliability problems that occur in large systems". For Shabaka and Elmaraghy [15] customized flexibility (i.e. customization) enables cost-effective reconfiguration when product or volume changes are introduced. Hence, customization means the system configurations adapt to changing market requirements.

As observed by Andersen et al. [14], compared to the wide literature treating reconfigurability at system level, a few authors deepened on reconfigurability at firm level. Moreover, literature investigating on core characteristics of reconfigurability at firm level is even scarcer. Wiendahl et al. [16] referred to characteristics of "transformable" factories. However, instead of introducing new definitions, within this paper the possibility to extend at firm level definitions of the six consolidated characteristics was explored. Therefore, the research questions addressed within this paper are the following.

- Can actions of manufacturing firms aimed at improving responsiveness be interpreted by means of reconfigurability?
- When focusing at firm level, can a reconfiguration be interpreted through the six core characteristics of reconfigurability?

3 Exploratory Research

In order to answer to the research questions, an exploratory and purely descriptive study, focused on manufacturing firms of different sizes, was performed. The cases, selected amongst successful companies in their own market, were three. A brief description of characteristics of analysed cases is provided in Table 1. Due to changed market requirements, i.e. in order to produce evolved product families, the selected cases had to reconfigure their plants.

The methodology required (i) visiting plants, and, at the time of the visit, (ii) asking experts, with long experience in the studied firms, to show and explain the main actions implemented on processes to face substantial changes in market requirements. Thus, questions were formulated about plant changes, their causes and consequences, the exploited actions, criticalities and solutions.

The focus of the following analysis of cases is on implemented actions at multiple levels, i.e. firm, production system (or production departments) and station ones. The

Table 1. Summary of characteristics of analysed firms

	Firm 1	Firm 2	Firm 3
Size[a]	Small enterprise	Small enterprise	Medium enterprise
Product sold	Food processing machines (the focus of this paper is on slicers)	Taps and fittings	Hydronic solutions (mainly, valves and mixers)
Main production phases	- Machining and tooling - Manual assembly	- Mechanical processing - Washing - Surface treatments - Manual assembly	- Plastic moulding and brass moulding - Mechanical processing - Manual and automatic assembly
Manufacturing system	Manufacturing cells. Stations within the cells exploit machines' multi-functionality for completing the entire processing of slicers' component	Job shop. Three departments equipped with numerical control stations and transfer machining stations	Job shop. Three departments equipped with numerical control stations and transfer machining stations
Assembly system	Assembly cells. Each cell is responsible for the assembly of a certain product family	Assembly cells. Each cell is responsible for the assembly of a certain product family	Assembly cells. Each cell is responsible for the assembly of a certain product family

[a]According to the European Commission

interpretation of actions was driven by the knowledge of the core characteristics' definitions, researching traces of reconfigurability aspects. Whenever actions have been associated to core characteristics, it has been clearly stated within the analysis.

3.1 Firm 1

In order to reconfigure processes according to changed market requirements, Firm 1 adopts a systemic approach at firm level. Indeed, when required, the general manager meets all functions (i.e. production, purchasing, and research & development functions), in order to make joint decisions related to lower levels. Consequently, the systemic approach – by means of the inter-functional meetings at firm level – has an impact on subsequent actions taken at production system level, i.e. related to both machining and assembly systems.

The product and process engineering integration is another example of systemic approach. Such integration led Firm 1 to actions of process standardization at the machining phase and actions of postponement of customized activities at the assembly phase. Thus, the firm selected machining processes that, even if not efficient for the single-piece processing, are adaptable – as they are general purpose for the capability of operations – for the whole (wider, compared to the past) production mix. Other activities, previously performed at the machining phase for efficiency purposes, were postponed at the assembly phase for customization purposes. To summarise, they moved and sometimes converted activities for the systemic goal of producing an increased variety of products.

At the manual assembly phase, each cell can be considered as a module of the assembly phase; indeed, each cell has a consolidated way of working, cells are "self-organized". Again, according to the systemic approach, to face changes, the firm formed operators to be polyvalent, allowing some freedom in changing their tasks, thus gaining in stations convertibility (whenever a new product family is introduced). However, due to market unexpected changes, recently, they have often been forced to move more than one operator from one cell to another. Such intervention perturbs the consolidated way of working of cells and, often, operators resistance to change emerges. Indeed, this cultural aspect is certainly an obstacle to stations convertibility. In this regard, one interesting operational matter is worth of a remark: the fact that operators, when assigned to new/changed products with higher throughput, still tend to preserve the pace of the old product, thus leading to a throughput loss. It is clearly an effect of people difficulty in converting to the new pace; this behaviour is probably reinforced by the "self-organization" within the cell (that is somehow a soft aspect within the module).

3.2 Firm 2

Within Firm 2, mechanical processing, washing, surface treatments, and manual assembly can be seen as functional production modules (autonomous and independent) and physical production modules (performed in different buildings). This modularity allows managers of Firm 2 best addressing reconfiguration actions, really focusing on specific needs (i.e. at department level). Nonetheless, even if modules are independent, the fact that they have to work together in a system is critical. Therefore, in order to ensure that process modules have also specific roles in achieving goals at the entire firm level, one of their most important decisions was adopting a systemic approach. Indeed, Firm 2 improved the coordination of such modules, by renewing the intermediate warehouse. In this building, components coming from the washing and surface treatment departments are stored, before the manual assembly. Indeed, the warehouse is a relevant element for coordination: with this regard, they also decided to implement an integrated software, capable to manage and coordinate products' flows and people activities; it allows picking – in the warehouse – the right part at the right moment in order to make the required tasks and move forward production, according to customer demand.

Regarding changes related to the individual production processes, they mainly acted on mechanical processing and washing systems.

At the mechanical processing phase, their systemic approach, enabled by a close collaboration with a technology provider, allowed converting the mechanical processing system. Before changes, they had anthropomorphic robots feeding highly productive machines. To do so, they had to deal with a machines' interoperability problem: the production manager said that, before then, they aimed at buying "machines"; whereas, from then on, they understood the importance of creating "a system" and not "a set of different machines".

At the washing phase, they deeply changed the washing department, again thanks to a close collaboration with a technology provider, by creating an automated "system" (in other words, they took an action of systemic automation, not mere department automation, meaning that – as systemic – the whole production logistics for the washing phase was considered). To ensure the systemic automation of the phase, they had to provide both robot and equipment with interoperability, exploiting the collaboration with the technology provider.

The main obstacle dealt with by firm 2 was related to operators: changing departments unavoidably changed their way of working. Indeed, convertibility problems were not related to required competences, but to the need to deal with their resistance to change. The firm was able to face this problem because the aforementioned adjustments of departments allowed reassigning and valorising professional roles, also thanks to improved working conditions. Thus, they motivated operators, somehow involving them in the change process, by giving them the opportunity to have a professional growth.

3.3 Firm 3

The focus of the analysis of Firm 3 is on mechanical and assembly processes, because they underwent a major reorganization to accomplish changed market requirements. To face changes, they adopted a systemic approach, by improving the coordination and communication of all departments (seen as component modules of the whole production system). This action allows finding appropriate solutions for the whole firm, not just for one or few departments. In order to do so, they acted on two levers. Firstly, they decided to implement a Manufacturing Execution System (MES), which allowed having real-time information about individual stations. Having every single station under control allowed shaping improvement actions (or conversions of the production system) in the most appropriate way, thus increasing firm responsiveness. Secondly, they modified the process engineering function. According to the production manager, before this action, each department (or module) was "self-organized" and dealing with its own problems, without any external support. Today the situation is different because the process engineering function gathers feedback directly from the field, putting together needs and problems of different departments (i.e. the modules of the production system).

Regarding changes related to individual production processes, each intervention was appropriately designed: they are gradually changing (converting) departments, thus the integration with additional modules is planned ahead. At this moment, they are mainly acting on mechanical processing. However, they are planning to act on assembly, too. As they are more advanced in converting the mechanical processing phase, this phase is the main focus considered in this paper. Therein, they are taking two actions of systemic automation. (i) They are replacing transfer lines, capable to ensure high volumes and low variety, with new flexible manufacturing lines, with longer cycle times but ensuring higher variety. Since the integrability of lines with additional modules is planned ahead, they are creating a system that, gradually, will be completely automated even for machines' loading and unloading, leading to the possibility of continuously producing and providing the greater variety required by the market. (ii) Within the washing area, four people involved in the cleaning of pieces have been replaced by the introduction of an automated and smart system. Thus, also in this area, they did not simply introduce a machine, but exploiting integrability of stations, they created a system, designed to be further automated in future, by automatizing also the loading and unloading of pieces.

To implement the aforementioned actions, high skilled operators will progressively replace low skilled operators. In fact, the capability to manage complex systems will be more and more required. The product manager pointed out that the main problem they are dealing with is "changing human resources ways of working". They are positively dealing with such problem by involving people (by asking for suggestions and ideas) in the change process.

4 Discussion

This paper is an investigation on implemented actions to adapt configurations of production systems to market changes. The aim is to explore reconfigurability characteristics at firm level. The results can be summarised in three main categories of actions and good practices taken by firms. These actions (i.e. systemic approach, modularisation and conversions) are reported and detailed in Table 2.

Firstly, to be effective, the actions taken at a certain production level (i.e. station, system and firm levels) should take into account the goal of the upper production level. In other words, the systemic approach drives individual modules (located at certain production levels) in having a role for achieving a systemic objective, otherwise not perceived by modules. Secondly, exploited at different production levels, modularisation supported in achieving responsiveness. Thirdly, conversion actions are evident in all firms, and they are manifestly related to the previous two categories.

In each of the three cases, the exploitation of the systemic approach at different production levels enabled convertibility that, in turn, allowed the firm to deal with the need to meet changed market requirements. For instance, actions of systemic automation (firms 2 and 3) accomplished conversions in terms of functionality of individual stations and, thus, systems.

Moreover, modularity had an impact on convertibility, both in a positive and a negative sense. On the one hand, modularity simplified the identification of specific problems and, thus, allowed shaping the most appropriate solutions. On the other hand, the resistance to changes of human resources is an effect having self-organized systems (modules) and, within cases, it was an obstacle to convertibility. Furthermore, while firm 1 is currently unable to deal with resistance to changes, in firms 2 and 3 this problem was overcome through a systemic approach (even in this example, the systemic approach was enabler of conversions). More precisely, in firm 2, operators were made aware of the possibility of having a professional growth; in firm 3, operators were engaged in the change process by promoting their new role in meeting systemic goals.

Table 2. Actions and good practices taken by firms

	Systemic approach	Modularisation	Conversions
Firm 1	- Making joint decisions - Integrating product and process engineering - Exploiting operators polyvalence	- Self-organized systems or stations composed of machines and human resources	- Process standardization actions - Changes of operators roles
Firm 2	- Making joint decisions - Introducing management and coordination software systems - Collaborating with technology providers to solve interoperability problems - Introducing systemic automation - Involving operators in the change process	- Departments as autonomous and independent production modules	- Changes of operators roles - Actions accurately shaped according to needs of given and well-defined modules - Introducing systemic automation
Firm 3	- Making joint decisions - Integrating product and process engineering - Introducing management and coordination software systems - Collaborating with technology providers to solve interoperability problems - Introducing systemic automation - Involving operators in the change process	- Self-organized systems or stations composed of machines and human resources	- Changes of operators roles - Introducing systemic automation

5 Conclusions

When referring to the characteristics of reconfigurability at firm level, modularity is an important one. In fact, each specific module has its role within a larger system, composed of many other modules. The set of these modules have to work together for a systemic objective. In other words, modules need to be integrated with each other in order to obtain a systemic functionality, useful for a certain systemic objective. Thus,

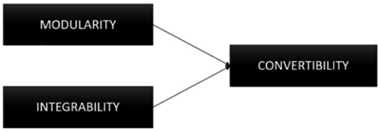

Fig. 1. An attempt to describe reconfigurations made in the three cases through some of the core characteristics of reconfigurability

also developing the systemic view is an important characteristic of reconfigurability and could be reasonably associated to the characteristic of integrability. In fact, in compliance with the aforementioned definitions provided by literature, integrability is closely related to modularity. More precisely, deductions from the analysed cases allow supposing that soft aspects of integrability should be reasonably considered, thus fostering an extension of the definition of integrability at firm level.

Due to the contextual and internal characteristics of analysed cases, within this paper, scalability and diagnosability were not investigated. Moreover, some scarce insights on customization were gathered, not allowing making relevant observations. Thus, further research is required. However, a preliminary answer to the research question is provided in the above figure (Fig. 1). Modularity, integrability and convertibility characteristics seem useful to describe a reconfiguration at firm level, widening the focus beyond highly automated systems. Moreover, the studied characteristics allowed the three firms to reconfigure their processes according to new market requirements thanks to the game of relationships among them (as shown in Fig. 1). Therefore, not only characteristics, but also their relationships are worth of further research. Concluding, this paper relies on the assumption that reconfigurability is sufficient to ensure responsiveness, however further research aimed at measuring the effects of reconfigurability on responsiveness improvement should be performed.

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Development Projects in SMEs

From Project Organization to Dynamic Resource Planning

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Abstract. Innovations and rapid product introduction are keywords for competitiveness in many industries. In larger companies with R&D departments these have often been organized as projects with dedicated resources. However, in smaller companies the project organization has been challenging, as their ability to dedicate resources from e.g. operational activities is more difficult. This is more and more evident in industries where the requirements of rapid product and process development is more demanding. In several research projects, we have investigated different approaches and enablers for a more dynamic way to meet the development requirements. Keywords for these projects have been modularity, inter-organizational collaboration, product-/and process intelligence, and process integration. In this paper, we have a particular focus on how development projects could be integrated in the operations planning, where these development activities become a part of the operations when resources (personnel and equipment) need to be "co-utilized" from production.

Keywords: Product development · Flexibility · Operational planning

1 Introduction

Most manufacturing companies are aware of the need for innovations and continuous development. However, with limited resources and a day-to-day business (production) to take care of it is very often difficult to combine these activities, that to a large extent compete for the limited resources, such as operators, machines/equipment/raw materials. The R&D manager or project manager could have advanced project plans and very good intentions, but will often loose the battle for key resources when there is a short-term production requirement from customers. This challenge is particularly true for small and medium sized companies in competitive markets.

Customization is one of the potentially most important competitive advantages for manufacturers in high cost countries such as Norway, especially when it is combined with innovations and frequent product introductions. However, this is challenging as design and development should be combined with efficient production processes. Mass

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customization and modularized design/production would normally be key elements in a strategy to meet such challenges. Modularization could also be a path for more efficient development processes as modules could be developed separately, thus creating less internal competition for resources. Modularization also goes "hand in hand" with outsourcing and more network-oriented business models [1]. This aspect has been the focus for the Norwegian R&D-project "Innovativ Kraft", where a network of manufacturing companies aim to share test facilities, experts and other capabilities. There have been developed several tools to facilitate such collaboration. This paper is also based on two other research projects "LIP" (Live Innovation Performance) and the EC-funded project LINCOLN[1], where the latter focuses on bringing live data to the design process while LIP focuses on organization, processes and technology for smoother collaboration between development tasks and operations.

Section 2 presents theoretical perspectives on product development and operations. Section 3 presents the R&D-projects, while Sect. 4 discuss more in detail how project and production could be integrated through operations planning and ICT-enablers.

2 Theoretical Perspectives

There has been a common understanding of *project* as a very suitable way to deal with a planned set of interrelated tasks to be executed over a fixed period and within certain cost and other limitations. Traditionally the project was considered a success if it delivered on time, within budget at the predefined quality. This is the famous project-triangle (time, cost, quality) [2]. This is a natural consequence of e.g. the PMI definition, where a project is seen as a unique task: "Projects are different from other ongoing operations in an organization, because unlike operations, projects have a definite beginning and an end - they have a limited duration".

Today it is more and more accepted that we need a broader set of criteria [3] (see also [4–6]). The project must also be seen in a relation to the basic organization, to assess, to which extent the project contributes to the company's strategic goals [7]. The term "governance" is now often used to describe a transition from the traditional hierarchical management into a management structure and principles, where common values enables the sharing of responsibilities between different bodies and collaboration to achieve the goals. When we look at the relationship between the basic organization and the project, it is just new forms of governance we want [8].

Foster [9] defines "lean" as "a productive system whose focus is on optimizing processes through the philosophy of continual improvement" [9]. Lean contains a range of methodologies and tools (e.g. A3) to involve people, capture and address issues and improvement areas. One crucial insight is that most costs are assigned when a product is designed. Lean Product Development (LPD) comprises:

- driving waste out of the product development process
- improving the ways projects are executed
- visualizing the product development process

[1] http://www.lincolnproject.eu/ (accessed March 15th, 2017).

As a consequence, product development activities should be carried out concurrently, not sequentially, by cross-functional teams [2]. At the system engineering level, requirements are reviewed with marketing and customer representatives to eliminate costly requirements. *Concurrent engineering* could be a key to collaborate in projects and mobilize knowledge from different parts of the organization [2]. Concurrent engineering is the term that is applied to the engineering design philosophy of cross-functional cooperation in order to create products that are better, cheaper and more quickly brought to market. In this way, the development projects not only get a better strategic foundation, but also input of the more operational effects. In concurrent engineering product design and production processes are developed simultaneously by cross-functional teams. The reason for this is the need to capture and integrate different aspects and the voice of the customer throughout the development process [10]. Concurrent engineering has the following four characteristics [11]:

- increased role of manufacturing process design in product design decisions
- formation of cross-functional teams to accomplish the development process
- focus on the customer during the development process
- use of lead time as a source of competitive advantage

Concurrent engineering significantly modifies the sequential development (waterfall method) process and instead opts to use what has been termed an iterative or integrated development method. A significant part of concurrent engineering is that the individual employee is given much more say in the overall design process due to the collaborative nature of concurrent engineering. Giving the designer ownership plays a large role in the productivity of the employee and quality of the product that is being produced. This stems from the fact that people given a sense of gratification and ownership over their work tend to work harder and design a more robust product, as opposed to an employee that are assigned a task with little say in the general product [10]. There is a motivation for teamwork since the overall success relies on the ability of employees to effectively work together.

One of the ideas in lean product development is the notion of set-based concurrent engineering: considering a solution as the intersection of a number of feasible parts, rather than iterating on a bunch of individual "point-based" solutions. Thus, concurrent engineering is enabled by a modular product design, where resources and knowledge related to the different modules are involved concurrently at different stages of product development. *Modularity* allows part of the product to be made in volume as standard modules while product distinctiveness is achieved through combinations or modifications of modules. Modularization could bridge the advantages of: (1) standardization and rationalization, (2) customization and flexibility, and (3) reducing complexity [10].

To develop a modular product platform is a comprehensive process. It is both time-consuming and costly, and for many businesses it is a completely new way of working. Often you have to plan even further ahead than you otherwise would have done, and are thus vulnerable to radical changes in the market. If the product does not yield expected/projected results, you risk being left with an even greater economic loss than would be experienced by conventional products [12]. Figure 1 gives an overview of the involvement of different stakeholder groups in a set based concurrent engineering approach.

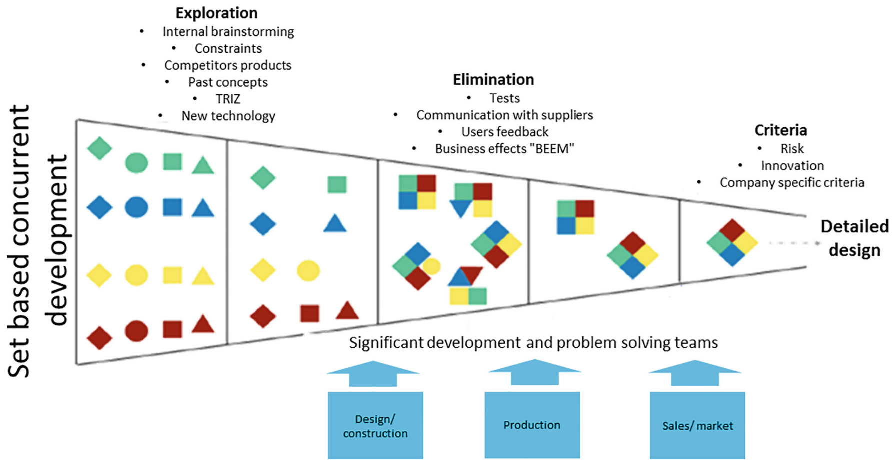

Fig. 1. Involving people from different functions through set based concurrent engineering

Module-based design is when you make a product platform consisting of modules connected together via common interfaces. To take full advantage of modularization all modules should be planned in relation to replacement due to development. A good example of this is Sony's Walkman, where a good product platform with opportunities for replacement of various modules without changing the whole product, was designed. This requires time and resources for initial planning and design, but in the long run this will enable reduced development costs because they do not have to change the entire product [13]. Modularization also impacts the whole lifecycle of products as modularization enables real-life up-, side- and downgrades of products based on their use real-life in the lifecycle itself ensuring the continued use of the products [14, 15]. This is now further enabled by the possibilities of IoT, Industrie 4.0 and the low cost of sensors, computing power and data-handling and transfer. This will impact the logistics and supply-chains as well as the requirements for information systems as these now must handle not only sourcing products and services, but also customized upgrades. Thus, modularization together with the ICT-developments the later years, yields new business-areas and creation of new service-concepts.

Material requirements planning (MRP) is a production planning, scheduling, and inventory control system used to manage manufacturing processes. Most MRP systems are software-based, but it is possible to conduct MRP by hand as well. An MRP system is intended to simultaneously meet three objectives: (1) ensure materials are available for production and products are available for delivery to customers, (2) maintain the lowest possible material and product levels in store, (3) plan manufacturing activities, delivery schedules and purchasing activities. A major drawback of MRP was that it failed to account for capacity in its calculations. This means it will give results that are impossible to implement due to manpower, machine or supplier capacity constraints. However this has largely been dealt with by MRP II. Generally, MRP II refers to a system with integrated financials. An MRP II system can include finite or infinite capacity planning but also include financials. In MRP II fluctuations in forecast data are taken into account by including simulation of the master production schedule, thus creating a long-term control [16]. A further extension to purchasing, to marketing and to finance (integration of all the functions of the company), resulted in what we normally recognizes as ERP. Demand driven MRP (DDMRP) is a multi-echelon formal planning and execution technique [17].

The motivation for *Dynamic Product Development* (DPD) is that concepts must be changed continuously is that projects are not isolated from the world. Things happen all the time and concepts must simply be changed to be kept up to date. DPD has a different mind-set and is the product concept developed as long as a project runs and not just before engineering starts [18]. In this way DPD could be considered as a way to integrate projects to operations. Feedback is in DPD based on management participation for immediate and qualitative information, which facilitates control and guidance in real time, reducing unwanted surprises to low levels. Frequent solution iteration is in DPD important. The focus on qualitative data represent contrast to the recent *Industrie 4.0* paradigm, which is much more focused on quantitative data, and enabling technologies such as IoT and automated (dynamic) processes.

3 The Projects

This paper is based on three projects, I-Kraft (Innovativ Kraft), LIP (Live Innovation Performance) and EU-LINCOLN. The aim for all three projects is to find new resource-efficient and dynamic ways to innovate in especially SMEs. The projects are linked to concrete product development cases in a number of industrial partners. The objects of the I-Kraft project are to create mechanisms for collaboration within a network of industrial companies. SINTEF, BIBA and Inventas are R&D-partners in all three projects.

Where LINCOLN aims to bring “live” data to product development, the objective of the LIP-project is to create the concrete processes and technology enablers for the manufacturing companies to work more dynamically with innovations, improvements and operations. The reference for this paper is the three above projects, but the main focus is on the solutions for integration of innovation, improvement and operations which are explored in the LIP project.

4 Enablers for Integrating Operations and Development

4.1 Resource Planning

Even in the larger industrial companies[2] in our projects we experiences that key resources are bottlenecks in product development. These key resources could be technical experts and foremen from production, but also managers responsible for product development. What we experience is that even if a company has a R&D manager/department) and top management well motivated for innovations and focused

[2] >100 mill. EUR turnover.

product development, their availability become unpredictable. Order processing is the priority and even the managers have to take their turn on the shop floor. As a result, the general picture is that "fine-tuned" project plans have almost no value, and even smaller projects are in general delayed for months.

An initial Value Stream Mapping (Fig. 2) showed a potential for increasing efficiency in production. Even though the VSM seems close to industrial "standards", the value-added time should be increased, and waste reduced. We learned that much could be addressed to the production planning, scheduling and the priority of orders.

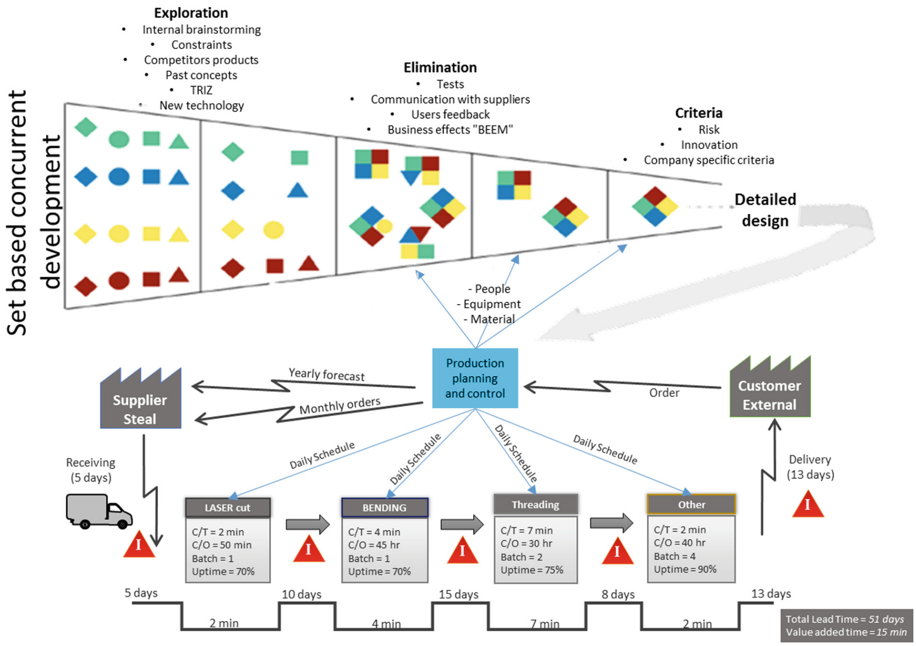

Fig. 2. Integrated resource planning – production and development

The case companies investigated could to some extent be considered doing DPD, as managers and key resources are very flexible. However, this flexibility seems to go only one way as the development projects almost always have to be set aside in favor of day-to-day business. However, as we see from the VSP, there are room for more value added time, time-and resources that could be made available for development projects. Our focus have been how to capture the "waste" and find practical ways to convert it to projects or value creation at a longer horizon through:

- more robust production planning: horizon, capacity etc. in MRP
- performance measurement, related to production planning and projects
- waste reduction, bottleneck planning

More discipline in order processing and prioritizing, e.g. using replanning and use of unnecessary overtime as indicators. The other important element in resource planning is to integrate projects and development in the production planning through capacity adjustments and/or making project deliverables as elements in production planning.

4.2 Enabling ICT

The case company in Fig. 2 has - over a 3-year period - implemented an ERP-system, but met a classical problem of misfit to the real life of the company. Not all modules have been implemented and parts of the organization and processes have been omitted from the ERP-solution. Projects and the project module are such an example. The ICT solution just doesn't fit the processes in the company and therefore has not been implemented. The approach in the I-Kraft project has been to improve the production planning and the data quality in the MRP-system, focusing on bottlenecks and reducing need for rescheduling. The aim is to free resources that could be scheduled for development projects.

The project has tested several tools and solutions and one of them is a very simple app that can be used on all platforms and is sky-based. The rationale for this specific test was to see how easy one can actually track and communicate tasks and activities in internal development projects. Findings and previous experience from such internal development projects in this setting indicates that you can't use larger/complex project management systems as these requires too much management and updating, thus immediately lose their validity as development work starts. The experience so far is very good as this is so easy to use that everyone can join. Both the development teams (including external companies involved) and operators in the production use and apply this simple app on their smartphones. We have also moved some information from mailboxes to the lists that are established and they are therefore accessible to everyone. The lists in the simple app have limited functionality, but this seems to be the big advantage when you have to limit yourself and it does not grow in size so you can not keep it up to date. We think this way of working is especially good for smaller projects with autonomous teams without appointed and dedicated project managers.

IoT also represents a window of opportunities for making both production and projects more dynamic. Smart products and smart processes could process messages and knowledge to operations and development projects, making them both more dynamic and robust. These opportunities and constraints are focus in LIP and LINCOLN, where important issues are related to data quality, filtering and presentation of key data.

5 Conclusion

In modern production customization and flexibility is more and more important as well as continuous improvement and development. In this dynamic context we see that the traditional demarcation between operations and projects are more and more erased. What we need, is to find ways to plan and use common resources and capabilities. In three projects, we have studied challenges in development projects and seen how project plans and milestones have had to be changed as priorities have been on day-to-day business and operations. A more robust and efficient production planning could free resources to development tasks. We also believe that simple ICT tools such as "to do lists" could be more fruitful for creating this dynamics, than big ERP-systems, in particular in SME's. There are still much research to be done in our projects and elsewhere to verify the above, and to give strong recommendations.

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Industrial and Other Services

Resource Planning for the Installation of Industrial Product Service Systems

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Abstract. In product-oriented Industrial Product Service Systems (IPSSs) the customers benefit from the combination of a product which offers some functionalities and a set of services. IPSS supports the provision of services which can be offered by the product manufacturer. The services can offer a wide range of functionalities that can range from ensuring the product's original functionality to augmenting the original functionality of the product. The shifting of a company to IPSS poses many challenges such as the changing of the company's business model. One of the most important challenges for the establishment of IPSS is the appropriate planning of the resources for production, deployment, and installation into the customers' site. However, companies that provide IPSS solutions are lacking the proper tools for resources' planning in a dynamic environment. In this work, a multi-criteria resource planning method and tool for optimizing the production, delivery, and installation of IPSS is presented. The proposed solution generates alternative IPSS's production and installation plans and evaluates them on performance measures for production and installation such as time and cost. Moreover, through the integration of the planning tool with the IPSS design phase, information for generating the Bill of Process and Materials is presented. The planning tool has been designed using the Software-as-a-Service (SaaS) approach and has been applied and validated in a pilot case from the laser cutting industry.

Keywords: Industrial Product Service Systems (IPSS) · Resource planning · Decision making

1 Introduction

In the new manufacturing revolution called Industry 4.0, the digitization of all the systems that comprise a manufacturing system is a key objective. The Industry 4.0 paradigm proposes the expansion of existing products, for example by adding smart sensors or Internet of Things (IoT) devices that can be used in tandem with data analysis tools, and delivers a completely integrated solution to the customers. Also, customer demand and globalization impose constantly new requirements to industries, making the manufacturing environment more complex and dynamic than ever [1]. The Product-Service-Systems (PSS) concept is the solution for providing services together

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or instead of a product's ownership, aiming to increase the adding-value of the products [2]. This solution promises improved competitiveness and sustainability. In the industrial sector, the servitization of manufacturing equipment has shifted the attention to the Industrial Product-Service Systems (IPSS). This strategy is satisfactory adequate considering an industry which requires being agile and getting full advantage of the complex integration process of mechanical parts, sensors and IoT components, which are critical elements for the control and monitor of the production lifecycle [3]. Following Meier's definition [4], an IPSS is the hybrid combination of a product and services e.g. a laser machine together with sensor enabled services that increase the value of the machine. IPSS aims at fulfilling contractually defined customer needs by the provision of product as well as service shares and moreover, the operation of an IPSS includes strategic and operative scheduling of processes and resources [5]. IPSS are characterized by five knowledge dimensions relative to the product, service, infrastructure, network and customer [6].

However, designing and planning the production of an IPSS is a complex task that requires the development of proper engineering, production and installation planning methods. IPSS is not the result of the simple connection of product with services. It is a rather complex integration process of mechanical, sensors and IoT components and software with the involvement of heterogeneous stakeholders along the whole IPSS lifecycle. In IPSS design and implementation, the resources related to the integration and configuration of the services, have an important contribution to the efficient development and use of an IPSS. This work presents a method for planning the production, deployment, and installation of IPSS taking into account various types of aspects such as availability of resources in IPSS provider side and resources on the services and sensors supplier side. The planning of resources should be taken into account both during the phase of IPSS design as well as in the phase of IPSS production and delivery. Planning is evaluated through a set of Key Performance Indicators (KPIs) which quantify the efficiency of alternative planning scenarios. The solution presented in this work can be used by IPSS solution providers to plan the resources of the IPSS ecosystem so as to improve the efficiency of IPSS delivery to the customers.

Regarding the design of PSS, the main focus comes to be the evaluation of the design [7–9]. The last decades, great effort has been devoted to the study of planning and scheduling problems encountered in the production systems [10]. There are several approaches regarding planning and scheduling [11] in the literature. The proposed approach for the IPSS planning is an artificial intelligence method (ISA) [12]. This one compared with other existing approaches outweighs in the direction of computational time and of multiple criteria consideration. Existing planning methods have been developed focusing on capacity planning for the delivery of IPSS, like the work presented in [13]. Additionally, relative research has been focalized on the different ways of resource planning in both centralized and decentralized networks [14]. A hierarchical planning for IPSS is proposed by [15] by focusing both on the strategic and operative planning level after identifying the planning problems concerning IPSS. Along similar lines, the work of [16] presents a heuristic resource planning approach to the resource planning of IPSS.

This work is part of the EU project ICP4Life that aims to develop a collaborative framework for supporting the entire development process of industrial PSS [17, 18]. The proposed approach is focused on the “Planner” software module. Based on the approach presented in [14], this paper aims to tackle the issue of providing a planning methodology for the production and installation of IPSS and also present a related software implementation.

The remaining of the paper is organized as follows: The proposed methodology is discussed in Sect. 2. Section 3 is devoted to the IPSS planning tool software implementation. Section 4 presents a pilot case from a laser cutting machine industry. Finally, the conclusions are reported in Sect. 5.

2 IPSS Production and Installation Planning

In this section, the problem under investigation is defined and the proposed methodology is presented. IPSS planning in real industrial practice is a complex problem that involves several actors and constraints. In this work, the IPSS planning problem considers the following generic scenario. The process starts when an IPSS provider receives an order for an IPSS solution from a customer (Step 1). Then, the IPSS provider starts designing an IPSS solution that meets the requirements. During the design phase, a number of alternative designs are being developed. A design is a solution that integrates a product and a number of services that are implemented through the utilization of hardware (e.g. IoT devices) and software (e.g. data analytics) (Step 2). Every new alternative IPSS design, before it starts being produced, needs to be evaluated with respect to the production feasibility (i.e. there is a feasible process plan that can actually produce the conceived design) and KPIs, such as delivery time and cost (Step 3). A production engineer takes as input the IPSS design and, using some process planning method and tools, develops a feasible process plan (Step 4). The IPSS planning method proposed in this work is used to provide a rough estimate on the time and cost KPIs to implement the process plan. The proposed planning method takes into account the fact that there is a limited number of resources to implement the new IPSS order and that there are already IPSS orders scheduled (Step 5). IPSS designer receives input from the IPSS production engineer and decides if the design solution is acceptable or not. The IPSS designer and production engineer may repeat the whole process several times until a satisfactory result is achieved (Step 6). Those generic steps are depicted in Fig. 1 below. This work focus on proposing a planning method and also its implementation for addressing Step 5 in the workflow presented in Fig. 1.

The planning problem considers the following constraints and assumptions. It is assumed that the IPSS provider is also the supplier of the product part of the IPSS. This makes planning simpler since there is only one supplier option for the product delivery and moreover the transportation of the IPSS solution is only transported from the IPSS provider to the customer. Another constraint is that the IPSS is composed of a product and a number S of services. The planning problem does not include the production of the product which is assumed to be available. In many IPSS cases the product is produced separately, as a first step, and then the tasks that integrate the services to the

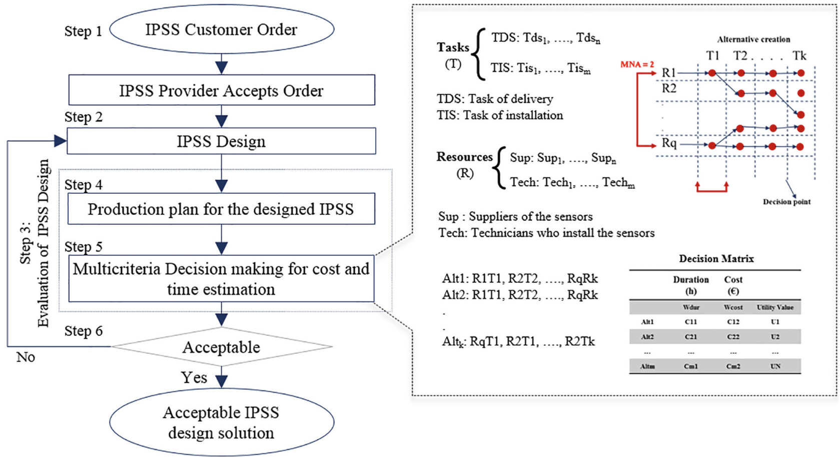

Fig. 1. IPSS production and installation planning flowchart

product take place. The process plan describes a number of ***N*** processes and the order in which they are executed. A process, for example, such as making a drill to mount a sensor or the process of mounting a sensor in a specific location in the product can be performed on the IPSS provider site. There are a number of ***R*** resources that can perform one or more of the ***N*** processes. Resources are possessed by IPSS suppliers, product suppliers and service suppliers on the IPSS manufacturing network. There is a transportation attribute related to a resource since a resource may need to travel to the IPSS provider site or to the customer's site in order to perform a task. Finally, there is a number of ***M*** of IPSS orders already scheduled in the IPSS provider's ecosystem. This practically means that one or more resources within a given time horizon are already scheduled to support the implementation and delivery of other IPSSs.

The objective of the planning method described below is to find an optimal solution that decides what IPPS equipment (e.g. sensors) suppliers to select, which resources (e.g. IPSS service installation technicians) and when they should perform which processes/tasks at IPSS provider or customer site.

The planning method proposed in this work, is based on the approach proposed by Doukas et al. [14] and it defines the approach for assigning a set of resources to a set of tasks under multiple and often conflicting optimization criteria. The planning method is composed of the following steps. The first step is the generation of a maximum number of alternatives (MNA). The second step is the calculation of decision-making criteria in order to satisfy a set of manufacturing objectives ($CR_1 \ldots CR_n$). Step 3 is the weight definition of those criteria. Subsequently, the calculation of the utility value of each one of the alternatives with respect to the selected criteria takes place. It is important to mention here that the utility value ($U_1 \ldots U_m$) where $m \in [1, MNA]$ is the weighted sum of the normalized values of the criteria and takes its values in the range 0 to 1. The final step is the ranking of the alternatives ($ALT_1 \ldots ALT_m$) and selection of the best alternative with the highest utility value [14], aka the best resource plan. In order to obtain a high-quality solution (high utility value) to the resource planning problem in a timely manner, the intelligent search algorithm (ISA) has been developed. ISA uses three adjustable control parameters, namely the maximum number of alternatives (MNA), the decision horizon (DH) and the sampling rate (SR). MNA controls the breadth of the search (i.e. the number of alternative trees to be created), DH controls the depth of the search (i.e. the layers searched forward) and SR guides the search through the solution space for the identification of high-quality paths (i.e. number of branches created for each alternative defined by the MNA). It should be noted that all assignments made by the ISA are random. The decision-making process can be formalized as a decision matrix (Fig. 1).

3 IPSS Planning Tool Implementation

The IPSS planning method has been developed as a Software-as-a-Service (SaaS) oriented web application. The IPSS tool consists of a user interface and the REST service oriented module. The user interface is developed as a Java portlet, following the JSR 168 specification that allows the user interface to be deployed in compatible Java portals, such as Liferay. The portlet has been developed using the Vaadin Java framework and exposes the functionality of the IPSS planning tool to the users. The IPSS Planning Tool Portlet can access a knowledge repository where all required information is stored in an Apache Jena semantic repository. In particular, the repository contains information such as manufacturing resources, existing manufacturing schedules, designed PSS systems, sensors and product descriptions. The module receives as input all the information needed by the IPSS Planning algorithm and produces as an output the result of the planning which includes calculations on the requested KPIs (such as cost and time) and a plan for the production of the IPSS. The input of the service is provided in a specific XML format, and in a similar fashion, the output is provided in an XML format. IPSS Planning Tool Architecture is presented in Fig. 2.

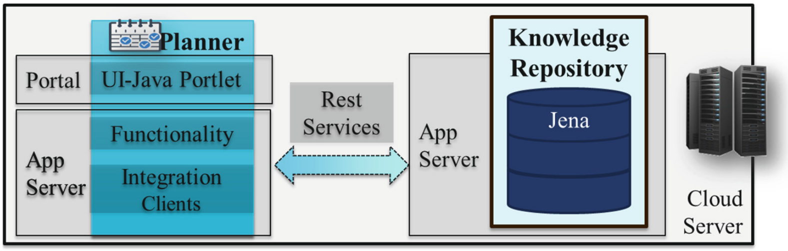

Fig. 2. IPSS planning tool architecture

4 Pilot Case: Laser Cutting Industry

The proposed method has been applied and evaluated in the case of a laser cutting machines provider. The IPSS under investigation is a Laser Cutting machine (product) together with a set of services which are implemented through the integration of sensors and software. An evaluation scenario has been setup with the following aspects:

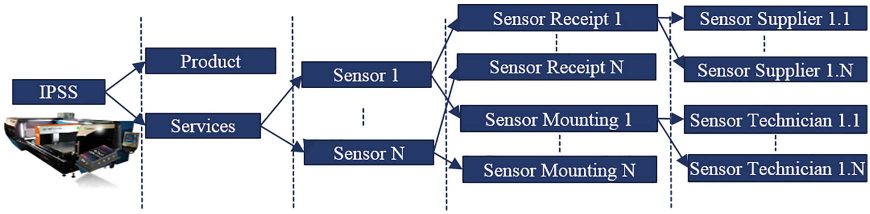

Fig. 3. Pilot case modelling

- An IPSS provider receives a new customer request for a Laser Cutting machine with three different services namely (a) machine performance monitoring using vibration sensors, (b) process quality monitoring using vision sensors and (c) machine health monitoring using temperature sensors.
- The integration tasks of a service are executed in two steps: (a) sensor delivery and (b) sensor mounting and service configuration. The modelling of the pilot is depicted in Fig. 3.
- Each task can be performed by a number of alternative resources (i.e. sensor supplier and service technicians). Each one of the resources is characterized by their cost C (€), operation time OT (h) and also transportation TT (h). The aforementioned resources, as well as their attributes, are given in Table 1. Also downtimes are considered (e.g. non availability during weekends).
- When the new customer request is received a number of 10 IPSS orders are being produced. Thus not all resources are available to produce the new IPSS.

First step is to add the new IPSS order in the workload and define its arrival and due date. The user may "lock" the tasks (see Fig. 4) of the ten PSS orders so they are not rescheduled for new resources and time frames. Then a new schedule is being

Table 1. Used resources and their attributes

Resources per sensor type	Attributes (C, TT)	Resources	Attributes (C, OT, TT)
Supplier 1 (Vibration S.)	94.55 €, 36 h	Technician 1 (Vibration S.)	320 €, 5 h, 2 h
Supplier 2 (Vibration S.)	89.49 €, 48 h	Technician 2 (Vibration S.)	335 €, 6 h, 1 h
Supplier 3 (Vibration S.)	96.15 €, 24 h	Technician 3 (Vision S.)	450 €, 3.25 h, 1 h
Supplier 4 (Vision S.)	560 €, 12 h	Technician 4 (Vision S.)	460 €, 3.5 h, 2 h
Supplier 5 (Vision S.)	610 €, 18 h	Technician 5 (Temperature S)	350 €, 3 h, 1 h
Supplier 6 (Temperature S)	647.28 €, 24 h	Technician 6 (Temperature S)	370 €, 3 h, 2 h
Supplier 7 (Temperature S)	660 €, 24 h		

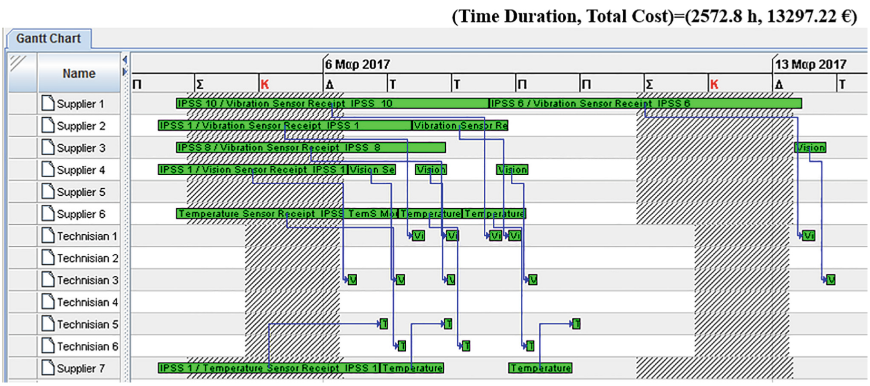

Fig. 4. Pilot case resource planning: 10 IPSS scheduled

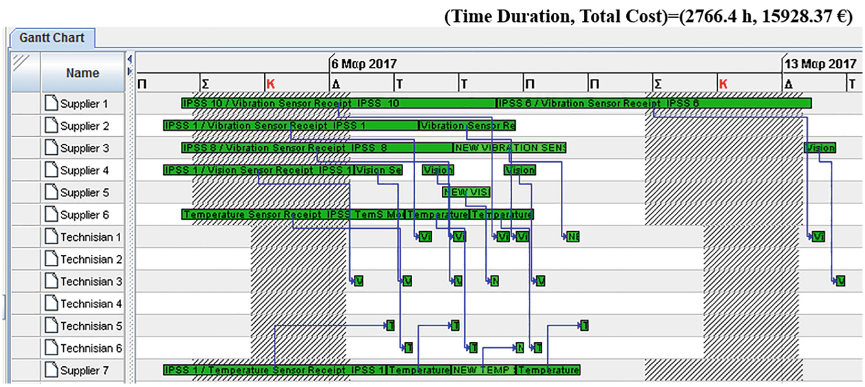

Fig. 5. Pilot case resource planning: 10 IPSS scheduled and 1 new IPSS order (Color figure online)

generated including the tasks for the new PSS order. The results of the resource planning for the ten locked IPSS orders and the new one IPSS order, depicted with red borders, are presented in the following Gantt chart (Fig. 5) including the best alternative combination of resource planning for the scheduled IPSS accompanied with the estimation of time and the cost of the generated resource planning.

In terms of competence, it is necessary to note that the industrial case modeling initially had been constructed taking into account more IPSS and more variations of resources and tasks in terms of validity of the results. A small scale industrial case was selected in order to give a comprehensive example of the implementation of the proposed tool. The proposed approach could be applied in several industries regardless their scale, considering the could-technology provided opportunities.

5 Conclusions

In this work, a multi-criteria resource planning method and a tool for optimizing the production, delivery and installation of IPSS is presented, with a demonstration case from laser cutting industry. The purpose of the planning tool is to provide decision support in the design and production of an IPSS order. The resource planning method generates a good plan by considering multiple and contradicting criteria such time and cost. Preliminary results gave a reduction of lead time and respectively cost per IPSS planning since all the available resources are occupied in the most convenient way based on the defined criteria. Future work will consider customer's time availability that adds a new constraint to the problem since the IPSS could only be delivered within the time window provided by the customer. Moreover, in the current study it is assumed that the product provider is the same as the IPSS provider. In future work, there will be alternative product suppliers from whom to optimally select the product.

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Morphology of Strategic Components for Data-Driven Industrial Services

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Abstract. The design of data-driven industrial services in the context of industry 4.0 represents a major challenge for industrial service providers and manufacturing companies for investment goods. Data-driven services require technological and strategic components that most companies have not build up yet and that differ from current configurations. That is why many companies lack a systematic approach and implementation competence for the use of data in the context of industrial services and therefore face the challenge of not being able to expand their market position in an ever-growing competition for data. The present paper addresses this research deficit with the aim of describing strategic features and characteristics of data-driven industrial services by identifying the related crucial features and characteristics through a morphological approach. This will enable industrial service providers to improve strategic and operative management decisions in order to define a specific strategy and to configure data-driven services.

Keywords: Industrial services · Data-driven services · Morphology

1 Introduction

Within the last 50 years, information technologies have changed the way companies conduct their business more than once: The rise of the computer in the '60s led to automation within value chains and raised awareness on the use of data. Afterwards in the '80s, the internet allowed real-time collaboration, facilitated global supply chains and boosted the generation and usage of data. The next transformation, the internet of things, has already started and impacts competition and strategy like none before [1, 2].

Parallel to that development, companies underwent a transformation process, developed from product manufactures to solution providers, and thus generate additional value for their customers. In practice, it can be observed that companies follow this transformation process, but the offering of operating models and output-based solutions is not established extensively: Service level agreements and output-oriented business models are offered by only 18%, respectively 13%, of global industrial companies [3].

This can be attributed to the relatively low usage of data that enables companies to learn from their products, learn from their customers and adapt their products and services to the needs of their customers [4, 5].

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2 Objective of Developing a Morphology

The use of data and big data in an industrial context is mainly driven by quality improvements and the resulting reduction in the frequency of errors and process efficiency improvements. Process engineers use enormous amounts of data to control, monitor, and optimize the performance of processes [6].

Although premium manufacturers have a high digital competitiveness and therefore the best conditions to compete in a data-driven world, they often fail to develop data-based value-added services [7, 8]. This can be attributed to the following practical problems: Most industries are lagging behind the chances and potentials of digital transformation. Decision-makers focus on the realization of internal potentials first, such as cost savings through technology use or cost reduction through more standardized service processes. However, the realization of potentials driven by innovations is largely neglected. This includes the use of data-based services to increase revenues [4, 9]. The same applies for the scientific research gap: Previous approaches dealing with digitalization, data-based business models, and digital driven services mostly describe case studies or individual characteristics of data-based services, but lack the provision of a detailed description, based on detailed features and characteristics (Table 1). In summary, there is a lack of a scientifically based, illustrative and practical systematization of industrial, data-based services.

Table 1. Literature review (Harvey Balls: meets the criterion/partially meets the criterion)

	Research area	data-base-services	Internet of things	Big data and analytics	Business intelligence	Business models	**Type of component**	technical	strategic	**Research method**	Listing of features	Classification	Morphology	Typing
Fleisch et al. 2014		◑	●		◑			●			●			
Saniat er al. 2015			●					●			●			
Stocker et al. 2010		◑		◑		●		◑	◑		●			
Porter u. Heppelmann 2014		●	●		◑			●	◑			◑		
Douglas 2014				●	◑			●			●			
Kemper et al. 2010			◑		●			●				◑		
Dijkman et al. 2015		◑	●			●			●				◑	
Wellsandt et al. 2017		●	●					●			◑			
Chen et al. 2015		◑	●	●	◑			●					●	
BITKOM 2015				●		●		◑	●				●	
Eckerson 2007; Fels et al. 2015					●			●				●		
BITKOM 2014				●				●					●	
Hagen er al. 2013				●				●						◑
Allmendinger u. Lombreglia 2005		●				●			●					◑
Keskin u. Kennedy 2015		◑				◑			◑		◑			
Hartman et al. 2016		●				●			●					●
Schuritz u. Satzger 2016		●				●			◑					◑
Dittmar 2016		●		●		◑			◑					◑

In order to describe data-driven services, the following definition is used in this paper: Data-based services are intelligent, internet-based services. They are either linked to physical products as data providers and in doing so complement the products, or are based on data-driven services that are detached from products. Smart services are data-driven services based on digital platforms that enable the formation of service ecosystems in which different actors are organized [7, 10–12].

3 Theoretical Foundation

The report of the working group "**Smart Service Welt - Internet-based Services for the Economy**" by Acatech represents a fundamental conceptual basis for the present paper. The scope of the report lies within the linking of processes, products and services with data. This connection is seen as the most important basis for the development of new services and business models. The developed layer model schematically describes the composition of digital infrastructures for smart service delivery in four levels: smart spaces, smart products, smart data and smart services. In accordance to the layer model of digital infrastructures, the following components are utilized in order to develop a morphology for strategic components of data-driven, industrial services: collect data, data transfer and backup, analyze data and service delivery [13].

Besides this fundamental work by Acatech, a literature review has been conducted. In Table 1, an extract of the central scientific approaches for the elaboration of this paper is listed. Previous research deals with technical or strategic components in the field of data-based-services, the internet of things, big data and analytics, business intelligence and business models. Regarding this research, features, classifications, morphologies and typings are developed. However, none of the previously conducted research delivers a consolidated morphology of strategic and technical features for data-based-services.

4 Methodology

Analytical research methods, such as classification, morphological methods or typing, are used to gain insights into research objects. They contribute decisively to generating new knowledge on investigation objects. According to the aim of the paper of describing the main strategic components of data-driven industrial services, the morphological method is particularly suitable, since the construction of a morphological box allows the derivation of multi-dimensional solutions to describe real situations with features and characteristics. The following procedure, consisting of three consecutive steps was conducted in alignment with a research approach following Zwicky [14] and Welter [15]:

(1) **Definition of the test area:** The formation of types starts with the analysis of the test area and the identification of the objects to be examined.
(2) **Selection of suitable features:** After the definition of the test area, the features are identified, with regard to the research objective. These features can be descriptive

or type-forming. Type-forming features are constitutive and define a type, while descriptive features build up a type. Characteristics of features can be distinguished in polar or scalable. If characteristics are discrete, assuming real values (e.g. company size); they are called polar features, while gradual characteristics (e.g. temperature) that can be described by an infinite number of characteristics are named scalable characteristics.

(3) **Determination of meaningful characteristics:** After the selection of appropriate features, the design of the corresponding characteristics is carried out. This is done by means of qualitative and quantitative descriptions of the subject of the investigation.

5 Morphology of Strategic Features and Characteristics of Data-Driven Industrial Services

Below, the features of the morphology are briefly described. In order to develop and offer data-driven services, companies need to consider the following components, derived from the layer model of digital infrastructures [13]: Collect data, data transfer and backup, analyze data and service delivery. Following the morphological approach, the strategic features and characteristics depicted in Fig. 1 have been identified.

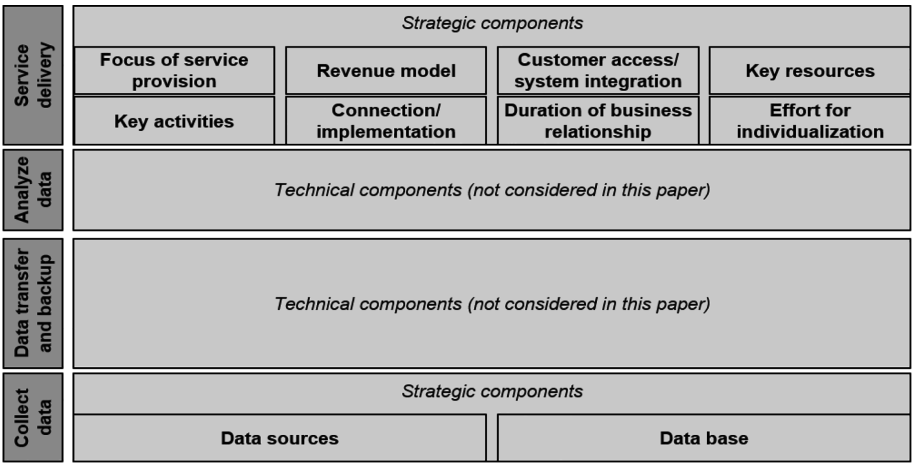

Fig. 1. Overview of strategic components of data-driven industrial services

Service Delivery

The **Focus of service provision** describes an object-oriented, value-chain-oriented or ecosystem oriented approach. In case of the object-oriented focus, own objects, foreign objects or both, own and foreign objects can be distinguished [6].

The feature **Key activities** consist of the virtual and physical provision of services. The virtual provision consists of the characteristics of the provision of raw data and the provision of knowledge [16]. An additional step lies within the virtual provision of services as the orchestration within a supply chain or ecosystem. The physical provision of services is based on the characteristics of the provision of services by the provider itself, or the provision by a third party.

The **Revenue model** for data-driven industrial services can be divided into three characteristics: Free add-on to an object, individual billing and performance related billing. The last characteristic can be divided into pay-per use, pay on availability and pay on production [17, 18].

The feature **Connection and implementation** is depicted through two main characteristics and describes the effort for implementation as purely administrative or physical. A purely administrative implementation occurs, when the object is already connected to the internet and a connection to the provider is established similar to plug and play. In case of a physical connection, objects and systems have to be connected to each other. This physical connection can be established by the customer itself, by the provider or by a third party.

The feature **Key resources** consists of physical resources such as plants and equipment, properties, machines, systems and spare parts. Intellectual resources are brands, knowledge, copyrights and the partner network [8, 16, 19]. In this case, the partner network is viewed as a separate characteristic.

The **Effort for individualization** describes the companies' effort, in order to provide standardized or customer-specific services. For this reason, the following characteristics are used: combination of standardized services, individually adapted services by occasion and customer-specific generation of overall services [17].

The **Customer access and system integration** is described by four main characteristics. The first characteristic describes the access to a service through manual channels (e-mail, USB-sticks, etc.), followed by the provision of services through the system of the provider. This could be a web-portal or a software that is distributed to the customer in order to deliver dashboards and visualizations. A deeper integration is achieved through the link into the customers' existing ERP or PLM system. The fourth characteristic describes platforms that can be closed (operated and organized by a single company) or open (provision of a technological basis that enables collaboration between different players) [13].

The **Duration of business relationship** can be divided into three characteristics. Short-term (single transaction), medium-term (<2 yrs.) and long-term (>2 yrs.) [20].

Data Transfer and Backup and Analyze Data

The components Data transfer and backup and Analyze data have no overall strategic importance. Following this paper, further research will be conducted for these technical components, including for example the **capability for data exploitation**, **data query**, **data quality management** or **method of data analysis**.

Collect Data

Data sources can be divided into internal and external data. Internal data itself can be divided into several data sources: data that exists or is created in IT-systems, but that is not used and data that is, among others, generated for a certain purpose through web tracking, physical devices, crowdsourcing and social collaboration methods. External data uses acquired data that is purchased, or provided by customers [16].

The **Data base** consists of multiple steps. At first, data of a single object is considered. This is expanded by the view of aggregated object data of a single customer. The next steps focus on aggregated object data of several customers or aggregated data of a value chain. The last characteristic is aggregated data of an ecosystem. The developed morphology helps service providers and manufactures to position themselves strategically by combining different characteristics. The validity of the developed morphology, consisting of strategic components of data-driven industrial services has been confirmed in several company workshops and expert discussions.

Morphology of Strategic Features and Characteristics of Data-Driven Industrial Services

Figure 2 shows the developed features and characteristics in accordance to the morphological approach.

<table>
<tr><th rowspan="2">Focus of service provision</th><td colspan="3">Object-oriented</td><td rowspan="2">Value-chain-oriented</td><td rowspan="2">Ecosystem-oriented</td></tr>
<tr><td>Own objects</td><td>Foreign objects</td><td>Own and foreign objects</td></tr>
<tr><th rowspan="2">Key activities</th><td colspan="3">virtual</td><td colspan="2">physical</td></tr>
<tr><td>Provision of raw data</td><td>Provision of knowledge</td><td>Orchestration</td><td>Service provided by provider itself</td><td>Service provided by a third party</td></tr>
<tr><th rowspan="2">Revenue model</th><td rowspan="2">Free add-on to object</td><td rowspan="2">Single billing</td><td colspan="3">Performance-related</td></tr>
<tr><td>Usage behavior</td><td>Performance level</td><td>Performance result/ output</td></tr>
<tr><th rowspan="2">Connection/ implementation</th><td rowspan="2">Purely administrative</td><td colspan="3">physical</td></tr>
<tr><td>By customer</td><td>By provider</td><td>By a third party</td></tr>
<tr><th>Key resources</th><td>Physical resource</td><td>Intellectual resource</td><td>Partner network</td></tr>
<tr><th>Effort for individualization</th><td>Combination of standardized services</td><td>Individually adapted services by occasion</td><td>Customer-specific generation of overall services</td></tr>
<tr><th rowspan="2">Customer access/ system integration</th><td rowspan="2">Manual</td><td rowspan="2">Own system</td><td rowspan="2">System of the customer</td><td colspan="2">Platform-based</td></tr>
<tr><td>Closed service platform</td><td>Open service platform</td></tr>
<tr><th>Duration of business relationship</th><td>Short (single transaction)</td><td>Medium term <2 years</td><td>Long term >2 years</td></tr>
<tr><th>Data sources</th><td>Internal data</td><td>External data</td><td>Internal and external data</td></tr>
<tr><th>Data base</th><td>Data of a single object</td><td>Aggregated object data of a single customer</td><td>Aggregated object data of several customers</td><td>Aggregated data of the value chain</td><td>Aggregated data of the ecosystem</td></tr>
</table>

Fig. 2. Strategic components of data-driven industrial services

The development of different types of data-driven industrial services represents a downstream research work and a logical next step. A possible type formation is briefly explained below.

Knowledge as Add-on to Own Objects: This type focuses on own objects. However, the raw data obtained through the object is transformed to information and knowledge through data analysis methods. In this case, it is no longer merely a matter of a dashboard for visualizing raw data, but rather the individual provision of customer-specific recommendations for machine optimization or use, comparable to a remote consulting service. The vendor is able to provide this knowledge since he can access aggregated object data of many customers through the installed base, create comparability and generate specific knowledge about the use and improvement of the object. Access to the data is important; however the intellectual ability to draw conclusions from data is a key resource. The billing of the virtual service is performed individually and the service is delivered virtually. Since the vendor only supports the customer with specific services on a selective basis, the service is based on one or more individual transactions.

6 Conclusion and Outlook

The scientific result of this paper is a morphology for strategic components of data-driven industrial services. The morphology depicts a detailed summary of strategic components for data-driven industrial services based on data collection and service delivery. The results enable strategic and operative decision makers to align the future service portfolio and configure data-driven services for individual domains. Therefore, the scientific result of this paper closes the previously stated research gap. Further research may be conducted in order to develop technical components of data-driven industrial services. These results will be developed in the follow-up to this paper and in accordance with the developed regulatory framework, especially with regard to data transfer and backup and data analysis. In addition, the model will have to be validated by industrial users.

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Support to the Public Services Mutation Through Continuous Improvement in a French Metropolis

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Abstract. Public services have their own principles and codes in order to address needs of general interest through the procurement of physical objects, information or services to various kinds of users. Characterized by a political context and a dedicated legal framework, public services have also specific constraints and objectives. This communication shows how continuous improvement methods born in an industrial context could be adapted for addressing the specificity of public service, especially in the new context of "Smart Cities".

Keywords: Public service · Service science · Smart City

1 Introduction

A Public Service can be defined as an action performed by a public authority in order to address needs of general interest. This communication aims at showing how various methods linked to continuous improvement, born in an industrial context, could be adapted to Public Services. This topic is here addressed in the context of a large French metropolis: Toulouse, which has the will to improve its processes using information technologies. The domain of activity of this metropolis includes various types of production of goods (e.g. meals for scholars) or services (e.g. transportation, cultural services like museums…), addresses thirteen "competences" (culture, transportation, public safety…) and employs persons representing nearly 200 professions.

Improving the performance of public services is not a new topic: in France, various reforms have occurred through time, e.g. the New Public Management (NPM) [1] or later, the so-called "Loi Organique relative aux Lois de Finances" (LOLF) [2]. These projects stressed the importance of efficiency within the organization of public services but suffered from difficulties for being integrated in the operational processes.

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Similarly, the use of improvement methods coming from the industrial sector, like Lean, also often resulted in failures [3, 4].

The new context of "Smart City" [5], based on an increased involvement of users in services through ICT (Information and Communication Technologies), may allow to redefine the performance of public services inside a metropolis. A project was so launched in Toulouse Metropole in order to investigate the possibility of embedding "Smart City" technologies and industrial improvement methods (like Supply Chain Management or Lean) in order to improve the performance of Public Services.

In Sects. 2 and 3 is provided a short state-of-the-art on methods for assessing or improving the performance of an organization. In Sect. 4, the guidelines of a method for improving the performance of Public Services are suggested. The method is illustrated on a project conducted in Toulouse Metropolis that showed encouraging results (Sect. 5).

2 SCM and Continuous Improvement for Public Services

Most Public Services are now produced by multiple partners, either public or private, grouped in real "Supply Chains". It is therefore tempting to try to apply the principles of Supply Chain Management (SCM) to Public Services. Based on this idea, this study began by three audits performed in the waste recovery and sorting center, in the central kitchen providing the meals for kindergarten and elementary schools, and in the mechanical workshop having in charge the maintenance of all the vehicles of the City. The "Supply Chain Master" reference framework was used [6] and showed a low penetration of the Supply Chain Management (SCM) principles within the metropolis (average score 1,4/4) [7]. These audits showed nevertheless a great potential of improvement through the two main pillars of SCM: integration and coordination.

A basis of SCM is to increase the interoperability of the partners through the standardization of the business processes (see the SCOR model [8]). Unfortunately, the broad spectrum of activities that defines the public services makes the standardization of the management processes difficult: each mode of management must be put in adequacy with a specific type of production, in a context of collaborative processes [3]. Furthermore, the integration of political aspects requires a complex management for addressing the issue of justice [9].

Some attempts for using industrial improvement methods in public services have nevertheless been made, e.g. Lean in Human Resources [9] or SCM in the hospital sector [10], sometimes with important benefits [11]. In 2015, South Africa published a report on the integration of SCM in its public processes, supposed to provide better planning, transparency, decreased costs and wastes, and decrease of corruption [12]. Continuous improvement may also help an organization to improve its performance level, for instance through the use of tools such as the Plan-Do-Check-Act wheel [13]. In the Public sector, tools like Jidoka and Poka Yoke were tested in prefectures, Value Stream Mapping in courts, and 5S in operating rooms of hospitals [14]. Lean and SCM may indeed be complementary for increasing benefits, as shown in the "SUCCESS" model of government management combining four methods: ABC, BSC, TQM et PPBS [15].

In all these cases, the principle of a participative system attracted the state agencies involved in these projects, but the integration of continuous improvement has often not survived the test phase, the performance assessment principles associated with these methods being badly perceived by the employees [16].

The adaptation of industrial methods to the specificity of Public Services is in our opinion a condition for their adoption. For instance, while the industrial sector is motivated by benefits and profitability supporting business sustainability [17], Public Service has to balance productivity and efficiency concerns with shared values like quality of result and equity for the users [18].

This short state-of-the-art shows the interest of public bodies for industrial principles, applicable in many services. It also shows the difficulty to adapt industrial methods to the specificities of Public Services.

3 The New Paradigm of the "Smart City"

As shown in [19], the "Smart City" concept develops a participative model for better involving the users (citizens) in their environment (urban life), which is also the case for the continuous improvement model. The concept of "Smart City" can make the city more attentive and attractive to individual (and sometimes versatile) needs [20, 21].

In order to measure improvements, smart indicators are defined and are usually grouped in six categories: (1) smart economy (e.g. Public expenditure on R&D), (2) smart people (e.g. Foreign languages or computers skills), (3) smart governance (e.g. e-Government use by individuals), (4) smart mobility (e.g. sustainable public transportation), (5) smart environment (e.g. efficient use of water) and (6) smart living (e.g. number of public libraries) [22]. However, these "smart standards" do not cover all the needs of nowadays metropolises and a brand new set of indicators (not listed here) has been published in the ISO 37120 standard dealing with sustainable development of public communities [23]. Both smart and sustainable indicators provide a performance level but are not sufficient to define and position improvement actions within a metropolis organization and regarding its stakeholders.

Like SCM, the "Smart City" principles promote collaboration between actors and could play a role in the supply chains in which the metropolis is involved through the implementation of new collaborative technologies [24]. In that purpose, there is a need for a performance measurement system enabling a link between smart initiatives and SCM indicators in order to assess the global performance of Public Services.

According to this short state-of-the-art, the authors consider that there is a clear opportunity in the integration of industrial improvement methods and "smart city" technologies in order to improve the performance of public services.

4 An Integrated Approach in Toulouse Metropolis

A new monitoring method, summarized in Fig. 1, has been instantiated on the case of the "central kitchen" of Toulouse Metropolis. This industrial kitchen has initially been designed for providing 12 000 meals/day and has to insure now 33 000 meals/day with an almost equal production system.

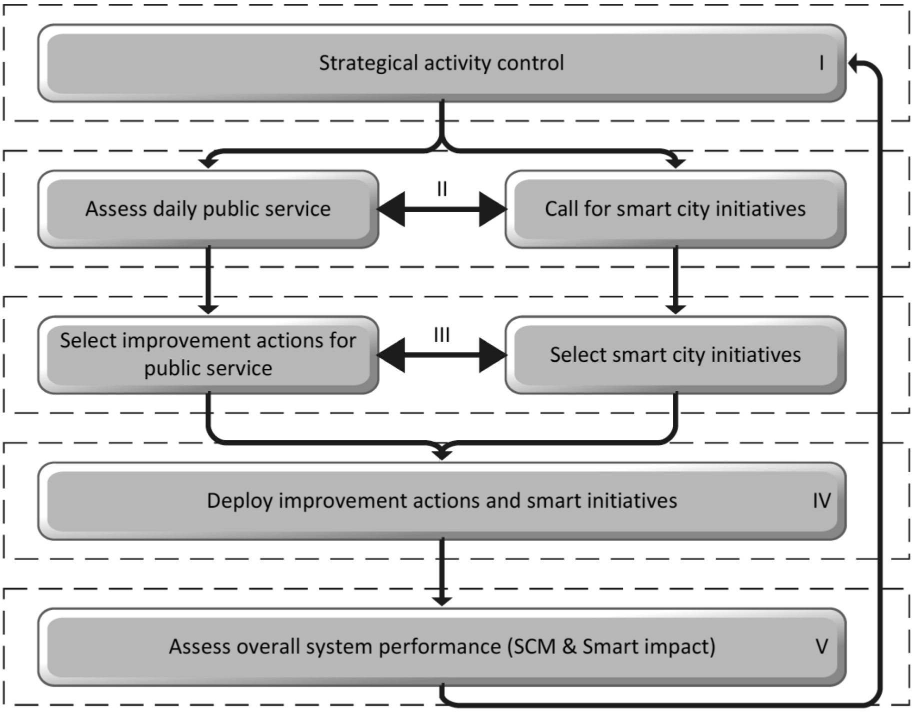

Fig. 1. Method of implementing SCM actions and Smart City initiatives in public functions

Step I considers the definition of a strategic control. In this case, the main problem of the central kitchen is to respond to a strategic plan created by the politicians for one to five years linked to the "Smart City" principles through a global roadmap involving the Toulouse metropolis in a global development of smart initiatives through an open call for projects and experimentations [25]. Moreover, the central kitchen has to be able to improve its shop-floor flow control and to decrease the wastes.

Step I leads to several SCM problems assessed within a comprehensive study encompassing a consulting work based on the audits introduced in Sect. 1:

- Improve the global SC performance,
- Gain agility for the incorporation of customized meals, local procurement and organic food,
- Improve the relationships with users and/or citizens through ICT,
- Find out any applicable proposals from calls for Smart City projects.

Process reengineering (step II of the method in Fig. 1) should allow to find out which processes may be embedded in these political and strategical objectives. A VSM (Value Stream Mapping) approach enabled the identification of the involved stakeholders, in addition to the usual customer-supplier relationship:

- the user: for whom the service is designed and who can say if it is satisfactory or not.
- the citizens: who provide a financial participation in the change of the deployed services through taxes and may discuss about its integration regarding other services or include some participation regarding distribution on finances in the municipal territory. Moreover, the citizen has the possibility to express an opinion about the services provided by a metropolis through the election process.
- the employees, at different hierarchical levels.

Indeed, the process assessment highlights difficulties in the demand management with a lack of global collaboration between stakeholders and an important lack of a performance measurement system. Thus, the metropolis has created a service dedicated to the assessment of the public policy with the objective to develop methods and tools assessing the performance service through the opinion of the final users, with the following objectives:

- Being reactive in order to have the changes applied for the next start of the new school year.
- Improve demand management for a better link between customers and suppliers,
- Promote Continuous improvement through better employee implication.

Two axes of performance improvement were defined: the User Relationship Management (URM) and the Citizen Relationship Management (CiRM). Both have to be considered in comparison with the classical CRM in an industrial context. The development of tools for the CiRM or for the URM is in progress in that purpose: studies and projects have been launched in the metropolis in order to standardize the data and increase their quality in order to establish a dashboard. This assessment has been positioned according to the smart performance axis (see Sect. 2): smart economy, governance, people and living while the others are not impacted in this case study. The application of the suggested method leads to the Key Performance Indicators listed in Table 1.

Step III and IV of the method (Fig. 1) led to the choice of an Internet application (accessible through a mobile app) that creates a direct link with the final users of the central kitchen: the pupils' parents. Through this application, the parents may have a direct access to the menus, give their opinion on the quality of the meals and can also look for allergens. A side effect is that they can adapt the meals prepared at home in the evening to what their children have eaten in school. Service disruptions are also directly notified. This application has demonstrated the lever of improvement that brings the Smart City approach within the processes of the public service. Moreover, this new technology facilitates the respect of legal responsibilities about the information about allergens to the users. In this application, parents can inform when pupils will miss the school, alert on allergen issues, asks for special meals, etc. By the end, it is also expected to decrease wastes using these information. It also increases the transparency in the public service and the direct involvement of the final users, which have a direct impact on the URM and CiRM. Based on the implementation of this experiment, we noted its contribution to the improvement of the interactions with

Table 1. KPI selection to improve both smart and SCM performance

Fields	Improvement actions	KPI	Smart dimensions
Human resources production and services management	Maintain a constant level of employee	# of employees	Smart economy
	Promote local economy/production	% food locally produced	
	Improve supply chain performance	Average of wasted meals a day	
		Follow-up rate of the daily production	
		Delivery fullfilment rate	
		Order Fulfilment rate	
URM	Measure users involvement	# of application users/# of service users	Smart people
	Measure user's global satisfaction	Average of the evaluation (# of complains)	
CiRM	Measure citizen involvement	# of evaluation received by the application	
Develop customized meals	Increase the share of organic meals	% of organic food	Smart governance
	Integrate new requirements: vegan food	% of meals with vegan food	
Health conditions	Provide information about menus	# of users adapting their menus/# of services users	Smart living

citizens and the qualitative evaluation of the service. The usual continuous improvement "industrial" methods did not have such effect on these problems in the past.

At step V, the joint use of SCM, continuous improvement and Smart City technologies has filled a gap in the supply chain process, especially by allowing users to assess the received service. They can express a subjective opinion (on the quality of the meals for instance) through quantitative appreciations (1, 2, …, 5). The first tests showed for instance a global dissatisfaction on the quality of the organic bread.

Finally, in order to close the loop and have a primary evaluation of the strategical objectives at step I, the required modification in terms of introduction of organic food have been made in the allocated time, showing the responsiveness of the supply chain. However, the policy is not yet fully effective as the users were not fully satisfied by the meals, while they appreciate the use of a new smart application. Nevertheless, the introduction of smart technologies had multiple effects. Firstly, it improved the URM and CiRM and the associated Smart People axis. Secondly, it supported the introduction of the continuous improvement and SCM principles among the stakeholders resulting in better smart governance. The economy became smarter as the local promotion of products increased.

Now, the direct feedback from users (parents and school restaurants) enabled a transparent assessment of the service. That transparent feedback is presently being used to improve internally the flows from the kitchen to the schools. But, this is a next story.

5 Conclusion

This communication addresses the problem of continuous improvement, supply chain management and performance assessment applied to public services. It emphasizes that more than a cosmetic adaptation, it is necessary to come back to their inner philosophy for taking into account the specificities of the context of public service.

After a long period of observation of the environment of public services, the method as described here is in test by the service in charge of modernising the metropolis. Several positive effects have already been noticed, like the improvement of the information chain by the introduction of ICTs (mobile app for instance); the integration of collaborative methods, both internal and for involving the citizen; a simplification of the public-private partnership, and an indicator-based control on external or internal actions. Nevertheless, the adoption of such ambitious method requires a long-term support and a Smart City approach gives a framework for this [26].

The perspectives of this study mainly concern a more precise formalization of the steps of the methodology allowing to transfer improvement methods from the private to the public sector, and on more exhaustive tests allowing to investigate the crucial problem of the adoption of the methods, supposed to create a real cultural change.

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Service Innovation and Performance in Mexican Service SMEs

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Abstract. This empirical research investigates the influence of service innovation on the performance of service SMEs, especially within the context of a country with an emerging economy as it is the case of Mexico. Data were collected through a survey instrument designed and distributed among service SMEs in the Aguascalientes state of Mexico to test a hypothesis formulated from the literature review conducted. The instrument was validated using Confirmatory Factor Analysis, Cronbach's alpha test and the Composite Reliability Index to ensure its reliability. The hypothesis was tested using structural equation modelling (SEM) using an as input 308 valid responses obtained from the survey. In general, the results obtained show that service innovation has a positive and significant effect on the performance of service SMEs. Specific research related to service innovation in service SMEs is limited. This paper therefore fills this research gap by expanding the limited body of knowledge in this field.

Keywords: Innovation · Mexico · Service industries · Service innovation · SMEs

1 Introduction

The concept of innovation has been recognized for decades in the literature of business and management sciences as one of the essential resources to achieve higher competitive advantages, not only in manufacturing enterprises but also in service companies [1]. Therefore, innovation in service enterprises has had an important growth and dynamism in the scholarly literature since the end of the previous and the beginning of this century. However, it is important to highlight that a high percentage of the empirical and theoretical research which has been published in the scholarly literature has been mostly focused on transnational and large enterprises; with only a limited

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number of investigations focusing on small and medium-sized service enterprises (SMSEs) [2].

Consequently, innovation in service enterprises has become, in the current literature, as one of the most relevant topics to improve in order to achieve a high level of business growth since innovation in services has focused on the creation of more and better competitive advantages [3]. Innovation in services has also been analyzed from a perspective of a predecessor of internal and external business innovation and the existing relation with firm performance that enterprises have achieved [2]. For that reason, de Brentani [4] concluded that companies that carry out modifications or improvements in their services generally have more benefits as well as higher performance which allow them to increase their innovation activities.

In this regard, innovation in processes is considered in the analysis and discussion of services innovation not only as an essential element that shows a strong organizational structure but also as a sequential process [4, 5] or a circular unstructured process in order to obtain a higher level of services innovation [6]. This sequential process can produce better results as well as a significant increase in the performance of service enterprises [7].

Similarly, it is possible to observe the development and implementation of processes innovation of new services in the literature, where the details are generally specified as well as the interactive activities, the negotiation and decision making which are present not only in the services innovation but also in firm performance [8]. Thus, there is theoretical and empirical evidence in the literature of business and management sciences that innovation in service enterprises is much more dynamic and has evolved at a faster pace that innovation in manufacturing enterprises [9].

However, relatively few publications have analyzed service innovation in SMEs, so it is necessary to increase the theoretical and empirical evidence of innovation activities within the context of service SMEs [10]. According to von Koskull and Strandvik [7], it is necessary to analyze and discuss what is really happening in service innovation and processes innovation in service SMEs. Therefore, the main contribution of this research is the analysis and discussion of the existing relation between services innovation and performance of service SMEs in a country with an emerging economy as it is the case of Mexico, and as it suggested by Perks et al. [10] and Tuominen and Toivonen [11].

2 Literature Review

There is a variety of definitions regarding the concept of services, but if the reader considers the definition coined by Sampson and Froehle [12] then it is possible to establish that services can be defined as a clear combination of co-produced resources and processed based on the provision of personal services. Similarly, this definition of services is based on the same processes that require the services which define accurately the importance of final clients and consumers in the processes of services creation [12].

Similarly, the services sector is usually one of the biggest economic sectors in both developed and developing countries. That is why service innovation is one of the essential elements that allow a higher level of growth and firm performance [13]. Moreover, in the literature it is possible to observe an important increase in theoretical and empirical investigations regarding services innovation in the last decade, which indicates that several research papers from the area of innovation are focusing more in the services rather than in the manufacturing sector [14–16]. This shows the importance that services innovation has in the current literature.

In this regard, the context of the concept of services is changing with the creation of the concept of *new services* or *services innovation*. These usually refer to the creation of completely different services that entirely satisfy the needs of the clients segments that have a lot of interest in getting intensive services in new knowledge [17]. As a result, service innovation researches are usually associated to the creation of new knowledge into enterprises and with the increase of competition of companies [18], as well as the growth of the development of new products [19] and the ability to innovate in the service enterprises [20].

The existing relationship between services innovation and firm performance has been analyzed and discussed marginally in the literature of innovation when compared to the innovation of manufactured products. This is because services do not have a physical component, it is complicated that consumers obtain immediate benefits after their purchase and it is difficult that they distinguish the components of services innovation [2]. Therefore, Voss et al. [21] established that service innovation probably takes more time to create positive effects in performance of the services sector when compared to the innovation of manufactured products in enterprises from the manufacturing industry.

Consequently, services are frequently perceived as basic by clients and consumers but the improvement, change or innovation in services is not as tangible as the innovation of manufactured products [2], even when innovation is usually much easier to implement in the services sector than in manufacturing enterprises, but at the same time it is also easier to be copied by the main competitors in service enterprises [21]. This situation can be the main reason as to why service enterprises have a lower number of innovation projects, especially regarding radical innovation, than manufacturing enterprises. As a result, it will be necessary to emphasize more services innovation as it also produces different economic and financial benefits, just like their counterpart from the manufacturing sector [21].

Thus, it is not surprising that in the literature of business and management sciences it is suggested that innovation in manufacturing SMEs produces similar benefits to the ones of service SMEs, except for the amount of innovations introduced to the market [22]. Therefore, the literature considers innovation as one of the business strategies that allow the significant increase of a number of competitive advantages as well as the level of performance in service SMEs [2]. As a result, both researchers and scholars have an area of opportunity to carry out empirical and theoretical investigations that focus on services innovation and the effects on firm performance, and in this way take advantage of the modifications and opportunities provided by this important sector [15].

Similarly, forthcoming theoretical and empirical investigations about services innovation will have to consider the difference between the diverse types or categories of services, the analyses made and their effects on the performance or organization [15, 23]. Upon this idea, Menor et al. [15] concluded that there is a gap in the literature about understanding the operationalization of the background of service innovation and its effects on firm performance. Moreover, it is not only necessary to differentiate the types of services in the literature but also consider the existing effects of the relationship between service innovation and the level of performance that enterprises have in the services sector [2].

Within this perspective, the categorization of services usually reflects the effects that discontinuous (radical) innovation and continuous (incremental) innovation have on service innovation [4], since the radical services innovation is completely different from the incremental services innovation [2]. Thus, Oke [24] considered that most enterprises of the service sector focus more on incremental innovation, which is commonly associated to firm performance. Similarly, Lubatkin et al. [25] discussed that services innovation is more incremental in SMEs since this provides them with a higher level of firm performance. Accordingly, Oke et al. [26] also considered that service innovation is mostly incremental because it produces a higher level of firm performance. Therefore, at this point it is possible to establish the following research hypothesis:

H1: The higher the level of service innovation, the higher level of firm performance.

3 Methodology

The business directory of the 'Sistema de Información Empresarial Mexicano' 2016 (Mexican Business Information System) for the Aguascalientes State was used to determine the size of the service enterprises that were considered for this empirical research. This directory had a register of 1,334 service enterprises between 5 and 250 employees by January 2016. Therefore, the sample contained 308 enterprises with a reliability level of 95% and a maximum level of error of ±5%. A questionnaire was designed, validated and distributed to the 308 selected enterprises by means of a simple random sampling method from January to April, 2016. The questionnaire collected data regarding the characteristics of service enterprises, the innovation activities in the previous two years as well as the firms' performance.

In order to measure service innovation, managers were asked to indicate if the enterprise had carried out innovation activities in the previous two years. In order to measure the importance of innovations, managers were asked to evaluate the innovation in services, processes and management systems with seven items by means of a five-point Likert scale (from 1 = Not Important to 5 = Very Important as their limits). The scale was adapted from those developed by Frishammar and Hörte [27] and Madrid-Guijarro et al. [28]. Regarding the measurement of firm performance, it was measured with eight traditional indicators constructed from the perception of the managers of service SMEs about their competitive position regarding market share, profitability and productivity [29]. These eight questions were also measured by means of a five-point Likert scale (from 1 = Not Important to 5 = Very Important) as their limits.

Similarly, in order to evaluate the reliability and validity of the two scales of this empirical investigation, a Confirmatory Factor Analysis (CFA) of second order was carried out by using the method of maximum likelihood with the software EQS 6.2. Moreover, the reliability was evaluated by means of Cronbach's alpha and the Composite Reliability Index (CRI) proposed by Bagozzi and Yi [30]. The results obtained are presented in Table 1 and they indicate that the model had a good adjustment of data

Table 1. Internal consistency and convergent validity of the theoretical model

Variable	Indicator	Factorial loading	Robust t-value	Cronbach's Alpha	CRI	EVI
Services innovation (**F1**)	INS1	0.919***	1.000[a]	0.835	0.837	0.722
	INS2	0.774***	20.561			
Processes services innovation (**F2**)	INP1	0.842***	1.000[a]	0.760	0.762	0.617
	INP2	0.724***	18.560			
Management systems services innovation (**F3**)	ISG1	0.711***	1.000[a]	0.843	0.844	0.646
	ISG2	0.804***	15.776			
	ISG3	0.886***	17.355			
Services innovation activities	**F1**	0.865***	7.131	0.876	0.877	0.705
	F2	0.832***	7.388			
	F3	0.819***	6.680			
Firm performance	REN1	0.780***	1.000[a]	0.913	0.914	0.671
	REN2	0.826***	20.753			
	REN3	0.801***	16.472			
	REN4	0.753***	15.340			
	REN5	0.714***	13.209			
	REN6	0.744***	13.664			
	REN7	0.713***	14.847			
	REN8	0.707***	14.221			
$S\text{-}BX^2$ (df = 83) = 205.576; p < 0.000; NFI = 0.924; NNFI = 0.941; CFI = 0.953; RMSEA = 0.061						

[a]Parameters limited to this value in the identification process
*** p < 0.01

($S\text{-}BX^2 = 205.576$; $df = 80$; $p = 0.000$; $NFI = 0.924$; $NNFI = 0.941$; $CFI = 0.953$; y $RMSEA = 0.061$). The values of Cronbach's alpha and the CRI were higher than 0.7, which provided evidence of reliability and it justified the internal reliability of the scales of the theoretical model [31].

Additionally, the suggestions made by Chou et al. [32] were observed for the corrections of statistics when it is assumed that the normalcy of the scales is present. Robust statistics were used in order to provide better evidence of the statistical adjustments of the scales [31]. As evidence of convergent validity, the CFA results of second order indicated that all the items of the related factors were significant (p < 0.01). The size of all the standardized factorial loads were above 0.60 [30] and the Extracted Variance Index (EVI) of each pair of constructs from the theoretical model had a value above 0.5 as suggested by Fornell and Larcker [33]. This indicated that the theoretical model had a good adjustment of data.

Regarding evidence of the discriminant validity, the measurement was provided by two tests that can be seen in Table 2. Firstly, with an interval of 95% of reliability, none of the individual latent elements of the matrix of correlation had a value of 1.0 [34]. Secondly, the EVI between each pair of constructs was higher than their corresponding variance [33]. Based on these criteria, it was concluded that the different measurements used in this research provided enough evidence of reliability and discriminant validity.

Table 2. Discriminant validity of the measurement of the theoretical model

Variables	Services innovation	Firm performance
Services innovation	**0.705**	0.158
Firm performance	0.302–0.494	**0.671**

The diagonal represents the Extracted Variance Index (EVI), while above of the diagonal the variance is shown (square correlation). Below of the diagonal, the estimation of the correlation of the factors with confidence interval of 95% is shown

4 Results

A structural equation model (SEM) of second order was used in order to answer the hypothesis stated in this research by using the software EQS 6.2 [35]. Similarly, the nomological validity of the theoretical model was analyzed through the Chi-square test. It was mostly based on the comparison of the results obtained from the theoretical model and the measurement model whose results were statistically not significant between the Chi-square of both models. This provided an explanation of the relationships observed between the constructs of the latent variables of the two models [34]. The results obtained by using the SEM of second order are presented in Table 3.

Regarding the research hypothesis stated in this investigation $\mathbf{H_1}$, shown in Table 3, it can be seen that the results obtained ($\beta = 0.435$ $p < 0.01$) indicated service innovation has significant positive results on the performance of service SMEs. In other words, service innovation activities (innovation in services, processes and management systems of services sector) that are adopted and implemented in service SMEs are good indicators to achieve a better level of firm performance. This would support service SMEs in achieving the necessary economic and financial resources to keep on with innovation activities.

Table 3. SEM results of the theoretical model

Hypothesis	Structural relationship	Standardized coefficient	Robust t-value
H1: The higher the level of service innovation, the higher level of firm performance	Service I. → Firm Performance	0.435***	4.430
$S\text{-}BX^2$ (df = 83) = 185.936; p < 0.000; NFI = 0.932; NNFI = 0.947; CFI = 0.960; RMSEA = 0.058			

*** p < 0.01

5 Discussion and Conclusions

Considering the results obtained in this empirical research, it is possible to conclude on two main aspects. Firstly, it is possible to measure services innovation activities through three activities: services innovation, processes of services innovation and management systems of services innovation. Therefore, it is important to consider that if executives of service SMEs want to adopt and implement innovation as a business strategy, and as part of their everyday activities, then they will have to develop activities related not only to service innovation but they will also have to pay special attention to innovation in processes that are needed for the production of services, as well as to implement systems that improve their management.

Secondly, since service innovation is regarded as a strategy that creates several benefits for enterprises, especially SMEs, then it is possible to conclude that enterprises that adopt and implement innovation activities as part of their routine will have more possibilities of significantly improving their level of firm performance. This will provide them with the basic economic and financial resources needed to keep on developing service innovation, and even SMEs will have the necessary conditions to implement radical innovation in their services by creating new services that do not currently exist in the market. Thus, they will be able to dethrone their main competitors as well as to significantly increase their firm performance.

Similarly, these results have several implications for both managers and service enterprises themselves. One of these implications is that, in general, the innovation activities carried out by service SMEs, not only in Mexico but in other countries, are focused only on the modifications or improvements of existing services in the organization (incremental innovation); that is why it is not possible to establish that service SMEs are innovative. Conversely, it cannot be said that service SMEs that develop new services (radical innovation) are the only innovative enterprises. Innovation does not refer exclusively to create services but also to change or improve the existing ones. Therefore, any SME that produces a modification, an improvement or creates a new service can be considered as an innovative enterprise.

Likewise, it is also possible to state that, considering the results obtained in this research, service SMEs that make modifications or improvements to their services, processes and management services, have higher possibilities of adopting and implementing the necessary activities to achieve a higher level of innovation and, consequently, significantly increase their level of firm performance. However, it is important to consider that in Mexico, just like other countries in Latin America, around 70% of service SMEs have an organizational structure based on their families, they include their own members in executive positions and they are managed by the families. As a result, decisions taken are controlled by the family that owns the enterprise and workers and employees are considered as part of the family.

In this regard, managers of service SMEs have to change the organizational culture of their companies in order to adapt it to the innovation activities as it is necessary for their employees and workers to suggest solution alternatives, not only to address the main problems faced by the organization but also to improve services. Therefore, the organization needs to create an environment that promotes team working, the participation of all employees in the design of innovation activities, and the freedom to express their ideas to produce changes or improvements in the creation of services, processes and management services. As a result, enterprises will be in a better position to increase incremental service innovation and the level of the firm's performance without further complications.

Additionally, managers of service SMEs will need to find a way to increase the innovation activities of their enterprises because this will determine their success. In a similar trend, managers will also have to find methods to have a better control on innovation activities. This will need the use of different training programs to improve innovation activities from government offices, business boards and associations. This will determine the level of a firm's performance as well as its growth, development and survival.

Finally, the results of this investigation provide enough theoretical and empirical evidence that proves that service innovation, processes and management services have different benefits for enterprises of the services sector. Therefore, managers will have to create in the organizations an environment with a positive and pro-positive attitude in the innovation of services and avoid as much as possible a "resistance to change" attitude from workers and employees and provide the necessary modifications demanded by the market, clients and final consumers. This will align the organizational culture of innovation with the general strategies of service SMEs.

By contrast, this empirical research has several limitations that are important to consider. The first one is related to the sample as the enterprises that were selected had between 5 and 250 workers. Further investigations will need to take into account enterprises with less than five workers as they represent more than half of SMEs in Mexico. A second limitation is that the questionnaire was distributed, exclusively, to service SMEs from the Aguascalientes State region, but a high concentration of this type of enterprises in located in the country's capital city. Further investigations can replicate this research in other states, or even countries, to expand and compare the results obtained from this study.

A third limitation is linked to the scales used for the measurement of service innovation and firm performance. In this case, only seven items were used to measure the information of services and eight items to measure firm performance. Future investigations can develop and use other scales to verify the results obtained. A fourth limitation is that only qualitative variables were considered for the measurement of barriers for innovation and innovation itself. Further researches will need to consider the use of quantitative variables such as investment in research and development in order to verify if there are significant differences in the results obtained.

Finally, a fifth limitation is that the questionnaire was distributed only to managers of service SMEs. This created the assumption that they had a lot of knowledge about innovation activities and firm performance, so further investigations will need to apply the same questionnaire to employees, clients and suppliers of enterprises to verify the results obtained.

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Operations Management in Engineer-to-Order Manufacturing

Project Execution Strategy and Planning Challenges

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Abstract. The planning process in Engineer-To-Order (ETO) projects is challenging due to: global network of participants within a project, dynamic iterations on design and engineering activities as well as the need for completing activities in a concurrent manner that shorten the delivery time. Moreover, managerial decisions on what and where to outsource disturbs the planning process due to lack of integration between different working methodologies or systems. In this article, we present some of the challenges faced during the planning process and connect them to the project execution strategy applied by ETO companies when managing their projects.

Keywords: Project planning · Project management · Engineer-To-Order

1 Introduction and Background

Generally, a project endeavor implies a temporary organization that requires an administrative and managerial framework, which according to [1], is defined as project governance model. In our paper, we refer to the management segment within the governance model [2] and do not consider the administrative part, which is performed by each organization by following own internal rules and regulations. Within this management segment, which we identify as Project Execution Strategy (PES), we analyze how the decision process approached at this level affect the project planning and control activities. PES is defined as management tactics applied by project-organized companies to plan, control and complete a project according to customer requirements [3]. The decision on which type of PES to apply is based in most of the cases on issues like (1) the size of the company and its position on the specific market; (2) the necessity to lower total project cost; (3) search for new and specialized knowledge, etc. [4]. However, based on our research it seems that most of the ETO companies do not consider how their choice of PES affects their planning process. As such, many project organized companies plan their projects by assuming that they either (1) have control over the whole project and plan its activities at a level that do not consider the effect of dependencies between participating organizations, or (2) they plan only the phases they are responsible for without considering the rest of the phases. In both cases, the result is a rigid planning process where each organization participating in the project optimize own activities at the expenses of the project as a

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whole. Consequently, most ETO projects lack a clear overview over the project status, which, in turn results in cost overruns that could have been avoided through a planning and control process that considers the choice of PES.

In this article we continue the work published at APMS 2016, where we proposed a classification of ETO companies based on their approaches to PES [3]. Through several of our research projects, we mapped PES for ten Norwegian ETO companies and the categories identified are: (1) vertically integrated type of company, (2) design and engineering, (3) production and testing type [3]. The first category owns most of the processes in each project phase. They acquire smaller local or global companies that deliver services or products able to increase companies' competitive advantage. As a result, their PES seems more integrated and gives better possibilities for control and improvement. The second category contains companies that own only concept, design and detail engineering part of a project. The third category contains companies that focus on core competencies like production and testing the final product. The ETO aspect of the third category lays in their ability to define engineering solutions coming from practical experience and they reveal a good understanding and translation of customer requirements into practice.

Each case company uses different approaches to the planning and control activities and all of them have ongoing projects that are looking on improvement possibilities. The scope of this paper is to increase awareness on the importance of adapting project-planning strategies to the particularities of each PES approach. Based on our case studies, we learned that challenges within the project planning are a direct result of the strategies used for completing each phase of an ETO project.

We analyzed ETO companies producing different types of customized products (ships, cranes, etc.) and we found that applying traditional project planning methods does not consider the choice of PES [3]. Furthermore, considering that more than 75 percent of the ETO product's value is built by involving suppliers of products and services [5], the importance of choosing the right planning process and methodology is important. The tactical decisions made by the project team regarding whom (what scope of work under which terms) will complete what within a project, has major ramifications on the probability of success or failure of the planning process. Thus, the main research question is what are the main challenges posed by the PES to the project planning process in the ETO environment.

2 Theoretical Background

In this section, we first introduce some relevant features and challenges when managing ETO projects. Then, in our attempt to structure the challenges for each type of PES, we introduce nine characteristics of an effective ETO project planning process.

2.1 ETO and Project Management

Due to an increasing demand for customized products, the number of ETO companies is growing at a fast pace [6] and advances in technology will intensify this pace even more. ETO is a type of production strategy where research and design activities are an important part of the project especially during the conceptual phase [7] when the customers define the specific features of the final product. ETO companies face great pressure to reduce cost, shorten lead-time, and maintain high quality while customers increase the complexity of their requirements. The main characteristics of ETO approach are project-based deliveries of products with a high degree of customization in low volumes [8]. Most ETO products are complex and, unlike other types of production approaches, customers are involved at a detailed level throughout the design, procurement and production processes. Such complexity requires often a project team that contain members from a selection of specialized companies that must work together to meet specific requirements [9]. Hence, most ETO companies use project management approaches to manage such teams. Nevertheless, the success or failure of a project is not completely under the control of the project leader and her/his team [2]. Project management literature recommends taking into consideration each project's cultural, social and physical environmental context while the same literature rarely discuss the project context and lack recommendations on "how to act, react or interact" (p. 33) to the context of a project [10]. Another focus area within project management literature is the planning process which is based on a linear strategy that implies dependent, sequential phases [11] executed according to the project plan. Moreover, project management literature does not discuss planning challenges for ETO projects characterized by iterative process, network organized projects and concurrent activities [12]. Thus, most ETO companies using standard project management approaches struggle to achieve a good overview over the status of the project [13]. Then, the fact that there are several suppliers participating in an ETO projects and each might have a different planning software, achieving an overall clear status of the project becomes challenging. To our knowledge, the planning challenges related to the PES are not discussed within the project management literature in any significant degree. Therefore, through the research presented in this paper we contribute to increase the body of knowledge concerning the need to adapt the project planning process to the context of the project, in our case the choice of PES.

2.2 Characteristics of an Effective Planning Approach

According to [14], there are nine important characteristics of an effective project planning process within ETO environment: (1) *Flexibility* refers to the frequency of updating and modifying the project plan with actual data, which is a challenge when several different suppliers complete a large part of the project. (2) *High level of integration* of project disciplines is about effectiveness and efficiency of the communication process among project participants. (3) *Collaborative planning process* is about the project plan created through agreement between project manager and each discipline team leader (not only top-down approach). (4) *Effective planning meetings* refers to meetings where project participants have the opportunity to effectively inform and be informed about relevant issues on the project status. (5) *Good performance measurement* system that inform project management team about the status (progress, hours used per activity and remaining budget) of the project. (6) *Good progress-measurement* *tool* that can indicate real progress of the production process. (7) *Effective re-planning process* indicating whom, when and how fast delayed activities can be completed to recover the project plan. (8) *Impact analyzing* refers to an increased awareness of interdependencies among project participants (visualized through a good planning process). (9) *Lessons learned* from project to project can be a difficult task in project organizations especially when these organizations are spread across several countries [14]. Therefore, most ETO projects are managed through a phase-based project management [15], approach. The scope of the characteristics presented here is to illustrate the main areas of a planning process affected by the adapted type of PES.

3 Methodology

The ten companies followed in this study are involved in different research projects with our affiliations. Most of these projects focus on improving project management strategies through better planning processes and procedures. However, during our research we learned that even though some of their problems seem similar, their root causes were different and they needed different tactics to the improvement process. Then, we mapped the project phases and the approaches used for completing them. While some of the companies were controlling more or less all phases, others outsourced several phases, so we took a closer look at these differences and their causes. We started by analyzing how the project is planned, where each project phase is executed and by whom. Based on these findings, we started an exploratory case study, which seemed suitable for this type of research [16, 17]. As [17, 18] state, qualitative case studies are suited for acquiring knowledge from practitioners and use them to improve existing theories or develop new ones. Further, exploratory designs are suitable in studies that address issues not yet thoroughly researched, aiming to extend emergent theory [19]. From our studies, we learned that the issue of project planning and control in ETO industry needs more research due to specific challenges within this type of production. Some of the research projects are still ongoing and we work on developing planning processes that consider the PES applied by these case companies. The authors were directly involved in improving project planning processes at three of the case companies. Through the work on these projects, we noted that implementing new planning processes was dependent on the control each company had on each of the project phases as well as on their relations towards the rest of the participating organizations. Thus, we started to search for solutions to improve the project planning process for each type of PES. In addition to the direct participation in several planning meetings, we also collected data through direct interviews, minutes-of-meetings and planning documents. We then analyzed the data and identified three main PES for ETO projects and several approaches to the planning process. The results were then discussed with employees from the case companies and their comments were integrated in our findings.

4 Three Types of PES and Planning Challenges

The idea for this research comes from our work with ETO companies that are preoccupied to improve the results of their projects by focusing on the planning methods used to manage these projects. One case company preoccupied by improving own project management results, started actually a project called "Project Execution Strategy" through which they identified several different informal PES that were dependent on project leaders' capability, teams expertize, organizational cultures and the level of involvement of suppliers within the project. While improving the internal processes was relatively easy, integrating all participating organizations proved to be challenging due to issues like trust among project participants, different software that are difficult to integrate, different applications and hierarchies within the planning process, interdependencies with suppliers, and so on. The company formulated procedures that could integrate supplier's deliveries within the planning process and create a better collaboration and commitment among the project participants. They also analyzed each project phase and defined criteria that helped project managers decide which activities to be performed by suppliers and which ones will be completed internally. Most case companies have similar improvement projects that focus on better planning and control. However, due to a lack of control over all project phases, improving the project planning process proved challenging.

4.1 Phase-Based Project Management

The three types of PES identified in our previous research are based on the project phases described in Fig. 1 [3]. In the conceptual phase, the customer together with the sale agents establish the main features and performances of the product. These are developed further during the basic design phase, which, together with procurement, generate the basis for detail engineering in 2D. The information from these drawings is conversed to the engineers working with the 3D model of the product. Customers' approval of the model triggers the completion of the production drawings that contain a higher level of details. Upon the completion of the production drawings, the fabrication process can start. This is followed by the outfitting and commissioning (testing) phases that are completed before the delivery of the final product.

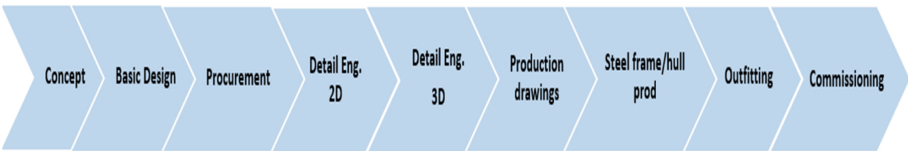

Fig. 1. Phase-based project management [3]

Many of the phases described here are either handled internally (specialized daughter companies) or by suppliers. Most phases are completed more or less concurrently due to pressure on the lead-time [3] and close collaboration between customer and project team. Indeed, many of the companies try to work according to concurrent engineering principles while the contract with the customer is normally phased-based in the sense that there are clear milestones on payments and phases at the top level. This creates a tension in the project between the contractual obligations and the physical realities in the project. Skillful project planning is necessary to facilitate this duality.

The strategies about what and how to outsource in these phases differ among our case companies. Some of them choose to outsource only some components and minor activities, while others outsource all the phases before the production. In the vertically integrated approach, the case companies have good overview over the whole process and are capable of involving external suppliers to a high degree. The design and engineering type has a good overview over the first part of the process and are highly dependent on good feedback from the companies responsible for the rest of the process. The production and testing type would have a good overview over the second part of the process and are therefore highly dependent on technical information from the company delivering design and detail engineering.

4.2 Challenges for Each Category

Considering the nine characteristics of an effective planning process, we studied the effect of PES on each one of them and we summarized the results in the Table 1.

Table 1. Effects of PES on planning characteristics

PES/Planning characteristics	Flexibility	Integrative	Collaborative	Effective meetings	Relevant perf. measurement	Relevant progress measurement	Impact analysis	Lessons learned
Vertical integrated	High	High	High	High	High	High	High	High
Design and engineering	Low	Low	Low	Partially	Partially	Partially	Low	Partially
Production and commissioning	Low	Low	Low	Partially	Partially	Partially	Low	Partially

From a planning perspective, it seems the vertically integrated type of company has better possibilities for achieving an effective project planning process. These companies were originally relying on significant amount of tacit knowledge, which kept them agile but prone to mistakes as performance was very people dependent. The response to this was twofold. One is that the company itself moves in the direction of improving its process control through formalization of processes, roles, systems and organizational structures. The other response is to outsource work to low cost countries by acquiring specialized companies. The planning process within a vertically integrated PES needs less alterations compared with the other two categories.

Within the two other categories, we identified challenges like low flexibility in updating the project plan due to lack of trust in sharing sensitive data as well as different software used for the planning process. They have several participating organization, but low integration. This is because everyone has to deliver according to contractual milestones even when there has been accumulating significant deviations from all parties. Each of the organizations participating in the project create own plans (based on contractual specifications) and have very little connection with the plans from the other participants. Besides, they are usually interested in optimizing their own planning process and that reduces the possibility to achieve an integrated project plan. In Table 1, we defined some of the characteristics as partially implemented by the case companies. That is a characteristic, which is common in one or several of the organizations involved in a project, but they do not comply with the project in its entirety. Thus, some phases of a project can be well executed, but the project suffers delays and budget overruns due to lack of a good overview over the whole project. Re-planning delayed activities that affect other activities, impact analyzing and lesson learned are slower and briefer than in vertically integrated PES. Another challenge is lack of feedback between organizations, which is an important aspect when aiming for developing new products. The challenges for the planning process in these types of PES are many. However, one advantage is that they need smaller organizations and the customer can decide who supplies design and who will produce it.

5 Discussion and Further Recommendations

We based our research findings on case studies within a Norwegian context. There is need for further research to gather empirical data from other ETO companies, challenged by a different context, to strengthen the validity of the findings.

The cases studied in this article are all ETO companies preoccupied to improve their project planning processes. In our research, we identified some of the challenges connected to the characteristics of an effective project planning process and the way these are affected by the PES. Based on our findings we argue for the need for a better planning process and one way to improve it is to consider the context of a project that is determined by the choice of PES. However, the organizations responsible for delivering the final product continue to create project plans that imply a good overview over the project status even when they have little or no control over deliveries from the rest of the suppliers. It is not possible for all companies to implement a vertical integrated PES. However, an understanding of the role of PES when planning a project can help these companies identify better approaches to more effective project planning. One approach would be more focus on coordination [20] of these projects and earlier supplier involvement during the project planning process [21].

Our research project is still ongoing and we work on developing project-planning methods that take into consideration the PES and their challenges. The next step of the research would be to test these methods at some of the case companies and present the results in a future article.

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A Three Steps Methodological Approach to Assess the Engineer-to-Order Operations Environment

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Abstract. For many companies, "customized" means products that even the most sophisticated of product configuration tools cannot define in advance. Such products need an engineer-to-order operations environment (ETO). This study focuses on the engineering activities of companies adopting an ETO strategy. We observed that these environments are significantly heterogeneous and that this is likely to limit any potential generic applicability of strategies and practices. In this paper, therefore, a three steps methodological approach to support companies in developing a better understanding of their ETO environment is presented: assessment of product variety and customization, modelling of the ETO process, and measurement of operational performance. Findings from the application of the approach to three industrial partners are then summarized.

Keywords: Engineer-to-order · Assessment approach · Engineering-design

1 Introduction

Product-variety management in today's market is, most of the time no longer an order-winning choice, but an order qualifier [1]. This means that in turbulent market conditions, customers seek out companies that offer shorter delivery times within a customers' price tolerance. In this context, engineer-to-order (ETO) is defined as an operations strategy that is oriented around a high degree of product customization and associated engineering processes for quickly fulfilling customer specifications.

The focus of this study lies in the design and engineering activities of companies adopting an ETO strategy. This encompasses product development processes (PD) – usually managed by the Research and Development (R&D) department – and order-specific engineering processes (OSE) – usually managed by the Engineering department [2]. These processes have a significant impact on the value chain's downstream material processes, like manufacturing, and therefore significantly impact the company's overall performance.

While working with the three industrial partners of the FastETO research project, in accordance with a literature review, we observed that ETO environments are fundamentally heterogeneous [3]. This is likely to limit any potentially generic applicability of strategies and practices in such a diverse range of ETO environments. Additionally,

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it also appeared that our industrial partners did not always have a clear understanding of their operations environment. These limitations, therefore, call for an assessment of the ETO firms with respect to engineering-design considerations.

In this study, we present the methodological approach we used to support companies in developing a better understanding of their ETO environment. A situation analysis, allowing a better understanding of the phenomenon, is indeed propaedeutic to the formulation of any company-improvement project.

2 A Three-Steps Assessment Approach

We propose an assessment approach for companies operating in an ETO environment based on three consecutive steps according to Fig. 1: First, assessment of the product variety and customization offered; Second, assessment of the ETO process by means of process modeling; Third, assessment of the company's operational performance.

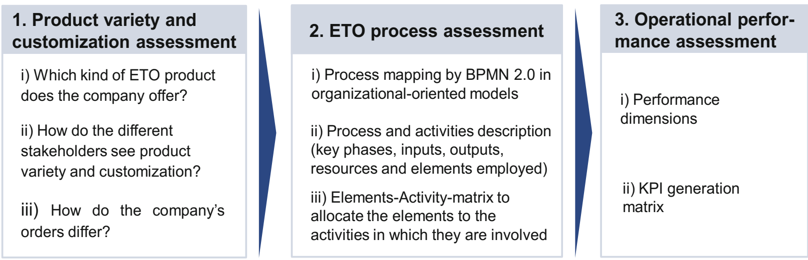

Fig. 1. Assessment approach for companies operating in an ETO environment.

2.1 Assessment of Product Variety and Customization

The first step of the assessment approach, the product-variety assessment, consists of guiding the company through answering the three following questions:

Which Kind of ETO Product Does the Company Offer? This first question adopts a high level and strategic point of view in the assessment of the ETO product. The aim is to be able to classify the company and the product being offered within one of the classifications of manufacturing and engineering strategy proposed in the literature.

The definition of the ETO product indeed encompasses a broad spectrum of products that calls for the use of different strategic approaches. The three variables considered are: (i) *Sales volume* or the number of orders [3]. (ii) *Level of engineering complexity* operationalized with a time-/effort-based criterion and defined as the average number of engineering hours per order [3]. For this variable, we also recommend distinguishing between *component eng. complexity* and *architecture eng. complexity* (i.e., respectively, commitment to adapting components, or developing new ones and the commitment in the combination of (main) components in the product). (iii) *Degree of customization*: Different definitions have been given for this. In defining it, we adopt the company's perspective: this means that a high degree of customization involves developing new components, rather than just adapting existing ones.

How Do the Different Stakeholders of the Value Chain View the Product? The aim of this question is to align these different standpoints on product structure and data, and emphasizes the importance of defining and managing the relationships between different department's points of view. Product variants are sometimes designed within a traditional new PD project, but, more likely in an ETO company, have been realized through the specification and delivery of customized products to meet customer requirements. In this way, product variety is generated progressively over several years. When customizing products, the entire product realization process, also referred to the value chain, is affected [4]. Such a process, for instance, can be described based on Suh's domain framework [5]. Within the various departments of a company, therefore, there are several ways of representing product variety and product customization. Indeed, in each phase of the value chain, one or more product structures are used that are pertinent for the overall product description [6]. Therefore, the company needs to conduct an assessment in which all pertinent departments collaborate in creating a general representation of the product variety range. In our approach, we consider it valuable to use three different views, briefly: customer, engineering and production view.

When necessary, the company has to refer to the concept of *generic product structure (GPS*) and work on a product model representing the product variety range. The GPS models the generic modules of the product and their organization in a *part-of* hierarchy. Concepts such as parametric, optional and alternative and components are normally encompassed. The problem of selecting parts for a product with high variety can be addressed by the GPS, with the use specialization and generalization semantics. These are typically in the form of *type-of* relationships between the variants (instances) and the generic modules. Briefly, the GPS aims at describing and modelling product variety without dealing with the product structure of each product variant. For examples of applications of GPS, the reader can refer to the *Generic bill of material* approach (GBOM) [7]; for an ETO-specific application, please see the *Adaptive generic product structure* (AGPS) [8]. A useful technique for supporting product modeling is the *Product variant master* method (PVM) [6].

How Do the Company's Orders Differ? The third question aims to raise a company's awareness of the heterogeneity of customer requirements, as of the non-linear consequences of those on the degree of customization and the operations of downstream processes. The goal for the company is to be able to identify, during the sales process phase and depending on the customer requirements, the typology of project/order required. Thanks to this order (or project, product) categorization, the company can then approach customers' requests with differentiated processes (e.g. by advancing engineering knowledge in the pre-award phase) and pay special attention to budgetary and planning activities (e.g. lead-time estimation). Indeed, the company has to be aware of the technical risk and challenges involved when agreeing to satisfy a customer requirement so as not to compromise its profitability.

A basic differentiation the company could make is between "*standard product* (or order)" and "*non-standard product*". Alternatively, it could define different classes of order complexity. However, we observed in our companies that even if this variable is usually understood and perceived by the Engineering department, that understanding is not valid for the Sales department. It is not always trivial during the offering phase to understand which order requires the development of a new module, the development or specification of a new variant or whether a standard module (or one developed in a previous order) can be re-used. The company should work on the definition of criteria (and, when necessary, of procedures) for identifying the degree of customization and therefore the category of the classification of the product offered.

2.2 ETO Process Assessment

The second step of the assessment approach is to map out the as-is process and identify the process activities and resources, particularly focusing on where product information is being processed and where product features and order specifications are produced. In turn, the ETO process model can be analyzed by identifying the most critical problems associated with the process. These provide insight into which problems need to be addressed by the engineering of new and improved processes, and implementation of new technical tools and organizational practices [9].

As-is Process Mapping. At this stage, the purpose is getting an overview of the as-is process by applying a widespread, easy-to-use and intuitive mapping tool. In this study, the result generated by the various means of data collection and analysis enabled the development of a process map for each of the companies investigated. Process mapping can be carried out using numerous process-mapping formats. The BPMN 2.0 standard is deemed suitable for the task at hand. The format used can include inputs and outputs as well as process parameters and the elements/resources (e.g., IT tools) used in this activity. Also, a characteristic of the ETO process is its cross-department and cross-functional nature. The use of an organizational-oriented process map, to illustrate the relationship between the functional units and the activities for which they are responsible is strongly recommended [10]. Another important characteristic of the ETO process is the variability of the process depending on the product variant of the order. To fulfill specific customer requirements, different levels of customization might be required, and consequently, different activities may or may not be triggered. Based on the results from the first step of the assessment approach, the company should be able to map when and how different activities are launched for the different product/order categories.

Element-Activity Matrices. Process modeling, as mentioned previously, should not focus exclusively on the activities performed, i.e. on the process side, but also take into account the resources required. Having completed the description of any process mapping and activities, a useful technique is the diagramming of elements/resources to activities in bi-dimensional *element-activity matrices*. Activities should be listed by type (i.e. PD, specification activities, planning and control activities) and by chronological order, to favor the subsequent qualitative evaluations. Thus, the perspective of element/resource involvement and the requirements of activities are covered with this technique. The diagramming should differentiate between the different types of elements/resources (i.e. departments, tools and technologies, product knowledge, order specifications, customer and suppliers).

2.3 ETO Operational Performance Assessment

The third step of the assessment is to understand which performance requirements are to be put on the process if the company has to meet its overall targets (e.g. profitability, product variety strategy, etc.). This then supports the formulation of the detailed objectives of the improvement project (as for instance the FastETO project).

To provide a framework that enables ETO companies to appropriately measure operational (PD and OSE) process performance, we describe a generic performance measurement system (PMS) for ETO operations called the ETO PMS. Companies, besides using the framework to support the third step of the ETO assessment, can use it to develop and revise their current PMS, used for diagnostic and monitoring purposes. Primarily, the relevant performance dimensions and a guideline for developing firm-specific indicators for performance measurement in all dimensions are presented.

Performance Dimensions. The following performance dimensions were adopted: price and cost, further divided in the variable and fixed cost; quality; delivery, both in terms of responsiveness and reliability; flexibility; and learning and innovation. Similar performance dimensions have been postulated for manufacturing operations in literature, such as [10, 11]. Also, the innovation and learning dimension is directly considered. This is due to its crucial importance to ETO companies that must profit from the knowledge generated during the extension of the product-solution space, a requirement that pertains to most customer orders. These performance dimensions also influence each other, and a resolution of conflicting objectives is necessary most of the time. The relative importance of each of these performance dimensions is of course determined by the strategic motivation to offer ETO products in the first place (e.g. customization as order qualifier, customization as order winner).

KPI Generation Matrix: Structure and Hierarchy. This matrix entails the classification of all performance indicators according to three different categories. First, each indicator can be allocated to one or several performance dimensions as above outlined. As is clear, companies can measure each performance dimension by combining input, output and process indicators [12]. Second, The ETO process model provides another classification, namely, the element or activity to which a specific indicator belongs. At this stage, the company should have obtained the list of elements and activities as an outcome of the process mapping and description. General indicators are also possible. Third, the PMS is characterized by two hierarchical levels. The higher level, Level 1, contains indicators that aggregate the performance of indicators at the lower level by, for example, providing the average of an indicator across an element type (e.g. a product family). More strategic and general indicators are also attributed to this level. The lower of the two levels, Level 2, details these indicators and breaks them down into components (that describe e.g. a single order performance). More specific, operational and disaggregated indicators are generally associated with level 2. This framework forms the basis for companies to define their own PMS and allows for a greater variety of perspectives than traditionally used.

3 Findings from the Case Studies

This assessment approach has been validated by applying it to three industrial partners of the FastETO research project, manufacturers, respectively, of high-rise elevators, industrial steam turbines, and co-generation plants (refer to [2] for companies' descriptions). The benefits of each of the assessment steps are below summarized.

3.1 Assessment of Product Variety and Customization

In summary, it emerges from completion of the first step of the assessment that the first question helps the company to familiarize itself with the objective differences that are present in the ETO environment and consequently in the manufacturing strategies. This also helps the company to familiarize itself with the terminology that can support internal communication, but also in benchmarking with other companies.

The second question helps to diagnose issues in the product variety range, particularly regarding the value created through variety and the understanding of the complexity of product variety. On the one hand, the company can visualize by mean of the product variant master the share of variants that is actually creating value. Indeed, any variant of a product function that does not relate to the customer view does not generate any customer value. On the other hand, the degree of complexity of the product range can be analyzed by observing the relationships between the various views. The higher the number of relations between views, the higher the complexity. Product changes indeed propagate through the value chain to downstream processes, generating tasks and introducing a certain degree of operational performance risk. Therefore, whenever a change is required in the product, the effort generated by the consequent engineering and manufacturing tasks, is proportional to the number of sub-systems that are affected by the change and in turn to the number of relations between views.

The third question highlighted how companies uniformly approached market opportunities and customer orders without considering the heterogeneity of the requirements and therefore the various degrees of customization required. The assessment approach instead raises the companies' awareness of the differences between *non-standard* and *standard solutions*, which are already part of the product solution space.

3.2 ETO Process Assessment

Companies' order-specification processes were not always mapped, visible and understood by all stakeholders. However, some process maps were present in all industrial cases: process modeling was not virgin territory. That said, process maps were mostly owned and developed by the quality department to fulfill the requirements for obtaining standard quality certifications. Existing maps and models were not developed within the scope of an improvement project by the other departments.

Product- and order-activity matrices are defined by replacing the generic element type of the *element-activity-matrix* with the type of product knowledge used as input, and with the type or order specification that is the in- or output of each activity. The process visualization enabled by the organization-oriented process map and by the *product*- and *order-activity matrices* supported fruitful discussion about cross-department coordination and cooperation issues to be solved [2]. Indeed, the relevance of stakeholder activity on the rest of the value chain, the interdependencies between downstream and upstream activities, as well as the criticality of the strong concurrency of the activities between different departments, were often unclear (e.g. handover from Sales to Engineering once a project has been awarded). Consequently, many improvement ideas arose, from clarifying and formalizing expected input and output to the definition of states and requirement for handover of order specifications. The combined use of the process model and the PMS presented also influenced the definition of new KPIs dedicated to monitoring the delivery performance to internal customers (e.g. technical quality of the specifications).

Attention has also been paid to identifying those activities where useful information and knowledge are generated and whether these are properly acquired and organized. In turn, the analysis focused on those activities where information and knowledge from previous projects are or could be distributed and re-used (e.g. a database of all engineering changes to support standard product-maintenance activities).

IT Tools-Activity matrices supported the investigation of the use of different IT tools and databases in each of the activities. Consequently, the company could often visualize the current fragmentation of product knowledge and order-specification information in several stand-alone databases and, in turn, the time wasted in data collection and transcription tasks, the redundancies of data in various systems, and the potential information discrepancies and specification quality issues.

In a nutshell, the second step of the proposed assessment approach allows companies to detect the above-mentioned criticalities of the current PD and order-specification processes. The PMS, at the third step, allows for generating KPIs to measure and quantify the monetary cost of these criticalities.

3.3 ETO Operational Performance Assessment

The KPI generation matrix, including the relevant performance dimensions, were based on the process maps and description obtained with the second step of the assessment approach. They provided structural support during the KPI-generation phase. In turn, these indicators supported the definition of the detailed objectives of the FastETO project at each company. A general finding regarding performance measurement is that the Engineering department was treated as a pure cost center and challenged on cost and efficiency in most cases. As part of the proposed assessment approach, implementation of an extended PMS that considers five performance dimensions enables a more realistic assessment of the benefits of engineering on the overall value chain.

4 Conclusions

From a practical perspective, a methodological approach to assess the ETO environment is presented. This innovative approach is a combination of and adaptation to the ETO environment of existing managerial techniques. In contrast to traditional methodological approaches, we emphasize the need to sequentially incorporate in three steps, the assessment of the peculiarities of the ETO product, together with the modeling of the processes, and the measure of the operational performance over five identified dimensions. The three steps of the assessment are all needed and in that specific order. Indeed, with the first step, it is possible to cluster orders into "standard" and "non-standard" categories. These imply different processes that can then be captured in the process-modeling step. Identified process activities and process elements are consequently used, during the third step, in the KPI generation matrix.

The approach supports managers of ETO companies in reaching greater transparency and a clearer overview, and thus a better understanding of their operational environment. The assessment approach has been validated through its application to three companies, differing in size, volume, maturity and product characteristics, and has been shown to be a fundamental step in the early phase of the FastETO improvement project in assessing and analyzing the initial situation of the enterprise before formulating objectives and searching for potential solutions.

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Operating Curves Based Working Capital Management for Engineer to Order Manufacturers

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Abstract. Working capital management is one of the key disciplines that must be prudently monitored for a firm in pursuit of profits, liquidity and growth. The focus of this paper is on the engineer-to-order manufacturers, and the objective is to analyze the correlations between the reference processes of the engineer-to-order production approach with the key postulates of working-capital management and deliver a mathematical operating curves model, whose purpose and goal is basing on the rationale, that is underlying in the parent logistic operating curves theory.

Keywords: Working capital management · Engineering to order · Logistics operation curves

1 Introduction

The appropriate levels of current assets and current liabilities, the way in which the short-term requirements of the firm are financed and the composition of the short-term and long-term financing, all involves a trade-off between the profitability and risk. The conceptual evaluation of the working-capital management, the engineering to order production approach and the operating curves theory accounts this trade-off to strike a sensible balance between the profit and the risk involved.

2 Analysis of Key Concepts

2.1 Working Capital Management

Working capital management refers to the underlying, structured and effect-oriented analysis to make comprehensive and sensible, short-term financial decisions. Short-term financial decisions seem relatively less complex to make, than the process for long-term and medium-term ones but are equally important and critical. This fact is put explicitly, as an organization still could fail in spite of identifying valuable investment opportunities, most optimal capital structure and most perfect dividend policies, just because it emphasized lesser on short-term planning [1]. The net-working capital of a firm is

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defined as its current assets minus its current liabilities. The net-working capital is that capital required by the firm to satisfy its short-term capital requirements [1, 2]. The working capital accounts implicate the free-cash-flow of the firm. The direct reason and relevance comes from the cash-cycle. The cash-conversion-cycle is an important concept in the working-capital management that potentially affects the components of working-capital. The cash-conversion-cycle is mathematically summarized as Cash-Conversion-Cycle = (Inventory Period + Receivables Period) − Accounts Payable Period [1].

2.2 Engineer to Order Production Approach

The continuously increasing demand for specific customer value orientation and the need to develop customized parts with longer lead times, expensive capital investments and technical expertise, is promoting the role of engineer-to-order manufacturers in the supply chain. The engineer-to-order (ETO) production approach enables firms to have increased agility and flexibility, positioning them ideally to respond against unexpected and rapid market shifts through their production of one-of-a-kind products [3]. But given all this, there has been relatively lesser research outputs exclusively to the ETO production models [4, 5]. Given a high level of product complexity and customization, engineer-to-order companies account critical factors during their planning phase as significant uncertainty in the operating times, limited resources to respond in a situation of demand fluctuation and complexity and concurrent product developments [6].

2.3 Logistic Operation Curves Theory

With difficulties in quantifying large number of variables and the limitations associated with the mathematical functions that could approximate the required primary scenario as close as possible, a complex production system cannot be absolutely reflected in a mathematical model. The activities within the production processes hence must be classified with respect to their objectives in the value chain. Production and testing, transportation, and storage and supply are defined as the primary reference processes [7]. Due to the embodied conflict in the objectives of the primary production reference process, it has been difficult for the practitioners to quantify the variables and interdependencies and thereby perform a targeted logistics positioning. Intuitive and experience driven decisions addressing this trade-off results in an imbalance, given the complexity of the production process. The logistics operating curves theory addresses this difficulty in quantifying the trade-off and interdependency between the objectives of the production reference process. A logistic operating curve visually represents the correlation between a specific parameter of interest (the objective or dependent variable) and an independent variable. Therefore, for every value of the independent variable that can be changed by external conditions, at least one value can be determined for the objective [7].

3 Operating Curves Based Working Capital Management for Engineer to Order Manufacturers

The targeted mathematical operating curves model must adhere to the ground rule stipulated by its parent logistic operating curves model, which is targeted logistic positioning between the key, fundamental and trade-off variables in production logistics viz: work-in-process (WIP) and the maximum possible output rate. Attempting the best to adhere to this ground rule, the ideal solution is to create a targeted positioning between the key trade-off variables that encompasses into its scope, the concept of working-capital management, ETO production approach and the operations of the ETO manufacturers. The key trade-off concept of corporate finance viz: profitability and the risk would address the challenge of encompassing the scope and are potential fundamental variables in the proposed operating curves model. The effectiveness of these potential fundamental variables in encompassing the scope could only be realized when the concepts of capital budgeting are included in the analysis. Hence the need for taking the concepts of capital budgeting becomes important and relevant.

3.1 Definition of Ideal and Calculated Operating Curves

As already stated the Operating Curves Model must at any chance not deviate the Basic and Fundamental, Yet Key and Very Important Answer that has been Delivered by the Parent Logistic Operating Curves Model - Which is the basis for this Operating Curves Model, to the Question of Conducting a Targeted Logistic Positioning.

This hence has become a Ground Rule stipulated by the Parent Logistic Operating Curves Model, to the Operating Curves Model. To answer this Ground Rule, this model should conduct a Targeted Positioning between Two Key Trade-Off Variables.

While there are Many Pairs or at least more than one pair of Trade-Off Variables, on a Holistic Approach and to answer the Problem Statement in Full and Complete, the Trade-off Variable that is of Potential Interest must encompass, in its scope the Underlying Concept of Working-Capital Management, the ETO Production Approach and the Operations of ETO Manufacturers.

While pursuing a Bottom-Up Approach from a Pure Operational Perspective to a Pure Financial Perspective although initially was felt much logical, could not contribute sufficiently and effectively towards Zero-in-On of a pair that can satisfy the Challenging Conditions and the Scenario that is being attempted to fulfill. Hence pursuing a Top-Down Approach from a Pure Financial Perspective to a Pure Operational Perspective, the Key Trade-Off Concept of Micro-Economics, thereby of Corporate Finance – of which the Concept of Working-Capital Management is a part. Profitability and Risk would address the challenge of encompassing the scope. This is a solution to the scenario for which the Operating Curves Model is being attempted to be built, and are hence declared as the Potential Fundamental Variables for the Operating Curves Model. The Declaration of Potential Variables of Interests Representing Conceptual Working-Capital Management are described and the Four Distinct Operating States that Encompass the Given Scenario will be shown in Fig. 1. Operation State (OS) 1 is Organic and Non-Significant Risk Growth as well as Organic and In-Organic Profit

Growth. OS 2 is Organic, Partially In-Organic and Non-Significant-to-Significant Average Risk Growth as well as Organic and Reduced (Relative to State 1) In-Organic Profit Growth. OS 3 is In-Organic and Organic Steady and Sustained Risk Growth as well as Implicated Organic Profit Growth. OS 4 Increased Organic and Significant In-Organic Risk Growth as well as Plummeting Organic Profit Growth.

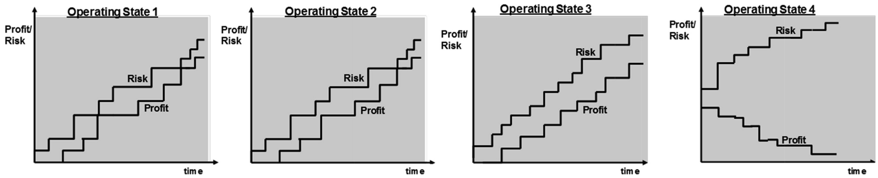

Fig. 1. Four distinct operating states that encompass the given scenario

Additional Cost Incurred by the Firm to Provide Necessary Liquidity Cushion, when its estimates face Upside Deviation. ($\boldsymbol{AC}$)

$$AC = TC_{\text{Changed}} - TC[\$]. \tag{1}$$

$$\text{TC} = [\text{R}_\text{c}[\$] \times \text{O}_\text{c}[\%]] + [\text{n} \times \text{AT}\ [\$]][\$] \tag{2}$$

$$\text{TC}_{\text{Changed}} = [\text{R}_{\text{c}-\text{Actual}}[\$] \times \text{O}_\text{c}[\%]] + [\text{n} \times \text{AT}\ [\$]][\$] \tag{3}$$

The Opportunity Costs Foregone by the Firm from Investing in Other Attractive Opportunities, due to its decision to pay a Reduced Monthly Principal Dues. ($\boldsymbol{OC_{EMSD}}$)

$$OC_{EMSD} = P[\$] \times [HFIR[\%] - FIR[\%]][\$] \tag{4}$$

The Opportunity Cost that is Foregone by the Firm from Investing in Attractive Opportunities due to a Postponement in the Repayment Schedule of its Debt. ($\boldsymbol{OC_{PRpSD}}$)

$$\begin{aligned}&(OC_{PRpSD}) = \\ &[[X[\$] + X[\$].FIR[\%]].FIR^2[\%] + [Y[\$] + Y[\$].FIR[\%]].FIR[\%] + \\ &[Z[\$] + Z[\$].FIR[\%]]] - [[X[\$] + X[\$].FIR[\%]] + [Y[\$] + Y[\$].FIR[\%]] + \\ &[Z[\$] + Z[\$].FIR[\%]]].\end{aligned} \tag{5}$$

The Magnitude by which the Profitability on Additional Sales-Generated due to a Relaxed Credit Standard, exceeding the Required Rate of Return on Additional Underlying Investment ($\boldsymbol{M - RC_{P_{AS} > U_{Inv}}}$)

$$(M - RC_{P_{AS} > U_{Inv}}) = [Profit_{TSV_{Increased} - TSV} - [[AI_{TSV_{Increased} - AI_{TSV}}] \times R[\%]]] \tag{6}$$

The Proportion of Receivables that is Defaulting ($\boldsymbol{DF_{RCT}}$)

The Magnitude by which the Profitability of Additional Sales, after Bad-Debt Losses - Generated Due to Re-Calibrated Credit-Terms, exceeding the Required Return on Underlying Investment. $(\boldsymbol{M - RC_{P_{AS-BDL} > U_{Inv}}})$

$$(M - RC_{P_{AS-BDL} > U_{Inv}}) = \\ [[Profit_{TSV_{Increased} - TSV}] - [C_{DF_{RCT}}] - [[AI_{TSV_{Increased}-AI_{TSV}}] \times R[\%]]] \tag{7}$$

The Magnitude by which the Reduction in the Cost of Bad-Debt Losses exceeding Additional Collection Expenditures $(\boldsymbol{M_{RCB > ACE}})$

$$(M_{RCB > ACE}) = \left[[C_{DF_{RCT}}[\$] - LC_{DF_{cp}}[\$]]\right] - [C_{CP2}[\$] - C_{CP1}[\$]] \tag{8}$$

Configuring these Potential Fundamental Variables to be an even effective Trade-Off Variables and analogous to those in the Parent Logistic Operating Curves Model, these become Maximum Possible Profit $Profit_{Max}$ and the Ideal Minimum Risk $IdealRisk_{Min}$ (see Fig. 2).

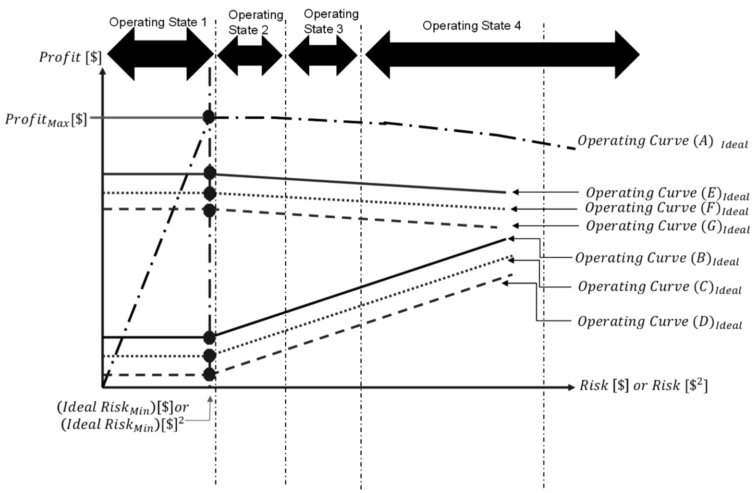

Fig. 2. Ideal operating curves model

$$OperatingCurve(A)_{Ideal} : \\ Profit_{Max}[\$] \text{ vs. } (Ideal\,Risk_{Min})[\$] \; or \; (Ideal\,Risk_{Min})[\$]^2 \tag{9}$$

$$Operating\ Curve\ (B)_{Ideal} : \\ (AC)[\$] \text{ vs. } (Ideal\,Risk_{Min})[\$] \; or \; (Ideal\,Risk_{Min})[\$]^2 \tag{10}$$

$$Operating\ Curve(C)_{Ideal}: \\ (OC_{EMSD})[\$] \text{ vs. } (Ideal\ Risk_{Min})[\$]\ or\ (Ideal\ Risk_{Min})[\$]^2 \tag{11}$$

$$Operating\ Curve(D)_{Ideal}: \\ \left(OC_{PRpSD}\right)[\$] \text{ vs. } (Ideal\ Risk_{Min})[\$]\ or\ (Ideal\ Risk_{Min})[\$]^2 \tag{12}$$

$$Operating\ Curve(E)_{Ideal}: \\ (M - RC_{P_{AS}>U_{Inv}})[\$] \text{ vs. } (Ideal\ Risk_{Min})[\$]\ or\ (Ideal\ Risk_{Min})[\$]^2 \tag{13}$$

$$Operating\ Curve(F)_{Ideal}: \\ (M - RC_{P_{AS-BDL}>U_{Inv}})[\$] \text{ vs. } (Ideal\ Risk_{Min})[\$]\ or\ (Ideal\ Risk_{Min})[\$]^2 \tag{14}$$

$$Operating\ Curve(G)_{Ideal}: \\ (M_{RCB>ACE})[\$] \text{ vs. } (Ideal\ Risk_{Min})[\$]\ or\ (Ideal\ Risk_{Min})[\$]^2 \tag{15}$$

3.2 Underlying Procedures Involved in Defining the Calculated Operating Curves

The following Eqs. 16 to 23 are a straight forward answer to the research questions. The Left Hand Side of the equations represent the variables that are identified from the analysis; and that which represent the efficiency of working-capital management of the firm. The Right Hand Side of the equations represent mathematical relationship that accounts the effects of operational variables, identified as potential for the engineer-to-order manufacturers. Equations 18 and 19 are a robust correlation between the extremities and the mean value of the fundamental trade-off variables.

$$(Risk_{Mean})[\$]\ or\ [\$]^2\{t\} = (Ideal\ Risk_{Min})[\$]\ or\ [\$]^2.\left(1 - \sqrt[C]{1 - t^C}\right) + \\ \alpha_1.(Ideal\ Risk_{Min})[\$]\ or\ [\$]^2.t \tag{16}$$

$$Profit_{Mean}[\$]\{t\} = Profit_{Max}[\$].\left(1 - \sqrt[C]{1 - t^C}\right) \tag{17}$$

$$(\mathrm{AC})[\$]\{\mathrm{t}\} = \\ \psi \times (\mathrm{Ideal\ Risk_{Min}})[\$]\mathrm{or}\ [\$]^2.\left(1 - \sqrt[C]{1 - t^C}\right) + \alpha_1.(\mathrm{Ideal\ Risk_{Min}})[\$]\mathrm{or}[\$]^2.\mathrm{t} \tag{18}$$

$$(OC_{EMSD})[\$]\{t\} = \psi_{OC_{EMSD}} \times (\mathrm{Ideal\ Risk_{Min}})[\$]\mathrm{or}\ [\$]^2.\left(1 - \sqrt[\mathrm{C}]{1 - \mathrm{t}^\mathrm{C}}\right) \\ + \alpha_1.(\mathrm{Ideal\ Risk_{Min}})[\$]\mathrm{or}\ [\$]^2.\mathrm{t}, \quad \mathrm{Where}\ \psi_{OC_{EMSD}} = Constant, \psi_{OC_{EMSD}} \\ > 0\ and\ Due\ to\ (HFIR[\%] - FIR[\%]) \tag{19}$$

$$\left(OC_{PRpSD}\right)[\$]\{t\} = \psi_{OC_{PRpSD}} \times (\text{Ideal Risk}_{\text{Min}})[\$]\text{or } [\$]^2.\left(1 - \sqrt[C]{1 - t^C}\right) + \alpha_1.(\text{Ideal Risk}_{\text{Min}})[\$]\text{or } [\$]^2.t, \quad \text{Where } \psi_{OC_{PRpSD}} = Constant, \psi_{OC_{PRpSD}} > 0 \, and \, Due \, to \, (FIR[\%]) \tag{20}$$

$$(M - RC_{P_{AS} > U_{Inv}})[\$]\{t\} = \psi_{\left(M - RC_{P_{AS} > U_{Inv}}\right)} \times \frac{1}{(\text{Ideal Risk}_{\text{Min}})[\$]\text{or } [\$]^2.\left(1 - \sqrt[C]{1 - t^C}\right) + \alpha_1.(\text{Ideal Risk}_{\text{Min}})[\$]\text{or}[\$]^2.t,}, \quad \text{Where } \psi_{\left(M - RC_{P_{AS} > U_{Inv}}\right)} = Constant, \ \psi_{\left(M - RC_{P_{AS} > U_{Inv}}\right)} > 0, Due \, to \, (FC_{Increased}[\$], VC_{Increased}[\$]) \tag{21}$$

$$(M - RC_{P_{AS-BDL} > U_{Inv}})[\$]\{t\} = \psi_{\left(M - RC_{P_{AS-BDL} > U_{Inv}}\right)} \times \frac{1}{(\text{Ideal Risk}_{\text{Min}})[\$]\text{or } [\$]^2.\left(1 - \sqrt[C]{1 - t^C}\right) + \alpha_1.(\text{Ideal Risk}_{\text{Min}})[\$]\text{or } [\$]^2.t}, \quad Where \, \psi_{\left(M - RC_{P_{AS-BDL} > U_{Inv}}\right)} = Constant, \psi_{\left(M - RC_{P_{AS-BDL} > U_{Inv}}\right)} > 0, \ Due \, to \, (DF_{RCT}[\%], VC_{Increased}[\$]) \tag{22}$$

$$(M_{RCB > ACE})[\$]\{t\} = \psi_{((M_{RCB > ACE}))} \times \frac{1}{(\text{Ideal Risk}_{\text{Min}})[\$]\text{or } [\$]^2.\left(1 - \sqrt[C]{1 - t^C}\right) + \alpha_1.(\text{Ideal Risk}_{\text{Min}})[\$]\text{or } [\$]^2.t}, \quad Where \psi_{((M_{RCB > ACE}))} = Constant, \psi_{((M_{RCB > ACE}))} > 0, \ Due \, to \, (DF_{RCT}[\%]) \tag{23}$$

As already stated, these variables take into their scope all the constraints that have been imposed by the described problem statement. All other equations are formulated in terms of the variable representing the x-axis in the operating curves model. The operating curves model with the identified set of equations clearly is a targeted positioning of the fundamental trade-off variable, and is a mathematical correlation between the dependent and the independent variable. Hence the mathematical operating curves model takes into its scope conceptual working capital management and the ETO production approach and clearly satisfies the purpose and rules stipulated by the parent logistic operating curves theory (see Fig. 3).

$$Operating \, Curve \, (A)_{Ideal} : Profit_{Max}[\$] \text{ vs. } (Ideal \, Risk_{Min})[\$] \, or \, (Ideal \, Risk_{Min})[\$]^2 \tag{24}$$

$$Operating \, Curve \, (A)_{Calculated}: Profit_{Mean}[\$] \, vs. \, (Risk_{Mean})[\$] \text{ or } (Risk_{Mean})[\$]^2 \tag{25}$$

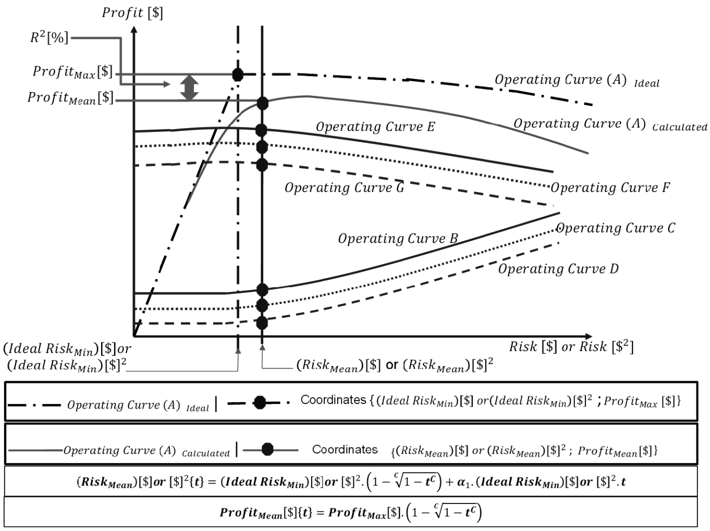

Fig. 3. Calculated operating curves model

$$Operating\ Curve\ B : (AC)[\$]\ vs.\ (Risk_{Mean})[\$] \text{ or } (Risk_{Mean})[\$]^2 \tag{26}$$

$$Operating\ Curve\ C : (OC_{EMSD})[\$]\ vs.\ (Risk_{Mean})[\$] \text{ or } (Risk_{Mean})[\$]^2 \tag{27}$$

$$Operating\ Curve\ D : \left(OC_{PRpSD}\right)[\$] vs.(Risk_{Mean})[\$] \text{or } (Risk_{Mean})[\$]^2 \tag{28}$$

$$\begin{gathered} Operating\ Curve\ E : \\ (M - RC_{P_{AS} > U_{Inv}})[\$]\ vs\ (Risk_{Mean})[\$] \text{ or } (Risk_{Mean})[\$]^2 \end{gathered} \tag{29}$$

$$\begin{gathered} Operating\ Curve\ F : \\ (M - RC_{P_{AS-BDL} > U_{Inv}})[\$]\ vs.\ (Risk_{Mean})[\$] \text{ or } (Risk_{Mean})[\$]^2 \end{gathered} \tag{30}$$

$$Operating\ Curve\ G : (M_{RCB > ACE})[\$]\ vs.\ (Risk_{Mean})[\$] \text{ or } (Risk_{Mean})[\$]^2 \tag{31}$$

4 Conclusion

A mathematical operating curves model, that correlates the important operations of the engineer-to-order manufacturer with the important postulates of conceptual working-capital management, has been formulated. In doing so, the model has completely complied with the rationale in the goal of the parent logistic operating curves model. Which is target positioning of the significant and important set of trade-off variables.

Orientation to the engineer-to-order production approach, has served as a constraint both qualitatively and quantitatively. As target positioning requires being most specific, a micro-level consideration for the important operations of the engineer-to-order production approach has been done. This consideration enabled recognition of potential variables of interests that satisfy the requirements as well as conceptually correlate with the postulates of working-capital management. It is a sincere belief that the output of the research potentially could be another small expansion, amongst many major expansions to the parent logistic operating curves theory.

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Resource and Information Sharing for the Installation Process of the Offshore Wind Energy

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Abstract. The costs of the installation phase of the production system offshore wind energy plant have a considerable influence on the electricity production costs. For this reason, there are efforts undertaken to reduce the installation costs. The resources (e.g. installation vessels) and information (e.g. weather forecasts) play a vital role in the logistics installation network. This paper investigates the potential of a shared use of resources and the sharing of different information in the installation phase of the offshore wind energy by means of an event discrete, agent-based simulation. This is motivated by the large number of wind parks still to be installed in the future. To this end, simultaneously installed wind farm projects are examined and the effects of exchange of different information are investigated. The impact of weather restrictions on the processes of loading, transport and installation is taken into consideration. By means of the resource and information sharing approaches, significant savings potential was identified for the offshore wind energy installation.

Keywords: Resource sharing · Information sharing · Offshore wind energy · Installation phase · Logistics · Simulation study

1 Introduction

The reduction of greenhouse gas emissions caused by fossil fuel fired energy generation has been urged by various initiatives worldwide [1]. In the context of the German energy transition, offshore wind energy (OWE) is a key technology [8]. This shift is mainly motivated by the high potential availability of wind, the resulting high number of full load hours and the good power plant characteristics of OWE [6]. Due to the planned exit from nuclear energy in Germany, OWE, as a form of energy generation that is able to provide base load, is an important component of the future energy mix. Both the specific challenges of OWE and the competition with conventional and other renewable energy sources lead to a need for optimization and the lowering of costs in all areas of the value chain of this young industry [8].

The logistics network for the installation of an offshore wind farm (OWF) is initially determined by the specific OWF project. Thereby, the number of wind energy

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turbines, the components to be installed and the characteristics of the construction site are defined [4]. The most important challenge of OWE logistics is the need to manage dynamic influences, especially the weather and sea conditions. Since logistics serve as a connecting element in SC, this requires that the optimization of logistics is considered as a cross-system matter [5]. In the context of the OWE installation phase, this does not only include considering the SC of one OWF but also taking into account OWFs that are to be installed at the same time. Thus, a consideration that extends across different SCs and projects is necessary due to the SC structure of an OWF as well as due to its project-based nature. The starting points for examining the network are the suppliers of semi-finished products and partial systems, which supply the majority of component and system manufacturers directly or via the ports of the network. Subsequently, the manufacturers deliver the components to the different ports from where the components are transported to the corresponding OWFs where they are installed [3]. The most critical processes for an economic OWF installation are the operations conducted by the installation vessel (IV). These vessels are cost intensive (up to 200,000€ per day) and affected by weather conditions. Furthermore, there are a limited number of installation vessels available on the market. For the case of a simultaneous installation of different OWFs, this resource has to be shared between different OWF projects. Therefore, all SC partners should have the same information base and align the processes for an optimal supply of the IV [4].

In this paper the authors examine the benefits of the application of the resource sharing (RS) and the information sharing (IS) approach to the installation-logistics of OWE. A presentation of previous scientific studies in the area of the planning and control of OWE installations, IS in supply chains (SC) as well as RS in logistics is presented in Sect. 2. Afterwards, in Sect. 3 the impact of IS in the RS logistics network for OWFs installation is evaluated by a discrete event simulation study. After discussing the simulation results (also in Sect. 3), a conclusion and outlook in Sect. 4 concludes this contribution.

2 Research Objectives – a Literature Review

The dynamic influences of weather and sea conditions make the transfer of planning and control concepts from other areas to the OWE a challenging task. Therefore, efficient planning and control of the logistics chain are expected to be an important contribution to reducing costs [13]. In scientific literature various works can be identified in this context. [10] describes the determination of an optimal installation schedule for OWFs based on a mathematical model using mixed integer linear programming. The approach involves different weather conditions, installation methods and layouts for the loading of the vessel. Due to the NP hard mathematical problem, the authors conclude that the approach is only usable for small scenarios. Based on the results of this contribution [11] presents a heuristic for the solution of larger problems. Several vessels, longer periods and a larger variety of weather conditions can be integrated in the heuristic. [2] presents another mathematical model for aggregated installation planning of OWFs. The model includes different operating conditions, such as weather conditions and vessel availability. [9] present a discrete event simulation for the transport and the installation of OWE turbines. The simulation model incorporates historical wind speeds and wave heights as well as a probabilistic approach to the analysis of the logistics chain. [5] discuss the scope and conditions of transferring the RS approach to the field of OWE logistics. As a result, the authors considered the needs of standardizing objects and processes as well as making supply and demand transparent as the basis for transferring RS into OWE logistics. [3] present a first simulation study to determine the benefits of RS in the OWE installation phase. The authors consider three simultaneously installed OWFs and include the transport and installation processes as well as the process times and the weather and seaway limits of the processes. The study considers the two approaches “OWF-specific resource allocation” and “resource pool for all OWFs”. By means of the RS approach, significant savings potential was identified for the OWE installation.

Uncertainty in the SC is mainly the driver of the IS in SCs. [7] describe that sharing information improves the time and resource efficiency, the service level, and the cycle time in SCs. This leads to the need for the integration of defined information flows into the processes. Uncertainty in the existing literature is primarily named on demand uncertainties of the retailer. The SCs considered are primarily two stages and consider a substitutable consumption product (e.g. [12]). In literature three levels of IS are distinguished. The first level (called decentralised information control) describes the approach of decentralised information storage without the exchange of information between actors in a SC. Level two (named coordinated control) includes the exchange of information with the upstream and downstream actor in the SC. The third level (centrally operating information) provides the full exchange of information within the SC [7]. [2, 4] present the first studies on IS in the installation phase of OWE. The authors analyse the effects of a limited information exchange. For this, the influences of weather conditions are included. The quality of the weather forecast for the transport and installation process is taken as uncertainty. [2] investigate the influence of the information items weather forecast and port capacity. [4] extend the analysis of [2] and consider a further information item (IV supply) and increase the number of OWT. The results of the two studies show that the high impact of the weather forecast on the processes can be reduced by the exchange of further information. Therefore, more accurate and reliable weather forecasts can help to improve the planning and control of logistics processes for OWF. Furthermore, the information exchange is a fundamental process for the industry to operate more effectively.

3 Simulation Study

3.1 Structure of the Simulation, Information Items and Simulation Scenarios

In this paper, an agent-based discrete event simulation model is proposed. This simulation model is based on real processes and process times. The partners of the OWE SC are represented as agents, that are able to take decisions based on available information and selected IS scenario. Based on the results of Beinke et al. [4], the information items “weather forecast” and “IV supply” are considered. The weather uncertainty comes essentially from the weather forecast. The decision-making is made based on this forecast in the simulation model and it is taken into account in the modelling of the processes. The objective of the “IV supply” information item is to use the suitable time windows of sufficient weather conditions for the installation processes. In this simulation model, the construction of three OWFs located in different distances from the shore is simulated. Due to the distance of each wind farm from the shore (OWF1 is the farthest, and OWF3 is the closest), the weather conditions of OWF3 are better than OWF2, and those of OWF2 are better than of OWF1. For the construction of each wind farm, the SC structure, the corresponding production ports, and the corresponding base port is determined. However, the resources like transport vessels and IVs are shared between different wind farms. Based on these two information items, there are four scenarios in this simulation study (Table 1).

Table 1. Simulation scenarios

Scenario	Weather forecast	Vessel availability
S1	No share	No share
S2	Share	No share
S3	No share	Share
S4	Share	Share

In the first scenario (S1), the shipment of the components from the production ports to the corresponding base port is performed as long as the base port still has capacity. In the base port, all incoming installation orders are collected in a pool. According to the FIFO principle, the project planner selects the installation order whose execution does not require a set-up of the IV. Indeed the shift from the top structure to the foundation and vice versa requires a set-up that can take until 7 days. In S2, the shipment of the components from the production ports is performed only if the weather forecast of the next days has an availability of 85%. Regarding the installation of the components, in this scenario, the orders are selected according to avoiding the setting-up of IVs and based on the weather forecast. In this context, the installation order with the best weather availabilities is selected first. In S3, the shipment of the components from the production ports to is performed only if at least one IV will be available in the next two days. The collection and the selection of installation orders is the same as for (S1). In the last scenario (S4), the foundations are shipped to the corresponding base port first. The shipment of top structure components are then performed after the final installation of all foundations. In addition, the decision when to ship a component depends, as in S2, on the weather forecast, and, as in S3, on the IVs availabilities. Regarding the installation of the components, the orders are selected according to the same logic adopted in S2.

3.2 Simulation Specifications

In order to specify the simulation, the specific parameters, the variables and restrictions as well as the indicators for measuring the performance will be presented in the following.

Parameter

WP_i	OWF i, with $i \in [1, 3]$
N_i	Number of wind turbines of OWF $i, \forall \mathrm{i}\ N_i = 80$
S	Set of information sharing scenarios, with $\|S\| = 4$
s	Index of scenario $s \in [1, 4]$
c	Type of component ($c \in [F, T, N, B]$; foundation, tower, nacelle and sets of rotor blades)
BP_{is}	Base port associated to the OWF i under scenario s
HLV_{sci}	Set of HLV used in scenario s to transport components from the production ports to base ports BP_{is}.
v	Index of a IV
vl	Index of a HVL
T	Planning horizon
Δt	time interval unit (1 h); $\forall t \in T,\ t_{i+1} - t_i = \Delta t = 1$
t	index of the planning period
$Start_i$	Planned start of the construction of OWF i
$MAXCap_{ic}$	Maximal capacity of base port BP_{is}

For further and detail information about the process times and the process restrictions see [3].

Variables and Constrains

$EndInst_{is}$	End date of construction of OWF i in scenario s
Cap_{ict}	Actual capacity of base port BP_{is} in time period t
XC_{cit}	Number of component of type c installed until planning period t in the OWF i
$StartHVL_{vls}$	Start date of usage of HVL vl used in scenario s
$RelHVL_{vls}$	Release date of HVL vl used in scenario s to transport components from the production ports
$StartIV_{vs}$	Start date of usage of IV v used in scenario s
$RelIV_{vs}$	Release date of IV v used in scenario s
$BinHVL_{vlst}$	Binary variable that indicates if the HVL vl is utilized at planning period t under scenario s
$StartBP_{is}$	Start date of operation at base port BP_{is}
$EndBP_{is}$	End date of operation at base port BP_{is}

$$\forall \mathrm{i} \in \mathrm{WP_i}, \quad \forall \mathrm{c} \in [\mathrm{F, T, N, B}]; \quad \forall \mathrm{t} \ \in [0, EndInst_i],\ \sum\nolimits_{\mathrm{i}} \mathrm{XC_{cit}} = \mathrm{N_i} \tag{1}$$

$$\forall \mathrm{t'} \in \mathrm{T}, \sum\nolimits_{\mathrm{t=1}}^{\mathrm{t'}} \mathrm{XC_{Tit}} \le \sum\nolimits_{\mathrm{t=1}}^{\mathrm{t'}} \mathrm{XC_{Fit}} \tag{2}$$

$$\forall \mathrm{t'} \in \mathrm{T}, \sum\nolimits_{\mathrm{t=1}}^{\mathrm{t'}} \mathrm{XC_{Nit}} \le \sum\nolimits_{\mathrm{t=1}}^{\mathrm{t'}} \mathrm{XC_{Tit}} \tag{3}$$

$$\forall \mathrm{t'} \in \mathrm{T}, \sum\nolimits_{\mathrm{t=1}}^{\mathrm{t'}} \mathrm{XC_{Bit}} \le \sum\nolimits_{\mathrm{t=1}}^{\mathrm{t'}} \mathrm{XC_{Nit}} \tag{4}$$

Constraint 1 restricts the sum of the built components during the planning period to the total number of wind turbines N for each wind farm. Constraint 2 ensures that the sum of installed towers for each wind farm does not exceed the sum of installed foundations. Constraint 3 guarantees that the sum of installed nacelles for each wind farm does not exceed the sum of installed towers. Constraint 4 ensures that the sum of installed sets of rotor blades for each wind farm does not exceed the sum of installed nacelles.

3.3 Simulation Results

From economical perspectives OIT and AUIV are the main important factors and the decision criterion for the SC partners in the context of OWF. For OIT, especially the scenarios S2 to S4 provide improvements to the basic scenario S1. In particular, the improvements of OWF1 and OWF3 in S4 have to be named (reduction of 17.08% and 30.90%). Generally, IS leads to a shorter OIT. Referring to the logic adopted in S2 and S4, the selection of installation orders in these scenarios is performed based on weather availabilities. Since the weather condition of OWF3 is better than other OWFs, the installation orders of OWF3 are always prioritized. This leads to a better planning of the installation orders, and hence, the reduction of the whole installation time, the reduction

Table 2. Simulation results

		Simulation results				Comparing of scenarios [%]		
		S1	S2	S3	S4	S2 to S1	S3 to S1	S4 to S1
OIT [d]	OWF 1	542.60	471.28	527.16	449.91	−13.14	−2.85	−17.08
	OWF 2	545.16	526.98	524.47	513.67	−3.33	−3.80	−5.78
	OWF 3	548.38	409.29	527.92	378.93	−25.36	−3.73	−30.90
	Total	**1636.14**	**1407.55**	**1579.54**	**1342.51**	**−13.97**	**−3.46**	**−17.95**
AUIV [%]	OWF 1	91.38	94.86	93.54	97.65	3.81	2.36	6.86
	OWF 2	91.48	94.24	93.60	94.54	3.01	2.31	3.34
	OWF 3	91.47	94.24	93.62	97.74	3.04	2.35	6.86
	Average	**91.44**	**94.45**	**93.58**	**96.64**	**3.29**	**2.34**	**5.69**
AUHLV [%]	OWF 1	55.06	48.41	52.19	48.38	−12.08	−5.21	−12.12
	OWF 2	55.11	44.63	52.39	43.78	−19.02	−4.93	−20.56
	OWF 3	55.06	51.59	52.13	51.90	−6.29	−5.33	−5.74
	Average	**55.07**	**48.21**	**52.24**	**48.02**	**−12.47**	**−5.15**	**−12.81**
ABPUT [d]	OWF 1	551.30	482.42	538.60	460.64	−12.49	−2.30	−16.44
	OWF 2	552.72	537.34	536.28	514.38	−2.78	−2.97	−6.94
	OWF 3	554.74	417.46	538.54	384.96	−24.75	−2.92	−30.61
	Total	**1658.76**	**1437.22**	**1613.42**	**1359.98**	**−13.36**	**−2.73**	**−18.01**
AUBP [%]	OWF 1	56.25	59.48	61.05	41.48	5.75	8.53	−26.26
	OWF 2	56.43	60.10	63.87	40.31	6.50	13.18	−28.57
	OWF 3	56.67	57.42	60.48	40.53	1.32	6.72	−28.48
	Average	**56.45**	**59.00**	**61.80**	**40.77**	**4.52**	**9.47**	**−27.77**

in the net usage time of the base port and an increased utilization of the installation vessels. As a result, the OIT of OWF3 in S2 and S4 is strongly reduced compared to the S1. The RS of IV slightly improve the OIT, however, the AUIV is increased due to the fact that the supply of components is based on the installation vessel availability. In addition, the OIT each OWF is identical due to not prioritizing the installation orders of OWFs. The importance of AUIV is due to high charter rates of IVs. The higher utilization is also due to the reduction of OIT. The sharing of weather data and availability of the installation vessel affects the supply of components from production ports to the base ports as well. Accordingly, the usage of HVLs is optimized. This explains the decrease of the AUHLV in contrast to S1. The fact that the supply of top structure components is only performed after the installation of foundations, leads to significant reduction of AUBP and ABPUT, without affecting the OIT. The following Table 2 summarizes the average values of the simulation results in relation to the performance indicators per OWF and in total or as an average, respectively.

4 Conclusion and Outlook

In this contribution, based on the theoretical background of planning of OWE installation logistics as well as the approaches of IS and RS, a simulation study was presented. The study examines the benefits of IS in a RS logistics network for the simultaneous installation of three OWFs. The simulation was able to prove that the impact of IS of different information items has a significant effect on the installation times and the usage times of the resources and ports as well as on their degree of utilization. By means of the IS and RS approach, significant savings potential was identified for the OWE installation. Summarizing the influences of the performance measures clarifies that sharing information has a positive effect on the logistics network for the installation of the OWE. Limited resources and infrastructures can be better used by the presented approach. This allows the installation of more OWFs with existing resources in a defined period of time and a reduction of installation costs. Furthermore, the results of this contribution could be transferred to other fields and domains like maintenance of OWF.

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Gamification of Complex Systems Design Development

Using a Serious Game Development Approach in the Learning Experience of System Engineering Design

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Abstract. This is a position paper, presenting also some preliminary results of an experiment in teaching and learning systems engineering design. Students were asked to develop games in conjunction with a system design project. We have measured the effects of the game development on the learned skills, via feedback questionnaires. The preliminary results indicate that students find the game development difficult but also like this aspect the most from the whole coursework. In terms of skills, the ability to adopt a holistic view is considered the most valuable by the students.

Keywords: Serious games · Functional architectures · Learning experiment

1 Introduction

At the University of Groningen, graduates, alumni, industry partners, and accreditation organizations of the study Industrial Engineering and Management in the Industrial Engineering and Management master (IEM), acknowledge positively the experience acquired via integrative courses present in the curriculum. The System Engineering course is one of them. This course applies both problem-based and project-centric learning. Within this course students are working in a close-knit group to develop a complex system design. The group, named a triad, and it is formed by three teams of three students and a student who acts as coordinator and integrator. Each triad models a different system, these being complex socio-technical systems, like for example a nation-wide bike theft prevention system, a large scale electric scooter sharing system, locally connected wind farms and consumers, an internationally integrated hydro-power storage system, and other large-scale multi-stakeholder systems. During the last four years (2014–2017) emphasis has been put on the use of serious games in the course, as both a learning experience enabler and knowledge acquisition enhancer. The novel approach presented in this paper encompasses not only the development of the triad's system but also the playing of a serious game that mimics the growth of the system.

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The advantages of playing sessions of a specific serious game (GasBoard, developed by university researchers together with industry partners) to support the motivation and learning experience of students during the Systems Engineering course work have been reported previously (Szirbik et al. 2015). To enhance further the students' experience in their system design, the development of a serious game that is specifically related to their triad's system design project was experimented with. The basic feature of this serious game is that the game has to reflect to some extent the system to be designed. In this paper, we are describing an experiment we run through the System Engineering course this year, to test if the development of a serious board game connected to the system to be designed can support positively the learning of systems design. A secondary goal was to find out how the game development can influence and improve the system's architecture.

The rest of the paper is organized as follows. First the context in which the experiment is taking place is described. Second the research question is operationalized. Third the experimental setting is described. As the data related to the experiment has been just gathered and it is under analysis and interpretation, only some preliminary results are presented. Finally, conclusions are then drawn.

2 The System Engineering Design Course as Context for Research and the Main Question of this Research

The system engineering design course is one of the oldest integrative course in the IEM master program at the University of Groningen. It started in 2004. The project that the students have to undertake is quite equivalent (albeit much shorter in time and smaller in scope) to the pre-inception phase in a real system development process (Buede 2009). The main output of the coursework is a design of a complex socio-technical system. This consists of a context-placed operational architecture of the system, comprising a functional architecture and a (mostly) generic physical architecture. There are two deliverables for each triad. The first is the Originating Requirements Document (ORD), which is a text augmented with functional and physical diagrams, and a System Requirements Document (SRD), which is a digital database for system design (developed in CORE, a computer aided systems engineering tool, by Vitech Corp.). These two deliverables have to be consistent with each other; the ORD is intended for system's stakeholders use and the SRD for the developers use. The system modelling in both deliverables is relying mostly on IDEF0 (CORE supports this graphical language) functional models – using hierarchical and interaction diagrams to depict the functional architecture. For the quality and detail of this functional architecture the students get more than half of their grade.

Each triad of students has to develop a system design of a complex socio-technical system. To prevent mimicking, no two triads have the same system to design, and from one year to the other, the systems are not repeated, to prevent inter-generational plagiarism. The choice for the socio-technical system to be designed is let to the members of the triad (i.e. they are playing the role of stakeholder and designer in the same time). To allow concurrent design, each team in a triad is responsible to develop a part of the architecture – roughly a third. These parts are delimited by the students themselves. In order to insure coherence between parts and organize the cooperation and the communication between the teams, a separate, tenth student in the triad is playing the role of system integrator. The coursework takes 10 weeks to complete. During this period, the individual teams and the triads have to deliver 3 intermediary ORDs and SRDs on which they receive feedback from tutors. The timing of these deliverables is illustrated in Fig. 1.

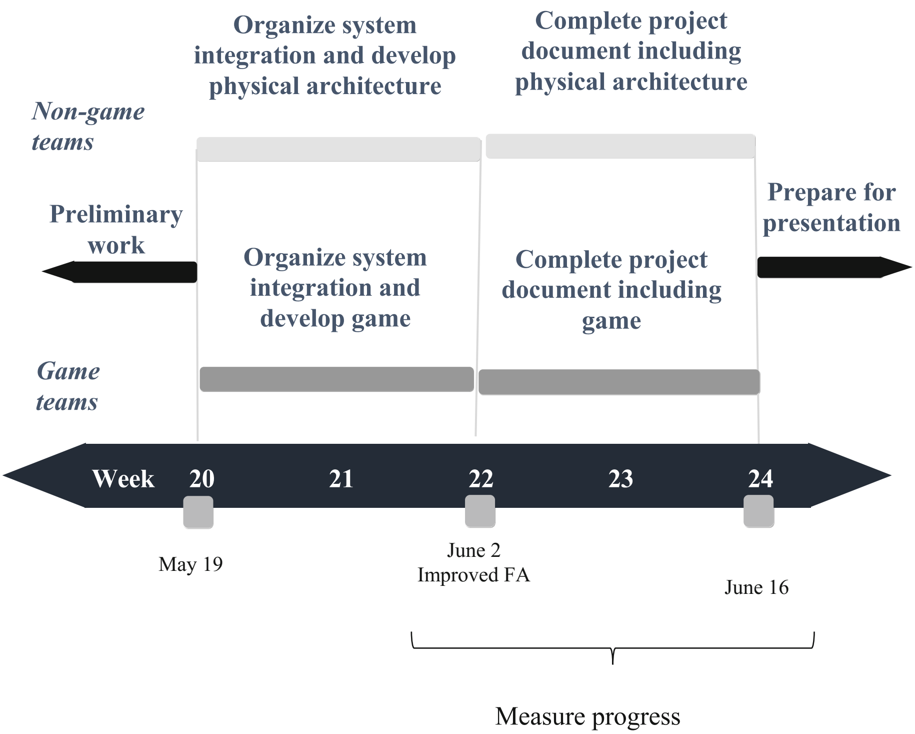

Fig. 1. The timeline and the three deliverables related to the experiment

In 2015, serious game playing sessions in GasBoard have been introduced into the course to address observed motivational and communication problems at team and individual levels. It successfully improved the cognitive engagement between the teams and individual students who were doing the designs. It also enhanced the communication and alignment in the integrative process, heightening the motivation to finish with an exciting result. Moreover, it challenged to explore and find new design ideas (Szirbik et al. 2015). Despite the observed improvements, the students who played this digital game reported that the game was "too restrictive and impossible to adapt to their own ideas" (Velthuizen 2016). They suggested a non-digital version in the form of a board game and argued that "it would have been more interesting and useful to have a flexible board game that was easy to change according to the changes they made in their own design" (Velthuizen 2016). Letting students to develop their own non-digital board game during their system design development has both material and educational advantages. Considering the material advantage, it saves the resources needed for the development and implementation of a digital game. In fact, it is possible to begin with a clean slate, developing the board game from scratch. The educational advantage is that it offers the flexibility required to try new ideas for the game, as it is easy to implement, change and adapt during a project development. These are features that are particularly important when exploring solutions for the blockage encountered in the preliminary development of socio-technical system of 'chicken-and-egg' development conundrum type (Szirbik et al. 2014; Ittoo et al. 2013a, b). This type of system is characteristically marred by the investment blockage phenomenon. Typically, there are stakeholders who are interested to develop a technology-heavy infrastructure for specific clients, but the development funding would be available only if the usage of the infrastructure would enable the users to pay for it (Wene 1996). This type of systems has been often encountered in multiple past and recent infrastructural projects such as renewable energy networks (Veeningen 2016) and liquefied natural gas infrastructure (Thunnissen et al. 2016) and are often chosen by students. The triads that have developed these kind of systems were the ones encouraged to undertake the supplementary task to develop a board game mimicking the growth of the system to be designed.

We expected that developing a board game and playing it can have multiple effects and yield various research results. First, the learning experience of the students is expected to be better than without the game development – we name this the *learning* effect. Second, the generic framework to develop games can be continuously validated, and if necessary, refined – we name this the *knowledge* effect. Third, the final system design in the project can be affected by the game development activities that take place in the same project – we name this the *design* effect. Though we pursue all three lines of investigation in our research, we focus here in this paper only on the learning effect. Therefore, this paper specifically describes the experimental setting that has been developed to answer the question: *How does the game development by students during the coursework support/influence/hinder their learning of systems engineering design.*

3 The Experimental Setting

In order to answer the research question, the study is focusing on the experience of the students who were part of teams designing systems having a chicken-and-egg characteristics. Seventeen out of the 27 teams of the class of 2017 had to design such a system. Six out of these 17 teams have agreed before the first deliverable date to develop a board game – and three of these games were specifically linked to an entire triad's system. Six other teams (actually two whole triads) out of the initial set of 17 attempted later to develop a game to support their final presentation. To keep the workload fair with the other teams, the initial six game teams did not have to finish the physical architecture part. However, this is not really a change, because the game itself contains in the end most of the physical elements of the system. The playing off the game is intended to mimic the growth of the system and it is supposed to help the stakeholders with the discovery of bootstrapping scenarios for the system that is designed by each team. These six teams were provided with a generic framework (architecture and guidelines) for developing chicken-and-egg problem serious games and a manual of how to apply it (Veeningen 2016). Both the game teams and the non-game teams were pro-actively supported by the instructors during tutorials and received feedback after each deliverable.

We investigated the merits and value of using a game development complementary to the system design that the students have to do for their team project. We focused on the learning effect, that is, the development of the game and its continuous refining and testing will affect in turn the depth of understanding of the students about how systems are designed. In the end, our hypothesis is that the skills and knowledge necessary to design a complex multi-stakeholder system design can be improved by complementing the design process with a serious game development that explores bootstrapping scenarios for its gradual development.

The experiment takes into account the learning results of all the 17 teams that chose a system design that have the "chicken and egg" characteristic. The hypothesis of this research is that these game development and play activities have some positive effects on how the students grasp the basics of systems engineering design. Data is gathered via the two last team's deliverables to assess the design effect of game on the output, and via general course feedback questionnaires that were handed out to all students of System Engineering to evaluate the effect of developing a game on the. The questionnaires inquire about the skills the students think they have learned, what they liked, what they found difficult, their proposal for course content change, participation in post-mortem workshops, continuing to be involved in System Engineering and any other comments about the course. The questionnaire did not contain any specific question about the experience with the game. For the purpose of this paper, we only looked at the skills the students reported to have learnt during the course, and the most liked and disliked aspects in the coursework. For each of the section, they were allowed to give multiple answers. In the next section, the answers provided by the students involved in teams designing chicken-and-egg type of system is presented and analyzed.

4 Some Preliminary Results

The original goal was to assess the effect of the game development on the quality/completeness of the final functional architecture. The analysis of difference between the improved Functional Architecture and the final one (the difference between the next to the last and the last deliverable) had proved to be inconclusive, as the student teams did not found the time to include any modification.

Out of the 52 students working on a chicken-and-egg type of system, 30 completed the course feedback questionnaires, which contained a number of 11 open questions – 3 of which are reported here. Fourteen of students were those out of 18 of the students who were part of teams committed to develop games, and 16 of students were those out of 34 the students who did choose not to develop a game. From these completed questionnaires, the information presented in Tables 1, 2, and 3 was compiled. Table 1 presents the answers collected that relate to the question about the skills the students openly reported to have learnt (without any suggestion for the response). Table 2 is about the aspects of the course that the students liked the most, and Table 3 about the one they liked the least (again, without any suggestion for the response in the questionnaire).

Table 1. Most important learned skills for different types of groups

Skill	Original game	Not originally game
Group work	4	13
Functional thinking	5	11
Holistic view	6	0
Abstract thinking	3	1
Creativity	1	2
Switching from FA to PA	0	2

The skills reported by the students in the course feedback questionnaires are: group work, functional thinking, holistic view, abstract thinking, creativity, switching from functional architecture (FA) to physical architecture (PA) (cf: Table 1). The skills the most often mentioned are group work (17), functional thinking (16) and learning to acquire a holistic view (7). The acquisition of the two first skills, group working and functional thinking, are in large majority acknowledged by the members of teams that did not develop a game. However, holistic views skills are mentioned **only** by the students that were member of teams that originally decided to develop a game.

The most liked aspect about the course are the aspects related to the game development (8), the group work (6), aspects related to course form (3), creativity (4), functional thinking (2), creation of a realistic, tangible system (1), holistic approach (2), developing the system (2), the freedom for own project (1) and playing the game (1) (cf: Table 2). The game development was mentioned eight times by eight different students. One of these eight students was a student of a late game development triad. Seven students mentioned the group work as their favorite aspect of the course; all of them were in teams that did not originally choose to develop a game. If we consider the students who chose originally to develop a game, the development of the game is chosen most often as most liked aspect, followed by aspects related to the course form. It is interesting to notice that none of them mention group work as most liked aspect of the course. For the students not originally choosing to develop a game, group work is the most popular aspect, followed by creativity and functional thinking.

Table 2. Most liked aspect about the course

Most liked aspect	Original game	Not originally game
Game development	7	1
Group work	0	6
Related to course form	3	0
Creativity	2	2
Functional thinking	0	2
Creation of a realistic, tangible system	1	0
Holistic approach	1	1
Developing system	1	1
Freedom for own project	0	1
Playing the game	1	0

The most difficult aspects about the course as reported by the students are functional thinking (7), game development (6), high workload (4), working on a large system (3), group work (4), functional architecture development (3), defining the initial system (1), managing the deliverables (1) and gathering real-world data to make the system feasible and real (1) (cf: Table 3). Depending if the students were making a game or not, the aspects found the most difficult differed from answer to answer. For the students making a game, the development of the game came first followed by functional thinking. For the students not developing a game, functional thinking came first as the most difficult aspect, with group work coming second.

Table 3. Most difficult aspects about the course

Most difficult aspect	Original game	Not originally game
Functional thinking	4	3
Game development	6	0
High workload	2	2
Working on large system	1	2
Group work	1	3
Functional architecture	2	1
Defining the initial system	0	1
Managing deliverables	0	1
Gathering real-world data to make system feasible and real	1	0

5 Conclusions

The students from the groups initially choosing to develop a game reported most often the ability to adopt a holistic view as most valuable skill, followed by functional thinking. In addition, **even if developing the game has been considered as the most difficult aspect they also liked this aspect the most**. Group work is only mentioned marginally by these students in each of the three questions. The students who did not choose initially to develop a game found the group working skills the most valuable skills learned during the course. It is also the most liked aspect and also considered the most difficult aspect of the course. Functional thinking was also considered to be one of the most difficult aspects of the course. From these observations we can conclude that developing a game indicates a perceived increase of the ability to adopt a holistic view as the most valuable, and it is noticeable that this skill is not mentioned at all by the students not initially choosing to develop a game.

These results pertain only to a quantitative interpretation of a small part of the data collected during the experiment. However, the games were filmed, hundreds of notes were taken, post-mortem focus-groups were organized, and the game themselves can be analyzed and compared. We still have to sift through this trove of qualitative data and find the right interpretations. For example, one triad remarked: *"with the creation* *of the game, we had to work completely together, everybody's ideas were discussed and considered, we agreed, we disagreed, we argued, and improved together our game. More collaboration than ever during the course came up with the game"*. Many more interesting remarks of this kind wait to be properly analyzed and interpreted.

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A Generic Architecture for Quickly-Deployable, Flexible, Scenario-Oriented Serious Games

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Abstract. Serious gaming can be used in system engineering design processes, in the pre-inception phase, where investment scenarios are explored in game sessions with stakeholders. However, scant knowledge exist in the literature about how to design this kind of games. Based on the experience of three consecutive phases of game development for infrastructure projects in biogas, local wind energy and LNG refuelling infrastructures, a generic architecture was developed and made explicit as design knowledge. This paper outlines the architecture, offers insights about its application, and explains how the validation of this knowledge takes place.

Keywords: Serious gaming · Scenario discovery · Generic design knowledge

1 Introduction

Serious games are typically used for educational and training purposes. Some games help various stakeholders (owners, users, customers) to understand better the working of complex systems. However, there are scant research results for using serious gaming as a tool to discover potential development scenarios in the design of complex scalable systems. The generic architecture presented in this paper is potentially useful knowledge for stakeholders who are willing use games in the design and development of complex systems. Such a kind of games has shown the potential to discover unforeseen scenarios based on the decisions that the players made in the game.

The architecture proposes a board game, partially supported by software - to allow players (namely the stakeholders) make calculations and decisions, and to allow the game master to give players an idea about the quantitative aspects on the board. The software's role is also to monitor and record the decisions of the players. The board allows stakeholders to have an intuitive visual feedback on the status of the game, which changes over time as the players make decisions, mimicking the growth of their target system. The decisions made in the game entail investments into physical elements of the system to be developed. On the

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board, physical playing pieces are placed to represent these investments, recorded by the software.

Results with games of this kind show that solutions not thought of before the game sessions started can be found by stakeholders - providing them with a stronger incentive to commit for development of the system to be. For example, in a setting of an energy infrastructure where producers and consumers of energy were operating individually, they did not realize that they can work together to gain a more optimal energy price for both parties. Through serious game sessions, those stakeholders can come together and play the game to discover what they can accomplish when they cooperate and understand each other better. Similar early findings were presented in the work of Tan [4], which investigates multi-stakeholder games used for urban development.

The paper is structured as follows. In Sect. 2 the research goal and the methodology used are described. Next, in Sect. 3 the generic architecture is presented and what is the novelty about this architecture is outlined. Section 4 shows how the architecture can be applied for new contexts and validated further. Section 5 concludes the paper and presents shortly the immediate next steps for future research.

2 The Research Goal and the Methodology

There is gap in the literature about serious games - that is, there are not yet any development frameworks for games that can be deployed very quickly. Moreover, the games are not flexible and adaptable from one gaming session to the other (or even within the same session). Finally, there is no knowledge to develop games that are scenario-discovery oriented. By studying the development of specific games for scenario discovery, the authors (who were sometimes involved directly in the development) gathered knowledge with the intention to build a framework (a generic architecture with its guidelines for application) for future game development that has as a main purpose the scenario discovery.

As a consequence of this goal, the methodology chosen in this research is design-science research [1]. This research method indicates that an artifact needed in practice is designed within the process, it is validated (in this case by successfully using the game), and generalizable contributions are made for future designs. Here, the artifacts are a series of serious games where consumers of energy, producers of energy and investors can together discover future potential scenarios for their energy infrastructure (e.g. biogas grids, locally distributed win-produced electricity, or an LNG-based infrastructure for road freight). This artifact is specifically designed to solve the real problem of mismatch between goals and perspectives on doing investments in energy infrastructure.

The extant design knowledge used to design the initial versions of the aforementioned games is mostly taken from the game design professional literature [2]. Next to this body of knowledge, the research framework (FASD) proposed by Velthuizen [3] after the development of the first game (named GasBoard) was used to position the next games and evaluate their design process. In the end, after developing three playable games, in order to contribute to literature, it has been decided that a generic architecture (accompanied by guidelines of how to use it) should be extracted from the lessons learned during each iteration of game design, development testing, and game validation.

3 The Generic Structure and Process Flow of Scenario-Centric Games

The novelty of these games is that they are explicitly deployed to explore investment scenarios in a complex socio-technical context of an early system development. The specific games developed over the years were related to environments where energy producers and consumers were solely dependent on a large monopolistic grid operator (for gas, or electricity, or LNG imports). The serious games let the players (which were playing the role of the stakeholders in these systems) to engage themselves with investment decisions in alternative and local energy infrastructures. They can make investment decisions and long term commitments, erase the slate, start again, discover alternatives for investment and commitments, negotiate, argue, and try to find win-win situation in the longer term. At the end of multiple sessions of game playing, the experience can offer insights to the players (i.e. the stakeholders) how to develop a decentralized energy infrastructure that is more profitable and efficient from their local points of view. As an outcome of the game, the investment decisions and commitments that the players make can be transformed into potential future scenarios for infrastructure development. These future scenarios help the design and development of the complex system envisaged (in these particular situations, the energy infrastructure, but it can be any kind of strategic infrastructure where the stakeholders are the local communities, the local economy, the local authorities, and potential investors and system developers).

Irrespective of the nature of the system to be, over the iterations made to develop these games it has been observed repeatedly that a game of this kind needs always to consist of the following **structural** elements:

1. Game Roles: These are place-holders in the game for the participants who play the game. For example, such a role can be "Investor", and to each role, we can assign a set of possible actions (e.g. "invest" for the Investor role). Some roles can be easily identified by matching the roles of the stakeholders of the system, but other roles (like Investor) can be added. One player can play multiple roles, and in a more advanced setting some roles (those can have simple and predictable behaviour, easy to capture in mathematical models) can be played by soft-bots specially implemented for the task.
2. Game Components: these are mimicking the physical components of the system. For example, in a game that explores the scaling up of a LNG infrastructure, the components could be: refuelling stations, pipes, storage facilities, supply means, etc. The game starts typically with a few elements, and the number of these is increased during the game. A price is attached to each kind of components.

3. Game Board: the components appear in a “geography” context”. To mimic this, a map-like support will be used to place the elements on specific locations.
4. Game Rounds: to mimic the passage of time, the game playing will be separated in rounds, each consisting of two parts: first, a mimicking of accelerated passage of time (for a given period like 1 month or 1 year, depending on the nature of the system to be); second, a period of discussion and negotiations between the players, and decision making.
5. Game Rules: because the players can interact informally during the rounds, it is necessary to establish rules for their interaction that constrain what they can do, and what they can produce.
6. Game Outcomes: these can be established formally at the beginning, but such a game should be able to discover outcomes (like a new kind of contract or agreement) during a game playing.
7. Scenario: the (time ordered) set of outcomes.
8. Means to record the state: besides the elements placed on the map, there should be some sort of recording the quantitative nature of states and outcomes (e.g. how much was invested at a given moment in elements).
9. Means to record the scenario: a more detailed recording mechanism for the outcomes.
10. A realism checking mechanism: an algorithm or set of algorithms that can infer the change of the state (physical and financial attributes) of the system, showing how the system grows from one round to the other.
11. Game Observers: non-player humans that have role to identify the growing scenario (this is not a task of the players – normally, the system developers fill this non-player role).
12. Game Master: a human who applies the rules, directs the rounds, mediates, and helps the players during a game.

Another part of the architecture is represented by the description of the **process**-related elements (activities) of playing the game. It has been repeatedly observed that the flow of activities is always similar to the following sequence of steps:

1. The players are instructed in the game playing and they are choosing their roles.
2. The game starts with a given situation of the board (some elements are set up – mimicking the small-scale state of the system).
3. A round starts: first, the players must interact: discuss, negotiate, and make decisions (like contractual agreements, investments, etc. – according with the rules). These are observed and recorded.
4. The rounds will end by applying the decisions on the board and in the realism checking mechanism, making an accelerated “jum” in time. The state of the system (in scale and output) changes accordingly. This step can be considered also the first part of the next round.
5. The players are informed about the new status, and a new round of negotiations starts from step 3.

6. The game master decides when to stop the game, after several rounds – most probably when a scenario has been found, and/or the system to be mimicked in the game is reaching a sustainable magnitude.
7. Post-mortem analysis: the scenario is discussed and refined, and agreements for an eventual new game session are made.

The game master is in the control of the game, its software, and it is responsible to inform the players about the status and evolution of the game from round to round. He is checking the time, forcing rounds to end, and players should ask the game master permission for actions that are not specified a priori, and he should be able to detect easily illegal actions (which violate the rules).

Besides and after the post-mortem analysis (which is centred on the scenario), at the very end of each gaming session, a formal discussion takes place on how players experienced the game and what they thought was positive and what could be improved in the game itself. The observers can record and analyse the results of these discussions, and for the next gaming session new roles, game components, rules, or outcomes can be implemented in a new version of the game - which can involve also changes in the realism checking mechanism and the software tool. It is important for a game development team to constantly have in mind that playing the game multiple times is mainly the way to gather valuable feedback about how the game could be refined and improved. For example, in a situation when the game was played successively, and the game itself evolved, the following feedback was recurring:

- About inter-player communication: communication about the deals were not supposed to be intercepted by other players, as this might contain valuable information. Therefore, it is wise change the layout of the game space, in order to allow pairs of players to negotiate "securely", in spaces (like separate cubicles or even rooms).
- About the tools used during the game: the tools were initially to difficult to use or did not allow for all the moves that were allowed by the existing rules of the game. A simple solution is to have a training round in the beginning of the game.
- About the number of players: it was always argued during the first sessions that adding more players can increase the number of interesting scenarios. A simple solution is to start with the highest number of players possible.
- About player roles and rules: some roles appeared to expand during the games, the investors for the example, in the initial rounds were only allowed to finance investments, but soon turned out to become asset owners and operators of elements in the infrastructure.

4 How to Use the Generic Architecture and Validate It Further via New Games

The most important insight related to this kind of games is that they should be focused on stakeholders' human behaviour. It was noted [6,7] that in the domain of networked infrastructures, the complex, multi-stakeholder, large-scale system design is perceived as a strategic process. However, this is not its main characteristic. It is neither predominantly financial, neither technological, albeit it has aspects related to these dimensions of analysis. In the end, what all complex system designs have in common is a dominant human dimension, given by the behaviour of various stakeholders, all competing to resolve their (sometimes opposite) goals, understand each other's different backgrounds, biases and prejudices. This is obvious for any large-scale and long term infrastructure project in energy, communication, transportation, defence, landscape transformation, or space exploration. Hence, the study of complex system design is also the study of stakeholders' social interaction and behaviours. All complex system designs (like the Delta project in The Netherlands for example) are part to particular contexts, to the societies and economies which source the resources to implement them, and are sometimes emotionally related to the technologies that are well-established and sustained in those societies (for example, currently nuclear technology is not supported by society in Sweden or Germany). A study of the process of complex system design, albeit it has to be technologically grounded, has to study the process on a behavioural, deeply human dimension. In such a project, each stakeholder tends to project its own beliefs about what the other stakeholders think, how they behave, and how they act toward a decision. Most of the time, exactly because of this projection tendency, the process to find a design and especially to find a plan to realize the design ends in failure.

4.1 Guidelines

In the following list of activities to implement a game based on the previously proposed architecture, the **fourth activity in the list is the most important** and should take most of the time of the game development and refinement. The proposed order of activities for implementations is:

1. Identify the physical elements of the game. Normally, these are the main physical components (modules, sub-systems) of the system to be. The elements are implemented as game pieces that can be placed on the board.
2. Identify the roles in the game. Roles may own or influence elements. For example, if similar elements are owned by two different players playing the same kind of role (e.g. an owner of an LNG refuelling station), different colors should be used for similar kinds of elements, to show different ownership (like in most of the board games).
3. Establish the board. Initially, it is advisable to start with a generic map, composed for example of a raster of equal hexagons. Physical attributes like distances can be inferred from the number of raster parts used for a certain placement of elements. Later, real life maps can be used, in conjunction with geographical elements (like rivers) and infrastructure (like cities and roads).
4. Establish a list of regulated interactions between the roles. For each kind of interaction, establish certain rules of conduct, and potential outcomes (like contracts, long term agreements, new regulations to be enacted, if the player is a regulating body).

5. Find ways to record the quantitative aspects of the state (magnitude) of the system to be at a given moment.
6. Find ways to implement the time advancing algorithms and the realism checking mechanism; initially these should not be too realistic, and should focus mostly on the financial aspects (revenue, losses and profit). Later, more physical aspects can be included in the realism enactment. It is recommended that each player should have a separate view about its own status, and everybody should have some sort of general idea of the evolution of the system to be - this sheet can be projected on a board visible for all players to see.
7. Find ways to capture the outcomes and the overall scenario that emerges.

The game should always exhibit the advancement of the game situation via the decision making of the players and not via stochastic mechanisms like dice or randomly extracted cards - for some degree of uncertainty, these can be used, but with parsimony. The outcome should be clearly a result of human interaction and not a mixture of chance and player skill like in entertainment games. There is no single winner in such games, but ultimately, what is sought after is a satisfying long term win-win outcome for all stakeholders.

4.2 Validation of the Generic Knowledge

In a design science approach, the validation of a generic architecture for a specific class of artifacts in is a gradual process. Basically, each successful implementation of an artifact in a given context that is using the knowledge embodied in the generic architecture is a validation step. More successful implementations in different contexts means a stronger degree of acceptance of the generic architecture and a growing perception in the professional community using it that this generic architecture is validated design knowledge.

In our years-long process of developing these games, the first game (GasBoard) was implemented by using extant knowledge about board games, and the game was gradually adapted to the requirements of the stakeholders from the biogas industry who were involved in the development project. When the game was mature, and validated itself as a successful artifact, the developers considered that the knowledge acquired about the development process of the game should be captured in some form. This is why the FASD [3] was created at that time. However, this did not represent an explicit form of a generic architecture, albeit the developers had at the time a clear implicit idea about such an architecture.

The next game (FromEnergy2Synergy, [8]), has used FASD as input, was successfully validated by playing it many times, and added to the design knowledge by adding guidelines for implementation and deployment of the game. However, only after the development of the third game (investments in the LNG-refueling infrastructure), the developers decided to explicitly build a generic architecture, which is to be validated separately. The first step towards validation was to enact a validation workshop [5], where the explicit architecture was discussed by the various developers of the three games. The net result was that the generic architecture was refined and better structured.

Finally, the generic architecture was recently (May–June 2017) used in an experiment with students, who developed games in a project. Three development teams were provided with this generic architecture (in the form of a manual) and three teams were not provided. Currently, the results of this experiment are analysed and will be published in a subsequent paper. Preliminary results show a clear advantage for the teams who used the generic architecture. For example, one of the teams, who was late in the development, managed to implement a playable, very immersive and engaging game in only three days. These developers, in a discussion after the last gaming session, considered the generic architecture document to be a crucial element in the speed of the development.

5 Conclusions

To our knowledge, this is the first attempt to build a generic architecture for scenario-centric games. These games have to be quickly enacted for the stakeholders in complex system projects. The game playing takes place very early in the development process (pre-inception), and the games have to be highly adaptable to changing requirements.

The next step is implement more of this kind of games that are using this generic architecture as design knowledge, and based on the success of these implementations, validate and refine further the architecture. The games can be either developed by students, for research projects, or by industrial partners interested in local infrastructural developments where "chicken and egg" situations appeared. These findings have to be reported and the generic architecture should be made available as open source for everyone who wants to develop such games. Any new successful implementations should be described along with the open source, as it validates further the architecture.

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Transforming a Supply Chain Towards a Digital Business Ecosystem

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Abstract. This study describes the intervention process of transforming a peat production supply chain towards a digital business ecosystem. We conducted a series of participative, co-creative workshops to facilitate and to research the transformation process. According to our findings, a wider ecosystem perspective to transformation helped to overcome the initial motivational challenges felt by the supply chain members. In the workshops, the participants were able to create joint meanings of social, financial, and use value of digital data, and to collaboratively make decisions about the transformation towards a digital business ecosystem. This was due to the participants' collaborative knowledge creation and negotiation processes, supported by the facilitators applying co-creative methods. Our results suggest that a developmental intervention provided a temporary governance structure for the participants to collaboratively create a shared logic for the digital business ecosystem creation.

Keywords: Digital transformation · Developmental intervention · Business ecosystem · Peat production · Supply chain

1 Introduction

The digitalization of data and business processes opens up new avenues for improving existing business and for creating new business. Companies often approach digitalization as a technical exercise – the right technical tools are thought to digitalize the business. However, especially in a supply chain, the biggest challenges hindering digitalization usually relate to the differing interests, working cultures, and economic models of the members [1].

Digitalization changes the interdependencies between existing supply chain members, and can open it to new members, so that the supply chain can start transforming towards a business ecosystem. The transformation threatens the members' existing roles and "micro-specialized competences" in the existing value network [2]. On the other hand, digitalization of a supply chain necessitates collaboration between the current and future potential members of the forming digital business ecosystem. Any single member alone cannot grasp the potential value of the forming business ecosystem as a whole [3], and thus the integration of the members' competences into

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collective value creation should be a shared responsibility. More research [3] is called for to understand the dynamics of ecosystem transformation. Our study addresses this need by analyzing the institutional characteristics of an ecosystem, and specifically, how these characteristics are co-created in an emerging ecosystem in a process of negotiation.

Our study focuses on the transformation of an established institutional value chain in the Finnish energy sector, namely the peat supply chain. We conducted a developmental intervention in this supply chain to facilitate its transformation towards a digital ecosystem and to study the transformation itself [4]. We aim at contributing to the emerging theory on creating digital business ecosystems that builds on organizational ecosystem and co-creation literatures.

2 Theoretical Background

2.1 Organizational Ecosystems and Negotiated Order

Thomas and Autio define an ecosystem as an organizational field that encompasses all participants that focus on collective value co-creation [5]. The interdependent participants of an ecosystem are bound together through three characteristics [5, p. 12].

1. *A network of participants*, each of them providing a particular, complementary *input* to the system. Through their cumulative interaction, the participants add value. The inputs of the participants need to co-evolve.
2. *A governance structure* coordinates the participants' interaction for collective value creation. It consists of an authority structure for decision-making, conflict resolution, membership control for handling ecosystem openness, and coordination.
3. *A shared logic* glues the participants of the ecosystem cognitively and socially together in understanding their interdependency: a sense of legitimacy, trust, and mutual awareness about being involved in a shared enterprise of the ecosystem.

The institutional approach on organizational ecosystems offers also theoretical insight into supply chain transformation. Negotiated order theory holds that organizations can collaborate in constructing their organizational field by agreeing on the rules for their interactions through negotiation [5, p. 23]. In practice-based theoretical research, negotiation is considered an important relationship between knowledge producing communities [6]. Negotiation is profoundly different from conventional organizational coordination: it is capable of creating dynamism in the organizational structure, and highlights the significance of balancing individual interests in inter-organizational collaboration [7]. Negotiation is also needed to deal with conflict in organizational transformation. Power asymmetries can result in a reduced likelihood of co-evolutionary change in the ecosystem [5].

2.2 Co-creation of Knowledge for Business Ecosystem Creation

The creation of a business innovation ecosystem proceeds in principle in three main steps [3]: first, the collaborators need to connect and define their relationships. Second, they negotiate shared objectives and define a common identity. Third, they define the actions needed to achieve the objectives.

When an existing supply chain begins transforming towards a digital ecosystem, it starts with the current members and their interdependencies, motives, and value adding logic. Transformation is a challenge for the current and new members of the emerging ecosystem. They have to collaboratively redefine their value adding interdependencies [4]. This requires sharing and co-creating knowledge [1]. Modelling the knowledge into visual boundary-objects supports knowledge sharing, collaborative ideation, and co-creation [8]. External facilitators help ecosystem members make sense of the situation, share, negotiate, collaborate, and design their changing interdependencies [3].

3 Research Approach and Methods

This study is based on an action research based intervention where the researchers have the role of network facilitators [7]. Action research allows both to increase scientific knowledge in the area and to initiate change in the studied organizations [8, 9]. Action research gave us the unique access into the case network for researching the transformation of the supply chain.

3.1 Developmental Intervention for Digitalizing Peat Production

We organized a developmental intervention to help in digitalizing a peat production supply chain for energy production. Figure 1 depicts the members of the peat production supply chain: sub-contractors, a hub company, and a power plant client. In addition to these members, we invited representatives from a peat harvesting machine producer and from software providers as co-creators of ideas for digitalization, and university professors, researchers, and students. Public environmental organizations and regulative bodies were not represented but are part of the forming business ecosystem.

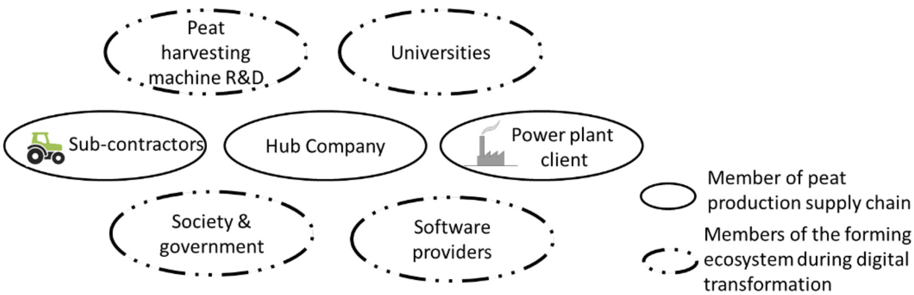

Fig. 1. The participants of the peat production ecosystem during digital transformation.

3.2 Data Collection and Analysis

The intervention was conducted during December 2016–March 2017. Researchers and students from Aalto University designed and realized the intervention and collected the research data that included interview transcriptions, process and value network models, notes from four successive workshops, participant observation, and video recordings. Data triangulation increased the validity of research [9].

In the first workshop, a preliminary understanding of the process was co-created. Then, eighteen participants were thematically interviewed. They were members of peat production supply chains in two locations in Finland. The interviews dealt with information flows and work practices in peat production, but also with the basic assumptions and motivations of the different participants towards digital transformation. Three researchers designed and analyzed the next three workshop based on progressive problem identification and solution finding; the goal of each workshop was set based on the findings of the earlier workshops (Table 1).

Table 1. Goals and outputs of the developmental workshops.

	Workshop I 21.12.2016	Workshop II 3.3.2017	Workshop III 17.3.2017	Workshop IV 31.3.2017
Goal	Understand current data flows in the peat production process	Understand the challenges in managing peat product quality data	Develop solutions for tackling the challenges	Develop a concept model for the digitalized peat production
Output	An initial process model of peat production	A value network model	Detailed peat production process and value network models	A concept model for digitalizing peat production

In the workshops, the participants were brought into facilitated dialogue about their forming digital business ecosystem, across their different views and goals. They discussed their networked operations and the possibilities of producing and exploiting digital data throughout their peat production process. Based on the research data, the researchers designed peat production process models and value network models that were used in the workshops as visual boundary objects [8] to support knowledge co-creation.

In data analysis, we followed the logic of abductive scientific reasoning [10, 11]. Abductive reasoning is well suited for interpretive action research, where analysis progresses as a continuous dialogue between theoretical knowledge and the data that was collected at different points of time [12].

4 Findings and Discussion

4.1 The Current Supply Chain and Its Transforming Characteristics

The governance of the current peat production supply chain is decided by the hub company - subcontractor relationship based on competitive bidding. The hub sets the objectives for subcontractors and controls the supply chain. The production responsibility is largely transferred to the subcontractors, who work independently according to their contracts.

The peat production process is well established as an operational process, but the product data concerning the quality of the peat is estimated by the members of the supply chain through subjective and manual practices, and communicated through various means in the different phases of the production process. The members of the peat production would benefit from the digitalization of peat data and its communication because up-to-date product data is critical for the energy efficiency of the clients' power plants, and it determines the payments to the hub and the subcontractors.

At the start of the intervention, the members of the supply chain had some ideas about digital sensors and data management systems for peat quality data. However, digitalization motivated mainly the hub company that would potentially gain the most business benefit from it. While the subcontractors in general welcomed new quality measurement technologies, they did not see how they could get any added value. With digitalization of the members' data input, their interdependencies in collective value creation could change, and the benefit that each member would gain from it was uncertain. There was no shared logic of being "in the same business ecosystem of digitalized peat production".

According to the interviews, the members had their own development agendas for digital solutions, and sub-optimization was felt a challenge. The companies did not yet perceive digitalization as a supply-chain wide effort. The powerful hub company was carrying out internal technology projects, and the sub-contractors were not part of the development work. The harvesting equipment manufacturers were only seen as providers of production machines for the current production process, not as partners in the forming ecosystem. The hub company's greater power in the present supply chain seemed to dampen the other members' motivation for transformation.

In the facilitated workshops, the supply chain members felt inspired by the idea of a wider peat production ecosystem that they could jointly start creating, supported by visual boundary objects. The competitors, technology providers, government bodies, and national policies (peat is classified as a fossil fuel in Finland and its use is considered as non-sustainable in the long run) create threats but on the other hand also offer resources and novel possibilities for digitalization. Digital transformation clearly expands the existing boundaries towards a wider ecosystem. Our results suggest that the digital transformation of the existing supply chain should be understood and facilitated from a wider ecosystem perspective (Fig. 1).

4.2 Knowledge Co-creation and Negotiation for Transformation

During the intervention, for the first time a substantial amount of knowledge concerning the data management of the current peat production supply chain was collected and shared among the participants. In the workshops, the participants clarified their tasks in peat production. They shared knowledge, views and, motives while discussing the challenges in data management, and jointly created digital solutions for tackling them. Further, they could now grasp the importance of digital peat quality data: the whole ecosystem is partly financially compensated based on the quality of peat. A shared logic of the forming ecosystem started to germinate among the participants as they jointly created meanings of social, financial, and use value of digital data.

At this point, we have not yet collected follow-up data on the effects of the intervention on ecosystem creation. However, we can already observe some early evidence. In the facilitated workshops, the participants could collaboratively negotiate and select issues that they considered most significant for the digital transformation of the peat production supply chain. The representatives of the hub company, the sub-contractors, and the wider ecosystem members all participated actively in the negotiations that resulted in focused project proposals for furthering the digital transformation, and in ideas for the implementation of those projects. The intervention thus contributed importantly to the governance of supply chain transformation. Summarizing these effects, the intervention provided a temporary governance structure and a shared logic for ecosystem creation (Fig. 2).

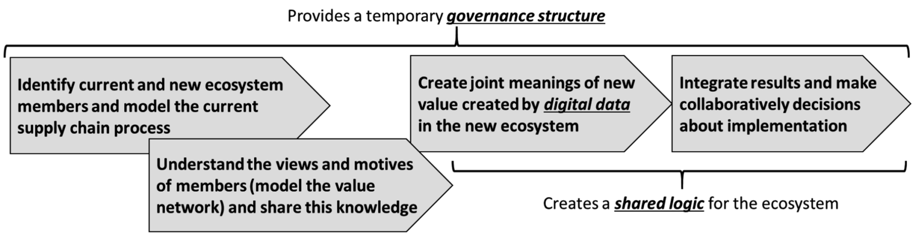

Fig. 2. The intervention created a "temporary governance structure" for digital transformation

5 Conclusions

We facilitated the transformation of a supply chain towards a digital business ecosystem systematically through a developmental intervention that included four participative workshops. In these workshops, the participants discussed, developed, negotiated, and agreed upon collaborative actions to digitalize their operations and to transform towards a digitalized business ecosystem. We contribute to the emerging literature on creating digital business ecosystems by showing how the members of the forming ecosystem can find common goals, discuss the value of digitalization, and make collaboratively decisions about implementation of digital solutions through facilitated knowledge co-creation and collaborative negotiation. Our results suggest that digital transformation of an existing supply chain should be facilitated from a wider ecosystem perspective which helps the supply chain members to overcome the initial motivational challenges and create a shared logic.

Based on our results, we create a hypothesis that a developmental intervention provides a temporary governance structure for the participants to collaboratively make decisions about the transformation of a supply chain towards a digital business ecosystem. The hypothesis should be tested in other supply chain contexts. Also, to what extent the temporary governance structure carries over to the real life ecosystem creation should be studied.

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Knowledge Fusion of Manufacturing Operations Data Using Representation Learning

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Abstract. Due to increasingly required flexibility in manufacturing systems, adaptation of monitoring and control to changing context such as reconfiguration of devices becomes more important. Referring to the usage of structured information on the Web, digital twin models of manufacturing data can be seen as knowledge graphs that constantly need to be aligned with the physical environment. With a growing number of smart devices participating in production processes, handling these alignments manually is no longer feasible. Yet, the growing availability of data coming from operations (e.g. process events) and contextual sources (e.g. equipment configurations) enables machine learning to synchronize data models with physical reality. Common knowledge graph learning approaches, however, are not designed to deal with both, static and time-dependent data.

In order to overcome this, we introduce a representation learning model that shows promising results for the synchronization of semantics from existing manufacturing knowledge graphs and operational data.

Keywords: Representation learning · Digital twin · Knowledge fusion

1 Introduction

The ubiquitous availability of data empowers manufacturing companies to embrace advanced data analytic technologies that allow to monitor, predict, and optimize manufacturing operations. Still, ensuring semantic interoperability within hardware-software integrated cyber-physical systems (CPS) and management applications requires extensive manual data modeling effort, thus introducing and maintaining these technologies is challenging for manufacturers [7]. For example, today, deploying a new device for machine condition monitoring at a shop floor means manual effort to model this device and all of its signals throughout several software applications (e.g. SCADA, MES). Otherwise, physical reality

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is not correctly reflected in existing models and there is no semantic interoperability between applications.

Recently, descriptive data models have been revitalized as part of a digital representation of physical systems, the so-called *digital twin*, which allows systems to discover, inherit, evaluate and share information across different subsystems [2]. From a data modeling perspective, structured information of digital twins can be represented as knowledge graph (KG), where relations and entities follow well-defined vocabularies and semantics.

Knowledge graphs are commonly understood as publicly-accessible Linked Data resources – prominent examples are Wikidata[1] and WordNet[2]. Similarly, Manufacturing Execution Systems (MES) and engineering platforms that are built upon sizable relational databases can be seen as domain-specific knowledge graphs, when lifted to a semantic schema [5]. Such a *manufacturing knowledge graph* should be able to automatically acquire updated information based on different operational data sources (e.g. SCADA, PLCs, etc.), even if these data sources are not aware of their semantics.

Continuing the machine monitoring example: By observing data coming from the newly added device (e.g. events) the KG should automatically recognize the type of device, its location, or its capabilities and therefore allow other applications to adapt to this updated context.

Machine Learning in KGs has emerged recently with the goal to enable automated integration of new facts into KGs without manual modeling efforts [9]. When multiple data sources are used to extract information, the problem further extends to so-called *knowledge fusion* [3]. The same problems apply to models in manufacturing systems that need to be in-sync with physical reality reflected by multiple operational data sources [4]. In this paper, we present an approach to support fusion of information coming from operational data sources with manufacturing KGs by learning latent representations of entities. The goal is to offer automated recommendations on how to integrate unknown entities into the existing structure of the KG and thus keeping the digital twin in-sync without manual modeling effort. Ultimately, this is beneficial to monitoring and management applications that rely on a immediately aligned digital representation of the manufacturing system.

2 Motivation Scenario

In this section we present an example scenario that motivates the application of machine learning (knowledge fusion) to manufacturing KGs in conjunction with operational data sources.

Consider an automated production line at a discrete manufacturing facility, consisting of multiple production units that can be configured to produce several variants of a product. The manufacturing KG (e.g. provided by an MES) of this production line gives information about device topology and processes executed

[1] http://wikidata.org.

[2] http://wordnet.princeton.edu.

by each of the production units, whereas a SCADA system observes sequences of events during operation. As shown in Fig. 1, at the bottom, sequences of events are continuously generated and aligned to entities in the manufacturing KG. Entities and their relations are denoted as triples (`head-entity`, `relation`, `tail-entity`), in the middle of the Figure. The schema (classes and relations) of the KG is shown on top of the entities using a simplified class diagram notation. For example, the triple (`Event 1`, `occurs at`, `Conveyor`) in the KG states that entity *Event 1* occurs at entity *Conveyor*. Additionally the conveyor entity is modeled as device that is involved in the board assembly process.

Assuming a new device is deployed to the production line to monitor temperature measurements of the conveyor. As production resumes, events of this new device are continuously observed, but they are lacking semantic alignment to the existing KG. Figure 2 shows a new sequence of events, where unknown entities in the triples are denoted with question marks. Here, the class of the unaligned event *Event 2* and its source (device) are unknown, (`Event 2`, `is-a`, `?`), respectively (`Event 2`, `occurs at`, `?`).

However, the distribution of events in the sequence data should give an indication about which device is most likely to be hold responsible (in this case the conveyor). Since other conveyor events are assumed to co-occur in similar fashion as the new monitoring events, this information can be exploited to re-engineer semantics. Presuming one could obtain a vector representation of all involved entities (events, devices, etc.), it would be possible to calculate a *similarity* between *Event 1* and *Event 2* that would allow to infer that both are related to the conveyor entity in the KG. The representation learning approach in the following is motivated by learning latent entity embeddings that reflect such similarity.

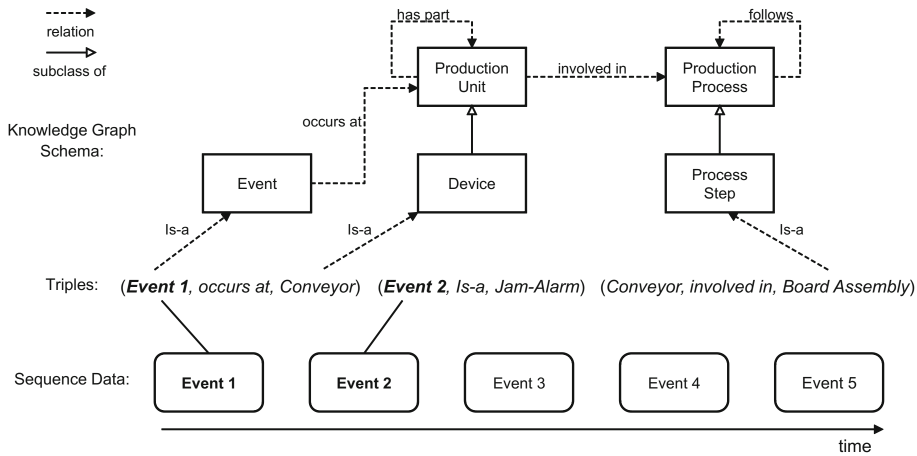


Fig. 1. Sequence data entities aligned to triples in the knowledge graph

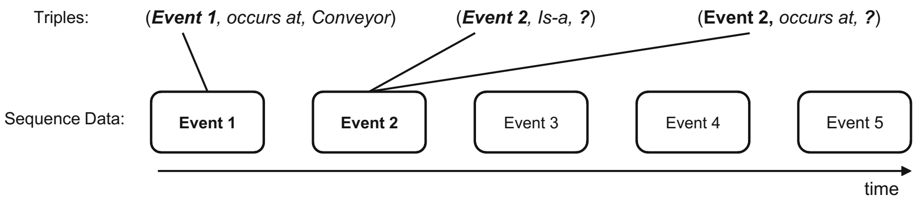


Fig. 2. Observing new events with unknown semantics

3 Problem Statement

In this section, we formally define the problem of learning joint representations of entities in KGs and operations data of manufacturing systems.
A **knowledge graph**, denoted as $\mathcal{KG}$ is a directed graph with labeled edges. Each edge is represented in form of *triples* (h, r, t) that indicates the existence of a relationship between the head entity h and the tail entity t by the labeled relation r. Head and tail are contained in the set of entities $h, t \in \mathcal{E}$ and each relation respectively in the set of relations $r \in \mathcal{R}$.
A **sequence data set**, denoted as $\mathcal{D} = \{(x_1, ..., x_i, ..., x_m)_j^T\}$, is a set of sequences, where each sequence consists of an ordered set of event entities x_i. The length m of each sequence can vary depending on a sequence window size. It is implied that there exists a mapping of event entities x_i to entities in $\mathcal{E}$, i.e. event entities are also represented in the KG.

Knowledge Graph Embeddings. Given $\mathcal{KG}$, the problem of learning **knowledge graph embeddings** is to encode all entities in $\mathcal{E}$ and relations in $\mathcal{R}$ in a continuous low-dimensional vector space, i.e. $\mathbf{h}, \mathbf{t} \in \mathbb{R}^d$ and relation $\mathbf{r} \in \mathbb{R}^d$. In order to learn useful representations, a meaningful distance measure has to be employed, e.g. in the original TransE model [1], $\mathbf{h} + \mathbf{r} \approx \mathbf{t}$. This means that *translating* entity h with relation r should end up close at its tail entity t in the latent d-dimensional space. It has been shown that these *translation embeddings* can be effectively learned by using a ranking loss with the intuition that $\mathbf{h} + \mathbf{r} \approx \mathbf{t}$ should be close for true triples and far apart for false/unknown ones. Formally, the learning objective is formulated as minimizing a margin-based ranking loss:

$$\mathcal{L}_{KG} = \sum_{(h,r,t) \in \mathcal{KG}} \sum_{(h',r,t') \in S'_{h,r,t}} max(0, 1 + dist(\mathbf{h} + \mathbf{r}, \mathbf{t}) - dist(\mathbf{h}' + \mathbf{r}, \mathbf{t}')) \quad (1)$$

where $dist(\cdot)$ is some distance function (e.g. Euclidian) and $S'_{h,r,t}$ is a set of negative samples, i.e. artificially constructed false triples by replacing h or t with a random entity. This loss is minimized when the translation of correct triples is closer than that of unknown ones by a constant margin, here 1.

Sequential Data Embeddings. Given $\mathcal{D}$, the problem of learning **sequential embeddings** of entities x_i is similar to knowledge graphs, i.e. encode all entities in the same low-dimensional vector space, $\mathbf{x_i} \in \mathbb{R}^d$, where semantically similar entities should end up close to each other in this latent space. Learning this kind of embeddings follows the distributional semantics hypothesis which states that similar entities occur in similar context. This has been one of the key ideas in the field of Natural Language Processing (NLP), since these embeddings tend to exhibit natural relations between words (e.g. capture synonymous meanings) [6]. Distributed representations are obtained by assuming that similarity between entities in the data can be modeled with a distribution, formally $P(x_i|W)$, i.e. the occurrence of entity x_i depends on and can be predicted from its surrounding window events W. Figure 3 displays how *Event 3* can be modeled from its surrounding events in a sliding time window of length m through the event sequences. It is assumed that events having similar causes and effects share similar semantics.

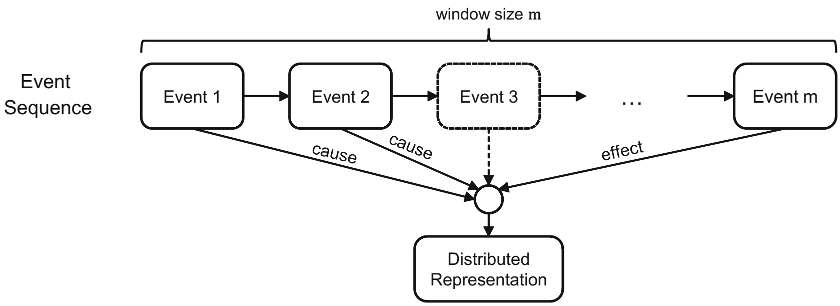


Fig. 3. Representations of event entities are learned from surrounding context

Mathematically, the probability distribution of predicting target entity x_i from its surrounding entities can be expressed by a categorical distribution, e.g. the Softmax function:

$$P(x_i|W_i) = \frac{\exp S(\mathbf{x_i}, \mathbf{W_i})}{\sum_{j \neq i} \exp S(\mathbf{x_j}, \mathbf{W_i})}, \tag{2}$$

where $\mathbf{x_i}$ is the vector representation of entity x_i and $S(\cdot)$ is some similarity function between entities and their surrounding window entities represented as matrix $\mathbf{W_i}$. The objective function in terms of loss is given by the negative log likelihood:

$$\mathcal{L}_{Seq} = -\sum_{i}^{n} log(P(e_i|W_i)) \tag{3}$$

Joint Embeddings. As the goal of this approach is to jointly model entities in the knowledge graph as well as in the sequential data, we propose a joint learning model that is trained by simply adding both loss terms:

$$\mathcal{L}_{Joint} = \mathcal{L}_{Seq} + \mathcal{L}_{KG} \tag{4}$$

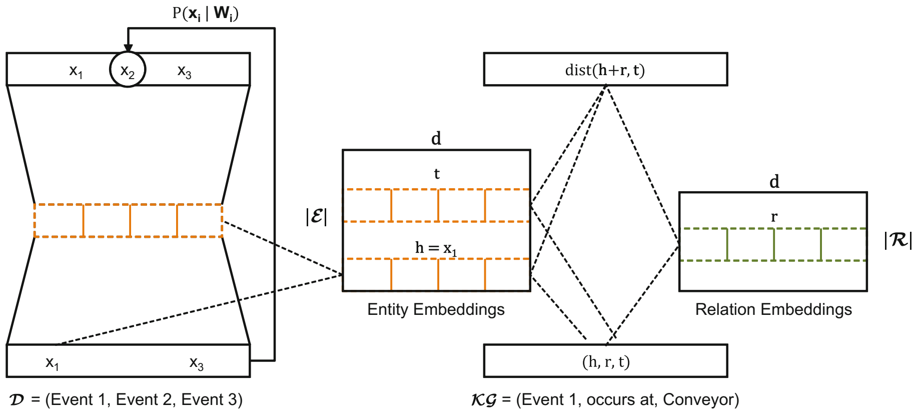


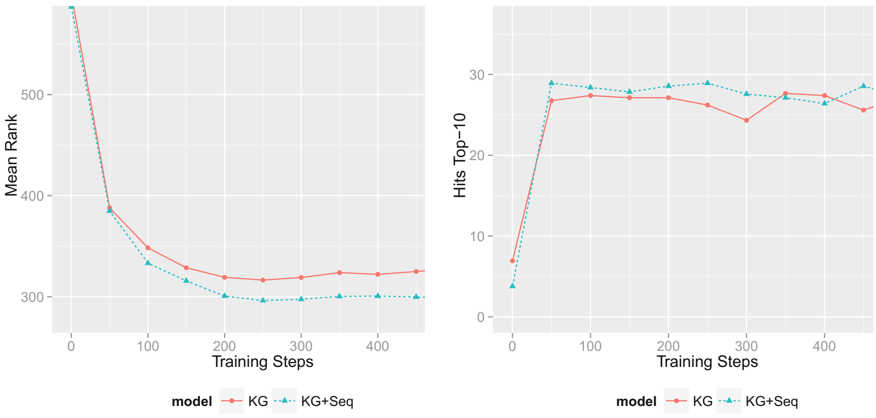
Fig. 4. Architecture of the joint embedding learning model

Minimizing the joint loss $\mathcal{L}_{Joint}$ should result in solid embeddings of both, entities in the knowledge graph and the sequence data set. In reality, joint loss minimization is approximated using a state-of-the-art stochastic gradient descent optimizer. The key idea here is that entity embeddings are shared across both tasks and therefore the outcome should reflect co-occurrence of sequential data as well as the structure of the knowledge graph. The architecture of the joint embedding approach is shown in Fig. 4, where the $|\mathcal{E}|$-by-d matrix of entity embeddings is located in the center. These embeddings are shared with the prediction model of entities in the sequential data on the left-hand side and the knowledge graph embedding model on the right-hand side. Note that in the depicted example this shared aspect is highlighted with *Event 1* having the same embedding (representation) in both models, i.e. $\mathbf{h} = \mathbf{x_1}$. The $|\mathcal{R}|$-by-d matrix of relation embeddings on the right-hand side is solely used for the knowledge graph embeddings as it only influences distance calculation between triples.

4 Prototype Evaluation

We evaluated this approach on a real-world manufacturing KG data set coming from an automated assembly line. The event sequences are taken from a SCADA-level Alarms & Events database, whereas the initial KG was extracted from several spreadsheet files and CAD models. The final KG ended up with a size of about 3,700 triples about processes, equipments, and events, whereas the sequential data consisted of 57 thousand events occurrences. A prototypical implementation of the representation learning was implemented using the $TensorFlow^{TM}$ library. For performance evaluation, the usual criteria are (cf. [1]):

- Mean Rank: The average predicted rank of the head or tail entity that would have been the correct one (1 indicating perfect rank)
- Hits Top–10: The fraction of predicted ranks that were in the top 10



(a) Mean Rank (b) Hits Top-10

Fig. 5. Evaluation on hold-out test data (unknown triples) during training

Table 1. Models and data sets with and without sequential data

Model	$\|\mathcal{KG}\|$	$\|\mathcal{D}\|$	Test size	Mean rank	Hits top–10
KG	$3.7k$	-	3%	316.46	27.66
KG + Seq	$3.7k$	$57k$	3%	**296.16**	**28.92**

We compare two models, KG (knowledge graph embeddings only) and $KG{+}Seq$ (joint embeddings). In Fig. 5, the performance of KG and $KG + Seq$ are visualized during model training on a hold-out (unseen) test data set of incomplete triples, e.g. (`Conveyor`, `involved in`, `?`). It can be seen that the joint model performs better in terms of lower mean rank and higher hits top-10 percentage (Table 1).

5 Related Work

We divide related work into two categories, limited to applications and techniques that are close to the one in this work.

Model Learning in Manufacturing. Machine learning has been used to discover influencing factors of manufacturing processes [14]. Other works of adapting to changing context have studied monitoring processing times in flexible production systems [10, 11] and more high-level architecture proposals for context extraction and self-adaption of production systems [12]. However, the authors do not specify a concrete methodology on how to extract context knowledge and align it with existing models.

Learning of Knowledge Graph Embeddings. Existing learning methods for KGs such as [1,9] have been extended to include many-to-many relationships [8] and to incorporate textual information to improve entity representation learning. Recently, word co-occurrences as sequential data were used in KG completion tasks [13]. In contrast to our approach, these works are focused on large-scale knowledge graphs containing noisy information.

6 Conclusion

An approach for automated recommendations for the alignment of semantics coming from operational data and manufacturing KGs was presented. Our model allows to predict missing relations introduced from changes in physical environments and unaligned event semantics, which can be detected and integrated into a global knowledge graph schema, thus lowering manual modeling effort. The joint representation of entities shows promising performance, which is vital for transition to fully automated synchronization, ensuring correct operation of monitoring and other management applications such as scheduling.

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A Framework for Mathematical Analysis of Collaborative SCM in ColPMan Game

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Abstract. ColPMan is a multi-player serious game through which a team of players can experientially learn how to collaboratively operate a virtual in-house supply chain. In this game, the problem of operating the whole chain is divided into sub-problems and each of them is addressed by a different player. While playing the game, the sub-problems distributed to the players can be linked to one another in a certain way through communication among them. This paper provides a framework for mathematically analyzing the effects of (the way the sub-problems are linked through) the communication. This also clarifies what the players should discuss and learn in the debriefing session.

Keywords: Experiential learning · Collaboration · Negotiation · SCM · Serious game

1 Introduction

Serious games have been successfully used for experiential learning and training in various fields including supply chain management. One of the most well-known examples of such a game in SCM is Beer Game (Sterman 1989), through which the bullwhip effect can be taught. It treats a supply chain as a network of stock points, and deals only with ordering decisions. However, in a large-scale in-house supply chain, the managers of different sites of the chain need to make not only ordering decisions but also production and delivery schedules, which are interrelated to one another. How to collaboratively make such decisions in an uncertain market environment is a big challenge. Thus, the authors have proposed a multi-player serious game named ColPMan, in which a team of players can experientially learn how to collaboratively operate a large-scale in-house supply chain (Furukawa et al. 2016; Mizuyama et al. 2016; Nonaka et al. 2016).

In a mathematical sense, operational decisions to be made for running a supply chain can be captured as a sort of combinatorial optimization problem. Since it is usually too huge to be addressed by a single decision maker, the whole problem is divided into sub-problems of manageable sizes and they are handled by different sites of the chain. However, it is often inefficient in practice to simply

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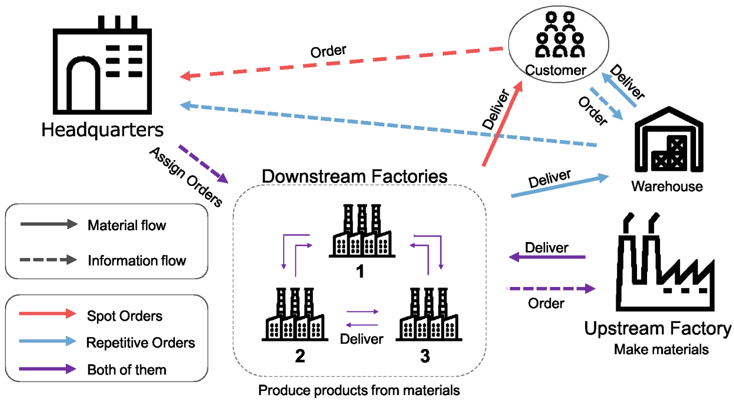

Fig. 1. Supply chain model

deal with the sub-problems individually without coordinating the interdependence among them adaptively in an uncertain environment. This is why collaboration among the managers of the sites is desirable and important. However, the desirable collaboration remains to be a vague concept, and should be refined into a well-defined one so that the ColPMan players can learn. Thus, this paper deems the collaboration as linking the sub-problems adaptively through communication, and provides a framework for mathematically analyzing the effects of the way the sub-problems are linked through the communication in ColPMan game.

2 Outline of ColPMan Game

There are two types of orders, repetitive and spot. The supply chain is composed of five main sites; a headquarters (HQ) which accepts orders from customers, three downstream factories (DSFs) which make products, and an upstream factory (USF) which manufactures materials for the products, as shown in Fig. 1. HQ assigns spot orders received from customers and repetitive orders to fill inventory to DSFs. Each DSF makes assigned products from materials and places material orders to USF. USF creates and delivers the materials to DSFs. After a product is made, it is delivered to the customer if it is a spot-ordered, and is kept in the warehouse until being pulled by the customer if it is repetitive-ordered. Each DSF and USF can hold the materials as inventory until processed or delivered.

Each player is assigned to one of the sites and makes its operational decisions such as production schedules. The time axis is divided into terms and periods, where one term consists of five periods. At the beginning of each term, HQ player assigns orders to DSFs, and DSF players make the production schedules for delivering ordered products to customers by their due dates and order some materials. USF player determines the material manufacturing schedule and material delivery plan. After they finished inputting those decisions, how the supply chain operations progress according to those decisions under uncertainty is calculated by a computer simulation. The uncertainty includes arrivals of new spot orders, variations in processing times, and occurrence of defectives. This cycle is repeated for a preset number of terms. At the beginning of each period, each player observes the operational progress and can modify the corresponding plans if necessary. The game score is defined by the sales revenue of fulfilled spot orders minus inventory holding costs, setup costs, late delivery penalty costs, and stock out penalty costs (Tables 1 and 2).

Table 1. Notations for HQ's sub-problem

d_n^S	Due date of nth spot order
f	Index for DSFs
g	Index for product grades
k	Index for material kinds
n	Index for spot orders
$q_{k,g,t}^R$	Quantity of repetitive order on product (k, g) in term t
q_n^S	Quantity of nth spot order
$r_{k,g,t}^R$	Demand forecast of repetitive-order product (k, g) in term t
t	Index for terms
$v_{k,g,t}^R$	Inventory level of repetitive-order product (k, g) at the end of term t
$x_{k,g,t,f}^R$	Assignment status of repetitive order on (k, g) in term t to DSF f
$x_{n,t,f}^S$	Assignment status of nth spot order in term t to DSF f
HC^R	Stock holding cost per term per unit of repetitive-order products
PC^R	Stock out penalty cost per unit of repetitive-order products
PC^S	Late delivery penalty cost per term per unit of spot-order products
$Q_{t,f}^{\max}$	Maximum number of products processed in term t in DSF f
$V_{k,g}^R$	Safety stock level of repetitive-order product (k, g)
SR^S	Sales revenue per unit of spot-order products

3 Formulation of Individual Subproblems

3.1 Order Planning Problem Addressed by HQ

HQ is not directly given the detailed information on the structure of manufacturing costs and production schedules in factories, and is expected to assign orders to DSFs so as to maximize the revenue. Thus, in the baseline problem addressed by HQ, order assignments $x_{k,g,t,f}^R$ and $x_{n,t,f}^S$ are determined so that the objective function

$$\sum_n q_n^S \sum_t \left[SR^S \sum_f x_{n,t,f}^S - \max(0,\ t - d_n^S)\ PC^S \sum_f x_{n,t,f}^S \right] - \sum_k \sum_g \sum_t q_{k,g,t}^R \left[PC^R \left(1 - \sum_f x_{k,g,t,f}^R \right) + \frac{HC^R}{2} \sum_f x_{k,g,t,f}^R \right] \tag{1}$$

should be maximized under the following constraints.

$$\sum_f x_{k,g,t,f}^R \leq 1 \qquad \forall (k,g,t) \tag{2}$$

$$\sum_t \sum_f x_{n,t,f}^S \leq 1 \qquad \forall n \tag{3}$$

$$\sum_n q_n^S \cdot x_{n,t,f}^S + \sum_k \sum_g q_{k,g,t}^R \cdot x_{k,g,t,f}^R \leq Q_{t,f}^{\max} \qquad \forall (t,f) \tag{4}$$

It is assumed that $q_{k,g,t}^R$ is approximated by

$$q_{k,g,1}^R = r_{k,g,t}^R + V_{k,g}^R - v_{k,g,0}^R \tag{5}$$

$$q_{k,g,t}^R = r_{k,g,t}^R \qquad (t = 2, 3) \tag{6}$$

3.2 Scheduling and Order Planning Problems Addressed by DSFs

Each DSF needs to determine its production schedule and material order plan so as to minimize related costs. Since the actual lateness penalty costs caused for each job is not directly visible to the DSF (but only to HQ), an arbitrary function is used here. The baseline problem addressed by each DSF f is a two machine flow shop scheduling problem, where the jobs are the spot and repetitive orders assigned to DSF f by HQ. In this problem, the objective function to be minimized is

$$\sum_{j \in J_f} sc_j + HC^M \left[\sum_{j \in J_f} q_j \cdot it_{j,1} + \sum_k \sum_t o_{k,t,f}^M \cdot (4 - t) \right] + \sum_{j \in J_f} q_j \cdot h_f(ct_{j,2} - a_j) \tag{7}$$

and the decision variable is the job sequence $\boldsymbol{s}$. When a job sequence $\boldsymbol{s}$ is given, setup costs sc_j and times st_j are determined as

$$(sc_{s_i}, st_{s_i}) = \begin{cases} (SCL, STL) & (g_{s_{i-1}} > g_{s_i}) \\ (0, 0) & (g_{s_{i-1}} = g_{s_i}) \\ (SCH, STH) & (g_{s_{i-1}} < g_{s_i}) \end{cases} \tag{8}$$

where s_0 is the last job processed in term 0. Further, the corresponding initiation times $it_{j,m}$, completion times $ct_{j,m}$, and material order quantities $o_{k,t,f}^M$ can be calculated as follows (Table 3).

Table 2. Notations for DSFs' sub-problem

a_j	Assigned term of jth job
$ct_{j,m}$	Completion time of job j on machine m
g_j	Product grade of jth job
$h_f()$	Lateness penalty cost function set by DSF f for a unit of products
$it_{j,m}$	Initiation time of job j on machine m
j	Index for jobs
k_j	Material kind of jth job
$o^M_{k,t,f}$	Oder quantity on material k in term t from DSF f
$pt_{j,m}$	Processing time of job j on machine m
q_j	Quantity of jth job
$r^M_{k,t,f}$	Demand forecast of material k in term t in DSF f
$\boldsymbol{s}$	Job sequence $(= (s_1, s_2, \ldots))$
sc_j	Setup cost necessary for starting job j
st_j	Setup time necessary for starting job j
v^M_k	Inventory level of material k
$v^M_{k,0,f}$	Inventory level of material k at the end of term 0 in DSF f
HC^M	Stock holding cost per term per unit of materials
J_f	Set of jobs assigned to DSF f
LT^M	Material delivery lead time
SCH	Setup cost required for changing product grade downwards
SCL	Setup cost required for changing product grade upwards
STH	Setup time required for changing product grade downwards
STL	Setup time required for changing product grade upwards
$V^M_{k,f}$	Safety stock level of material k in DSF f

Step 0: Set $v^M_k = v^M_{k,0,f}$, $o^M_{k,1,f} = o^M_{k,2,f} = o^M_{k,3,f} = 0\ \forall k$, $i = 1$, $t = 1$.

Step 1: Calculate the initiation and completion times of job s_i as

$$it_{s_i,1} = \begin{cases} LT^M & (ct_{s_{i-1},1} < LT^M \wedge v^M_{k_{s_i}} < q_{s_i}) \\ \max(0, ct_{s_{i-1},1}) & (otherwise) \end{cases} \tag{9}$$

$$ct_{s_i,1} = it_{s_i,1} + pt_{s_i,1} \tag{10}$$

$$it_{s_i,2} = \max(ct_{s_i,1}, ct_{s_{i-1},2} + st_{s_i}) \tag{11}$$

$$ct_{s_i,2} = it_{s_i,2} + pt_{s_i,2} \tag{12}$$

and update the inventory level as $v^M_{k_{s_i}} = v^M_{k_{s_i}} - q_{s_i}$. Further, if $ct_{s_i,1} \geq t + LT^M$ holds, then set $o^M_{k,t,f} = \max(0, V^M_{k,f} - v^M_k)\ \forall k$, $v^M_k = \max(v^M_k, V^M_{k,f})\ \forall k$, and $t = t + 1$.

Step 2: If $i = |J_f|$ go to **Step 3**. Otherwise, go back to **Step 1** after setting $i = i + 1$.

Step 3: If $t \leq 3$, set $o^M_{k,3,f} = \max(0, V^M_{k,f} - v^M_k + r^M_{k,4,f} \cdot LT^M)$.

Table 3. Notations for USF's sub-problem

ct_j	Completion time of job j
it_j	Initiation time of job j
k_j	Material kind of jth job
pt_j	Processing time of job j
q_j	Quantity of jth job (=15)
sc_j	Setup cost necessary for starting job j
st_j	Setup time necessary for starting job j
$u^M_{k,t,f}$	Quantity of material k delivered in term t to DSF f
v^M_k	Inventory level of material k
$v^M_{k,0,0}$	Inventory level of material k at the end of term 0 in USF
J_0	Set of jobs assigned to USF
PC^M	Shortage penalty cost for a unit of materials
SC^M	Coefficient of setup cost required for changing material kind
ST^M	Setup time required for changing material kind
$V^M_{k,0}$	Safety stock level of material k in USF

3.3 Scheduling and Delivery Planning Problems Addressed by USF

USF needs to determine its production schedule and material delivery plan so as to minimize related costs, where an arbitrary value is set and used as the shortage penalty cost per unit of materials. The baseline problem addressed by USF is a sort of single machine scheduling problem. In this problem, the objective function to be minimized is

$$\sum_{j \in J_0} sc_j + HC^M \left[\sum_{j \in J_0} q_j \cdot (3 - ct_j) - \sum_k \sum_t \sum_f u^M_{k,t,f} \cdot (4 - t) \right] + PC^M \sum_k \sum_t \sum_f (o^M_{k,t,f} - u^M_{k,t,f}) \tag{13}$$

and the decision variable is the job sequence $\boldsymbol{s}$. When a job sequence $\boldsymbol{s}$ is given, setup costs sc_j are determined as

$$sc_{s_i} = SC^M \cdot |k_{s_i} - k_{s_{i-1}}| \tag{14}$$

where s_0 is the last job processed in term 0. Further, the corresponding initiation times it_j, completion times ct_j, material delivery quantities $u^M_{k,t,f}$ can be calculated as follows.

Step 0: Set $v^M_k = v^M_{k,0,0}$, $i = 0$, $t = 0$.
Step 1: If $\max(0, ct_{s_i}) \geq t$ holds, go to **Step 2**. Otherwise, go to **Step 3**.

Step 2: If $t = 3$ holds, finish the procedure. Otherwise, set $t = t + 1$ and determine $u^M_{k,t,f}$ by minimizing

$$PC^M \sum_k \sum_f (o^M_{k,t,f} - u^M_{k,t,f}) \tag{15}$$

subject to

$$\sum_f u^M_{k,t,f} \leq v^M_k \qquad (\forall k) \tag{16}$$

$$u^M_{k,t,f} \leq o^M_{k,t,f} \qquad \forall(k,t,f) \tag{17}$$

and update the inventory levels as

$$v^M_k = v^M_k - \sum_f u^M_{k,t,f} \qquad (\forall k) \tag{18}$$

Step 3: Update the inventory level as $v^M_{k_{s_i}} = v^M_{k_{s_i}} + q_{s_i}$ and set $i = i + 1$. Calculate the initiation and completion times of job s_i as

$$it_{s_i} = \max(0, ct_{s_{i-1}}) + st_{s_i} \tag{19}$$

$$ct_{s_i} = it_{s_i} + pt_{s_i} \tag{20}$$

Go back to **Step 1**.

4 Possible Linkages Among Sub-problems

4.1 Sharing Inventory Information

There are some parameters, which can be exchanged by the communication among the sites and change the form of each sub-problem. We call them as link-parameters and sort them out based, for example, on the communication logs obtained from the game sessions conducted in the past. One of the most frequently mentioned information was on material inventory. Possible linkage patterns based on material inventory information can be classified as follows.

Pattern 1: DSFs share the material inventory levels with HQ
Pattern 2: USF shares the material inventory levels with HQ
Pattern 3: USF shares the material inventory levels with DSFs

The inventory levels shared here may include not only the current levels but also the future levels estimated with ordering, production and delivery plans.

In pattern 1 and 2, the inventory levels shared with HQ will pose additional constraints on the quantity of products of each material type assignable to each DSF. It is also possible to add a term corresponding to the material inventory costs to the objective function and thereby enhance the turnover rate of the materials. In pattern 3, Eq. (9) can be modified incorporating the shared information.

4.2 Sharing Demand Information

Demand related information is also appeared often in the communication log. Possible linkage pattens based on demand information can be classified as follows.

Pattern 4: HQ shares the future demand with DSFs
Pattern 5: HQ shares the future demand with USF
Pattern 6: DSFs share the future demand with USF

Information sharing of pattern 4 and 6 is formally made between the corresponding sites for three terms. However, it will make a difference whether the future demand values informed are fixed or not. USF can utilize the information shared in pattern 5 for double check.

4.3 Sharing Other Information

If HQ is notified that a setup operation is required when changing product grades in DSFs and when changing material kinds in USF, HQ will try to reduce the number of setup operations necessary by adding appropriate penalty terms to its objective function (1). Further, if it is informed that the processing times $pt_{j,2}$ are dependent not only on the grades but also on the DSFs, HQ can refine the constraint (2) by incorporating the difference. The lateness penalty cost function $h_f()$ set in each DSF and the shortage penalty cost per unit PC^M set in USF can be refined if the factory obtains information on how the actual cost changes according to the completion time of the job from HQ.

5 Conclusions

The problem of operating the whole supply chain is divided into sub-problems, and they are handled by different players in ColPMan game. While playing the game, the sub-problems may be linked to one another in a certain way through communication among the players. How they are linked together affects the performance but how they should be has not been clearly understood. Thus, this paper first mathematically formulates each sub-problem, and provides a framework for analyzing the effects of the way the sub-problems are linked. Next step will be to compare the performance of the chain under different linkage types through numerical experiments. Since the relative performance may be dependent on the environmental conditions, the numerical comparison should be made in different conditions.

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Identifying Scenarios for Ambidextrous Learning in a Decoupling Thinking Context

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Abstract. The human perspective and the flow perspective of businesses represent two areas of competence that study similar systems but with different frame of references. The human perspective involves ambidextrous learning that concerns how knowledge is developed and used for different purposes by individuals or groups of individuals. The development of knowledge for new situations is referred to as 'exploration', while 'exploitation' refers to execution in known and stable contexts. Furthermore, decoupling thinking is important from a flow perspective and concerns how a value-delivery package is created. This type of thinking decouples the flow perspective into segments with different characteristics that are significant for process management. The examples presented in this paper are distinctive drivers of flow in terms of speculation or commitment, and the level of customisation. By combining these two perspectives, a set of 15 scenarios is identified for further research on ambidextrous learning in a decoupling thinking context.

Keywords: Organisational ambidexterity · Learning · Efficiency · Effectiveness · Decoupling points · Customisation · Customer order decoupling point (CODP)

1 Introduction

Combining effectiveness with efficiency has been identified as a fundamental challenge for business managers [1]. Drucker [1] summarises this challenge as: having the ability to do the right things (effectiveness) in combination with the ability to do things right (efficiency). For an individual task, this can be considered as a chronological challenge where the first step is to establish effectiveness. Once this is achieved, the focus shifts to efficiency. This can be summarised as: first decide what to do and then decide how to do it. From the human perspective of an organisation, tasks develop over time and in aggregate; therefore, the organisation must sustain a mix of these two capabilities. Such a mix enables the organisation to execute well-defined tasks through a process of *executional learning*[1] (EL) and to develop the same tasks and identify new tasks through a process of *developmental learning* (DL) [2]. The ability to handle both types of learning simultaneously is referred to as *organisational ambidexterity (OA)* [3–5].

[1] The concept of executional learning corresponds to the theoretical concept of *adaptive learning* used by Ellström [2].

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This relates to March's [6] idea about an organisation's need to explore and exploit. Exploration involves effectiveness and a search for new knowledge, discovery and learning to find new products and new ways of working. Exploitation focuses on the already known and involves efficiency, control, certainty, variance reduction and learning to execute tasks according to existing products and processes. March [6] argues that exploration and exploitation are competing logics, and exploration generates more bad ideas than good ones. Therefore, exploitation is favoured over exploration, and if nothing is done to counter this prioritization, failure is the inevitable result. Tushman and O'Reilly [7] began addressing this dilemma by bringing Duncan's [8] largely overlooked work on organisational ambidexterity into the mainstream: 'Periodically in scholarly research there emerges a topic that catches the interest of researchers and leads to an outpouring of studies. In the study of organisations, organisational ambidexterity appears to be one such topic.' [4], p. 253.

Shifting the focus from individuals performing tasks to the context of the tasks (i.e., the value-adding flow) reveals a different perspective on why the balance between effectiveness and efficiency is such an important concept. From a flow perspective, the activities of a flow segment exposed to individual customer requirements face greater uncertainty then activities of more standardised characters. In a standardised context, activities can emphasise efficiency as the repetitiveness of the activity supports continuous improvement. However, a customer facing activity has a greater need to support the variety of requirements that the customers can state, and in such a context, the emphasis on effectiveness is much greater. This dual capability separates flow into different segments where, for example, one segment is forecast-driven (also known as speculation-driven) and another is customer-order-driven (also known as commitment-driven). Alternatively, one may be based on standardised offerings and the other may be based on customised offerings. This paper refers to such a flow approach as 'decoupling thinking'.

A flow-based learning environment involves collaboration between individuals. Based on the decoupled flow perspective, the organisation can be seen as consisting of different flow segments. Each flow segment provides unique conditions for decision making and performing activities and, hence, learning. The purpose is to identify scenarios that represent the relationship between the human perspective, which is based on learning and is related to ambidexterity, and the flow perspective, which is based on balancing and is related to decoupling thinking.

The paper is organised as follows: the next section outlines the research approach and theoretical background, which covers the human and flow perspectives. Thereafter a synthesis is provided, resulting in 15 scenarios, as well as empirical observations and managerial implications summarise the findings. Finally, some concluding remarks are made.

2 Research Approach

The empirical data in this paper is based on experience from four different research projects performed from 2008–2017, which were designed as qualitative case studies in more than 10 industrial companies. Two of the research projects employed a human perspective and the other two research projects were based on a flow perspective.

The data were collected through interviews, shadowing, observations of work meetings, diaries and workshops.

3 Theoretical Framework

The activities performed in a business can be seen as the aggregate of all actions performed by machines and humans. In this paper, an action denotes the smallest entity of work (i.e., transformation) that an activity can be divided into. The human perspective focuses on a business' resources, which perform tasks that are a collection of activities. Each activity also represents a building block for the flow segments, which are related to processes that provide customer value. This paper refers to this as the flow perspective of a business. The aggregate of the tasks in the human perspective and the aggregate of the segments in the flow perspective represent the same amount of work because they each represent all work performed in a business (i.e., the same total set of activities). However, the two perspectives represent different contexts: the human perspective is closely related to organisational entities (e.g., individuals or teams, which are related to ambidextrous learning) and the flow perspective involves work performed from a process perspective, which is related to decoupling thinking.

3.1 Human Perspective: Ambidextrous Learning

As the name suggests, the human perspective involves humans, which Dewey [9] describes as complex. On one hand, humans need and ask for structures, instructions and guidance in social systems in order to achieve safety and control. On the other hand, as soon as tasks become routine, humans try to improve and do things more quickly and efficiently. Therefore, structures are often challenged and questioned. When humans follow their impulses, they follow structures and change them, often simultaneously. Humans getting together in complex settings are part of an organisation that is dealing with different tasks. In the current study, this scenario is referred to as 'the ambidexterity dilemma', which refers to the ability to deal with two different types of logic at the same time.

The literature on learning in organisations identifies two different logics of learning that are related to the ambidexterity dilemma [2] and are associated with tasks that are performed in order to be executed or developed. Exploitation requires executional learning (EL) that focuses on gathering knowledge and problem solving based on a given set of skills, concepts, rules and methods. This logic of exploitation emphasises efficiency and refutes variations and new ideas. In contrast, exploration involves developmental learning (DL), which focuses on change, renewal and development of new knowledge where established concepts and knowledge are questioned. Therefore, this logic of exploration embraces variation and promotes new ideas. Both exploitation and exploration play a significant role and should be taken into account and regarded as complimentary rather than competitive. The two different logics can sometimes be in opposition to each other in terms of using an organisation's finite resources and require balance for the product or system that is being transformed or developed [2, 6].

They may also come into conflict during work meetings when groups are expected to handle issues of routine character (exploitation) while adapting to new preconditions (exploration). Previous research has noticed that these two dimensions could to be separated in time and space and approached by different types of communication during team meetings in order to be effective [10].

The dilemma of OA has received considerable attention and a great deal of research has been conducted over the last 15 years. However, many questions remain unanswered. Some studies have been undertaken at the firm level in relation to the market and business units, while some projects focus on structural or contextual ambidexterity and use large samples and longitudinal data [4]. Other researchers [11] have focused on individual ambidexterity in isolated experimental studies in a controlled laboratory. Individual ambidexterity is known as a person's ability to apply exploitation and exploration in the same task. However, little evidence and limited organisational and psychological literature exists to determine what conditions support high individual performance in the modes of exploitation and exploration. In structural ambidexterity, the organisational focus categorises individuals into different functions within business units. Contextual ambidexterity emphasises how culture can foster environments where individuals can move between exploitation and exploration [12]. Less research has been performed on the role that teams play in dealing with the OA dilemmas according to different actions of learning.

A review [3] of the empirical literature reveals two approaches to balance the OA dilemma. One approach involves the notion that exploration and exploitation occur simultaneously, often in dynamic environments, and to be efficient, the organisation must balance the two types of actions simultaneously. Stable environments support different approaches based on periodically switching between the two types of actions. Chen and Katila [3] found that successful firms in the industrial sector managed uncertainty by moving from a simultaneous approach to a sequential one. The objective for this shift was to make the environment more stable, make the two dimension of the task easier to handle and reduce the risk of maladaptation in the direction of either exploitation or exploration. In a study on ambidexterity at the project level, O´Reilly and Tushman [4] found that the separation of exploratory and exploitative projects was associated with improved performance. O'Reilly and Tushman [4] recommended that future research on OA should focus on the dilemma identified by March [6] to avoid a 'smorgasbord of organisational topics' [4]. However, the missing link in the research is finding other structures and mechanisms to transfer knowledge from individuals in communities of practice to other entities (e.g., teams) within the organisation. There are also some indications that time, tensions and contradictions are neglected as important factors of change in organisations [13].

In summary, exploitation and exploration represent two learning-related dimensions of an action where an action is defined as the smallest building block of a task performed by an organisational entity. By combining the two learning-related dimensions, it is possible to identify three types of learning (see Table 1). By combining the two dimensions in this fashion, a scenario indicating 'no learning' is identified. In practice, it is reasonable to expect that some type of learning take place; hence, this is indicated by N/A in the table. EL and DL each represent a fundamental approach to learning where only EL or DL is valid. In EL, a task is already planned and the focus is on the action to be executed because the action is already well defined. Variation should be avoided in this scenario. In DL, the action involves significant variety and usually involves exploration of new challenges. Consequently, actions that involve routinized procedures and only concern existing knowledge are less suitable. Finally, DEL is a challenge that deals with both dimensions of an action where a task requires new ideas and new ways of thinking in the same situation (i.e., developmental and executional learning). There are situations where both dimensions are mixed unconsciously at the same time, such as when DL and EL actions are performed simultaneously. Those situations can be handled easily by separating the different types of actions in time and space, meaning they are not handled at the same time and probably not at the same place (e.g., in different meetings). The more complicated situation, which is identified here, is when a situation requires both dimensions at the same time. These situations require special action that is yet to be defined. In other words, integrated DEL should not be neglected but, rather, encouraged as a separate type of learning challenge and positioned in relation to other similar types of action (DL and EL).

Table 1. Identifying three types of actions based on ambidextrous learning.

	No exploration	Exploration
No exploitation	N/A	DL
Exploitation	EL	DEL

3.2 Flow Perspective: Decoupling Thinking

Customer value is created by the resources that a business possesses and the processes represent how resources interact. The value-adding flow is defined based on some key properties of the customer's requirements. The main input from a process perspective is the trigger of the process, which this paper refers to as the 'flow driver' [14]. If the customer triggers the flow, it is referred to as 'commitment driven' (CD). In this case, the customer must wait for the delivery activities to be performed (delivery here represents all types of activities performed when the customer is waiting). An alternative is for the business to initiate the activities of the flow on speculation about future customers, which is referred to as 'speculation driven' (SD). In practice, providing customer value also involves the uniqueness of the offering, which this paper refers to as the 'differentiation of flow' [15]. A standardised flow is customer generic (CG) and fits all customers based on the flow. At the other extreme, a flow may be unique for each individual delivery to the customer, which this paper refers to as delivery unique (DU). Any activity that is DU should only be initiated based on explicit customer requirements (CD) in a 'one-off' fashion that creates the combination of DU-CD in Table 2. Correspondingly, a SD flow should never be performed if DU, as illustrated by N/A in Table 2. On the contrary, a standardised offering can be created for future use on speculation (CG-SD) or in response to a delivery request (CG-CD). In-between these two types, a flow may be unique for a specific customer (customised) with recurring deliveries. For recurring deliveries, it might be appropriate to speculate

(CU-SD) even if the preferable approach usually would be to focus on individual delivery requests from the customer (CU-CD).

Table 2. Identifying the five types of flow segments for decoupling thinking.

	Speculation driven (SD) (efficiency)	Commitment driven (CD) (effectiveness/responsiveness)
Customer generic (CG) (standardised)	CG-SD	CG-CD
Customer unique (CU) (customised - recurring)	CU-SD	CU-CD
Delivery unique (DU) (customised - one-off)	N/A	DU-CD

4 Scenarios for Ambidextrous Learning in a Decoupling Thinking Context

By virtue of their inherit focuses, ambidextrous learning is based on the human perspective and decoupling thinking is based on the flow perspective. The human perspective represents individuals or groups of individuals (i.e., teams); therefore, learning is explicitly related to the human resources of the business. The flow perspective represents the business logic in terms of activities that provide customer value. Consequently, these two perspectives each has weaknesses that reflect the strength of the other perspective in the sense that learning has weak bonds with the customer-oriented value-creation process and decoupling thinking considers all resources, including humans, simply to be objects with certain well-defined characteristics. By integrating the two perspectives (see Table 3, which is a combination of Tables 1 and 2), it is possible to identify 15 different scenarios of ambidextrous learning and decoupling thinking. Each scenario represents a unique combination of action of learning, which is related to different dimensions of tasks to be performed, and decoupling thinking, which is related to flow segments as a pattern of activities to be performed. Since the flow perspective is based on the customer's requirements and the business model, this approach offers a transitive relationship that leads to a connection between types of learning and how it should be positioned in relation to how profitability is established through the value-adding flow. Some overall observations can be made with a closer look at Table 3. In general, delivering unique offerings requires a more innovative approach that is typical for developmental learning, which is represented in the top left-hand corner of Table 3. In comparison, flow segments with more standardised characters are more prone to executional learning because there is a limited need for innovation in this context (see the bottom right-hand side of Table 3). As a consequence, the diagonal from the top left to bottom right of Table 3 is expected to represent the best match between the flow segments of the rows and learning actions of the columns.

Table 3. Fifteen scenarios for ambidextrous learning in a decoupling thinking context.

	Developmental learning (DL)	Developmental and executional learning (DEL)	Executional learning (EL)
Delivery unique and commitment driven (DU-CD)	I	II	III
Customer unique and commitment driven (CU-CD)	IV	V	VI
Customer unique and speculation driven (CU-SD)	VII	VIII	IX
Customer generic and commitment driven (CG-CD)	X	XI	XII
Customer generic and speculation driven (CG-SD)	XIII	XIV	XV

5 Conclusions

Learning is traditionally approached from a task perspective where the focus is on the actions required to perform a specific task. This paper outlines a process-based approach where the requirements for learning actions are identified in relation to the flow segments. The activities of the flow segments also constitute the foundation for the tasks and provide a gateway between the customer's requirements, which are related to flow segments, and organisational entities, such as teams, and related learning. Moreover, the transitive relationship between the customer's requirements and learning actions identifies a new type of learning challenge that is based on an integration of exploration and exploitation and cannot be disintegrated into either exploration or exploitation. This learning challenge represents an integrated combination of developmental learning and executional learning that this paper refers to as DEL and is an interesting topic for further research. Besides this finding, the most obvious path for future research is the matrix presented in Table 3. The 15 scenarios in Table 3 have been identified, but more work is necessary in order to understand how to approach these scenarios. For example, it could be possible to identify opportunities for more normative descriptions by using empirical observations to populate all of the scenarios. Based on such information, the framework outlined in Table 3 constitutes an important foundation for providing decision making support for developing organisational learning.

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Lean and Green Manufacturing

Lean Manufacturing and Environmental Performance – Exploring the Impact and Relationship

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Abstract. The relationship between Lean Manufacturing and Environmental Performance has attracted much debate but at the same time lack of empirical evidence leaves haphazard opinions on this matter. The objective of this paper is therefore to provide some insight into the impact of Lean Manufacturing on Environmental Performance and the existing relationship of these two concepts. Four semi-structured interviews with industrial and academic experts provided a solid ground to suggest that the relationship does exist, despite the fact that these two concepts were developed independently from each other. Being the exploratory nature of this study and its purpose to ignite further research, it does not employ a quantitative approach. The results of this study can help managers to better understand and concurrently tackle both the economic and environmental challenges faced by their organizations.

Keywords: Lean Manufacturing · Environmental performance · Value · Wastes

1 Introduction

In the presence of growing competition, depleting resources, rising costs, and escalated concerns for the environment, businesses have been pushed to explore new ways to maximize efficiency and effectiveness by developing new philosophies/methods to improve production/services while at the same time minimizing the negative impact of the operations on the environment. After the World War II, Toyota was faced with fierce competition by its US rival car manufacturers [1], and in order to keep themselves operational in excelling manner, it developed the Lean Manufacturing (hereafter referred as LM) framework [2]. Since then, the concept has been widely appraised and

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adopted by a wide range of companies and industries around the world [1, 3] to improve the competitive edge [4] for their businesses.

There are numerous approaches that constitute the structure of a lean system, e.g. Total Quality Management, Just-in-Time [5], Kanban, and Jidoka [6]. Lean helps to identify and eliminate non-value added activities and optimize performance [7]. Hence, organizations implement lean in order to increase production flexibility and improve product quality while keeping costs low [8].

For the lean theory, wastes refer to any activity that do not add value [7], whereas from an environmental perspective waste refers to the unnecessary consumption of resources and/or release of harmful substances into the environment, creating a negative effect on this and human health [9]. For example, waste of overproduction – producing without demand – is waste of resources/energy. Thus, an organization implementing lean is not only reducing cost, but is contributing to resource preservation.

The attention to the relationship between lean and green has gained momentum recently [1]. However, the academic literature examining the impact of LM on environmental (also known as 'green') performance still remains in early stages [1, 10]. Thus, the aim of this article is to investigate the relationship and impact of LM on Environmental Performance and the existing relationship of these two concepts. In this way, this article mainly focuses on the meaning of the green concept waste so as to investigate the relationship between LM and environment. Moreover, only the original seven manufacturing wastes, as defined by Toyota, are considered in this study.

The study in this article provides a brief overview of the literature to explore the relationship between seven wastes identified under the lean philosophy and environmental performance (hereafter referred as EP). Each of the manufacturing wastes that lean attempts to reduce is somewhat associated with EP. Hence, attention is focused on if and how lean creates more environment friendly production processes.

2 Theoretical Background

2.1 Lean Manufacturing

The development of LM dates back to as far as 1927, when the embryonic idea was laid out by Henry Ford [11]. However, its more rigorous development has been associated to the Toyota Production System [1]. Krafcik was the first to coin the term 'Lean Production' [7, 12]. Lean's unique blend of focusing on reducing waste and maximizing value attracted the attention of business practitioners to adapt this approach [13] and has hence gained tremendous magnetism in the US since the 1960s [11]. Scholars also believe that Lean is not just related to manufacturing as it is mostly known for, but is a business culture [14]. The Toyota's LM system identifies 7 types of wastes, and an addition to those seven wastes was made by Liker [15]. These wastes are in the area of; (1) Overproduction, (2) Waiting (time on hand), (3) Unnecessary transport, (4) Over processing or incorrect processing, (5) Excess inventory, (6) Unnecessary movement, (7) Defects, (8) Unused employee creativity.

Despite its mass appraisal/adoption in manufacturing and service industries, and by academics, there is a lack of agreement for a common definition of the concept [11, 16]. Thus, it becomes hard to define its overall goals [17]. However, LM is a major contributor to revolutionize businesses in their pursuit of doing more with less, while preserving value [14]. At the core of Lean, waste is defined as any non-value adding activity [18], and the focus is to promote a continuous improvement culture [14] and customer value enhancement by eliminating waste [7].

2.2 Metrics of Environmental Performance

The World Economic Forum (WEF) developed the Pilot EP Index in collaboration with Yale Center for Environmental Law and Policy, and Center for International Earth Science Information Network of Columbia University [19]; utilizing 4 dimensions (see Table 1) to measure the EP of any institution. The Department for Environment, Food and Rural Affairs (DEFRA) [20] in the UK also used similar measuring dimensions (see Table 1). The Global Environmental Management Initiative (GEMI) [21] in the US identified a longer list of measures being used by companies surveyed by them. This list does covers the 8th waste of Lean identified by Liker [15], however the dimensions mentioned revolve around the four core aspects identified by WEF and DEFRA (see Table 1).

Table 1. Dimensions used by different organization to measure EP.

WEF	DEFRA	GEMI
Dimensions of measures in use for environmental performance metrics		
Air quality	Emission to air	Permitted air emission
Water quality	Emission to water	Amount of water used
Land protection	Emission to LAND	Quantity of toxic chemical released
Climate change	Resource use	Amount of hazardous waste generated
		Number of recordable injuries/illnesses
		Number of lost workday cases
		Number of notices of violation
		Type/volume of non-regulated materials recycled
		Type/volume of non-regulated materials disposed
		Amount of dollar fines
		Number/type of reportable releases
		Amount/type of fuel used
		Total annual EHS operating costs
		Number of regulatory inspections
		Ozone depleting substance use
		Total annual EHS capital costs

Overall, it would be correct to say that the four common dimensions of air, water, climate, and land, mentioned in Table 1 are at the core of the measurement of EP [22] in any organization. However, it is important to understand that the choice of measures would depend directly on the type of industry/organization and their activity. Some indicators are common, as mentioned above, whereas others might be unique to a specific industry [21]. Therefore this research takes the basic general overview of EP measures and explore its relationship with LM.

2.3 The Interaction Between Lean and Environment

There is both positive and negative opinions on the matter of the interactions between LM and Green under the realization that the core focuses of Lean and Sustainability are different [23]. However, scholars do believe that the LM and Green approaches are conceptually similar [24] and that Lean's focus on the reduction of waste, in itself, proves its positive environmental effect [23]. Therefore, the alignment of LM and Green seems natural [25]. Consequently, the term Green Lean has emerged [26]. While it is true that LM does seem to have a direct relationship with EP, it is also evident that the environmental aspect has not been the core reason for the development of LM [27, 28], and that initiatives of EP (Green) and LM have been developed independently from each other [29].

Regardless of the core reasons for the development of LM and Green, and the fact the two cannot be perfectly combined [25], scholars agree that there are synergetic opportunities between lean and sustainability [23] and that they are concurrent and can effectively work together [23]. The U.S. Environmental Protection Agency [8] published a report referring to a strong linkage between LM and its impact on the environment. There is a shortage of in-depth research on their correlation and output [1], as well as the empirical evidence is sparse [10]. As a result of that, this paper further examines this with empirical evidence.

It is evident that the implementation of LM is not with concerns for the environment but is for business improvement. Scholars did raise concerns regarding the cost of improving EP initiatives being high may undermine the economic sustainability of the business [30]. But authors do agree that LM, alongside improving industrial performance, also contributes to environment performance improvement [10, 31].

Figure 1 below portrays the authors' understanding in light of the published articles and empirical evidence explored in this study, about the relationship between LM's 7 areas of waste and the 4 core dimensions to measure EP. The 8th waste of lean, unused employee creativity, has not been included as it's not directly linked with EP, although indirectly it does play a role in assessment and policy development for EP.

3 Research Method

The scope of this paper is to explore the impact of LM on EP and their relationship. For this purpose, empirical evidence and opinions were collected from industrial leaders/practitioners from China and Hong Kong. Four interviewees were carefully selected to represent a diverse range of industrial backgrounds/experience, and were interviewed independently from each other. A brief profile of the research participants

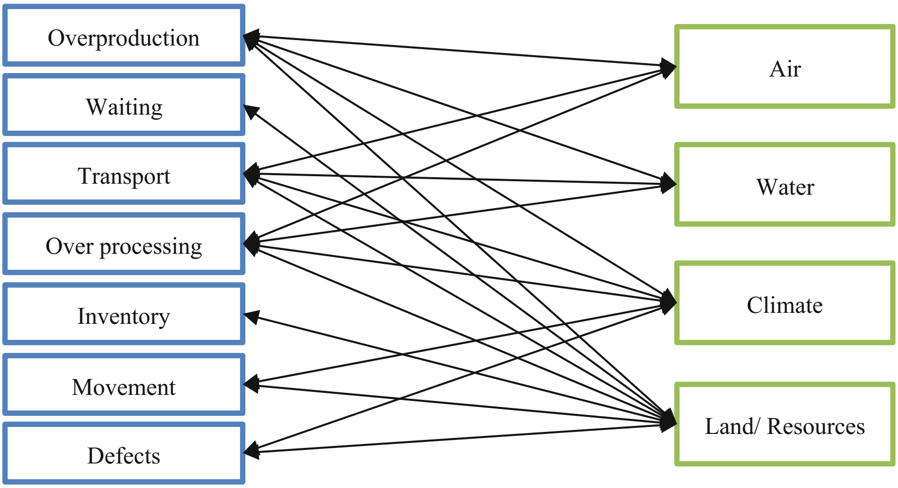

Fig. 1. Relationship between Lean's 7 wastes and environmental performance measures

Table 2. Research participants profile

Participant	Position	Industry affiliation	Experience
A	Project manager	Food	Over 8 years of experience in implementing LM principles in production/processing industry
B	Project manager	Machinery production	Over 10 years of industrial experience on LM
C	Director	Garments accessories	Over 17 years of industrial experience on LM
D	Associate Professor	Textiles/academic	Over 22 years of experience as Researcher on Lean Manufacturing

is presented in Table 2. Names of the individuals, and their companies, are kept anonymous under a confidentiality agreement.

The interviews were conducted via Skype and were audio recorded. Since all respondents were from different industries, it would be complex to compare their responses but at the same time it does give a good diversified understanding and eliminates bias.

3.1 Research Question/Framework of the Study

A questionnaire that consisted of 16 open ended questions was developed, with two major dimensions in focus on which the whole of this study hinges:

1. Are Lean and Environmental Performance related?
2. Does lean impact/improve environmental performance?

4 Results and Analysis

The interviews helped to collect primary data from industry leaders/practitioners. The responses provided a glimpse of diverse opinions on the matter and yet uniformity to some extent as well. The collected results are summarized in four dimensions (see Fig. 2) highlighting the core essence of this study, and are discussed below.

4.1 Are Lean and Environmental Performance Related?

The respondents' opinion leads to an inconclusive estimation about the relationship between LM and EP, except for one respondent whose opinion was based upon implementation perspective, rather than their rational nature. The reason to base their inconclusive opinion was the very core reasons for the development of these concepts.

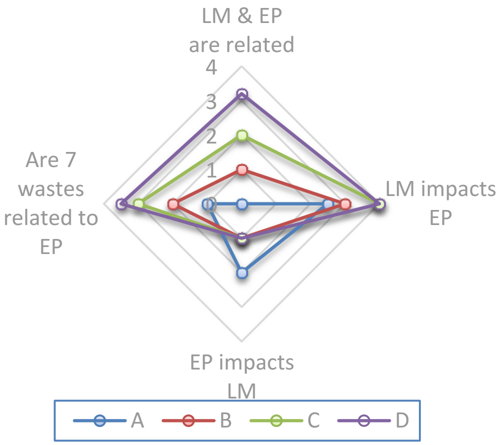

Fig. 2. Summarization of results in four dimensions

The respondents believed that the development of both concepts is independent and irrespective of each other and with very different focuses, one being on production/service optimization in a cost effective manner and the other being on environmental improvement, with a much broader prospective than just the economic benefit. However, they do believe that in the practical output they do seem to relate, and this is discussed further.

4.2 Does Lean Impact/Improve Environmental Performance?

All the respondents acknowledge the positive contribution of LM towards EP. Some of the views are as follows:

- Implementing lean does foster EP.
- EP improvement is an added/bonus feature of LM.
- Some examples shared by respondents are:
  - Usage of plastic pallet instead of wooden one was adopted under lean due to short lifecycle and less durability of wooden pallet. This did improve EP by

utilizing reusable material (plastic) and preserving resources by not using wood and not burning it at the end of life cycle.

- Reduction in transportation of material has a dual effect. Positive effect by optimizing the operation time, reducing cost, as well as reducing emissions. But at the same time, lower inventory requires more frequent deliveries, thus an increase in emission, but it does balance itself by decreased/delayed resource extraction, and no stagnation of material in storage.
- The food industry greatly benefits from LM, as by adopting JIT principles it minimize the obsolescence and wastage contributing to environmental pollutants.
- Another respondent highlighted the indirect impact on EP through the utilization of Kanban systems to optimize information flow and reduce the usage of energy by avoiding over processing or incorrect processing.
- With reference to one of the participants' responses, the design of assembly/production line affects efficiency. In general, a U-shaped assembly line system is given appraisal by participants, which is also highlighted by scholars [32]. It can improve efficiency by reducing motion within the processes, increase labor productivity by using less people to do the same work - so as to reduce the usage of natural resources and loss of other potential usage.
- By applying the TQM and Lean approaches, the possibility of defective product is minimized to the maximum possible extent, thus resulting in the preservation of natural resources and energy utilized for production.

In general, the environmental impacts of allocation of inventory, volume of production and defects have a strong linkage to the lean strategy.

4.3 Does Environmental Performance Impacts Lean?

The respondents tended to have negative opinion about EP impacting LM. Based on their opinion, businesses are more concerned with economic performance and would only (or mostly) act to improve EP if the regulatory authorities require so or otherwise if they come implicit in the management philosophies such as in the case of LM.

One respondent described implementation of lean in relation to the cost charged by the government, for the amount of polluted water released from their production facility and the need to keep it low. Therefore, the regulatory institutions with the EP goals of reducing polluted water and by placing cost on its disposal, resulted in the company adopting Lean. But such scenarios may not be very common. Mostly its other way around, where business improve EP to increase their market share or that EP come inherent within the optimization of operations through implementation of Lean.

4.4 Are 7 Wastes of Lean Related to Dimension of Environmental Performance?

Participants believe in the synergies between LM and EP but there are mixed reasoning on the linkage between the seven wastes of Lean and the four dimensions of EP.

Participants reason that LM might not always contribute to EP, as is the case with frequent deliveries, discussed above. Also, in the food industry and other operational facilities, water and other chemical fluids are used for cleaning equipment, which has to be done at least daily and sometimes several times a day. Thus, LM processes requiring frequent cleanup result in the release of more polluted liquid waste. Another participant argued that by doing so, process efficiency/accuracy is achieved which indirectly links to EP.

Finally, all the respondents suggested that LM has no relationship with toxic pollutants. If the regulatory authorities do not allow their usage or cap it to specific limit, industries will have to follow the guidelines.

5 Conclusion

This article provides an overview of the conceptual understanding of LM, EP, and their relationship. The qualitative analysis of empirical data collected through in depth interviews has provided understanding from the practitioners' point of view. Based on the survey results, it would be correct to say that both the LM and EP are interlinked to some extent but their development and implementations are done with totally different focuses. However given the dual nature of LM, it might be best for institutions promoting EP among industries to highlight LM as an enabler/approach in order to be more appealing and motivating to businesses. Due to the limitation of small sample size of interviewees, the study results cannot be generalized. Further research is highly recommended to expand the understanding and strengthen the implications of these two concepts to each other.

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Industry 4.0 and Lean Management – Synergy or Contradiction?

A Systematic Interaction Approach to Determine the Compatibility of Industry 4.0 and Lean Management in Manufacturing Environment

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Abstract. Considering the ongoing trend of digitalization of the manufacturing industry to Industry 4.0, this paper assists in the transformation. The research work is focused on studying the possible impacts of Industry 4.0 on lean management (LM) tools which play a vital role to foster quality and reliability of products and services that are delivered to the customers. The LM tools which are impacted by the advent of Industry 4.0 and assisting in successful implementation of future smart factory will be investigated in particular focus. An interaction plot matrix is established to quantify the influence of LM tools on Industry 4.0. Interaction between these Industry 4.0 design principles and LM tools reveal several opportunities for achieving synergies thus leading to successful implementation of future interconnected smart factories. Overall, the research work serve as a guideline for industries that are under the transformation phase towards future smart factory and offers space for further scientific discussion.

Keywords: Industry 4.0 · Lean Management · Production Management

1 Introduction

Industry 4.0, the high-tech strategy initiated by the German government, is changing the way the products are manufactured which leverages the advancements of internet of things (IoT) and information and communication technology (ICT) to integrate digitalization into the production process. Businesses are in pressing need to respond to these evolving trends and develop the capability to produce highly customized products until the lot size of one in order to meet the rapidly changing consumer preferences thus managing to stay competitive in the today's dynamic market environment.

Manufacturing companies are looking for efficient means to accommodate the integration of Industry 4.0 concepts into the existing setup. Here, the complexity to effectively manage the implementation of new technologies arises and studies are required to find its impact on the existing shop floor practices. Particularly, the potential

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dilemma over the compatibility of lean philosophy and Industry 4.0 existing together in future smart factory arises owing to the reason that lean principles try to reduce complexity but Industry 4.0 increases the complexity. On the other hand Industry 4.0 can also be seen supportive for the idea of a lean production as the emerging transparency due to the introduction of intelligent networked systems will benefit the essential continual improvement process (CIP). This research aims for a broader understanding of the above mentioned impasse and for the identification of the impact of Industry 4.0.

2 Method

In this work, firstly a general overview about the topic of the compatibility of Industry 4.0 and LM is given. Then an interdependence matrix of the LM tools from Toyota's lean house and design principles for Industry 4.0 is formulated. The basic notion in framing this plot is to identify the LM tools which are getting benefited (beneficiary coefficient) from the induction of Industry 4.0 design principles into the existing production setup and also determine the cumulative support (supporting coefficient) that each Industry 4.0 design principle offers to the considered LM tools. This matrix is then used to solve the dilemma of whether Industry 4.0 and lean philosophy compliment or oppose each other by highlighting the basic LM tools that are required for Industry 4.0 implementation. The LM tools from TPS house are considered for detailed analysis about their functionality and applicability in Industry 4.0. Then by means of the interdependence matrix, the beneficiary and supporting coefficient scores are calculated and their interaction effects are explained in detail by considering specific scenarios inside the future smart factory.

3 Background and Literature Review

Lean production as a subfield of lean management can be defined as an intellectual approach comprising of a set of principles, methods and measures which when implemented provide waste elimination and competitive advantages [1]. Therefore, the lean production principles have been widely accepted by the companies in early 1990s [2]. Thus lean production with its simplicity, higher productivity, improved quality, reduced development time and inventory were able to capitalize on the decline of CIM and became the status quo of production [3]. However, lean production also has its limits with regard to addressing the futuristic highly volatile customer demands (until lot size of one) which lead to highly fluctuating work content. This acts against the lean production's aim of evenly flowing production [4]. Also the TPS forecasts demand based on the actual demand in the market which cannot be increased or decreased arbitrarily [5, 6]. Thus the suitability of lean production to assist Industry 4.0 for tackling the challenges of highly volatile customer demand and requirement of customized products with short life cycles (which Industry 4.0 is focused on) are put to question.

It can be understood that a skepticism prevails over the compatibility of Industry 4.0 and lean philosophy but there are also supporting aspects. The concept of lean automation was proposed in the 1990s whereby most of the tasks in auto assembly were automatized and the productions units were populated with highly skilled problem solvers whose responsibility was to ensure smooth and productive running of the production system [7]. This term was just a watchword in the last decades which was not paid much attention [2, 8]. However, [2] argues that in the context of Industry 4.0, automation and lean technology can be combined for realizing more benefits. Industry 4.0 can be considered as a logical evolution of lean principles which will assist to realize its complete potential. So on the first hand, the lean concepts and lean thinking can be embedded firmly into the business model for being able to build towards Industry 4.0 [9]. Further it is shown that research activities in Industry 4.0 even enable the philosophy of lean manufacturing [10].

A central difference between LM and Industry 4.0 lies in the strategic approach. Lean tries to reduce complexity for achieving simple solutions by simple means whereas Industry 4.0 simplifies the complexity from the view point of user by decentralized control and intelligent assistants. But still some questions remain about which lean methods supports Industry 4.0? Which lean tools benefit from the introduction of Industry 4.0? Will there be some principles that needs to be adapted? Moreover, which LM tools will become obsolete with manufacturing digitalization? This research will shed light to answer these questions.

4 Compatibility of Lean Management and Industry 4.0

In this section an interdependence matrix is formulated in order to solve the above questions and skepticism that is prevailing over the compatibility. The basic concept in building this matrix is to develop an individual two-way interaction between LM tools and Industry 4.0 design principles where each interaction is rated. Individual rating in each cell signifies the supporting and hindering effects of Industry 4.0 design principles on LM tools in the matrix. The support that each LM tool offers to Industry 4.0 is not rated but the basic lean elements for implementing Industry 4.0 are highlighted. To create this matrix the tools/principles of both lean and Industry 4.0 have to be defined.

4.1 Lean Management Tools

Employees influence the organization culture by means of their practices thereby each organization possess its own characteristics and dimensions [11]. Thus LM tools and practices are influenced by the organizational culture and varies between different business contexts [12]. This diversity led to creation of different versions of lean models [13, 14]. In order to provide a common and widely accepted source, the TPS lean house was chosen as it is the base for LM tools and techniques in practice [15]. While it comes in many variants the version in [14] is considered as the standard model for competitive manufacturing in this research work. This plethora of LM tools, techniques and methodologies aim at elimination of waste [16]. However, these tools possess multiple names and potentially overlaps with each other and could also have different methods of implementation by various researchers [17].

Based on the TPS-House, the technical requirements of lean practices to be adopted by the companies [18] and the LM tools which are addressed in a thorough literature review in [19] 14 LM tools (Fig. 1) are identified which will be the basis for further analysis.

Kaizen	Takt time
Total Productive Maintenance (TPM)	Value Stream Mapping (VSM)
Standardization	Heijunka (Production Smoothing)
Forms of wastes (Muda)	Autonomation
5S (sort, set in order, shine, standardize, sustain)	Andon (Visual Control)
Total Quality Management (TQM)	Poka Yoke
Kanban (JIT/Pull)	Single Minute Exchange of Dies (SMED)

Fig. 1. Lean management tools

4.2 Industry 4.0 Principles

In order to assist in successful implementation of pilot projects of Industry 4.0, six design principles are derived from independent Industry 4.0 components (CPS, IoT, IoS, Smart Factory) by means of extensive literature review to identify the central aspects of Industry 4.0 [20]. These principles are used in this paper as the Industry 4.0 principles for further analysis (Fig. 2).

Real-Time Capability	Decentralization
Modularity	Interoperability
Service Orientation (SOA and IoS)	Virtualization

Fig. 2. Lean management principles

4.3 Interdependence Matrix

Using the identified lean and Industry 4.0 design principles, the interdependence matrix can be formed by inserting the LM tools in vertical direction and Industry 4.0 principles in the horizontal direction (Fig. 3). Each Industry 4.0 design principle has a benefiting effect, hindering effect or no effect on each of the identified LM tools and these effects are represented with scores ranging from 10 to −10. The interaction scores are allocated based on literature and on the authors' perception.

The interdependence matrix portrays a two-way interaction between LM and Industry 4.0 principles: (i) To what extent the Industry 4.0 design principles are supporting LM tools (represented by beneficiary and supporting coefficient) (ii) The basic

		Beneficiary Coefficient	Industry 4.0 Design Principles: Real- Time Capability	Decentrali-zation	Modularity	Interoperability	Service Orientation (SOA and IoS)	Virtualization
	Supporting Coefficient		6.6	6.1	3.1	6.2	4.7	6.1
Lean Management Tools	Kaizen (PDCA)	5.3	10	5	0	10	0	7
	TPM	9.5	10	10	7	10	10	10
	Standardization	2.8	5	0	0	7	0	5
	Forms of wastes	7.3	10	10	7	5	5	7
	5S	2.5	5	7	0	3	0	0
	TQM	4.7	7	7	0	7	0	7
	Kanban (JIT/Pull)	7.0	10	10	5	10	0	7
	Takt Time	-8.0	-7	-10	-10	-7	-7	-7
	Value Stream Mapping	4.7	10	5	0	3	0	10
	Heijunka (Smooting)	7.7	10	7	5	7	10	7
	Autonomation	7.0	5	10	3	10	7	7
	Andon	4.0	5	7	0	5	0	7
	Poka Yoke	4.7	3	8	3	7	0	7
	SMED	6.0	10	3	5	10	3	5

Legend											
	Value	10	7	5	3	0	-3	-5	-7	-10	Basic lean tool for Industry 4.0
	Degree of influence	Full support	High support	Moderate support	Limited support	No impact/ neutral	Limited hinderance	Moderate hinderance	High hinderance	Full hinderance	
	Range	9.1 to 10.0	6.1 to 9.0	3.1 to 6.0	0.1 to 3.0	0	0.1 to 3.0	-3.1 to -6.0	-6.1 to -9.0	-9.1 to -10.0	

Fig. 3. Interdependence matrix (color figure online)

LM tools which assist Industry 4.0 implementation (no scoring, colored blue). The beneficiary coefficient implies the extent to which each single LM tool getting benefitted from the Industry 4.0 design principles. It is calculated by summing up the scores for each interaction and dividing it by the total number of Industry 4.0 design principles. On the other hand, supporting coefficients imply the degree of support that each Industry 4.0 design principle gives to all the LM tools. It is calculated by summing up all the values except for the fields which have no impact and dividing it by the total number of LM tools that has a score value other than 0 [21]. This is done to negate the neutral effect of LM tools on the overall score. The other way interaction is represented by the cells which are highlighted in blue. It signifies that they are the basic lean elements that serve as a foundation and support successful implementation of Industry 4.0 (detailed in Sect. 5.3).

5 Discussion of Results

The matrix displays that most of the LM tool interactions with Industry 4.0 design principles receives either a supporting or at least a neutral effect. Only exception is the takt time which encounters a hindrance effect. This signifies that the concept of takt time will be eliminated in future smart factories. On the other hand, TPM had benefited the most from the Industry 4.0 design principles with a beneficiary coefficient score of 9.5. Since these two LM tools are lying at the opposite extremes on the scoring scale, they are considered for detailed explanation in the following. With regard to supporting coefficient, real-time capability is offering the highest support to the LM tools with a score of 6.8. Rest of the Industry 4.0 design principles are offering high to moderate support. The other way interaction (LM tools that support Industry 4.0 design principles) is highlighted in blue. It indicates the basic LM tools which are essential for successful implementation of Industry 4.0.

5.1 Interaction of TPM with Industry 4.0 Design Principles

TPM receives a comprehensive support from all the stated design principles of Industry 4.0. TPM will execute its functions more effectively in the future smart factory with assistance from Industry 4.0 techniques. The interaction of TPM and real-time capability yielded a score of 10 due to the fact that machine and plant conditions can be monitored in real time (e.g. energy consumption, machine breakdowns, output quality, OEE). By means of intelligent algorithms, failure patterns can be predicted in advance and concerned personnel can be notified which in turn makes the maintenance planning, forecasting, spare parts logistics more easy and efficient.

After failure detection, maintenance engineers will be notified with the location of the component in which failure is imminent. They can then use the machine history and detailed step by step 3D troubleshooting procedures which promotes high autonomy problem solving. Augmented reality and interactive 3D trouble-shooting guidelines on smart devices assist to carry out maintenance activities. On account of such highly decentralized activities, the interaction of TPM and decentralization was awarded with a score of 10. In case of a bigger malfunction, others machines can be contacted via M2M to find their availability for taking over the workload. Alternatively, the service availability of CPS and CPPS devices in other plants can also be verified via IoS to transfer the production orders to other units. After rectification, the solution is stored into the cloud. This along with failure pattern can be communicated with other machines which can then learn the mistake and prevent it from happening again. TPM highly benefits from interoperability and service orientation principles that the score of 10 is awarded.

If a failure demands a part to be replaced, then the new spare part can be printed using 3D printer. Parts of the machines are made modular for easy plug and play changeover, which enables maintenance replacement of the newly manufactured part. This often exclude parts which are more complex and require precise machining. So a score of 7 is given to the TPM and modularity interaction. CPS and CPPS devices perform data collection (e.g. tool wear) and data analysis. This data is compared with the stored standard reference models, its own historical performance data and performance data of other machines in the cloud to determine the current operating performance. Thus TPM and virtualization interaction is granted with a score of 10. TPM tool will serve as an important enabler for successful functioning of a connected industry [22].

5.2 Interaction of Takt Time with Industry 4.0 Design Principles

The interaction of takt time with Industry 4.0 design principles range from high to full hindrance. Decentralization was evaluated with a full hindrance score of −10 owing to the fact that decision about production planning, takt time calculation is made centrally with the help of forecasted demand and product variants. So rush orders cannot be easily integrated into the production with fixed takt times which is completely contradictory to the Industry 4.0 objective of decentralization and autonomy. Modularity also cannot be enforced as production schedules, product variants and the takt time are fixed. Real time product demand fluctuations cannot be accommodated into the production line which is a complete hindrance. Communication with other machines about delay and quality issues are of less importance if the takt time and work steps are already determined and it has to follow only a fixed production sequence. Also, takt times will not allow flexible capacity planning thereby blocking the services of machines and workers to other participants. Even data collected from the physical process cannot be used for implementing an immediate change in the production of successive products owing to limited flexibility, variants and output, which are already determined by the takt time. Changes can be implemented only during the next production cycle. Because of all these reasons, a high hindrance with a score of −7 is assigned to their interactions with takt time. In summary, takt time will be an obsolete LM tool in the future smart factory. This conception is also supported by various industry statements [23, 24].

5.3 Basic Lean Elements for Industry 4.0 Implementation

Some of the LM tool interactions (like modularity vs. standardization, decentralization vs. SMED) might have scored less with regard to the beneficiary coefficient but these LM tools in turn assist successful implementation and functioning of Industry 4.0. The most important of which is muda (waste). It is very much essential, that most of the waste in the factory and entire business process must be removed before digitalization. Standardization is also equally important for achieving modularity and interoperability as all the CPS and CPPS devices in a smart factory should have a standard protocol (e.g. OPC UA) for communication. To enable Plug&Play principle for flexible interchanging machine modules different manufacturers of the module should adopt standards for integration. It is important for virtualization to maintain consistent data standards for further processing. Likewise, SMED assists Industry 4.0's target of reduced batch sizes for achieving a lot size of one by reducing the setup time. The value streamed data is fed into cloud and machines access it continuously via IoT. The present status of value stream is monitored and if there are any discrepancies, it reacts independently to solve the problem without central control.

6 Summary and Outlook

This paper provides an explanation to the co-existence of lean management and Industry 4.0 in future smart factories via an interdependence matrix. The results of the matrix show the existence of numerous synergies between the considered LM tools and Industry 4.0 design principles. From the two-way interactions, LM tools like TPM, Kanban, production smoothing, autonomation and waste elimination benefit the most by the introduction of Industry 4.0. Real-time capability, decentralization and interoperability design principles offer highest support to the LM tools. Furthermore, it is shown that the concept of takt time will no longer be needed for production lines in future smart factories. The other way interaction shows that LM tools like SMED, VSM, standardization and waste elimination are supporting and represent the prerequisites for upgrading towards Industry 4.0. As a result, integration of Industry 4.0

modules in a lean manufacturing environment will add considerable value to a company. The authors are aware of the subjectiveness of the scores and therefore this paper aims for further discussion in the scientific community

Finally, it can be concluded that the concept of lean management will not fade away with the advent of Industry 4.0 but it is likely to become more important for successful implementation of Industry 4.0. The provided interactions between lean management and Industry 4.0 serve as basis for further research regarding the implementation of the lean philosophy into the future smart factory.

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A Method of Multi-perspective Assessment of Lean Management

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Abstract. Lean Management (LM) can harm corporations when unconditional implementation takes place. This paper proves that LM implementation brings negative side effects. Main reason for this can be stated as dysfunctional assessment of projects. Neither management control nor any other known method or mechanism can prevent side effects at present. As outcome of this paper a method for multi-perspective assessment is proposed, to resolve this problem.

Keywords: Lean Management · Negative side effects · Lean Assessment

1 Introduction

For Japanese, LM means looking at the timeline, starting with placement of customer order to the end of process when the company collects the cash of produced product. The period in between has to become shorter by elimination of all activities, which are considered as waste and not value-adding for the customer [1–3]. Literature research reports about positive effects, which can be achieved by implementation of LM. In contrast experts with practical background and some journals exhibit that side- or negative effects frequently appear by wrong implementation of LM. The definition for westernized business environments is considered a rigid framework in a medium term lasting project to reduce resources, mainly cost and headcounts mostly within the field of production, while level of innovation and quality is kept steady or increasing.

Its claimed that research about LM lacks credible qualitative data [4, 5] to analyze and diagnose phenomena why companies rarely obtain planned objectives of LM programs, neither match performance of Toyota, known as best in class LM benchmark. The literature around LM, mainly stress positive effects. Observable attention is on dedicated areas in production or supply chains, but rarely considering effects in other departments, interfaces, nor in the companies' environment. This leads to an underestimation of side effects. Finally the problem of negative side effects remains hidden or achieves minor attention within publications.

The described problem leaves a research gap in relation to qualitative data studies, root cause analysis and diagnosing of positive or negative side effects.

The contribution of this paper is constructive research to build a method to tame unwanted side effects and dysfunctionality of assessment of LM. This method in

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contrast to other existing methods proposes a detailed way to assess LM projects ex-ante and a methodology of monitoring during implementation to exclude side effects.

2 Research Method

Firstly a detailed analysis of qualitative data of a previous research in the machine building sector is exploited and summarized. It is used to reflect on structure and frequency of negative side effects of LM and their root causes.

Secondly dilemmas of controlling, which describe architectural shortcomings in performance management systems are researched to contribute to construction of multi-perspective method of assessment of LM.

Thirdly phenomenological research and abundant reasoning of side effects, root causes and dilemmas of controlling, lead to a conceptualization of structure and guidlines for method of multi-perspective assessment of LM. Additionally a methodology of decision making in case of detection of negative side effects is suggested.

3 Effects of Lean Management

A majority of authors in the area of LM report and endorse positive effects when using LM principles, methods and philosophy [1–3]. Findings of frequently cited authors promoting increased business performance by LM, follow a similar pattern to obtain data and publish findings in recognized journals e.g. (a) questionnaire summaries from short interviews or large pools [4, 5] and (b) sophisticated analytical research methods i.e. Cronbach Alphas or Regression Analysis [6, 7]. None of those papers or contributions explain why assessment of LM implementation could be dysfunctional [8]. Besides, it is proven in professional magazines that turbulences appear as negative effects, which can be directly allocated to LM programs or methods [9, 10].

In reflection of this contrast, a series of 30 field cases, from 8 globally operating machine building corporations was obtained. Cases were developed with experts from senior and executive management. As outcome of a four year study it was concluded:

Existence of negative side effects is unneglectable. In total, 40% of all cases exhibited negative effects higher than the initially planned positive effects. Furthermore 73% of all cases had a negative effect which is greater than 50% of the initially planned benefits. No case was without any negative effect. The structure of effects, typically reported are: (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 of experts outside of their professionalism/fluctuation of core employees; (v) Increased cost through i.e. exceeded budgets of Lean projects/initiatives [12, 13].

As main root causes for negative effects following items have been identified:

(a) focus on direct effects i.e. cost, manpower (80% of all cases), (b) Time related inconsistency of planned effect (73% of all cases), (c) Non-holistic assessment of project and environment (70% of all cases), (d) Scope related effects i.e. bypassing effects in other departments (67% of all cases), (e) Dysfunctionality in prior risk assessment (63% of all cases) [11].

It can be concluded, that most of the identified root causes are subject of management control; they manifest weaknesses in project assessment and project controlling. LM has synergetic side effects, which appear to be complex. Negative effects can accelerate or grow until financial loses for the companies appear. These dysfunctionalities need a guiding structure to allow observance ex-ante and reduce risks, plus a methodology to identify appearing deviations from project plans and countermeasure them.

4 Dilemmas of Controlling for Lean Management

The research field of performance measurement also known as controlling, embraces various methods or approaches to control improvement programs [14–16]. Considering application, the subjects of control consider: Activities, processes, projects, value streams, etc. The means of measuring are linked to accounting, intending to plan, monitor, predict and countermeasure effects. The nature of controlling is more quantitative in nature than qualitative. Qualitative approaches rooting from the Eastern hemisphere have not much importance. 5S, Poke Yoke or Hoshin Kanri [17] got introduced into westernized companies and became fashionable, lately. Others tried to align LM to number oriented measurement [18, 19]. The research on performance management is generally positive towards LM controlling, while just a few authors summon that number based controlling might corrupt effects of LM [20].

In this relevance six dilemmas of controlling are outlined [21, 22]. (I) The look at management, indicating that effects of quantitative nature play a dominant role while LM is more qualitative in nature. (II) Control, with suggestions to plan targets and possible deviations i.e. through influence factors of scope, time, activities and aim of controlling, always under consideration of environment factors (internal and external) and deviations at any time. (III) The factor of risks and steady control of it. (IV) Measurement theory in particular to decompensate targets to certain levels of the company, needed to be successful with LM. (V) The decision making process based on information, referring to real data monitoring, the existing quality of information and process to handle deviations. (VI) The choice of method how to manage LM [22].

Concluding, it becomes evident that all six quoted factors have relevance in the planning stage and being important ex-ante to implementation. A secondary issue, are planning related parameters i.e. qualitative, quantitative and risk, which require assessment, monitoring and decision making in case of deviation, while the decision making requires clear rules, responsibilities and competences allocated.

5 Method of Multi-perspective Assessment of LM

The method of multi-perspective assessment combines all researched weakness and overcomes the dilemmas of controlling in a structured way, exhibited in Fig. 1.

A detailed description of the method in six stages is listed as follows.

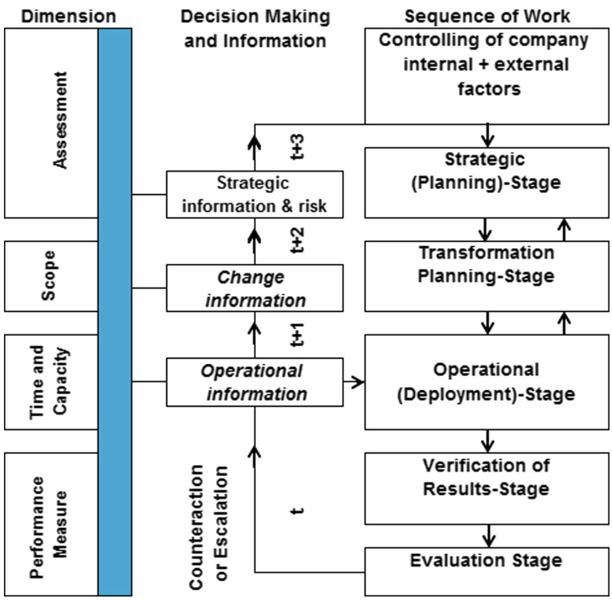

Fig. 1. Method of multi-perspective assessment of Lean Management

(1) Strategic alignment of executive management to strategic, operational controlling of internal and external factors is a prerequisite to lead in the strategic planning stage. This stage is prepared by financial advisors, the Chief Executive Officer and the head controllers, this relates to:
   (a) Internal parameters, i.e. human resources, cost, benefits, safety, quality, delivery, productivity, products, services, etc.
   (b) External parameters, i.e. markets, legislation, technology, competitors, growth, margins, etc.

(2) Strategic planning stage, objectives and planning are rooting from information of controlling and being deployed into the organization. The executive committee or managing directors jointly steer decisions with head controllers. Following stages have to be covered:
   (a) Objectives are decompensated or reversely aggregated in categories, i.e. quantitative, and qualitative, like quality, safety
   (b) Hoshin Kanri is used to visualize planned efforts i.e. projects, corporate/divisional target allocation of priorities and capacities
   (c) Time frame to transform targets based on resources, i.e. milestones, phase planning, resource planning and recruiting
   (d) Methods of management adjusted to objectives, targets, etc., i.e. revolutionary/evolutionary, convergent/radical or other tactical
   (e) Risk assessment, i.e. interdisciplinary team to detect risks, visualization in comparison matrix, ranking or risk impact
   (f) Control strategic parameters, i.e. success/failure parameters (a)–(e), agreement on possible deviations (a)–(e)

(3) Transformation planning stage is led by change agents, managers or mentors jointly with the divisional controllers. Following items are essential for success:
   (a) Targets planning and deployment, i.e. benefits or costs are mapped into business cases or provisional plans, layouts, timelines
   (b) Resource and team definition, i.e. structure of team, responsibility, roles and capacity planning
   (c) Capability analysis of team, i.e. experience, accuracy, willingness to change, drive or transform initiatives
   (d) Hoshin Kanri is used to visualize planned efforts i.e. projects, divisional/departmental objectives or allocation of priorities or sub-initiatives, etc.
   (e) Method and methodology of controlling and reporting, i.e. parameters like benefit, cost, man power or periods i.e. daily, weekly, monthly or medium of reporting like meeting, written, online, etc.
   (f) Risk control, i.e. defined risks
   (g) Reporting of actual, forecasted and planned results and risks
(4) Operational (deployment) stage is consisting of team leaders, experts and project managers, executing change, being supported by operational controllers in stages:
   (a) Goals deployment, i.e. execution of change or tracking of performance indicator development
   (b) Scope and timeline for transformation
   (c) Hoshin Kanri is used to visualize planned efforts i.e. projects, departmental/team based objectives or allocation of priorities or sub-initiatives, etc.
   (d) Preventive action for risk related issues
   (e) Reporting of actual results
(5) Verification stage, proven results by operational controller. In form of:
   (a) Qualitative control of operative/strategic parameters
   (b) Quantitative illustration and verification of results, i.e. charts
(6) Evaluation stage and preparation of information for decision making. Information in form of operational, change or strategic relevant purpose is processed to right decision taker via steering committee, according sequence below:
   (a) Progress, stagnation, stop
   (b) Corrective action, regulation of objectives, targets, goals
   (c) Escalation/De-Escalation to defined stage.

6 Validation of Method

The method has been used in improvement programs within the machine building sector and among the case study participants within the last 2 years. It is approximated that till now 100 projects (individual and multi-project approach) have been finished, without mentionable side effects.

Several critical elements define success or failure of proposed method. (i) It is suggested to run the method in co-existence of a project management department, consisting of a controlling specialist in charge of maintenance and tracking of improvement parameters, an experienced transformation manager and a LM specialist

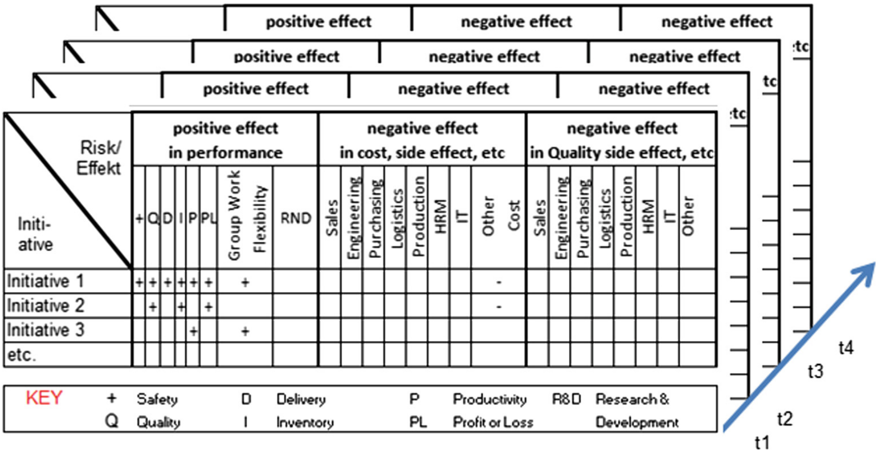

Fig. 2. Effect risk assessment and trade off

to observe transformation in practice, led project meetings and get a decision committee together, when needed i.e. progress report, escalation, etc. (ii) LM has to be aligned to the strategic planning of the company, to ensure management attention and commitment. (iii) A Hoshin-Kanri approach to decompensate initiatives throughout the company. (iv) An interdisciplinary risk assessment in form of an effects evaluation is essential. A vital element to avoid risk is Hoshin Kanri, combined with a risk assessment matrix shown in Fig. 2. (v) The risk matrix compares risk/effect of every project against every initiative i.e. project 1, 2, 3, or 5S, Just in Time, TPM, etc. The comparison suggests to multi-compare i.e. Q/Quality, D/Delivery, P/Productivity, others. In the columns displayed either positive or negative effects can be supervised on performance, department basis, etc. by indication positive or negative impact ±. It is suggested to constantly update the matrix to derive changes over time. All negative correlations should be counter measured. (vi) Projects should be used as medium to carry transformation. (vii) Formation of work streams i.e. purchasing, production, etc., business units or initiatives i.e. value stream improvement, just in time, etc., with particular responsibles to enhance progress and contribute with senior expertise, is advised. (viii) Controlling considers a decomposition and aggregation of effects in up- and downstream hierarchy, (ix) Controlling is not static, following budget or plans but allowing certain deviations until identified effect or problem is resolved or defined escalation bears progress. (x) Lastly, a methodology of how to make decisions [21] in terms of deviations from planned effects is illustrated in Fig. 3.

The moment a side effects is recognized: A stage of visualization i.e. graphs, charts, etc., is started, afterwards the problem is monitored, analyzed. If necessary at this point additional information from internal or external environment can be used to support the analysis. The decision making starts, but can just proceed if credible information is available. Afterwards a decision can be made but defined as acceptance, conditional acceptance or decision to provisionally stop and change the mapping or visualization

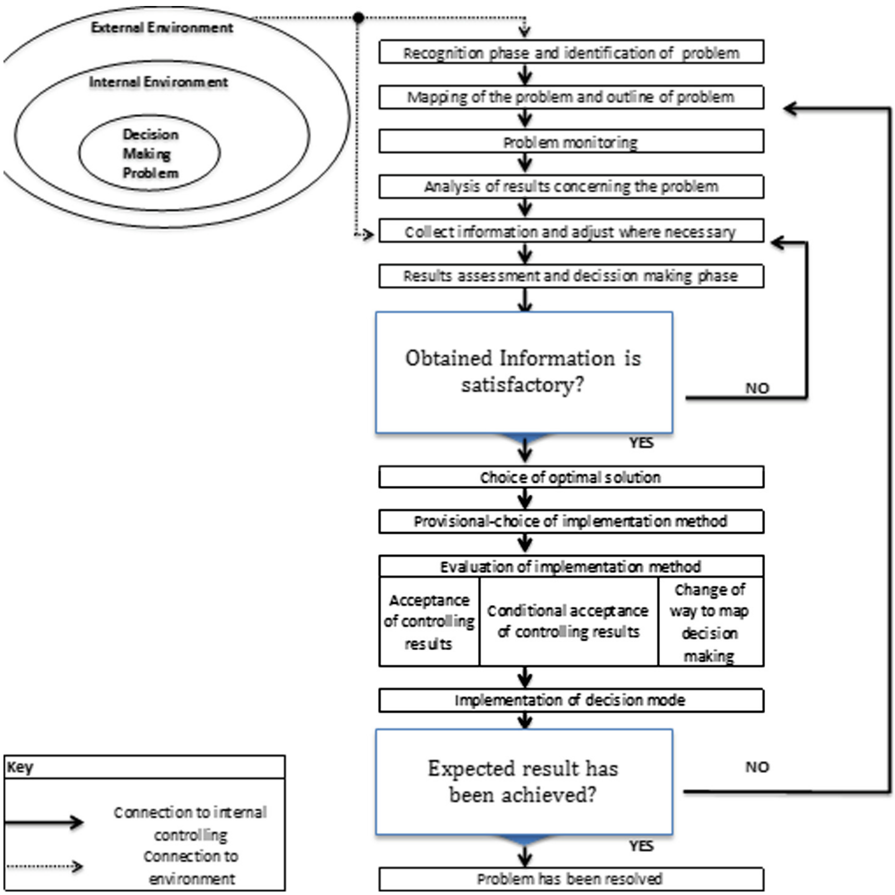

Fig. 3. Decision making process

method. To avoid negative side effects an understanding of impact should be aimed by decision maker/s.

7 Summary

A combination of the multi-perspective method and guidelines can monitor, detect, tame or overcome potential side effect of LM, ex-ante and during project implementation. This paper objects a broad based opinion of positive effects resulting from LM. It is evident that negative side effects exist. The proposed method, which is verified can be further developed in future research. This paper should motive other researchers to collect and study more qualitative data in the field of LM.

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Sustainability Strategies in Industrial Practice

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Abstract. Sustainable product development (SPD) is a prerequisite to meet United Nations sustainable development goals (SDG). Manufacturing companies take on different strategies and ambitions in their sustainability approach. In a case study with four manufacturing companies; two automotive suppliers and two furniture companies, it is shed light on various strategies and practices for sustainability in industrial practice. The furniture companies have sustainability as a foundation for their business strategy and every day activities. On the other hand, the automotive suppliers obey regulations and their customers' demands. One reason for different approaches is the companies place in the value chain. A company with the product focal brand is more likely to gain from sustainability strategies and actions.

Keywords: Sustainability · Strategies · Manufacturing · Industry

1 Introduction

For companies competing in the global market place, there is no longer a debate on whether one should consider the social and environmental impacts their activities and products have on external stakeholders. The interesting question now is how to integrate sustainability considerations and actions into day-to-day decision-making and strategic priorities. However, sustainability improvements must compete for attention in organizations that are also concerned with adapting new materials and technologies, increasing brand value, fulfilling user demands, or designing products with new meanings [1].

The principle of sustainable development was first introduced by the Brundtland Commission in 1987 as "development that meets the needs of the present without compromising the ability for future generations to meet their own needs" [2]. Today, sustainability is most commonly considered to have three dimensions, the economic, the social and the environmental, often referred to as the "triple bottom line" (TBL). Sustainable solutions are "products, services, hybrids or system changes that minimize negative and maximize positive sustainable impacts – economic, environmental, social and ethical – throughout and beyond the life-cycle of existing products and solutions, while fulfilling acceptable societal demands and needs" [3].

There is a large difference between companies and industries with regard to sustainability strategies. Based on Willard (2005), Hallstedt et al. [4], summarized these strategies into five groups: (1) Pre-compliance – ignoring sustainability and opposing relating regulations, (2) Compliance – obeying laws and regulations on labor,

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environment, health and safety, (3) Beyond Compliance – recognizing opportunity to capitalize on resource efficiency and reduction of waste, however, sustainability is not integrated into core businesses, (4) Integrated Strategy – sustainability is integrated into company vision and strategy to be more successful than competitors, and (5) Purpose and passion which is more like a special type of companies, with a mission to save the world.

This article shed light on this issue by comparing four leading manufacturers and investigating how far they have come towards integrating sustainability strategies into daily business activities. The presented work builds upon and elaborates on the main author's previously published research from the Norwegian industry. The case study is limited to the social and environmental aspects of the sustainability notion. Hence, this article investigates the following research questions more in depth: What types of sustainability strategies linked to sustainable product development (SPD) are currently used in the manufacturing industry? Which differences exist between industrial sectors?

2 Background Studies

Drivers for motivating or "pushing" companies to become more sustainable have been widely addressed by researchers over the past years, linking companies' overall sustainability performance to sustainable product development, as one cannot exist without the other. Legitimacy, competitiveness and social responsibility are categories for motivating companies into more sustainable actions [5, 6].

Legitimacy concerns complying with legislation and requirements from local authorities, national government, but also from international protocols and directives from the European Committee (EC) [6]. These directives are mandatory and are most commonly adopted and transposed into national legislation [7]. For manufacturing companies, the product-oriented environmental policies are particularly relevant. These include the Waste Electronics and Electrical Equipment (WEEE) Directive, the End of Live Vehicle (ELV) Directive, the Energy-Using Products (EuP) Directive, and the Restriction of the Use of Certain Hazardous Substances (RoHS) Directive. Such directives are expected to have growing impacts on industries in the years to come, both on products and processes [6]. The extended producer responsibility (EPR) principle is also expected to play a similar role. The purpose is to promote life cycle environmental improvements and to reduce pollution including resource and energy use. The EPR principle extends the responsibility of the producer to other parts of the life cycle, especially the product's end-of-life (EOL) phase [8].

Legitimacy also goes beyond mere complying with rules and regulations. It also includes a wider set of actions like audits, committee work and developing networks with local communities to provide a "license to operate" [6]. Such networks and committees involve both internal stakeholders within a company, but also relevant external stakeholders. Relevant internal stakeholder groups are management, employees, and labor unions. External stakeholders within this context are financial institutions, Non-Governmental-Organizations (NGOs), media, government, competitors, customers, suppliers, industry associations, and academia [9]. Different approaches have been suggested by researchers for useful stakeholder interaction on different levels between companies and its external environment. NGOs may for instance be engaged in ad hoc or long-term collaboration with companies, for example co-creating sustainable products with companies. In some instances, they may have the power to create market demands for sustainable products and thus foster sustainable consumption by linking consumer and company sustainability objectives closer to product development [10].

Competition concerns how sustainable strategies and actions may improve companies' competitiveness instead of being a cost factor. A recent literature study of the correlation between environmental and economical performance indicates that companies with a proactive strategy towards sustainability are likely to have economic benefits. On the other hand, reactive companies acting purely on enforced laws and regulations, are likely to experience additional cost and expenses related to sustainability strategies and actions [11]. A previous study also claims that larger environmental improvements following environmental investments are associated with expectations of higher financial gains [12]. Competitive benefits highlighted in literature for sustainable companies include, but not limited to: increased resource efficiency, increased return on investments, product differentiation, increased sales, improved image and development of new markets [6]. There is also a growing awareness among public agencies and large institutions who have developed guidelines for big volume purchases and for environmentally responsible public procurement, giving preferences to environmentally friendly products, and creating markets for environmentally benign products [8]. Hence, being a first mover may provide companies with a competitive advantage.

Activities upstream or downstream of the company's own production sites are important for the products' sustainability impact. Sustainable supply chain management (SSCM) have advantages like increased sales, more satisfied customers, smoother supply systems, and reduced costs [13, 14]. Involving suppliers in product development may additionally reduce time to market and improve product quality [15], however, supplier development and training may be required before the focal firm can offer more sustainable products [13, 16].

Stakeholder interaction may also contribute to a competitive advantage. "Participatory design", "co-design", and "design for all" are design movements that actively involves the end user or consumer as a resource in the design process [18]. The main purpose of involving end users it to understand their needs and behavior. Additionally it is a way for the company of connecting customers closer to a company and creating brand loyalty.

In some industrial areas, eco-labels, certification and standards may give a competitive advantage. The ISO 14000-standards for instance, are based on guidelines and principles, in which some are third party verified product labels for environmental excellence, some are based on self declarations (green claims), and the third type is based on product environmental declarations with quantified product life cycle data. Eco-labels and sustainability related labels include the Nordic Council White Swan, German Blue Angel, EU Flower, Fair Trade, and the Forest Stewardship to mention a few. These labels make sustainable products easily recognizable for the customer [6, 17].

Social responsibility as a motivation to take on sustainability strategies and actions is the third motivational category for companies [5], and is highlighted as an important strategy for the UNs SDG. This category embraces corporate social responsibility (CSR) and ethical responsibility, both concerning manufacturing and product, but also in the wider value chain. Important issues include, but not limited to, adherence to human rights principles, code of conduct, work conditions, employment in developing countries, ethical marketing, bribery, honesty and trust in business relations. That is, the strategies the company adhere to, and the action to operationalize them [17].

3 Research Design

To answer the research questions a comparative case study was conducted. Selecting an appropriate sample is important in case study research [19]. The first two companies, AutoA and AutoB were chosen based on literal replication, based on similar business contexts. Both are direct suppliers to original equipment manufacturers (OEM) in the global automotive industry and have co-located manufacturing plants and in-house product development departments. AutoA operates within the segment of commercial vehicle systems and produces fluid transfer systems worldwide to medium and heavy commercial vehicles. AutoB is a leading supplier of engineered surface-treated interior and exterior plastic components.

The other two companies in the study were chosen based on theoretical replication and belong to the Norwegian furniture manufacturing industry. Their business context is entirely different from the automotive suppliers'. They sell their products directly to consumers via retailers. CompA and CompB have co-located manufacturing plants and in-house product development departments. CompA is an international firm which develops and manufactures premium brand office chairs, conference furniture and cafeteria furniture for private and public office environments. CompB is an international firm that develops and produces premium brand recliners, sofas, loveseats, and mattresses.

During the case study, assessments, observations, semi-structured (group) interviews, and reading of company documentation were performed to gain understanding of company performance on sustainability strategies related to sustainable product development. Product designers, engineers, including environmental managers, purchasing managers and development managers were interviewed. The collected data was analysed in data displays with the aim to identify current sustainability strategies and practices in the companies linked to sustainable product development.

4 Results and Discussion

Comparison of four manufacturing companies demonstrates significant differences with regard to sustainability strategies and industrial practice. Table 1 reports the overall findings linked to motivational categories for the companies.

Table 1. Industrial practice on sustainability strategies and performance

Motivation	Environmental and social sustainability strategies	CompA	CompB	AutoA	AutoB
Legitimacy	Compliance with regulations	X	X	X	X
	Sustainability clearly defined in strategies and policies	X	X		
	Eco-branding of products	X	X		
	Stakeholder (external) interaction in i.e. product development	X	X		
	Internal stakeholder interaction (educational programs, task forces etc.)	X	X	X	X
Competition	Environmental management systems (ISO 14001, EMAS etc.)	X	X	X	X
	SPD tools implemented	X			
	Product sustainability labels	X			
	Sustainability focused supplier development programs	X	(X)	(X)	(X)
Social responsibility	CSR strategies, standards and actions (SA 8000, AA 10000, etc.)	X			
	Philanthropy activities, community engagement, sponsoring	(X)	X		
	Company ethical guidelines	X	X		

4.1 Maturity Level

CompA may be regarded as industrial best practice among these companies. CompA is known far beyond its marked segment to take necessary actions to ensure environmental and social responsibility. The organization demonstrated a high maturity level on sustainability matters throughout the organization that goes beyond management level. CompA provided examples of changing product design, material choice or suppliers due to poor social, ethical or environmental performance of certain product parts. Based on Hallstedt et al. [4], CompA fits the "Integrated Strategy–level 4" category, in which sustainability is integrated into all business activities from strategy, innovation, design and improved financial risk assessments.

Sectorwise, the study reveals predicted difference between the furniture sector and the automotive sector. In terms of integrated sustainability strategies [4], AutoA and AutoB are within the "Compliance–level 2" category with regard to environmental sustainability, obeying what they must, without recognizing opportunities and gains of doing more in the sustainability field. There seem to be fewer motivational factors to push these automotive suppliers into more sustainable actions. A plausible interpretation may be the companies' different places in the value chains. The automotive companies operate within a minimum compliance sector in the business-to-business (B2B) segment. The furniture companies on the other hand, operate in the business-to-consumer segment (B2C). Attention for negative or positive sustainability performance from consumers, media and NGOs is often given to the focal firm in a value chain; the brand itself or the brand owning company. Hence, brand owning companies downstream a value chain like the furniture companies, are more likely to be negatively exposed, and also more likely to receive financial returns on sustainability improvements.

Currently, the main drivers for improvements in AutoA are safety and quality, and lightweight interior for AutoB. Both companies reported that they would wait for customer requirements or governmental regulations before taking on more sustainability strategies and actions. The furniture companies on the other hand expressed a wish to be in the driver's seat in sustainability issues in order to capitalize on first mover advantages. Significant SPD investments had already been made, despite currently small markets for such products. These investments were mostly motivated by eco-efficiency strategies for financial gains for CompB. CompB therefore falls into the "Beyond Compliance–level 3" category [4].

4.2 Management Commitment and Training as Supporting Practices

Interestingly, all four companies reported management commitment to be the most important factor when working with sustainability issues. The accepted norm is based on what management do, not what they say, hence management must "walk the talk". Literature reports that employees are directly and indirectly affected by managerial attitudes and positions as motivators when it comes environmental pro-activity [20]. All four companies suggested that sustainability actions should be linked to economic performance and shareholder value as a way to keep long-term management attention.

Only CompA had designated and trained designers within SPD, and worked actively with various SPD tools to reduce negative social or environmental impacts. Many SPD tools are comprehensive, they require special training for correct use (e.g. LCA). This increases the threshold against using these tools. In addition to increasing the sustainability performance of a product, designers can also influence and encourage consumers towards more sustainable consumption by providing more sustainable product alternatives and by making such features visible and apparent [21]. Hence, SPD training will become more important in the future for companies that wish to enhance their product sustainability performance.

Related to this issue is the overall sustainability competence level in a company, a prerequisite for sustainable actions. The need for a "sustainability champion" to help with competence was highlighted by all interviewees. CompA was the only one with a designated sustainability champion (environmental manager). However, the responsibility for sustainability changes in CompA remains within each management level.

Furthermore, CompA pointed out that working with sustainability issues goes beyond mere sustainability competence. Despite adequate training, they have observed that employees' personal motivation influence how they react and respond in day-to-day actions. Some employees search actively for relevant information and act upon it. Others are satisfied to fulfill minimum requirements. Employees in different functions and hierarchical levels have different backgrounds and experiences, and also different worldviews on sustainability. Consequently, organizations also needs to go beyond competence and training and work with motivational issues and culture.

Our case studies based on the framework of Willard (2005) and Hallstedt et al. [4], demonstrate companies with different levels of sustainability strategies. To operate on a higher level, environmental and social sustainability issues are embedded in the entire organization and demonstrating a broad motivational ground from legitimacy, competition and social responsibility.

5 Conclusion

Increasing global competition is forcing manufacturing companies to continuously improve their business with sustainable and innovative products. From the presented case research of four manufacturing companies, we have learned that companies adapt different sustainability strategies and actions dependent on their business context. Focal brand companies, and “first movers”, may have the best financial gains from sustainability improvements. Best industrial practice in the current study include: sustainability clearly defined in company strategies and policies, product sustainability labelling, SPD tool implemented, sustainability focused supplier programs, adherence to CSR strategies and standards, philanthropy activities and different stakeholder interaction programs for both internal and external stakeholders.

This study indicates that in order to succeed with sustainability strategies and actions in industrial practice, organizations need more than competence and training programs for designers. Management commitment, task forces as well as “sustainability champions” are important pieces in the overall “puzzle”. In addition, companies need to work with personal motivational issues and culture, because employees’ personal motivation influence how they react and respond in day-to-day actions.

Although much research has been conducted on sustainable companies, little focus has been directed towards identifying best industrial practice for other companies to learn from. To enhance the results more research is needed from multiple organizations trying to implement sustainability strategies and actions.

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Introducing Buffer Management in a Manufacturing Planning and Control Framework

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Abstract. Buffer management is not of a great concern when there is a perfect match between demand and supply. Demand represents the requirement for resources, and supply represents the collective capability of the resources to fulfill the requirements. A perfect match would then represent that supply can fulfill demand without any buffers involved, such as materials prepared in advance or capacity not being fully loaded. Such a perfect match is usually not possible to achieve since demand is frequently difficult to predict and the agility of the supply is limited. As a consequence, supply cannot perfectly match demand which may result in insufficient delivery performance. Different types of buffers may be employed to improve performance but they should only be used when the contribution of a buffer is greater than the cost of it. Hence, management of buffers is an important part of manufacturing planning and control (MPC) in order to mitigate such imbalances in pursuit of a competitive supply. The purpose here is therefore to define a framework for MPC that reflects the significance of buffers. To actually establish competitive supply is a complex challenge and four management perspectives are identified to support the balancing of supply with demand. Buffer management is here defined based on the intersection of these four management perspectives related to the transformation flow: the resources employed in the flow, the risk involved in the flow, the decision making related to the flow, and finally the planning and control to balance the flow.

Keywords: Manufacturing planning and control · Balance management · Resource management · Risk management · Hierarchical management

1 Introduction

Manufacturing planning and control (MPC) has developed from relying on completely manual routines to integrated computer support in terms of e.g. advanced planning and scheduling systems [1]. Independent of the level of computer support there are some fundamental logics that should be recognized. A key component in this context is that demand defines the requirements and supply employs resources to fulfil that demand. This is also referred to as the mutual relationship between availability of resources and the fulfilment lead-time when supply is responding to demand. A significant part of a lead-time is the queue time which is heavily influenced by the utilization rate. It basically

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means that if the utilization rate is high (i.e., most of the capacity is loaded) the queue time is extensive and correspondingly if the utilization rate is low the queue time is negligible [2]. This relation is based on the impact on lead-time by uncertainties and indicates that buffers must be carefully located both in terms of capacity, to obtain an appropriate utilization rate, and in terms of materials, to reduce the risk of resources being starved or blocked due to imbalances in the material flow [3]. Even without consideration of uncertainty there may be deviations between demand and supply. A typical example is the financial evaluation of ordering costs resulting in economic order quantities where level demand is balanced with lumpy replenishment of an inventory buffer. This could also be exemplified by seasonal demand for stocked items and level supply where seasonal inventory works as a buffer. Depending on the situation it might also be necessary to have capacity buffers. Buffers are therefore an important component for balance management but due to costs a buffer is always limited and with limited buffers a system is exposed to variability and the delivery capability may be compromised. As a consequence, the location and dimensioning of buffers is a key challenge for MPC and understanding how to use resources to establish buffers is an important capability.

The two categories of resources (i.e., materials and capacity) have been highlighted in the MPC literature since the inception of the research area. To have enough materials and capacity is a key challenge and in combination they provide great complexity. Therefore, they are traditionally handled in sequence where one is managed before the other. In MRPII for example the first focus is on balancing materials and thereafter the capacity balancing between required and available capacity is performed. In some process industries the approach is reverse where key resources are loaded and then the resulting inventory levels are checked. In either case, the expected plan is determined using the appropriate buffers to handle different types of variability. In some cases, the buffers are estimated based on formal procedures and updated periodically but usually they are handled in a more informal way far from the statistical methods of inventory control.

The purpose of this research is therefore to outline a refined framework for MPC that explicitly highlights the significance of imbalances between demand and supply and the consequent requirements for buffers. Next, balance management, resource management and risk management are outlined followed by introduction of hierarchical management. Thereafter, the conceptual framework for MPC is introduced where the sixteen components of buffer management are defined and the design of units of analysis is outlined. Finally, some concluding remarks and implications of the framework are indicated.

2 Frame of Reference

MPC is fundamental for the business to be profitable and to provide a competitive return on investment. At the core of this challenge is supply in response to demand with the purpose of striking a competitive balance between efficiency and responsiveness [4]. This balancing act is based on resource management covering all the available resources. In an MPC context, the resources are usually divided into the objects being transformed (i.e., materials) and the objects actually performing the transformation (i.e., transformands). In particular, the capacity of the transformands are then emphasized and hence resource management is performed in terms of materials and capacity. Balancing is exposed to uncertainty in supply as well as in demand and this is covered by risk management. Risk is a general concept but traditionally risk in MPC has been associated with some measure of uncertainty and the most common is the standard deviation [5]. When the uncertainty is identified the remainder is the expected outcome, the target for regular MPC. Finally, decision making in MPC is complex and covers long term strategic decisions involving positioning of the business in relation to the context of different markets where suppliers and customers meet, as well as short term execution challenges. To manage this type of complexity a hierarchical approach has evolved that is case specific. Still some general guidelines for hierarchical management can be identified. In total this means that four management perspectives of MPC are identified and constitute the foundation for buffer management in this research:

- Balance management: Demand and Supply
- Resource management: Materials and Capacity
- Risk management: Regular and Safety
- Hierarchical management: Structural, Aggregate, Detailed and Execution

2.1 Balance Management: Demand and Supply

The fundamental principle of logistics in any setting is the balancing of demand and supply. Demand can originate from external customer requirements as well as internal requirements related to internal customers such as a stock point that needs to be replenished. External demand can either be a projection of future requirements in terms of a forecast or based on actual customer orders. Also, internal demand can be based on expected future requirements or actual requirements. Demand may therefore be considered as certain or uncertain. Supply represent all the activities related to fulfilling these requirements. In the same vein as demand, supply may be uncertain or certain in terms of both volumes and timing. Consequently, balancing is challenging due to the combination of certain and uncertain variations in demand and supply. Buffers are used to mitigate the imbalances between demand and supply. A buffer is thus a key element in balance management and the challenges of positioning and dimensioning buffers is here referred to as buffer management. A buffer basically enables decoupling of supply from perfect tracking of demand. In summary, the two types of balancing can be categorized as either being performed at a "macro" level related to external customers or at a "micro" level related to internal customers and in both cases buffer is a key mechanism for mitigating imbalances.

2.2 Resource Management: Materials and Capacity

Resource management is complex since it involves the timing of numerous transformations being performed by a wide range of transforming resources. To simplify matters the objects being transformed are managed separate from objects performing the transformation. The objects being transformed are here referred to as materials and consequently the management of these resources is referred to as materials management (MM). One unique characteristic of materials is that when produced materials is not utilized immediately, it can be inventoried for later use. In some cases, there are some further constraints related to for example perishability, that further complicates MM.

The transformation of an object requires transforming objects. These transforming objects are here referred to in term of their capacity, and the management of these resources is referred to as capacity management (CM). When there is a mismatch between demand and supply there is a need to either adjust supply or demand, where adjustment of supply is primarily by making changes in capacity. The resources that typically are used to adjust the capacity level in the long or short term are buy/sell capacity, personnel, and machines each with their unique properties in terms of flexibility. High flexibility also correlates with higher capability level and can be achieved by flexible machinery, cross-trained employees and quick changeovers. In contrast to materials, capacity cannot be saved from one point in time to later since an hour lost is an hour lost forever.

2.3 Risk Management: Regular and Safety

Borrowing from the language of quality management and forecasting the concept of regular is associated with systematic variations (i.e., expected events) and safety associated with stochastic variations (i.e., unexpected events, uncertainty). Risk management is a quite general challenge but as outlined above it can be identified as identifying and managing uncertainty in the system. Aspects not involving any uncertainty are referred to as regular and can be symbolized by the Greek letter mu (μ), which in statistics is associated with the expected outcome. In terms of a material requirements planning (MRP) system the regular part would concern the net planning mechanism and the fundamental principles for generating the planned orders. The safety part can be symbolized by the Greek letter sigma (σ) and is represented by for example safety stocks or safety lead-times that are added to the generation of planned orders. In general, two different types of uncertainties can be identified; uncertainties in demand and uncertainties in supply. When and how much a resource is needed is based on uncertainties in demand, while questions about a resource and its availability is based on uncertainties in supply. The uncertainties vary to some extent depending on the types of resources concerned. For materials, an uncertainty buffer can be in the form of a safety stock of materials and for capacity it can be safety capacity, both referring to some additional amount compared to the regular level required to meet occasionally higher demand. Capacity can refer to resources in terms of machinery as well as personnel. In addition, safety buffers can be placed in different parts of the value flow based on their purpose.

2.4 Hierarchical Management: Structural, Aggregate, Detailed and Execution

A monolithic approach to MPC is extremely challenging since the amount of information available is overwhelming and in addition different types of decision concern different time horizons. When performing strategic positioning of the company information about the queue in front of an individual machine provides limited value. Instead the information of value to each individual balancing decision should be identified and both resource management and risk management have unique characteristics for different time horizons. The long-term decisions concern the positioning of the company network of sites in relation to markets and are considered as part of the operations strategy. This strategic positioning is here referred to as the Structural level (StL) and fundamental for multi-site scenarios and supply chain design. Once the positioning is performed the next logical issue to manage is dimensioning of resources at each node of the network, often seen as tactical demand and supply balancing. Some decisions related to dimensioning are made at StL but other aspects are still possible to adjust such as personnel, contracts with suppliers, machine utilization, seasonal inventory or backlog. This type of planning is usually performed at the Aggregate level (AgL) under the heading of sales and operations planning (S&OP). Once dimensioning is performed the actual volumes possible to produce are set and focus shifts to the mix of the output. In most cases the mix is considered at the independent level (master scheduling) and the dependent level (materials planning) but in general this planning issue concerns the coordination of resources at an item level and in some cases at an operation level. This level concerns detailed planning and scheduling of materials as well as capacity with the objective of fulfilling customer orders and is therefore referred to as the Detailed level (DeL). Once the detailed planning and scheduling is performed the last step with the shortest time-horizon is the actual execution of the plan, at the Execution level (ExL). In summary, hierarchical planning is split into four distinct levels based on the type of decisions to be made, the details of the information considered and on the time-horizon employed. From longest to shortest time-horizon these are: Structural level, Aggregate level, Detailed level and Execution level.

3 Framework for Manufacturing Planning and Control

The four management perspectives outlined above is each important for MPC. It is however in combination that their significance for buffer management unfolds and provides support for positioning problems. By combining the four management perspectives it is possible to identify sixteen components for buffer management. These components can be combined in terms of different unit of analysis for buffer management.

3.1 The Sixteen Components of Buffer Management

The sixteen components are identified through logical deduction using a combinatorial approach. By combining resource management (materials and capacity) with risk management (regular and safety) it is possible to identify four combinations between these concepts. The identified combinations are materials-regular, materials-safety, capacity-regular and capacity-safety. Since risk management is significant in both MM and CM, safety management is highlighted in relation to regular management and the identified combinations is thus referred to as Safety Materials Management (SaMM), Regular Materials Management (ReMM), Regular Capacity Management (ReCM), and Safety Capacity Management (SaCM) as shown in Fig. 1.

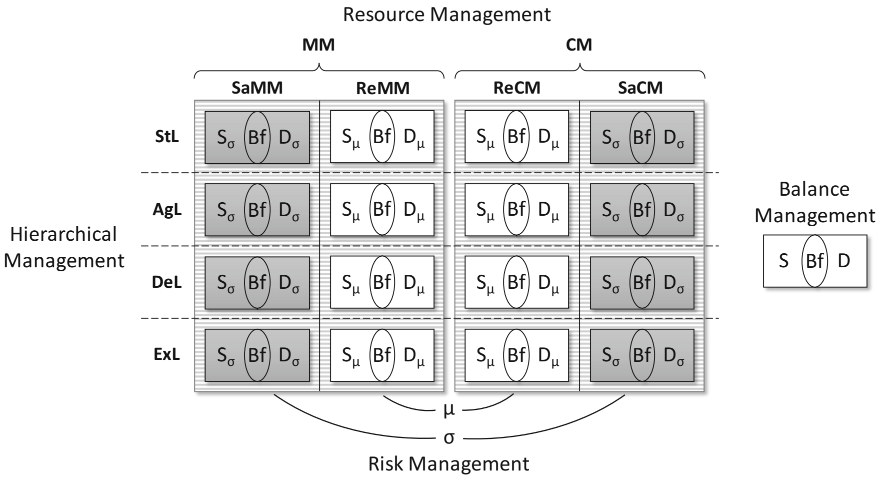

Fig. 1. MPC framework combining resource management, risk management, hierarchical management and balance management

As mentioned above, “regular” represents expected events and probable outcome of demand and supply in MPC, thus considering systematic variations but ignoring uncertainty. Regular involves much of the fundamental planning principles. Dimensioning in ReMM concerns for example buffers in terms of cycle stock with the counterpart of ReCM which then would concern cycle capacity. The opposite of regular is irregular, which represent uncertainties (stochastic variations) that are handled with safety buffers. Safety buffers should also be based on expected values with the difference that buffers are a matter of expected properties of fluctuations. SaMM includes, for example, dimensioning of safety stocks based on the planning levels’ requirements. In analogy with material buffers, the capacity buffers can be highlighted in a similar manner as for materials, which here is represented by SaCM.

In total MM and CM can, as indicated above, be divided into four management approaches (ReMM, SaMM, ReCM and SaCM) and by also including hierarchical management levels the framework of Fig. 1 is derived. By combining the four types of regular and safety management with four levels of hierarchical management it is possible to identify the sixteen supply-demand balancing elements represented by S, D and Bf (Buffer) in Fig. 1. For each element, that represents a unique supply-demand balancing task, the subscript μ is used for regular and σ for safety.

3.2 Unit of Analysis for Buffer Management

Buffer management takes care of the imbalances between demand and supply. The components identified in Fig. 1 constitutes the components of scenarios for buffer management in the sense that a unit of analysis includes a set of components. A unit of analysis is therefore here defined as a set of components. For example, buffer management related to AgL, in a S&OP process, would cover all four components of AgL including the intersection between AgL and SaMM, ReMM, ReCM and SaCM. Each component presents specific balancing challenges for mitigating the imbalances between demand and supply. A different unit of analysis would be to for example only focus on uncertainty based buffers, i.e. safety buffers at specific hierarchical levels. The framework explicitly highlights the need of covering uncertainties in MPC by including buffer management in terms of SaMM and SaCM. The distinction between regular and safety is often implicit in the literature on MM, while it traditionally is hardly present in the literature related to CM (see e.g. [2]). Uncertainties are often included in MM (e.g., safety stock calculations) but are usually not visually illustrated separate from their use in SaMM. In the context of capacity, risk management is managed as a whole without this distinction. There are several methods for capacity planning, utilization and making capacity changes, which all relate to ReCM. Although, methods and techniques for the actual dimensioning of safety capacity have not been clearly indicated in the literature. In this sense, SaCM is an extension of a traditional view of MPC. Even though SaCM has not been much highlighted in the literature it still exists in practice, although it is mostly based on experience rather than on formal methods. The characteristics of SaCM in practice was indicated in a case study conducted 2016 [6], where several case companies used safety capacity buffers to handle unexpected events. One of the companies' targeted 20% extra capacity in relation to regular capacity requirements in order to supply potential new market demand, that however might never occur. This type of dimensioning is in particular associated with AgL but based on explanations from the case companies it actually spans over several additional hierarchical levels to different degrees and is considered to be of different character based on the planning levels. When referring to dimensioning of different degrees it primarily indicates that the ability to make changes at lower planning levels are constrained by higher level decisions, since higher level decisions set the boundaries for the next lower planning level. As mentioned above, a safety buffer provides a margin to protect against uncertainties such as random variations in demand and is important to consider in order to be competitive. Thus, the proposed framework distinguishes between regular and safety to illustrate the two fundamental parts of buffer management in terms of MM and CM. Subsequently, it also highlights SaMM as a separate part of MM instead of being implicit and adding SaCM as part of CM, which in turn leads to an indication of a knowledge gap about SaCM.

4 Concluding Remarks

Buffer management has traditionally not been a clearly elaborated part of MPC. In particular, the dimensioning of resource buffers has been implicit in MM and CM with limited support on how to determine the buffer sizes. A distinction is made in this research between regular and safety. Note that the framework indicates different types of buffers and it can be used for design of MPC but also be used to indicate how to perform the actual operation of MPC. The difference can be explained for MM in terms of MRP and safety stocks, where the use of a buffer such as a safety stock in MRP would be in ReMM since the operation is completely based on expected outcome. The decision about the size of the safety stock SS would however be covered by SaMM as a design issue. When it comes to CM, SaCM has been identified in practice as important for competitiveness but actual decisions regarding the buffer size is mostly based on intuition since the availability of formal methods for this purpose is limited. In this context capacity requirements planning (CRP) would use for example utilization rate in operation as an indication of required buffer capacity in ReCM but the actual estimation of the utilization rate would be covered by SaCM as a design issue. In addition, buffers are needed on all planning levels but the question is how to determine the buffer size and where to position them. Hence, decisions regarding the buffers at different hierarchical levels could be elucidated further in the areas of SaCM to complement SaMM.

This research provides a complement to the traditional view by a refined framework for MPC that highlight the significance of buffer dimensioning, see Fig. 1. The framework identifies sixteen different components for buffer management. The components constitute building blocks for a buffer management unit of analysis defined for a particular case. The MPC framework could be generalized to an operations planning and control (OP&C) framework by also considering services. The framework offers several paths for further research but the SaCM part of the framework lacks formal support and is of particular interest to gain further insights on from both a theoretical and empirical perspective.

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Bottleneck Prediction Using the Active Period Method in Combination with Buffer Inventories

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Abstract. Knowing the bottleneck is one of the keys to improving a production system. The active period method is one approach to detect shifting bottlenecks that most other bottleneck detection methods have problems with. Yet, like many other methods, these detections are limited to detecting the past and present bottlenecks. In this paper, we combined the active period method with the buffer inventories and free buffer spaces of the adjacent inventories to statistically predict not only an upcoming change of the bottleneck, but also where the bottleneck will move to.

Keywords: Bottleneck detection · Inventory · Bottleneck prediction · Active period method · Bottleneck walk

1 Introduction and Literature Review

Bottleneck[1] detection is the key to improving output in any production system, and also the basis to predict the shifting of a bottleneck. Only the improvement of the throughput of a bottleneck process will lead to an improvement of the throughput of the entire system. Unfortunately, real-world systems are dynamic and rarely have a single, permanent bottleneck. Instead, the bottleneck shifts between different processes. Therefore, we define the bottleneck as follows:

> *Bottlenecks are processes that influence the throughput of the entire system. The larger the influence, the more significant the bottleneck [1–4].*

[1] Please note that throughout this paper we will occasionally abbreviate "bottleneck" as "BN" in graphics.

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To detect shifting bottlenecks, it is necessary to determine how the momentary bottleneck changes over time. Hence, it is necessary to determine the momentary or real-time bottleneck. Due to the nature of the shifting bottleneck, however, it is not possible to determine momentary bottlenecks using long-term averages.

Unfortunately, many bottleneck detection methods presented in academic publications or used in industry are based on long-term averages, as for example the average cycle time or utilization [4–8], total waiting time [5], average waiting time [9], average length of the queue [10, 11], or combinations thereof [12], and average time blocked or starved [13–15]. Overviews of different bottleneck detection methods can be found, for example, in [3, 16, 17].

There are very few methods available that are actually able to detect the momentary bottlenecks. These are the active period method and the bottleneck walk. The active period method determines the momentary bottleneck through the process that has currently the longest period without interruption through waiting times (the active period) [18, 19] and a simplified variant thereof [20]. This method is very precise but has high requirements on the quality of the data.

The bottleneck walk looks at both processes and inventories to determine the direction in which the bottleneck is likely to be found [1, 21]. This approach is very well suited for practical use in flow lines, although it has difficulties with job shop-type production systems. These two methods consistently outperform other bottleneck detection methods [3, 16, 22]. Within this paper we will use the active period method, and hence will present this approach in more detail below.

2 Need for and Use of Predictive Methods

Detecting the past and current bottleneck is one step to improving system output. Yet another major step is to predict the behavior of the bottleneck in the future. If a shift in the bottleneck can be predicted before it happens, then it is possible to counteract this change and prevent a shift. While this will not eliminate the bottleneck in the system, it can avoid or reduce the negative influence of shifting bottlenecks among each other.

Wedel et al. investigated the effect of the buffer preceding the bottleneck on the prediction of the change in the bottleneck [23, 24]. However, while they investigate both upstream and downstream buffers, they do not investigate where the bottleneck shifts to.

3 The Active Period Method

As this bottleneck prediction method is based on the active period method, we will briefly describe the bottleneck walk. More details on this method can be found in [18, 19], and an evaluation of its abilities in [3, 16, 22, 25].

The active period method is based on the status of the processes across time. For the duration of the observation, the status of all processes is monitored. While the process can be in many possible status situations, like working, repair, waiting for parts, changeover, maintenance, waiting for transport, etc., these are aggregated into two groups: (1) Waiting on another process, called inactive; and (2) NOT waiting on another process, called active. These active periods are plotted as shown in Fig. 1 for a simple example using four processes in sequence.

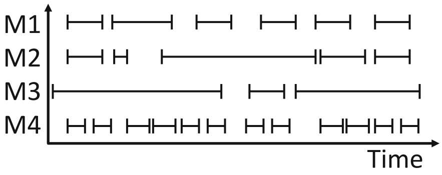

Fig. 1. Simple example of the active periods for two processes

At any given time, the process with the longest active period is the bottleneck. The bottleneck shifts when one longest period overlaps with the next longest active period. Figure 2 shows how the bottleneck changes from machine M3 to M2 and back for the simple example from Fig. 1.

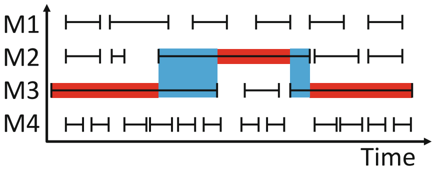

Fig. 2. Simple example of the active periods for two processes showing the bottleneck shift

This active period method is very precise and well suited for many different kinds of production systems. Its drawback is the data requirement, as a continuous data stream from all processes is necessary.

4 Adapting the Active Period Method for Prediction

The active period method analyses an entire data set from beginning to end. Hence, it must be adapted before it can be used for bottleneck prediction.

4.1 Floating Observation

The major difference is that for a bottleneck prediction, we do not know the future behavior of the production system (otherwise no prediction would be needed in the first place). Figure 3 shows the example from Fig. 1, although with an unknown future development.

Here, too, the current bottleneck is the process with the longest active period until now. Unfortunately, we do not know a shift until it happens. However, we do know

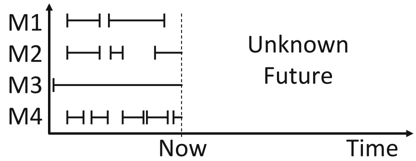

Fig. 3. Simple example with active periods up to the current moment of observation

which process would be the runner-up. Figure 4 shows the current bottleneck M3 in red and the possible next bottleneck M2 in blue. If the process marked in blue will become the bottleneck or not is not visible from this data until it happens.

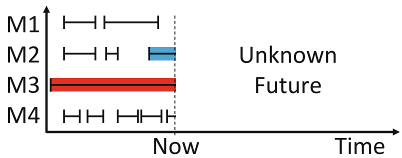

Fig. 4. Floating bottleneck observation and runner-up (Color figure online)

4.2 Prediction of Bottleneck Shift Event

Hence, the second problem is to predict when the bottleneck will shift. A bottleneck will shift if the so-far-longest active period is interrupted. This can happen in two cases: the process with the longest active period so far runs out of parts or runs out of space to store parts. These two situations are commonly known as starved and blocked.

The likelihood of this happening can be directly observed from the buffer before and after the currently longest active process. If the buffer before the currently longest active process starts to run empty, then the risk of interruption through starving increases. If the buffer after the currently longest active process starts to run full, then the risk of interruption through blocking increases.

4.3 Prediction of Future Bottleneck

When a bottleneck shifts, the future bottleneck is the process that at the moment before the shift has the second-longest active period, and is therefore the longest active period after the shift. The example in Fig. 4 shows the possible future bottleneck as process M2.

5 Simulation Verification

The above approaches have been verified using simulation data. Our system consisted of eight processes in sequence, as shown in Fig. 5, always separated by a buffer with a capacity of 10. There is infinite demand and supply at the system boundaries. The cycle

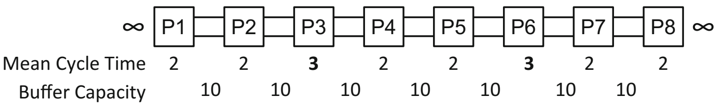

Fig. 5. Simulation example

time of the processes are exponentially distributed with a mean of 2, except for process P3 and P6, which have a mean of 3. Hence, processes P3 and P6 are likely to be the bottlenecks. The simulation was run for 8000 time units.

Figure 6 shows the results of the active period analysis. As expected, the bottleneck changes mainly between processes P3 and P6. Overall, P3 was the sole bottleneck 29% of the time and shifting for 31%, whereas P6 was the sole bottleneck 39% of the time and shifting for 30%. All other processes have a negligible impact on the system performance with below 2%.

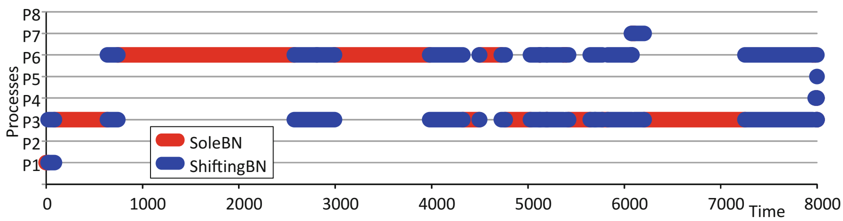

Fig. 6. Active periods of simulation example

For all bottleneck shifts within the simulation, we plotted the behavior of the buffer before and after the currently longest active period up to the moment of the actual shift. This is shown in Fig. 7. The x-axis is the negative time until the shift of the bottleneck away from the currently longest active period. The 22 graphs overlap each other partially. All of these graphs start when the bottleneck shifted to the process, and end when the bottleneck shifts away (time 0 on the x-axis). The y-axis shows the available parts in the buffer in front of the bottleneck on the top half, and the available free spaces inverted on the bottom half of the graph.

The results are very concise. When the bottleneck shifts to the process observed, the process was already active long enough to be the second-longest active period until the moments before the shift. Hence, the buffers before the process have a tendency to be full and the buffer after the process have a tendency to be empty.

Interestingly enough, this changes only when a bottleneck shift approaches. With very few exceptions, a nearly empty buffer before or a nearly full buffer after the process quickly leads to a shift in the bottleneck.

This is also confirmed through another analysis. Figure 8 shows the mean time until the shift of the bottleneck depending on the available parts before the bottleneck and the available spaces after the bottleneck. It is clearly visible that as the number of available parts or spaces approaches zero, the mean time until the next bottleneck shift

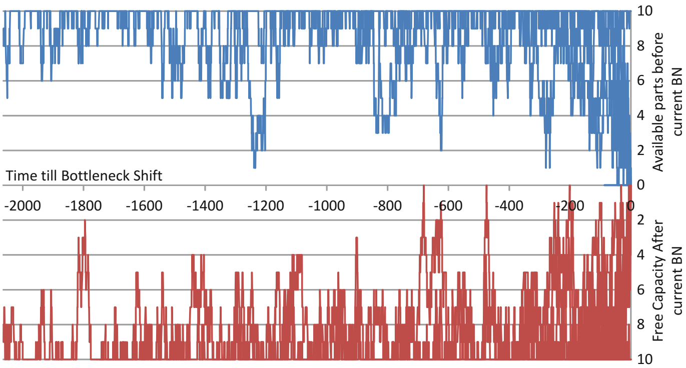

Fig. 7. Critical buffers before and after longest active period before switch

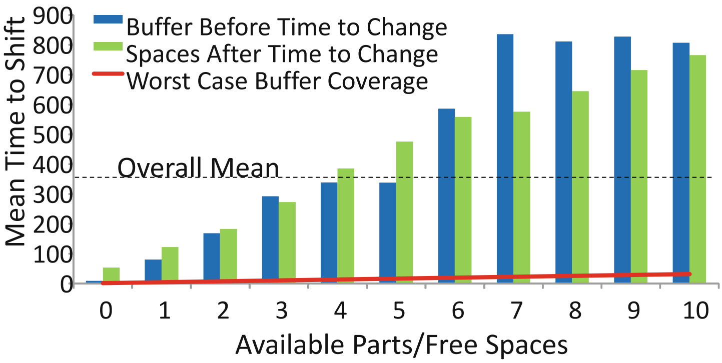

Fig. 8. Mean time until shift for different inventory levels

is significantly reduced. Figure 8 also shows the time that is covered in a worst case, which is directly related to the number of parts or number of free spaces in the adjacent buffer. This worst case is only a fraction of the mean time to shift, as there are usually new parts constantly arriving and leaving the buffer before and after the current bottleneck respectively.

6 Summary

Overall, the active period method can easily be adapted to detect the current bottleneck in real time. Furthermore, by simply analyzing the buffers before and after the current bottleneck, it is possible to estimate if a shift may occur sooner or later. Finally, the process to which the bottleneck will shift to is also already known as the process with the second-longest active period before the shift. Hence, the presented method allows not only the detection but also the prediction of bottleneck shifts in real time. Similar to the normal active period method, the approach is very accurate and intuitive, but requires detailed process data of all processes in the system.

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Relationship Between Variants and Inventory Under Consideration of the Replenishment Time

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Abstract. It is common wisdom that the finished goods inventory increases with the number of variants stored in that inventory. However, to the best of our knowledge, this has never been verified. This paper presents research where this relationship has been analyzed both by applying theory and through analytical simulation. The result shows that this common wisdom is not always true. The number of kanban increases as the customer takt decreases if the customer takt is smaller than the replenishment time. If the customer takt is larger than the replenishment time, a change in the customer takt will not change the required minimum inventory of one. Similar holds true for the number of variants.

Keywords: Finished goods inventory · Customer takt · Replenishment time · Variant reduction

1 Introduction

In many companies, the idea of inventory reduction and hence reduction of the associated costs is well received [1–3]. Unfortunately, the implementation is often lacking [4, 5]. In particular, inventory reduction is often a simple reduction of the target inventory, without the understanding of the underlying relationships. Hence, the relationship of inventory to production has been studied intensively, for example [6–8]. This paper aims to dig deeper into this relationship, especially the relationship between customer takt and inventory, as well as the related relationship of the number of variants and the inventory.

2 Relevant Concepts

To understand the following theoretical and practical analysis, a few concepts from lean manufacturing have to be described briefly.

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2.1 Customer Takt

The customer takt (or takt time) is one of the fundamentals for determining the speed of a production system. It represents the average demand of the customer during a time period. To calculate it, you divide the available working time by the customer demand during that time, as shown in Eq. (1) [9]:

$$TT = \frac{AT}{CD} \tag{1}$$

where TT is the customer takt, AT is the available work time, and CD is the total customer demand across all product variants. The calculation hence results in the average time between a customer demand, and therefore is also the target speed a system must achieve to satisfy this demand in the long term. The customer takt can be calculated for the total of all products, as well as for an individual product variant.

2.2 Kanban-Based Pull System

The analyzed system is based on a pull system using a kanban-based pull system. This is a common approach in lean manufacturing [10]. Pull production has many advantages over conventional push production, most significantly a consistent and stable management of inventory, requiring less inventory than a push system and hence avoiding the associated costs (see above) [11].

2.3 Replenishment Time

The replenishment time is the time needed to replenish a part. This does not mean when the next part comes down the line, but instead how long it takes for a work order to come back with a part. Figure 1 illustrates this, for an example, with three processes.

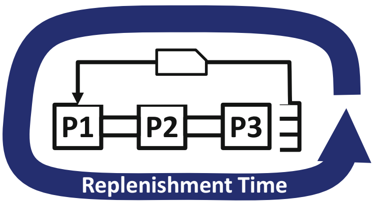

Fig. 1. Illustration of replenishment time using value stream mapping notation. Source: Author

3 Theoretical Approach

First we start with a theoretical approach. For simplification we assume that our system has no variation or fluctuation. This of course is a widely optimistic assumption for practical use. However, it is useful to determine the theoretical best-case scenario. We also assume that there is only one finished good inventory from which the customer demand is satisfied. Multiple inventories for different customer groups would of course increase the total inventory.

3.1 Customer Takt Larger Than Replenishment Time

Assume the system produces one product and the customer takt is significantly larger than the replenishment time. In order to be able to deliver to the customer without delay, we need to have at least one of these products in stock. If the customer wants a product, he receives the single piece in stock, and then we reproduce it to increase stock again to one piece. Hence, the behavior of the inventory over time may look like Fig. 2. Overall, we require only a single kanban card to manage production. Hence we have at most an inventory of one.

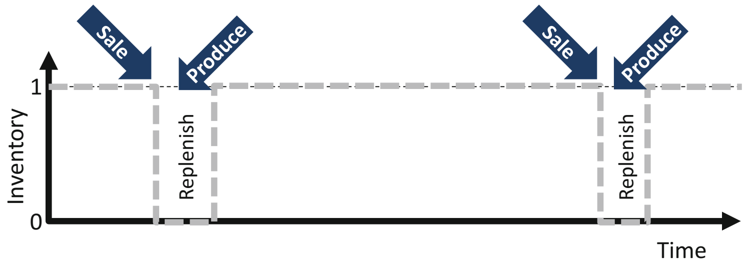

Fig. 2. Theoretical behavior if customer takt is significantly larger than the replenishment time. Source: Author

3.2 Customer Takt Smaller Than Replenishment Time

In a second theoretical example, we assume that the customer takt is smaller than the replenishment time. In other words, the customer orders faster than the time it takes to reproduce one part. This is easily resolved by adding multiple kanban to the system. The number of kanban needed is shown in Eq. (2), where K is the number of kanban.

$$K = RoundUp\left[\frac{RT}{TT}\right] \tag{2}$$

Please note that this formula is valid regardless of the relationship of replenishment time and customer takt, but is still assuming no fluctuations. If the customer takt is much larger than the replenishment time as in the previous theoretical assumption, we need only a single kanban as shown in Sect. 3.1.

3.3 Kanban and Inventory Over Customer Takt

Now it is possible to calculate the number of kanban for any customer takt. Please note again that the assumed lack of fluctuations prevents the use of these simple equations for practical applications, but it is to serve a best-case illustration. The resulting general behavior is shown in Fig. 3. The time where the customer takt equals the replenishment time is indicated with a vertical gray line.

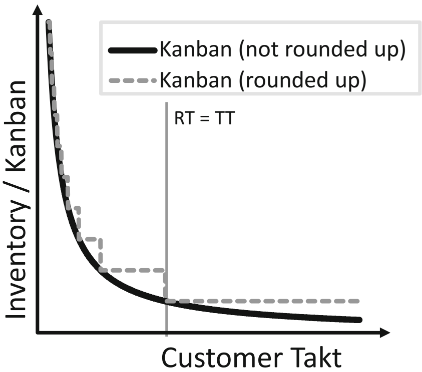

Fig. 3. Behavior of the number of kanban and inventory in relationship to the customer takt. Units are intentionally missing, as this is a thought experiment. Source: Author

3.4 Kanban and Inventory Over Variants

Using the previous equations, it is also possible to make a theoretical model of the kanban in relationship to the number of variants. In industry, additional variants are introduced with the hope of selling more products overall, although the actual outcomes vary. To allow easier comparison of different number of variants, we assume that the total quantity of products sold remains constant. In a second simplification, we assume that the total quantity produced is always split evenly across all available variants. Naturally, in industry applications this is rarely the case. Yet, this assumption allows for easy comparison of different production quantities with different variants. Similar results should hold true also if the quantity for the different variants vary. As we will see later, it all depends on whether the customer takt for a variant is faster or slower than the replenishment time. The customer demand for one variant CD_i is as follows:

$$CD_i = \frac{CD}{n} \; for\, all\, i \in (1, n) \tag{3}$$

Substituting gives us the equation for the takt time and the number of kanban for product i.

$$TT_i = \frac{AT \cdot n}{CD} \; for\, all\, i \in (1, n) \tag{4}$$

$$K_i = RoundUp\left[\frac{RT \cdot CD}{AT \cdot n}\right] \tag{5}$$

From this we can easily calculate for all variants n of the total number of kanban K as shown in (6) and (7), which are the same equations with different substitutions.

$$K = n \cdot K_i \tag{6}$$

$$K = n \cdot RoundUp\left[\frac{RT}{TT \cdot n}\right] \tag{7}$$

Figure 4 shows the results for keeping the total customer demand constant and varying only the number of variants. Again, please note that this is an idealized case with no fluctuation.

The time where the customer takt derived from the number of variants equals the replenishment time is indicated with a vertical gray line. Of interest again is the number of kanban that are not rounded up. If the number of variants is below the threshold where the customer takt equals the replenishment time, then the total number of kanban (not rounded up) does not change regardless of the number of variants.

On the right of the threshold, the minimum number of kanban cards increases with

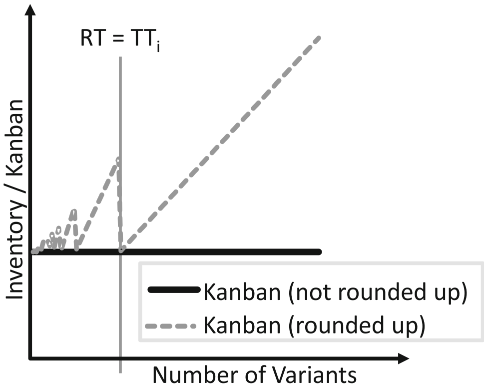

Fig. 4. Behavior of the number of kanban and inventory in relationship to the number of variants. Units are intentionally missing, as this is a thought experiment. Source: Author

the number of variants. Hence, while the right side supports the initial theory that the inventory increases with the number of variants, the model to the left of the threshold does not hold true to this theory. We will discuss this highly interesting result later in the conclusions. However, these theoretical results have the limiting assumption of no fluctuations or variations in the customer takt and replenishment time. Before we analyze these interesting results in more detail, we will investigate the same questions using an experimental approach.

4 Experimental Approach

To test these results analytically, we used a commercially available simulation tool Simul8. This analysis was conducted as part of a master thesis by one of the authors [12]. Please refer to [12] for details on the simulation set up.

4.1 Kanban and Inventory Over Customer Takt

Figure 5 shows the resulting experimental relationship between the inventory and the customer takt. For clarity we also added the theoretical model with the not-rounded-up number of kanban. Please note that due to the large numbers involved, both axes of Fig. 5 are on a logarithmic scale, resulting in straight lines rather than the curves seen in Fig. 3. The data is shown for different delivery performances, representing the percentage of customer demands that could be fulfilled immediately. The actual replenishment time of the simulation is also added as a dotted line where the replenishment time equals the customer takt.

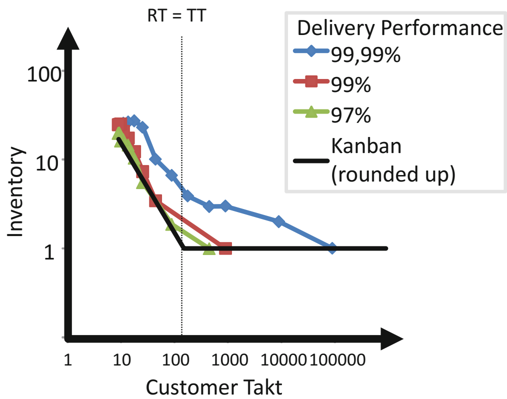

Fig. 5. Simulated behavior of the inventory in relationship to the customer takt. Source: Author

4.2 Kanban and Inventory Over Variants

Figure 6 shows the resulting experimental relationship between the inventory and the number of variants. For clarity we also added the theoretical model with the not-rounded-up number of kanban. Please note that again due to the large numbers involved, both axes of Fig. 6 are on a logarithmic scale. Again, the actual replenishment time of the simulation is also added as a dotted line where the replenishment time equals the customer takt for a given number of variants.

Overall, the simulated results overlap very nicely with the theoretical assumptions, therefore verifying the theoretical model. The full data is available through [12].

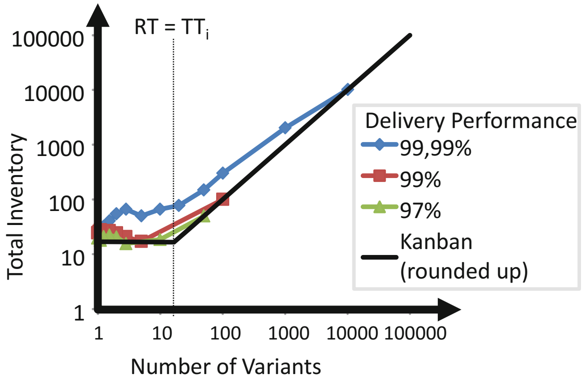

Fig. 6. Simulated behavior of the inventory in relationship to the number of variants. Source: Author

5 Conclusions

Our research shows that the number of kanban increases as the customer takt decreases as long as the takt is smaller than the replenishment time as shown in Figs. 5 and 3. Surprisingly, however, if the customer takt is larger than the replenishment time, it has no influence on the total number of kanban and the inventory.

The situation becomes even more interesting for the number of variants as shown in Figs. 6 and 4. On the right-hand side, you get the results expected by common wisdom on the shop floor. Your inventory increases as the number of variants increases. The most interesting result of this analysis, however, is on the left side. The inventory remains constant in theory and nearly so in practice. This means that as long as both the old and the new variants have a customer takt smaller than the replenishment time, you can add additional variants without incurring the penalty of additional inventory. The common wisdom on the shop floor is not true as long as you sell enough products.

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Health Impact of Electric Vehicles Considering Environmental Leakage. The Case Study on Japan, China, UK and Poland

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Abstract. In recent years the topic of air pollution is gaining more attention due to the health effects its has on human lives. At the same time, we can observe popularization of Electric Vehicles (EVs), due to their environmental and economic benefits. However, a few studies suggest that EVs might be not environmental friendly in the long term. Hence, there is a need to investigate the emissions produced by EVs and the monetary cost of them on the health. This paper aims to quantify the cost of health diseases by employing life cycle assessment of EVs in Japan, China, Poland and the United Kingdom. The results of the study imply that the total cost of health issues is lower when import of EVs is from the nearby countries, which generate electricity from clean energy resources or when it is produced in a low emission country locally.

Keywords: Production · Electric vehicles · Life cycle assessment · Health issues · Emissions · Air pollution

1 Introduction

Air pollution is one of the top greatest risk factors for human health. According to pundits, roughly 6.5 million premature deaths are the aftermath of air pollution [1]. The cost of the health problems originating from air pollution stood at $330-940B in 2010 for European Union [2]. Industry, power plants, households, transport, agriculture and waste treatment are human-made sources of air pollution [1]. Inefficient fuel combustion, residential heating, vehicles exacerbate the impact of emissions [3].

Those activities cause emissions e.g. sulfur oxides (SO_2), particulate matter (PM) and nitrogen oxides (NO_x). More than a quarter of total energy-related emissions of SO_2 are made in China [1]. Transportation attributes to over 50% of all energy-related emission of NO_x. For instance, only in China, more than 1 million premature deaths were recorded due to outdoor air pollution caused by particulate matter. In the European Union, more than 175,000 were recorded due to outdoor air pollution caused by PM. At the same time, it was more than 1 million in China [1]. In 2014 in Cracow (Poland), there were 188 days, in which PM was higher than advised 50 $\mu g/m^3$. In January 2017, in Warsaw (Poland), the PM level was seven times above

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the secure PM level described by World Health Organization (WHO) [4]. According to [5], the most common impacts of pollutants are chronic mortality and acute and chronic morbidity, which are caused by i.e. respiratory problems, asthma, cardio-pulmonary, leukaemia, ear infections etc. In this study SO_2, PM and NO_x are investigated, because they are the main pollutants, which damage cost is the highest among all primary pollutants [5]. Moreover, there are international standards in road transportation for the emission of those pollutants [5].

Alternative Fuel Vehicles (AFVs) are getting attention due to their environmental and economic advantages. However, there is a need to investigate the benefits and impact of AFVs during not only use phase, but at stake is the total lifecycle assessment of these vehicles. Wide studies have investigated the introduction, proliferation and portfolio of AFVs [6–9]. Only a few of papers have focused on the impact of AFVs on air pollution. However, most of the studies focus on GHG emissions and neglect other pollutants e.g. SO_2, PM and NO_x [10, 11]. A Life Cycle Assessment (LCA) study by Hawkins et al. [12] provided a thorough analysis of EV over their total life cycle and their impact on different environmental categories. Nevertheless, the health impact of EVs was not considered in that research [12]. Health effects are neglected in most of the studies, only [13, 14] conducted the analysis while incorporating the effects of vehicles on health issues. However, the before-mentioned studies concentrate on only one country, China. Moreover, most of the papers investigate only one stage of vehicle's lifecycle, mostly usage [7, 15]. In this paper, we consider environmental leakage, which happens when rich country imports dirty products from developing countries. This phenomenon leads to displacement of emissions abroad and often an increase in the global pollution [16]. According to [17], the consumption-based approach is necessary to calculate the impact of production activities. There has been no study conducted on environmental leakage and the production of AFVs. Therefore, there is a necessity to examine the above-mentioned gaps. Hence, in this study, we quantify environmental leakage according to consumption-based approach and base the calculations on 'who consumes the product'. Therefore, the objective of this study is that it estimates the health effects cost of EVs throughout the total lifecycle and compares it among several countries while taking into consideration environmental leakage. This study might help governments and producers while making crucial decisions for long-term investments. The results might encourage switching to EVs, and in order to do that, governments can implement either subsidy or environmental tax deduction. For this purpose, governments need to create target for policy creation, which was already studied by [6, 18]. The case study was conducted on Japan, China, Poland and the United Kingdom (UK). According to [19], China, UK and Japan are the countries with the largest EV sales and market share till 2015. Moreover, China was the largest market for electric cars with over 200,000 new registrations [19]. However, in China, most of electricity is produced from coal and according to [20] EVs could hinder health and the environment quality [20]. Japan is a country, which produces Nissan Leaf, the Nissan LEAF, which is the world's best-selling EV [21]. The United Kingdom is not a main automotive producer, but invites investment from manufacturers, moreover its electricity mix consist of high percentage of renewables [22]. On the other hand, Poland's electricity is based on coal and the air pollution is high. Poland has just established an "Electromobility Development Plan for Poland", which implies that till

2025 there will be a million EVs on the polish roads. The government of Poland is also interested in investment in automotive industry [23]. Section 2 explains the LCA method for evaluation of health cost of EVs. The results and discussion are presented in Sect. 3. Finally, Sect. 4 concludes the research.

2 Methods

2.1 Life Cycle Assessment Outline

The LCA is the most broadly used tool for analyzing vehicles throughout different stages of their lifetime. This method was used in this paper to quantify the health impact of EVs during their manufacturing stage, transport, use phase and end of life stage. The case study was conducted for four countries and includes environmental leakage issues. In line with it, we calculate 16 cases of vehicle life cycle. EVs are used during a 10-year period. Moreover, the scenarios for 2016 and 2025 are being investigated as well in order to compare the improvements in the technologies. The evaluation formula of LCA is shown in Eqs. (1)–(5).

$$LCA_{e,k}^{total}(y) = \left(LCA_{e,k}^{prod}(y) + LCA_{e,k}^{trans}(y) + LCA_{e,k}^{use}(y) + LCA_{e,k}^{EoL}(y)\right) \times R \quad (1)$$

$$LCA_{e,k}^{prod}(y) = \sum_{m} n_{m,k}(y) \times C_k(y) \times E_{e,m,k}(y) \times PH_e \quad (2)$$

$$LCA_{e,k}^{trans}(y) = F(y) \times E_{diesel}(y) \times PT_e \times D_k \quad (3)$$

$$LCA_{e,k}^{use}(y) = \sum_{m} n_{m,k}(y) \times C_k(y) \times E_{e,m,k}(y) \times PH_e \times M_k \quad (4)$$

$$LCA_{e,k}^{EoL}(y) = \sum_{m} n_{m,k}(y) \times C_k(y) \times E_{e,m,k}(y) \times PH_e \quad (5)$$

e: emission type [NO_x, SO_2, PM]
k: country investigated (Japan/ China/ UK/Poland)
n: energy ratio (Japan/ China/ UK/Poland)
y: year [2016-2025]
m: type of energy used (coal, nuclear, gas, etc.)
C: energy consumption [kWh]
E: air emissions of NO_x, SO_2, PM from energy production[kg per kWh]
M: mileage [km]
R: production rate [units]
F: energy used to transport one vehicle on a diesel MSD ship per km [kWh per km]
E_{diesel}: air emissions of NO_x, SO_2, PM from energy production in MSD ferry ship [kg per kWh]
D: distance in ferry transportation [km]

PH_e: Monetary damage conversion cost of high-height emissions (energy production) [€ per kg]

PL_e: Monetary damage conversion cost of low-height emissions cost (transportation) [€ per kg]

PT_e: Monetary damage conversion cost of diesel ship transportation emissions cost [€ per kg]

$LCA_{e,k}^{total}$- stands for total cost [€]; $LCA_{e,k}^{prod}$- cost in manufacturing phase [€]; $LCA_{e,k}^{trans}$- cost in transportation [€]; $LCA_{e,k}^{use}$- cost in use phase [€]; $LCA_{e,k}^{EoL}$ – cost in End of Life phase [€]

Due to size limitation of this paper, the detailed description of methods and data used in LCA are described in details in [3] paper. The changes and additional data gathered for the model are defined in the below sections. Furthermore, we are considering environmental leakage and therefore we use consumer-base approach [17], which assumes that consumers are bearing the full responsibility for the impacts of producing the goods they consume. Due to the above, we are taking into consideration the total emissions that were produced i.e. manufacturing and transportation and add them to the cost of the importing country.

2.2 Electricity Mix, Emissions, Cost, Vehicle Assumptions, Transport

The data for China, UK and Japan were taken from IEA for both the present situation and the future forecast [22]. IEA predicts scenario for Europe as a whole, which is an inaccurate scenario for Poland, since the electricity mix is based on coal. In view of this fact, we use the forecast conducted by the Polish government [24].

Emissions from electricity generated from coal for Poland were taken from IEA [25] The government implemented new emission standards for coal from 2016. The future emissions from electricity generated from coal were adjusted to the UK levels.

The emission cost for both electricity production and use phase of EVs were gathered in the previous study [3]. Emission prices for maritime transportation were calculated as an average price of the available damage cost of pollutants in sea regions [5].

The basic assumptions correspond to the previous study published in [3]. The EV under review is Nissan Leaf, with a 24 kWh Lithium-Ion batter. For this case study, we assume no battery replacement in the 10 year usage period, since the Nissan Leaf guarantees the battery for around 160,000 km [26]. Annual average vehicle mileage differs among the case study countries. For China it is 14,496 km [27], for Japan 9,300 km [28], UK 12,713 km [29] and 8,257 km in Poland [30]. Since the data do not distinguish types of vehicles, we assume that the distance is same for all types of passenger vehicles.

Global transport of large quantities of new vehicles is primarily carried by ships. We calculate the emissions produced during transportation from the main port of dispatch to the main port of arrival. For Japan, the port of entry is Yokohama, for the UK is Bristol, for China is Shanghai and Gdańsk for Poland. The distance is calculated according to data from [31]. The assumption is, that the shipping takes place on Roll

On Roll Off (RORO) base [32], which capacity is 7,200 eV vehicles [33]. This type of vessel is used to due to the fact that most of the vehicle producers use this type of shipment in order to maximize capacity and minimize time. The g/kWh emissions of medium speed diesel vessel (MSD) were taken from [34] and the energy cost in kWh/t-km of freight-transport was based on [35].

3 Results and Discussion

The comparisons of results for the 16 cases of vehicle life cycle are presented in Figs. 1 and 2 below.

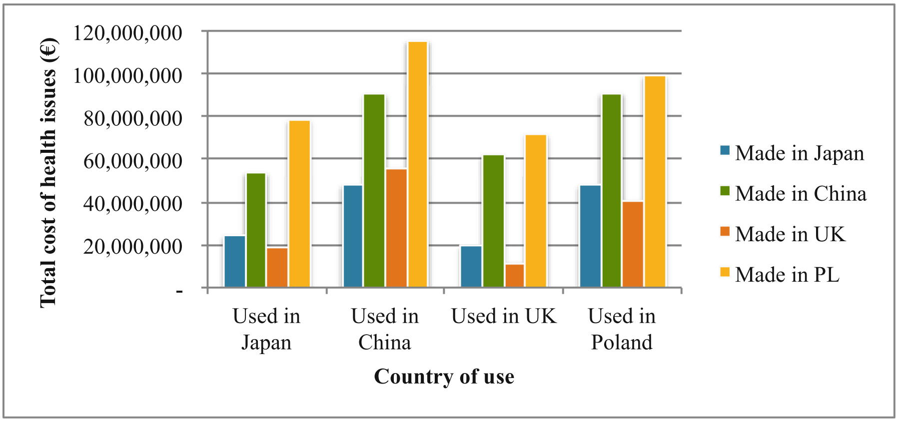

Fig. 1. Total health cost associated with EV life cycle (production in 2016)

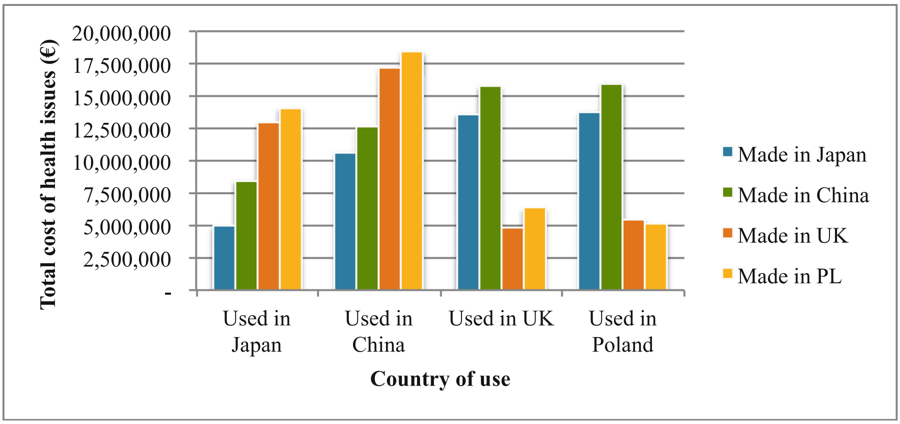

Fig. 2. Total health cost associated with EV life cycle (production in 2025)

The findings from Figs. 1 and 2 clearly present the fact that if we consider environmental leakage, import and export of EVs is not justified in some situations e.g. where emissions during manufacturing are high or the distance between the countries is substantial. According to the outcome of the research, the production and use of vehicles in the UK contribute to the lowest health cost among all 16 cases analyzed for both 2016 and 2025. Provided that, it would be advised to set the production of EVs in the UK due to the advantageous electricity mix and the proximity to other European markets. It is seen, from the Fig. 1, that for Poland, the apt solution would be to import the EVs from the UK in 2016. In this situation, the total health cost that Poland would have to bear stands at around €40 M. In contrast, there was a 95% decrease in the case of the production and use of the EVs in Poland from 2016 to 2025. The slump of the total monetary cost can be explained by the fact that improvement in electricity production technologies and the change of the electricity mix in Poland takes place. Moreover, the driving distance in Poland is shorter than in the UK. In China, for both 2016 and 2025 scenario, the most appropriate solution would be to import the EVs from Japan due to the short distance and the lower emissions of pollutants in Japan. Surprisingly, in Japan in 2016, the lowest total health cost would take place in the scenario when EVs are imported from the UK. This has a reflection in the change of electricity mix in Japan after Tohoku Earthquake in 2011. Instead of nuclear energy, Japan is using a higher percentage of gas and coal for electricity generation. In 2025 in all cases, the total monetary cost of health diseases drops dramatically due to significant improvement in electricity production, technology efficiency of vehicle and battery production, and new standards for air pollution. The most substantial decrease in terms of value can be noted in the case of producing the EVs in Poland and exporting them to China. This case scenario is worth around €115 M in 2016 and no more than €18.5 M in 2025. Another interesting aspect that emerges from analyzing the data is that during the maritime transportation the emission of air pollutants is significant. The analysis showed that only the transportation of an EV from Japan to Poland in 2016 accounted for almost 20% of total lifecycle emissions of NO_x 13% of SO_2 and 55% of PM. In terms of the import of an EV from Japan to the UK in 2016, those results were even higher and amounted to 30% of NO_x, 43% of SO_2 and 76% of PM. The result from this study can be substantiated by the data from [36], which shows that a ship can emit around 5,000 tons of SO_2 annually.

The author of the previous-mentioned study asserts that one container ship can produce "almost the same amount of cancer and asthma-causing chemicals as 50 M cars" [36].

4 Conclusions

To sum up, the majority of human-made air pollution originates from energy use and production, combustion of biomass and fossil fuels [1]. Health problems associated with the aftermaths of air pollution are causing a considerable monetary cost for the global economy. In this study, we believe that developed countries, producers and consumers and are to be blamed for the aftermaths of the environmental leakages. Developing countries imports dirty products and this lead to displacement of emissions abroad and often an overall increase in the global pollution [16]. Hence, the present study was designed to determine the cost of health problems associated with air pollution, while incorporating environmental leakage. In this research, the rich countries carry the cost of locating production in developing countries and pay the abatement cost back to producing countries. The numerical results of this study prove our concern about environmental leakage and the danger of importing the products from developing countries. This study has found that it is advisable to keep local production if the country's electricity is generated from the clean energy source. Additionally, if the electricity mix is unfavorable, it is recommended to import from a nearby-located country of a clean electricity mix.

There is a strong need for further regulations and implementation of standards for not only vehicle transportation emission but also maritime transportation. It is also recommended to switch from using marine diesel to ships fueled by liquefied natural gas (LNG), this can considerably reduce not only SO_2 but also PM emissions. At stake is implementing regulations, global policy towards decreasing the air emission level, and unification of the alarming standards. Furthermore, it is also crucial to note that this paper has only analyzed the cost of the health from production, transport and use of EVs. If the cost of GHG emissions would be analyzed the final result would differ. Further improvements in the study could investigate a broader view and include total sustainability analysis of EVs' impact.

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A Multi-agent Approach to Implement a Reverse Production Virtual Market in Green Supply Chains

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Abstract. The implementation of internal reverse production process programs often involves significant allocations of capital and resources for the construction and implementation of all the steps in the process. But, what if we think of reverse production process as a service-based manufacturing network, in which all the activities are outsourced and the only thing that a manufacturing company needs in order to participate is an interface/service to "play" in that ecosystem. In this work we present an approach to implement reverse production process following a Service-Oriented Manufacturing paradigm by means of a virtual market supported by intelligent software agents.

1 Introduction

Over the last few years there has been a well-recognized need for achieving overall sustainability in manufacturing activities [6,8], due to several established and emerging causes: environmental concerns, diminishing non-renewable resources, stricter legislation and inflated energy costs, increasing consumer preference for environmentally friendly products, etc. In this way corporate environmental responsibility has gradually and more consistently extended beyond complying with increasingly stringent environmental regulation and also beyond the taking up of proactive initiatives. Many research works have demonstrated the positive effects of internal measures towards sustainability [9]. Lately the goal has begun to shift to integrating all of the business value-adding operations, including purchasing and in-bound logistics, production and manufacturing, distribution and out-bound logistics, in such a way that activities associated with these functions have the least harmful environmental impact [13]. Greening the supply chain is one such innovative idea that is fast gaining attention in the industry [3].

There are a number of definitions and philosophies on what a green supply chain may be. These vary from something as small as buying green products from a supplier to the much broader context of an industrial ecosystem [5]. Sustainable supply chain is an active research field in which new techniques are continuously proposed to reduce negative environmental impacts while pursuing production

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economy [13]. Sustainable supply chain network consists of forward production processes and reverse (recycling) production processes (reverse logistics). In the specialized literature, most of the attention is targeted to the forward action of the supply chain [5], whereas few manufacturers have considered how this supply chain can or should work in reverse to reclaim products at the end of their life-cycle and return them through the supply chain for decomposition, disposal or re-use of key components. Systems in which the two approaches (forward and reverse) are combined can drastically reduce the negative impacts to the environment [17]. These systems are called closed-loop production systems[1].

The implementation of internal reverse production process programs often involves significant allocations of capital and resources for the construction and implementation of all the steps in the process. But, what if we think of reverse production process as a service-based manufacturing network [7], in which all the activities are outsourced and the only thing that a manufacturing company needs in order to participate is an interface/service to "play" in that ecosystem.

In this work we present an approach to implement reverse production process following a Service-Oriented Manufacturing paradigm by means of a virtual market supported by intelligent software agents [18]. In a nutshell our approach consists of an ecosystem of services (i.e. web services) that implements a virtual market for buying and selling items subject to be recycled (i.e. old materials, wastes, used products, etc.). A company will participate in the market: (i) when the company gets economic profit from buying or selling those items, or; (ii) when the company is trying to reduce its "cuota" of negative environmental impact (i.e. reducing CO_2 emissions, waste of materials, pollutants, etc.).

2 Green Supply Chains

Translating the definition of sustainable development to supply chains impose the need to migrate from a field that myopically addressed only operational and economic matters to one that comprehensively considers the broader environmental and social issues that face organizations of today [5]. A consensus definition of green and sustainable supply chains does not exist (for a large review on definitions see [1]). It is identified as a sub-discipline of supply chain managing expanding the work in a variety of areas. An in-depth state-of-the-art review on green supply chains can be found in [5]. In this work we consider a manufacturing supply chain as a system that consists of 5 layers, including raw material supply, manufacturing, wholesaling, retailing, and end-customers. Whereas, a used-product and/or waste materials reverse logistics chain includes

[1] A closed-loop production system is defined as the "taking back of products from customers and recovering added value by reusing the entire product, and/or some of its modules, components and parts" [16]. The closed-loop construct consists of the common forward supply chain and the so-called reverse supply chain which closes the loop. In summary, there exist three different options to close the loop: reusing the product as a whole, reusing the components or reusing the materials.

collecting points, recycling plants, disassembly plants, secondary material markets, and final disposal locations of wastes. All these activities are executed with the purpose of capturing value, or proper disposal.

The keys to the successful design and use of reverse logistics systems include costs, overall quality, customer service, environmental concerns and legislative concerns. Other factors to consider are: cost-benefit analysis, transportation, warehousing, supply management, remanufacturing and recycling, and packaging. All these factors require high economic costs for a company to implement a reverse production process. In this way financially attractive approaches are urgently required to facilitate the participation and commitment of manufacturing companies and customers in green supply chains. Bearing this issue in mind and trying to contribute to the state-of-the-art on research works related with reverse production systems, recognized as still low [5], we propose a virtual market of used-products and/or waste materials supported by artificial intelligent techniques and service oriented manufacturing approaches.

3 MAS and Intelligent Manufacturing Systems

New technologies are revolutionizing the way manufacturing and supply chain management are implemented. Initiatives such as Industrie 4.0, Smart Industry, Industrie du Futur, among others from Europe; Industrial Internet Consortium from USA; Industrial Value Chain Initiative from Japan; Made in China 2025 from China, are trying to integrate Internet and manufacturing systems in order to fully digitalize the factories of the future. This new production paradigm is based on concepts as autonomy and co-operation because both are necessary to create flexible behavior and thus to adapt to the changing production conditions. One such approach is the Intelligent Manufacturing Systems (IMS) paradigm. In IMS the manufacturing system is conceived as a distributed system in which its constituent components, such as machines, resources, products, and staff, have intelligent capabilities for acting in its environment pursuing global system goals; and have autonomous execution for decision making, social interaction with other intelligent entities, and collaboration for achieving the system goals.

Agent based Manufacturing Systems, are based on Multi-Agent System (MAS) technology [2]. MAS is focused on the co-ordination of entities, called agents, with intelligent behaviors that interact in a group of (possibly pre-existing) agents. A closely related approach to MAS is Holonic Manufacturing System (HMS). HMS is based on the concept of "holonic systems" to describe autonomous manufacturing modules (holons) with distributed control. In a HMS, a holon can be used for transforming, transporting, storing and/or validating information and physical objects. A holon has an information processing part, in charge of the logical and intelligent computation; and often a physical processing part (optional), in charge of controlling a physical component: a machine, a tool, etc. In this way holons are a powerful approach to implement Cyber Physical Systems for the factories of the future in Industrie 4.0.

The specialized literature in IMS, focused on MAS and HMS, offers successful approaches for achieving sustainability in manufacturing systems. The concept of

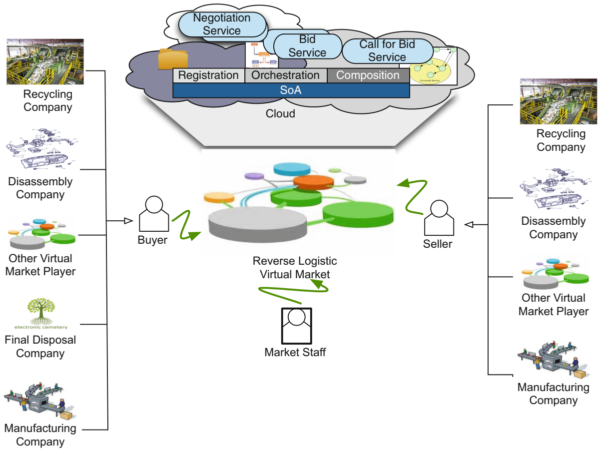

Fig. 1. Reverse logistic virtual market ecosystem

Go-green Holon proposed in [15], is a pre-built development artifact that includes efficiency-oriented mechanisms (optimizing sustainability means), in addition to classical effectiveness-oriented mechanisms, to make a decision and/or execute an operation in IMS. Go-green ANEMONA [10] is a complete software engineering method for developing sustainable IMS. The method helps the designer to specify and implement sustainable optimization functions in IMS providing development guidelines and modeling templates. On the other hand, in [11] it is proposed the application of agent-based systems for supply-chain synchronized production planning including management of raw materials flow as well as flow of returned by customer obsolete products and defected semi-products and products that are refused by quality control within the factory. Whereas, in [12] a multi-agent system framework to achieve coherent and consistent workflows that can meet order requirements is proposed.

4 A Virtual Market Approach for Reverse Production Systems

The overall idea behind the proposed approach is to facilitate the participation of stakeholders in the activities of green supply chains by means of Service Oriented Manufacturing Systems [7], providing an easy to use interface for the players of a wider reverse logistic ecosystem as a step towards virtual outsourcing of reverse manufacturing processes.

The focus of the work presented in this paper is the market of products subject to be recycle. Figure 1 shows the structure of the virtual market. In the market we can find different roles: Buyers of items (old materials, wastes, used products, etc.) that want to further process the items or just want to re-sell them in other markets; Sellers that want to get economic profit (or even "green" profit) from the disposable items (i.e. if the seller is a manufacturing company, the items may usually come from their production activities, being wastes, old materials or used products. etc.); Market Staff which is a special role that is in charge of ensuring the supporting activities in the market (i.e. execution control activities, enforcement activities for the market rules, etc.). The virtual interaction among these roles are implemented by means of web services, that are published in the Cloud and managed by a Service Oriented Architecture (SOA) framework. The services provide the basic functions to play in the market ecosystem such as: Negotiation Protocol Service, Call for Bid Service, Bid Service, etc.

The three roles of the market are implemented by means of agents. In our approach we follow the guidelines from Go-green ANEMONA [10] in order to design the agents and the negotiation interactions in the market. The Buyer and Seller roles are specified as Go-green Holons [15]. Whereas, the interaction functions of the market are encapsulated as web services following the process definition of Service Oriented Manufacturing System approach [7].

Picture a market, where customers (Buyers or Sellers) are involved in face-to-face negotiation, participate in auctions or convene to consolidate an offer to other large customer. A market with several *negotiation dialogs*, each with a specific negotiation protocol and each with its own access and termination conventions (and other rules). Moreover, a market that also allows information exchange among the participants, request to open or enter a *negotiation dialog*, invite players to *negotiation dialogs*, and participants to reconvene after leaving a *negotiation dialog*. We capture this global arrangement with the MAS approach described in next sub-sections.

4.1 The Agents

The three main roles mentioned above are, in turn, specialized into five roles that may interact. The customer (or party agent) of the market that can participate as **Buyer** (b) and/or **Seller** (s). Finally, there are three types of **Market Staff** roles. The **Mediator** role (m) represents framework agents who run standard negotiation activities for example managing the users data, the structure, the specific parameters of the negotiation protocols, etc. The **Negotiation Dialog Manager** role (dm) represents framework agents who execute activities that are specific of a given negotiation protocol, for example accept valid negotiators, tune negotiation parameters of the dialog, mediate in the negotiation process, expel negotiators, etc. The **Legal Authority** role (la) represents framework agents who are in charge of activities for agreement enactments that are executed as a result of a successful negotiation process.

The ontology structure of the negotiation framework is defined by the following key entities in the market which constitute the core concepts that the framework recognizes:

An **item** is defined as $\iota = \langle \tau_\iota, O, \rho_\iota \rangle$, where τ_ι is the item type, O is the ontology where the item ι is defined, and ρ_ι is a set of property values that define the particular attributes that characterize the item itself. The list ρ_ι is domain-dependent, and is defined using the approach presented in [14]. For example the following is a fragment description of a waste *ItemX* that also specifies its component materials.

```
Individual: ItemX
Types: GenericProducts, Waste
and (contains some((material-value some Glass) and (material-percentage value 35))
and (contains some((material-value some Plastic) and (material-percentage value 62)))
and (has price((price-value 40) and (price-currency Euros))) ...
```

This ontology description is used by the agents in the market to reason about the items and evaluate the profit they can get from the item negotiation.

A **deal** $\delta = \{\iota\}$ is a sequence of items ι that can be negotiated.

An **agreement** is a full instantiated deal among two or more parties. It is defined by a tuple $\alpha = \langle P, \delta', d, st \rangle$, where P is the set of parties that enact the deal; δ' is an agreed deal from a previous negotiation process; d is the agreement date; st represents the stage where the agreement currently holds—it can take a value from a enumeration, e.g. pending, executed, cancelled, etc.

4.2 The Negotiation Structures

The virtual market provides a set of services that are organized in two different groups: informational, and negotiation (see Table 1). The informational set of services lists ongoing deals and active agreements, and also provides invitations or call for negotiations. Whereas, the negotiation set allows to create a negotiation dialog, to participate into a negotiation dialog, and once an agreement on a sequence of items has been successfully reached, it allows to settled the agreement according to the given conventions.

In order to assure a regulated execution of the virtual market, special attention is made in order to enact an agreement. First of all, the Mediator checks whether or not the agreement satisfies some formal conditions. If the agreement complies with these, a transfer contract is agreed upon and signed by the customer agents involved, and then the agreement becomes active. Once an agreement is active it may be executed and, consequently, other customer agents may initiate a grievance procedure that may overturn or modify the agreement. Even if there are no grievances that modify a contract, customers may not fulfill the contract properly and there might be some contract reparation actions. If things proceed smoothly, the agreement subsists until maturity.

5 Conclusion and Future Works

In this paper a MAS supported Virtual Market approach for reverse production process was presented. The goal of the proposed approach is to facilitate the participation of stakeholders in the activities of green supply chains by means of Service Oriented Manufacturing Systems [7], providing an easy to use interface for the players of a wider reverse logistic ecosystem as a step towards virtual outsourcing of reverse manufacturing processes. The proposed framework define three different players: Buyer, Seller and Market Staff. The virtual interaction among these roles are implemented by means of web services, that are published

Table 1. Negotiation services

Inform. services	Specification
QueryNegotiation	$informNegotiation(m, p_x, dialog_{ID}, error)$, where m is the manager, p_x is the customer, $dialog_{ID}$ is the ID of the negotiation dialog, or a *nill* value when there is an *error*
QueryAgreement	$informAgreement(m, p_x, \alpha_{ID}, error)$, where α_{ID} is the ID of the agreement
CallForBid	When the negotiation dialog has a *Public* type of access, m broadcasts an invitation message to all the participants: $inviteAll(m, dialog_{ID}, protocol, \delta, C)$, where $dialog_{ID}$ is the negotiation dialog that is receiving players; the negotiation protocol *protocol* used in that dialog; the set of issues, δ, that is being negotiated; and the set of constraints, C, to participate in are also made public. When the negotiation dialog has a *Private* type of access the invitation message is $invite(m, p_y, dialog_{ID}, protocol, \delta, C)$, where each candidate $p_y \in P_{dialog_{ID}}$
Negotiation services	Specification
CreateNegotationDialog	$request(p_x, m, open, protocol(params), \delta, pt, at, C)$, where the semantic is as follows; Party agent p_x requests to the Mediator, m, to *open* a negotiation dialog with the negotiation protocol *protocol*. The negotiation protocol is instantiated with the set of values for the parameters *params*. The dialog is created to negotiate about a deal δ. The requesting party, p_x, will participate as pt that can take one of these values: p, that is an observer Party; a Buyer party b; or a Seller party s. at is the access type that can be: *Public*, any body can be invited; or *Private*, only Party agents that fulfill the set of constraints C can participate in the negotiation dialog
EnterNegotiationDialog	$informRole(p_x, dm, dialog_{ID}, pt)$, where p_x is the participant; dm is the negotiation dialog manager; $dialog_{ID}$ is the dialog ID; pt is the participation type, b or s
LeaveNegotiationDialog	$informLeave(p_x, dm, dialog_{ID}, pt)$
Bid	$sendBid(p_x, dm, dialog_{ID}, pt, \pi_x, \delta)$, where p_x is the participant; dm is the negotiation dialog manager; $dialog_{ID}$ is the negotiation dialog ID; pt is the participation type, b (the bid is a Put) or s (the bid is a Call); π_x is the offered price; δ is the item set that is being negotiated
AcceptAgreement	$acceptBid(p_x, dm, dialog_{ID}, pt, \pi_x, \delta)$
RejectAgreement	$rejectBid(p_x, dm, dialog_{ID}, pt, \pi_x, \delta)$

in the Cloud and managed by a SOA framework. The services provide the basic functions to play in the market ecosystem such as: Negotiation Protocol Service, Call for Bid Service, Bid Service, etc. The framework is currently under development in order to implement a first prototype to perform validation tests. Moreover, the authors are interested in enhancing the work in order to "close-the-loop" allowing to retro-feed the internal sustainable manufacturing operations scheduling functions (such as [4]), that are running in the manufacturing companies, in order to fine-tune the values of the sustainable variables used by these internal algorithms for better optimizing the sustainable constraints.

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Eco-Efficiency in Manufacturing Operations

Product Circularity Assessment Methodology

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Abstract. In today's dynamic economic environment, industry is facing global challenges such as meeting the needs of a growing population, resource scarcity and landfill space shortage. These issues highlight the need for a dramatically more efficient use of natural resources to create social and economic value for society while respecting the carrying capacity limits of the planet. Additive manufacturing technologies provide opportunities to support sustainable manufacturing and the circular economy paradigm. These opportunities can be leveraged throughout the product lifecycle: energy and material consumption reduction in manufacturing, lower material use through maintenance, reuse, remanufacturing and recycling. Despite these benefits being more broadly recognised in recent years, industrial applications are still scarce. This work proposes a quantitative methodology to assess the circularities arising along the lifecycle of a product fabricated with additive manufacturing technologies, thereby supporting the shift to more circular industrial systems and sustainability.

Keywords: Circularity · Assessment methodology · Additive manufacturing

1 Introduction

1.1 Background

The digital world is becoming an integral part of industrial systems and of our society, and is enabled by new technological developments such as Additive Manufacturing Technologies (AMT). ASTM international defines Additive Manufacturing (AM) as a fabrication process used to build physical objects, starting from 3D computer-aided design (CAD) file and by adding material layer upon layer until the final object is completely formed [1].

Advances in science and technology contribute to the evolution and betterment of our society, but also result in unintended impacts on natural resources' availability and the surrounding environment. Increasing consumerism and irresponsible use of virgin materials (that lead to natural resource depletion and to dangerous and irreversible environmental damages) affect the economy and society at large. Therefore sustainability is an

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essential prerogative to ensure the stability of economic systems and natural ecosystems within which manufacturing companies need to compete responsibly [2].

Beside technology innovation, recent financial and environmental crises have caught the attention of many world governments. Furthermore, acceleration in global growth and the gap between the world leading and developing countries creates an imbalanced environment for competition. In this context, traditional models for the economic development have proven to be unsustainable and the growth trend characterizing the last century is not feasible anymore.

Industry and society need to change the way it operates by undertaking intelligent and integrated actions to enable long-term development while respecting human values, monitoring of our impact on the ecosystem and sustain economic growth. The circular economy (CE) paradigm has been emerging among other economic philosophies as it pursues the goals of economic, social and environmental sustainability [3].

1.2 Circular Systems and Circular Economy

Industrial Ecology (IE) and Industrial Symbiosis (IS) are often associated with the CE philosophy, despite some differences in principles and definitions. The ability to reuse resources and trigger circular flows has a strong analogy with the natural eco-systems as advocated by IE proponents [4]. IS promotes the exchange of waste and by-products from geographically delimited sites, where the contribution to CE stands in the intensive action of co-located manufacturing processes to drain the maximum value from local resources [5]. While IE and IS promote closed loop resource flows with an end-of-pipe approach, CE highlights the role of design in drawing end-of-life consideration as a starting point for resource reuse and value retention within the industrial system.

Circular systems provide a value-creation mechanisms decoupled from resources depletion. This can be supported by the creation of a sustainable model able to better capture and maintain the value embedded in resources while avoiding economic loss and environmental impacts on the long term [6]. Flows are dynamic and move in a circular manner in a closed loop (same application) or open loop (for a different application) [6, 7]. Thus, CE is “a continuous positive development cycle that preserves and enhances natural capital, optimises resource yields, and minimises system risks by managing finite stocks and renewable flows” [8].

Opportunities for circularities might occur at different phases of the product lifecycle. When occurring closer to the consumption point, fewer additional resources and actions are required for recovery and treatment activities to restore the product value.

Therefore, *Reuse* is the most advantageous scenario as resources or products can be used again without the need for additional resources and circularity is maximized. *Maintenance & Repair* enhances the product lifecycle stretching, bringing the product back at his original working conditions by repairing, reconditioning or replacing damaged parts. *Recycling* aims to recover materials back into the system as crude feedstock and substitute virgin material inputs. This work accounts for material quality and properties as they change through recycling activities [8], and for the economic viability of recycling [9]. *Energy Recovery* is generally characterized by a waste incineration process from which energy is generated and handed back to the system, lowering the need for energy provision. *Landfill* is the least sustainable scenario as resources leave the economic and industrial system, preventing the chance for further exploitation.

1.3 Additive Manufacturing and Sustainability

Current literature highlights the benefits of AM for efficiency and sustainability. Potential savings of 170–593 billion$ and CO_2 emission reduction of 130.5–525.5 Mt by 2025 [10] are estimated based on opportunities for dematerialization and simplified logistics, improvements in parts design intended for better performances in use, new recycling opportunities and landfill avoidance [11]. AM has the potential to reduce virgin materials mining and polluting auxiliary inputs in the production phase and subsequent activities [12]. Faludi et al. propose a LCA comparing the environmental sustainability of AM and CNC, and found that Fused Deposition Modelling (FDM) is more sustainable than CNC [13]. While software and hardware cost are still high, reduction in tooling and lead time from design to production are making AM competitive and cost-effective [14]. Baumers et al. also performed a cost assessment of AM use and determined that, despite economies of scale still applying for AM, machine cost has the highest impact on the overall cost [15]. Further benefits might come for the product lifecycle stretching by means of reuse, repair and remanufacturing, together with new business model opportunities, shorten and high-value supply chains, lowering in production volumes and stocks due to customization [16]. Despite the chances for AM in terms of CE, further work is required to address this topic.

Apart from Ellen MacArthur Foundation's proposal of performance indicators specifically intended to capture the impact of the design phase on the ability to reduce waste and sustain circularity [8], it is mainly about adapting ecology and sustainable assessments together with cost-driven tools to CE purposes. Starting from a lifecycle perspective and resources flows analysis, the next sections are intended to propose a methodology to assess products' ability in triggering circularity.

2 Product Circularity Assessment (CPA) Methodology

This section describes the CPA methodology, a quantitative tool intended to capture and quantify the amount of circular flows occurring along the product lifecycle. The expected outcome is the circularity product indicator (CPI), a percentage value intended to capture the product performances in terms of circularity.

2.1 CPA Methodology Principles

While the CPA methodology is not sector- or technology-specific, it is adaptable and flexible to a broad range of applications. It accounts for various types of circular flows based on four principles:

1. Use less: reduced resource requirements for a given useful output (i.e. thermodynamic efficiency and eco-efficiency), enabling a reduction of mining activities and impacts deriving from treatments, consumption and disposal activities.
2. Absorb circularities: use of recycled materials, reuse and energy recovery intended to reduce the need for virgin materials to be processed and energy to be provisioned.
3. Generate circularities: opportunity generated from the product-system for material to be reused, recycled and for waste to undergo the energy recovery.
4. Use of renewable energy sources: renewable resources can be used at a sustainable rate, if exploitation does not exceed regeneration rate.

Circular flows cannot be categorized *a priori* as generated or absorbed, but depending on the resource flow history. Absorption of resource flows coming from within the product-system itself or from other systems is counted when defining the CPI. Circular flows generated by the product-system and re-entering the system as absorbed circularities are neglected, as to avoid to double counting. Finally, generated circularities for external systems are not accounted at this stage of development of the methodology.

The circular flows are evaluated as the ability to reduce the use of energy, materials or auxiliary resources along the product's lifecycle compared to more traditional alternatives where circularities are not exploited. The circularity scenarios and traditional alternatives are listed in Table 1. Note that landfill does not have a circular scenario as the product or resource permanently leaves the system.

Table 1. Circularity scenarios compared to traditional alternatives.

Circularity	Traditional alternatives
Reuse	Manufacture (and all upstream related activities and resources usage) of a new product/component
Maintenance & Repair	Manufacture (and all upstream related activities and resources usage) of a new product/component
Recycling	New raw material extraction, treatments and related activities (including resources usage)
Energy recovery	New energy production and related activities (including resources usage)

2.2 CPA Steps

The proposed CPA methodology is designed in four steps:

CPA Step 1: Objectives and System Boundaries. The functional unit is the product or component considered for the assessment. Electricity, thermal energy, materials and other auxiliary resources embody the reference flows. The methodology follows a "cradle to cradle" approach and the boundaries of analysis account for inter-systemic exchanges, relying on an open-system frame.

CPA Step 2: Inventory Analysis. System mapping and data specification provide a detailed description of the product-system analysed, the related processes and the resource flows. Then, the inventory analysis is performed and data gathered include power consumption [Wh] and resource quantities [kg].

CPA Step 3: Resource Circularity Indicators. Following the circularity principles abovementioned and the opportunities for circularity at different stages of the product lifecycle, the circularity indicators for materials ($MCI_{m,p}$) and auxiliary resources ($RCI_{r,p}$) are calculated for each process step p and respectively for each material e or auxiliary resource r. The circularity indicator for energy (ECI_p) is addressed for each process but are not detailed at material or auxiliary resource level as power requirements and consumptions are usually monitored at machine/process level. Then, the circularity indicators are aggregated to obtain overall product-system level circularity indicators for energy (ECI), materials (MCI) and auxiliary resources (RCI).

CPA Step 4: Product Circularity Indicator. The last step consists of the CPI calculation as geometrical combination of ECI, MCI and RCI:

$$CPI = \frac{K}{\sqrt{3}} = \frac{\sqrt{ECI^2 + MCI^2 + RCI^2}}{\sqrt{3}} * 100 \tag{1}$$

where $0 \leq$ CPI ≤ 1, and

$$K^2 = ECI^2 + MCI^2 + RCI^2 \tag{2}$$

In this research, all three variables are considered to have an equal impact on efficiency and sustainability as the relative importance of each type of resource is specific to individual companies. Therefore, weight can be assigned to energy, materials and auxiliary resources based on specific industrial sectors, regulations, incentives, market or supply-chain structure (e.g. risk or difficulties in the supply of specific resources), material (e.g. physical requirements guaranteed by virgin materials only), etc.

The CPI is expected to range from 0 to 1. If ECI, MCI and RCI are all equal to zero, then the CPI will have a null value, meaning that the product-system is purely linear with no resource recovery and no renewable sources. On the contrary, a CPI value equal to 1 is the ideal scenario where all resources involved in the product-system originate from and generate circular flows.

3 Short Application and Results

The CPA methodology is applied to a simplified case study of a mono-material biomedical product fabricated by Direct Metal Laser Sintering (DLMS) technology (EOSINT M270 machine). The data available on material and energy are used to quantify the CPI of a metal (CoCr) dental crown which is the functional unit of analysis. The product-system is characterized by four processes as follow: (i) atomization, (ii) production, (iii) sandblasting, (iv) heat treatment. For this simplified lifecycle assessment, material processing (metals mining and forming) is neglected, together with the creation of ingots used in atomization. Due to some gaps in the data available, data from literature and estimations along with data supplied by the company were used for this analysis, even if limited to the production steps. The lack of experimental data related to the product use and maintenance phases, this application is limited to the production processes. It is assumed that the product cannot be recycled, but landfilled at its end-of-life. The volume and mass values of dental crowns are shown in Table 2.

Table 2. Material volume and mass of a dental crown

Dental crown	Sacrificial structures	Total
50.889 mm^3	28.373 mm^3	79.262 mm^3
0.443 g (54%)	0.247 g (46%)	0.69 g (100%)

(i) **Atomization.** Powder formation is one key factor for resource consumption as it affects both the potential for dematerialization and the reduction of energy usage within the production phase.

(ii) **Production.** DMLS technique relies on a powder bed fusion process. Such metal AM processes often require post-processing for supports removal and surface finishing, depending on powder grains size, which is usually energy intensive.

(iii) **Sandblasting.** The dental crowns are mechanically treated by corundum (aluminium oxide) to clean the metal surface from leftovers and corrosive deposits.

(iv) **Heat Treatment.** Once blasted, the platform enters the furnace for the thermal treatment to release internal stresses. This is an energy intensive process which significantly impacts the overall efficiency and circularity of the product-system.

Figure 1 schematizes the flows within product-system pinpointing the opportunities for circular flows to occur. Thus, circularities are quantified to determine the ECI and MCI at system level. From the available data it comes to ECI = 33,20% and MCI = 20,10%. Thus, CPI = 22,41% meaning that about a fifth of the resources used to produce the dental crowns are originating from or generating circular flows.

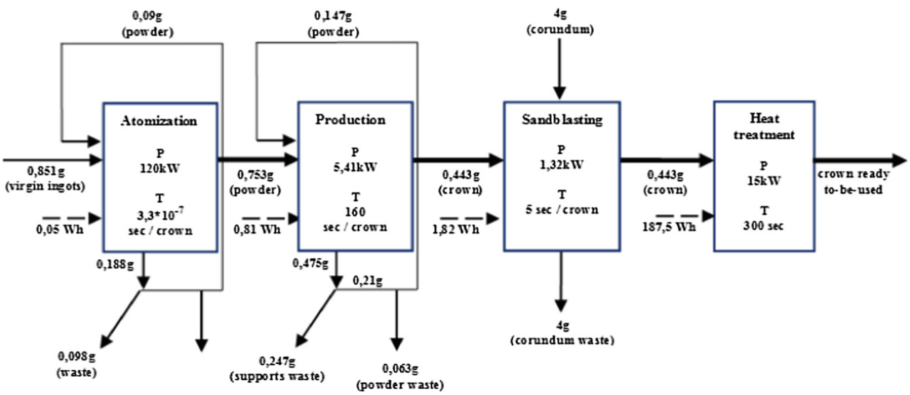

Fig. 1. Product-system characterization and resource flow mapping where P the nominal power and T the processing time for each process.

Energy has high impact on products' circularity (non-renewable energy sources). This case study excludes the ingots formation which is an energy intensive activity, and the thermal power as it does not significantly to influence the system's energy consumption. The material waste cannot undergo energy recovery and generate a positive impact on energy circularity. Materials' circularity is mainly linked to the possibility for atomization and production phase to recover powders from downstream and replace virgin feedstock. It is estimated that ingots fabrication could enhance material circularity as it is an efficient process. Due to the product's characteristics, it is not possible to account for a different EoL scenario from landfill. Finally, CoCr is produced from non-renewable resources and is currently not recycled. In order to create opportunities for non-virgin inputs of material, recycling of the supports and EoL products, further development of recycling technologies is required.

4 Conclusions

Technological and societal advancements have triggered innovations and development while causing undesirable consequences such as natural resources depletion, waste generation and damages to the natural ecosystem. It is clear that we need a more sustainable economic and industrial model. The CE paradigm along with IE concepts respond to these needs with the aim to maximize economic, environmental and social value created from industrial activities. Among other advanced technologies, AM holds the potential to trigger circularities through dematerialization, manufacturing systems reconfigurations, extended product lifecycle, etc. generating economic and environmental benefits.

This paper proposes an assessment methodology to quantify the circularity of a product by a simplified lifecycle perspective and accounting for inter-systemic exchanges of resources. The methodology outcome is the circularity product indicator (CPI) which represents the percentage value of circular flows along the product lifecycle. In other word, it is the ability of the product to reduce natural resource consumption and waste generation along its lifecycle compared to more traditional alternatives in which circularities are not exploited. This paper presents an application example of the methodology using a simple mono-material biomedical product to assess the potentials of circularities created through the use of AM. The results show that the use of renewable energy sources together with the characteristics of the production process positively affect the ECI value. As expected, powder recovery and reuse without further treatment or resources addition can improve the MCI. The overall CPI revealed that about a fifth of the resources used to produce the product are originating from or generating circular flows. This result would need consolidation by expanding the scope of the assessment to the full product's lifecycle. However, this could not be achieved due to data availability issues and thus the assessment focus on the production stage only.

Future research is needed to test the methodology on more complex products such as multi-material, multi-component products where more circularity opportunities arise (e.g. product life extension through the repair, remanufacturing and upgrades). Moreover, CPA improvements should account for the generation of circular flows absorbed outside the system boundaries (i.e. open-loop recycling of the waste and by-product of the product system considered). A more advanced application should be conducted to show the wider impact of product circularity on the overall sustainability performance of manufacturing systems.

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Teaching Energy Efficiency in Manufacturing Using Gamification: A Case Study

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Abstract. Sustainability is a critical topic and needs to be systematically integrated in engineering education and professional training courses in manufacturing organisations. Eco-efficiency is a key sustainability concept but it can be challenging to teach as it is highly practical and thus ill-fitted for purely classroom environments. Games and simulations provide a good mechanism for effective and engaging teaching on such practical topics. This paper describes a case study of four game sessions ran in a manufacturing company. This empirical research shows how the card game 'One thousand kWh' enabled participants to actively learn about energy efficiency in manufacturing operations, and to explore sustainable manufacturing practices and barriers to implementation.

Keywords: Eco-efficiency · Energy efficiency · Manufacturing · Games · Teaching and learning · Education

1 Introduction

Complex issues, such as globalization, industrial digitalization and sustainability, need to be more systematically integrated in engineering and management education. Broadening the set of learning experiences and teaching methods in engineering curricula is crucial to provide engineering students with the skills and knowledge required to respond to new industry needs [1]. Typical production engineering courses largely consist of lectures in which concepts and theories are conveyed. Short projects and practical exercises give students the opportunity to put this knowledge into practice and attain deeper learning by engaging more actively with the course material. Ideally, students should also carry out industry projects to experience the challenges and complex phenomena occurring in real-world manufacturing environments.

Focusing on sustainability, the skills required to address today's industry needs are envisioning, critical thinking and reflection, systemic thinking, collaboration and decision-making in uncertain and paradoxical conditions [2–5]. To address this challenge, a toolkit (Fig. 1) was developed to engage students (in higher education) and trainees (in professional courses) to learn more actively about eco-efficiency and sustainable manufacturing [6]. The toolkit aims to simplify and gamify sustainability concepts.

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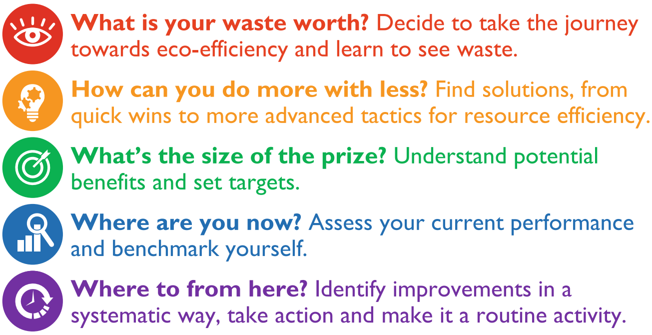

Fig. 1. The five elements of the eco-efficiency toolkit

This eco-efficiency toolkit is composed of five activities (or "elements"): (1) see waste, (2) find solutions, (3) set targets, (4) assess yourself, and (5) create good habits [6]. One notable tool in this eco-efficiency toolkit is the card game 'One thousand kWh'. It addresses various aspects of the toolkit with practical, industry-relevant learning outcomes. The game focuses in good practices for energy efficiency in manufacturing operations along with the typical barriers of implementation. In this paper, we describe how the game is designed, the mechanics of its game play, and the results of an experiment composed of four pilot sessions conducted with Airbus employees. Finally, we discuss the pros and cons of using games for education and provide some next steps for the sustainability games.

2 Game Design and Development

The card game was developed incrementally based on a trial-and-error approach. Three prototypes, each being iteratively improved based on player feedback, were produced and tested before the final product was professional printed and packaged. The rules are largely based on a French card game, *Mille Bornes*, developed in the 50 s. It was selected for its simplicity and popularity which is proof that the format and concept work well for a broad audience.

The game is set to be easy to learn and playable within 30 min. Besides keeping the rules as simple and intuitive as possible, it is critical to provide sufficient context to make the learning experience as quick, effortless (and fun) as possible. This is important to address a typical drawback of using games as an educational tool: players can easily get carried away and forget about the learning experience.

The first two prototypes were tested multiple times in informal meetings with co-workers at the University of Cambridge during breaks and after work. This provided a more robust content for the third prototype which was then presented to industrial partners. The prototype format was good enough for the purpose but lacked the intuitive design to make the rules and mechanics quickly understood. The final product was largely improved by using bright colours, symbols and large fonts to clarify the cards categories and their relationship. A sample of the final card game is shown in Fig. 2.

Fig. 2. Samples from the One thousand kWh card game

The card game consists of four categories of cards described in the next subsections.

(1) Improvement Cards (Plain Background). This category consists of a collection of sustainable manufacturing practices focused on energy efficiency. These practices were mainly sourced from the IAC database [7]. The practices selected were:

- the most recommended, capturing the most often overlooked practices;
- the most implemented, considered as the easiest practice to implement;
- the shortest payback time, representing the most economical practices;
- the largest savings, often associated with the most expensive practices as they require high capital investment in new equipment/machinery.

Due to the space constraint and the need for the improvements to be quickly read and understood while playing, some of the practices were rephrased or simplified based on formulation found in other sources [8–10]. This aspect was crucial as there is little time to reflect on the meaning of the practice in a game environment.

The practices were then sorted and grouped into seven types of improvement and associated with a generic value to reflect its average impact on energy savings:

1. Switch off lights (25 kWh);
2. Good housekeeping (25 kWh);
3. Process controls and production planning (25 kWh);
4. Challenge set points (50 kWh);
5. New, more efficient technology (75 kWh);
6. Switch off equipment (100 kWh);
7. System-wide improvement (200 kWh).

(2) Barrier Cards (Striped Background). There are five types of barriers. Each barrier can be removed by two types of remedy [name in brackets], with improvement exceptions *[italic name in brackets]* for the first two barriers.

1. Too high investment cost: Player can still play *[Switch off lights]* improvements as they are relatively high budget, until [Budget] or [Repair] remedy is played;
2. Lack of knowledge: Player can still play *[Good housekeeping]* improvements as they are basic improvements that do not require advanced knowledge, until [Learning] or [Budget] remedy is played;
3. Lack of communication: Player cannot play any improvement until [Crisis team meeting] or [Learning] remedy is played;
4. Factory closure (for non-compliance): Player cannot play any improvement until [Intervention] or [Crisis team meeting] remedy is played;
5. Leak, accident or product defect: Player can't cannot play any improvement until [Repair] or [Intervention] remedy is played.

The first three barriers capture some of the findings from previous research on barriers to industrial energy efficiency [11] and the last two aim to reflect the potential negative consequences on product quality and environment, health and safety aspects when good practices are not systematically implemented.

(3) Remedy Cards (Dotted Background). As mentioned in the previous section, there are five types of remedies. Each remedy addresses two barriers [name in brackets]. This is to ensure that there are sufficient solutions to barriers so players would not get stuck for too long and could go through more *Improvement* cards.

1. Repair (and replace): Solution to [Leak, accident or product defect] and [Too high investment cost];
2. Budget (for pilot project): Solution to [Too high investment cost] and [Lack of knowledge];
3. Learning (from colleagues): Solution to [Lack of knowledge] and [Lack of communication];
4. Crisis team meeting: Solution to [Lack of communication] and [Factory closure];
5. Intervention (to bring perf. up to min. standard): Solution to [Factory closure] and [Leak, accident or product defect].

(4) Immunity Cards (Crosshatched Background). There are five unique *Immunity* cards in total, each based on a principle from the Lean manufacturing and addressing a specific barrier [name in brackets]:

1. Hansei and sustainability vision: Sustainability as a mindset and core business value, making the player immune to [Too high investment cost];
2. Genshi genbutsu and routine training: Go and see problems on-site to experience them first-hand and develop better solutions, making the player immune to [Lack of knowledge];
3. Yokoten and collaborative teams: Outstanding communication within the company to enable broad dissemination of new good practices, making the player immune to [Lack of communication];

4. Kaizen and energy champion: Performance beyond legal compliance, making the player immune to [Factory closure];
5. Muda walks and preventive maintenance team: Outstanding shop floor layout and maintenance, making the player immune to [Leak, accident or product defect].

3 Results

Four pilot sessions were conduct with Airbus employees to test the game and get feedback on the usability and usefulness of the game. The four different focus groups were selected to capture a broad range of opinions on the game effectiveness and ideas on how this could be deployed at Airbus. This section describes each focus groups, the sessions' setting and the feedback provided by participants.

3.1 The Four Focus Groups

Trade Union Safety Representatives (TUSR). The first pilot involved five senior safety representatives (four playing, one observing). TUSR work closely with the shop floor and were able to provide practical feedback on various elements of the game. The pilot session took place in their office which is on the shop floor, thus in the actual manufacturing environment simulated in the game. Being so close to the real-world environment provided the ideal conditions to get the "blue collar" insight into the game.

The session started with a very high level of engagement and competition between the representatives – even to the extent that they joked about putting a financial stake on the table. The focus was very much on winning with most attention given to the practices with the highest savings, and often the practices with lower savings being overlooked or trivialised. The language used on the cards was sometimes considered too technical, requiring explanation by the facilitators, which reinforced the focus on the value on the card rather than the practice itself.

The feedback from the representatives was that the game itself seemed complex to begin with but that it was easy to pick up. They thought this could be a problem with introducing it more widely to the shop floor workers. The game lasted 30 min which would mean it would be difficult to introduce either during normal working time or during breaks, which are short.

However they proposed a targeted approach, perhaps to other representatives first who could then cascade it to others or via a specific training session. The practices on the cards were seen as broadly relevant and the representatives were pleased to see examples of practices that they had already implemented or that they could implement in their production area. They also recognised the barriers and were pleased with the ratio of barriers to practices which made the game more free-flowing.

Facility Management. The composition of the group for the second pilot session was quite varied and included people working on a variety of infrastructure projects and with some, but limited experience, of energy efficiency from a buildings perspective (as opposed to a manufacturing perspective as primarily addressed in the game). Two of the participants in this group already played the game before in a previous meeting in preparation for this pilot session. This function in the company is the ideal customer for the game so the feedback from this session is the most important. Despite some initial scepticism, the session was carried out successfully with good results in terms of engagement and quality of discussions after the game.

As the function responsible for energy consumption, Facility Management staff played the game with some ideas in mind about how they would like to deploy it. During the game, they considered how it could be played during the energy awareness campaigns. Although the game was shorter than the first pilot session (20 min), they had concerns that this would still be too long to engage with employees.

They also made the same observation as the TUSR that it was difficult to begin with but very enjoyable once the game was underway. Some of the people who played had no experience of energy efficiency and found the language difficult, but the other players with experience were able to explain.

Also as above, it was noted that it was easier to focus on the value rather than the practice. One member of staff suggested that a way of overcoming this could be to use the cards in a different way as a “higher-or-lower” style game, where the practice on the card is read out and players have to determine if the savings are higher or lower. This could also be suitable for a small number of players (perhaps only two) and a larger number of observers, which would work well with the person-at-a-stand approach for the awareness campaigns.

Manufacturing Engineering. This third pilot session was conducted with engineers who had good technical knowledge and some grasp of energy efficiency. It also was the biggest session with six players and took 45 min to complete. The group experience was ranging from engineering apprentices to people who have worked for Airbus for many years. Their primary interest laid in how they can build energy efficiency into their specifications for new equipment/machines rather than continuous improvement activities.

The game was picked up quickly but the level of engagement seemed lower than the other sessions. The main feedback from the engineers was that they wanted it to be highly relevant to their work and would appreciate it more if the practices were based on specific projects with specific savings figures. This would also help with understanding the practices more – and how they could be applied. One engineer suggested that a good understanding of the practices in the deck could be a useful aid for writing a specification for new manufacturing equipment and that the deck could be used a reference source.

Environment Health and Safety (EHS). The final session was with the EHS team. The shop floor workers invited to this session did not join as there was no interest in the session due to skepticism and limited willingness to engage. The EHS shop floor staff are mainly responsible for health and safety, with environment added as an extra responsibility but often overlooked. However, the “white collar” EHS staff were also invited and were more engaged, one of whom had played the game before. This session was the shortest at only 15 min in length – but even this was considered too long for using with shop floor workers.

Most of the comments from this team were related to how it could be deployed and the constraints associated with delivering it as a piece of training, either standalone or as part of another course. The team also commented on what the expected outcomes could be; gaining an awareness of good practices, barriers and their remedies is good, but this should lead to actions which allow the practices to be implemented.

3.2 Summary of Feedback on Format and Content

The four pilot sessions ran for a reasonably short time with the game time itself ranging from 15 to 45 min. There were only few issues with learning the rules and game mechanics. Most players learnt quickly and helped other players, reducing the need for external facilitation. This ensures that the game can be further deployed as experienced players can easily teach others and scale up the use of the game.

The practices on the *Improvement* cards, despite being considered too technical at times, was mostly relevant for the companies. A few practices were not relevant due to specificities of the production facilities at Airbus. For instance, the site does not use steam and thus all practices connected to energy savings in steam networks were not applicable. Some suggestions were made to customize the game to Airbus and include actual examples of past projects. The format in which this could be achieved was shortly discussed as including actual value of the energy savings and a full description of the practice on the cards would make it less user-friendly. Instead a reference or code could be added on the card to link to external resources and provide more complete information which could be consulted outside the game.

The *Barrier* and *Remedy* cards were also considered as relevant and sometimes added a comical element to the game. Some players invented stories explaining why their opponents would face a specific barrier or how they can solve this challenge. It is hypothesized that this type of emotional engagement with the content can enrich the learning experience and make it more memorable. Therefore, it has been suggested in subsequent games to engage with the card content through storytelling.

Finally, the *Immunity* cards may be considered as the most technical ones (terminology from Lean and Toyota Production System). However there was little discussion on their meaning and applicability at Airbus. This could be addressed by highlighting the importance of these cards as they are very powerful, like the "joker" or wild card in a regular playing card game. A short dictionary of the terminology used in the eco-efficiency card game could be included in the rulebook in order to give the opportunity for players to further explore Lean principles and concepts after the game.

4 Conclusions

Overall, the format worked well for all focus groups. Participants quickly understood the purpose of the session (learn about eco-efficiency and get examples of practices) and the objective of the game (score 1,000 kWh of energy savings). Despite some initial difficulties to learn the rules and game mechanics, all players succeeded in playing without additional guidance, typically after one full round.

The main intended learning outcomes are to learn about: (1) sustainable manufacturing practices; (2) typical barriers to improvement; (3) remedies to these barriers; (4) systematic ways to overcome barriers based on Lean principles. The team dynamic and storytelling are instrumental to enrich the learning experience through deeper discussions on specific practices, barriers, remedies and immunities. It shows potential for the game to be a platform for knowledge exchange. Additional objectives were to increase the acceptance of serious games as educational tools; to promote experiential learning on practical topics; to enable team building and engagement with the topic of sustainability; and to encourage the recognition that eco-efficiency is feasible and actionable.

Further work is currently underway to test the card game in university lectures. So far, the card game was used for team building during the induction week of MPhil students in Industrial Systems, Manufacture and Management, and in modules on Industrial Sustainability, Sustainable Manufacturing and Energy Technologies with under- and postgraduate engineering students. Early findings reveal polarized reactions amongst students with a majority of the responses strongly positive trend on gaming as a mean to learn about eco-efficiency.

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Organizational Designs for Sharing Environmental Best Practice Between Manufacturing Sites

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Abstract. Development and sharing of environmental best-practice manufacturing has been studied extensively in the literature. Most studies have focused on areas such as: inter-/intra-organizational relationships, supply chain collaborations and networking capabilities. However, little attention has been paid by academia and practitioners to the concept of system designs that enable these intended functions. The research gap is quite evident in the case of energy efficiency, especially in multi-site manufacturing operations. This paper explores organizational models that can facilitate the development and sharing of best practice (DSBP) for energy efficiency and the conditions that enable these to be more effective vehicles of improvement. As part of a larger research project on practice maturity for eco-efficiency, the authors conducted semi-structured interviews with industrial practitioners that are directly involved with energy efficiency improvements in two large multi-site organizations. The authors recognize two DSBP organizational models: (a) networks of practice (a decentralized approach) and (b) model-factories (more linear approach). This study aims to demonstrate the challenges and opportunities that each model brings and narrates the enabling conditions of their adoption.

Keywords: Best-practice sharing · Eco-efficiency · Maturity

1 Introduction

Many manufacturing companies operate across multiple sites. The choice of expanding manufacturing operations from a single factory to multiple ones, within the same country or abroad, is a matter of strategic importance and very closely linked with the corporate business strategy [1]. Sustainable manufacturing in this context is defined as a way of making products that eliminates environmental hazards (pollution prevention) and waste in energy and materials [2]. Abdul Rashid et al., identify four sustainable manufacturing strategies that are available to practitioners to explore: waste minimisation; material efficiency; resource efficiency; and eco-efficiency. Achieving improved energy and resource utilization by following one of those strategies is also a matter of scalability for multi-site manufacturing operations. It is logical to assume that the faster and better improvements are developed and replicated across sites, the higher the gains

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for the environment and the business. Existing techniques to reduce manufacturing variability may be applicable to eco-efficiency but researchers show that there may be complementarity with more focused efforts to reduce environmental impacts [3]. Nevertheless, there is evidence that a performance gap exists between factories, within multi-site operations, in energy and resource efficiency [4, 5]. The study here also serves as a response to information silos and local or fragmented development of best practice in manufacturing [6, 7].

2 Methodology

This study is concerned with the mechanisms that mature manufacturing companies deploy to develop and share environmental best practice across these factories. The research question that this paper explores is: “How do multi-site companies develop and share environmental best practice (DSBP)?” This study draws theoretical grounds from the resource based view of the firm, extended by Hart to account the natural environment [8]. Understanding how to best utilize resources and internal capabilities can be a driver for improvement and lead to competitive advantages [9]. This work here is part of a larger research plan based on Design Research Methodology that seeks to generate practical support for energy and resource efficiency in manufacturing [10]. The authors conducted interviews with environmental management practitioners in two multinational corporations in Europe in the automotive and aerospace sectors that operate 9 and 11 factories respectively (8 interviews and energy efficiency workshop with 11 delegates). The interviews were exploratory in nature to gain rich perspectives of the way that DSBP is approached in these companies [11]. Both companies pursue environmental best practice at process level in their factories, they are both ISO14000 accredited and have been actively involved in common research activities for eco-efficiency [12]. The interviewees were people in charge of environmental management in factories, with a wealth of experience in developing and sharing of best practice (lean, operational, environmental).

3 The Case Studies

3.1 The Aircraft Manufacturer

This company operates in the aerospace sector and owns 11 manufacturing sites that employ approximately 50000 people across four European countries. Most of the sites are responsible for specific parts of the aircraft i.e. fuselage, wings. These parts once manufactured are sent to two final assembly sites. Developing energy efficiency solutions in manufacturing has practically been a major issue for the company for several years. It has not been until 2006 that a corporate policy was developed that would formalize the efforts towards energy efficiency and set a 20% reduction in energy by the year 2020 across all manufacturing sites. The year 2006 became the baseline year for energy savings and performance measures. The resources available for the implementation of improvements were based on lean practices, manufacturing engineering implementations and research and development (R&D). A business case for each project is a necessary part of the improvement process and it helps to assign responsibilities and accountability to the people in charge of the improvements. However, energy efficiency improvements at process level (i.e. the painting process) did not necessarily adhere to a strategic improvement program. A recent study in this company identified a set of barriers to energy efficiency such as [17]: lack of accountability, no clear project ownership and no sense of urgency to improve. It was agreed in 2012, that to replicate and scale up localised improvements across the sites, a process of cross-plant coordination was required. The company had previously done this when seeking to harmonise its manufacturing processes through international process technology groups within the manufacturing engineering function [5]. This approach consists of each plant nominating a representative who takes the lead and coordinates activities. The same approach was applied to the creation of an industrial energy efficiency network. In the second half of 2012, each plant was asked to nominate a representative. Notably in this case the representatives of the industrial network came from a range of functions: industrial maintenance (5), manufacturing engineering (3), lean operations (1), health & safety (1), facility management (1) [5]. It is expected that the industrial network would contribute to a significant 7% share out of an overall 20% energy reduction target for the year 2020: "*By having the network we meet and we select together a list of projects that we want to put forward to access central budget. So we know roughly how much capital will be allocated to industrial energy efficiency and so we select projects across all of the sites that we think will get funded and we support them all together as a group, instead of having lots of individual sites making individual requests for funding and being rejected. We go together as a group and have some kind of strategy as well.*"—as the network leader commented.

The network's operations are further facilitated with typical corporate resources available, such as online tools that help practitioners report and track the progress of current projects, review past ones and learn about best-available techniques. On average, a 5–10% time allocation is approved for all network members to engage with the network functions (sub-contractors are also an acceptable solution).

Most of the network members also act as boundary spanners [13] in the sense that they have established connections to process technology groups or they are members of these groups too. These boundary links help the network establish strong communications with other functions within the organization and act as conductor for information flows. This type of social capital has been shown to improve performance by enabling employees to access the resources that are embedded within a given network and by facilitating the transfer and sharing of knowledge [14].

3.2 The Automotive Manufacturer

The automotive company is a global leading Japanese manufacturer and a lean management pioneer. The company actively pursues environmental and social sustainability improvements and other companies find their methods inspirational or exemplar [5, 15]. The interviews were held with the environmental and social responsibility general manager for Europe and one of their factory managers in the UK. The company has been continuously improving on various environmental indicators and they feel that a level of proactive sustainability thinking already lies within the staff. The company operates 9 factories across the broader European region with some of them making engines and transmissions that are then shipped to the other car assembly factories. In terms of environmental performance improvements, the UK plant, for example, between 1993 and 2013, reduced its energy usage per vehicle by over 70%. In the same period, it also reduced water use per vehicle by over 75%, and waste produced per vehicle by nearly 70% [16]. In terms of developing and sharing of best practice this company applies the concept of the model factory. Two factories in Europe have been assigned by top-management the role of model factories for energy (UK) and water efficiency (France) respectively. The decision to assign the title of a model factory to those sites made further business sense (i.e. the cost of energy in the UK is a potent driver for energy efficiency).

An example of how this model works is described in the case of energy efficiency improvements. The energy efficiency improvement was focused on the plant's control systems in the paint booth process. An opportunity to improve was at hand but the financial risk of failure to achieve the perceived benefits was unbearable for the model factory's budget. However, the environmental and social responsibility general manager for Europe decided to fund the trial in one of the several paint booths in the UK model factory: "*We need to make the step change. This is the amount of money we will pay. We will invest this money one time in one booth only in UK as our model plant*". The fact that the UK site was already nominated as a model factory made the decision easier to justify and manage. The results were satisfactory and the plant managed to improve paint-booth energy-efficiency by 40%. The improvement was then justifiable at plant level and carried out in all the plant's paint booths, thus achieving better scales of efficiency. Through standardization and kaizen activities the results became the efficiency norm in the paint booth processes. In addition, the achievement was communicated through intra-organizational networks in the company and this was then replicated in other sites that the improvement was relevant.

Another function that the model factory may serve is technology management. For example, the model factory in the UK serves as an improvement hub and testbed for more conventional technologies. The French site is the newest one in Europe and therefore serves as a hub for advances in manufacturing technology. The distinction makes it easier for top-management to decide where to allocate resources and address specific issues related to technology improvements. Even though there may be local budget per site for improvements, there is a budget range that could be considered too risky without a model factory to test it first. Without a model factory, plants may be in internal competition to secure central funds for improvements.

4 Conceptualisation of DSBP Models and Discussion

The case studies describe two distinct pathways for energy efficiency improvements across manufacturing sites. The first one is the "industrial network" and the second one is the "model factory". The observations in these cases have produced the conceptualization of models to develop and share environmental best practice (DSBP) across manufacturing sites. In this section, these DSBP models will be described as processes that deliver eco-efficiency improvements across multiple sites. It is the author's intention to conceptualise these processes to industrial practitioners and academics and raise considerations about the way that improvements can be aligned to systemic capabilities. It needs to be noted that the authors here, focus less on the development stage of best practice and focus more on the process of sharing best- practice to other sites as the literature gap tends to be less popularised in the literature with case studies.

In the following figure the DSBP models are graphically described through three scenarios where an improvement has been developed and tested in one of the plants (i.e. site A) and can be replicated across sites with confidence. The word scenario is used to describe the situations and avoid confusion with DSBP models and model factory. In each scenario, the authors assume that the information related to the improvement can have multiple receptors. The scenarios that describe the DSBP models are compared to a default scenario 1, where information silos and poor communication links between sites inhibit replication of improvements and knowledge transfer.

Scenario A: The information silos: This scenario represents the "business as usual" case, where little attention is paid to the way that plants share knowledge and information with each other. It offers a contrast to the authors arguments Information flows would follow the operational links between the factories (i.e. material flow through internal logistics – parts being shipped between factories). Figure 1 demonstrates how some of the sites will be carrying out the improvement that has been suggested by site A and little will be known about this in other manufacturing sites because of weak communication flows that do not stretch beyond operational efficacy.

Scenario B: The model factory: The second scenario is a prototype-based approach where a manufacturing line or factory is selected by top-management to become a best-practice centre of excellence for other factories. Lessons learned are replicated vertically rather than horizontally in other sites by expert staff and reported back to top-management through typical communication routes. This scenario may incorporate some networking activities to advertise achievements horizontally across the organization. However lateral sharing of best practice could be controlled through formal communication and reporting processes. The suggested improvement is tested in the model factory with centrally authorised funding, thus reducing financial risks and system friction (easy to choose where to make the test). The solution may be relevant to other sites (if successful) and will be replicated quickly through their own allocated budgets with confidence. Some sites may not be affected (i.e. site D in the Fig. 1) and there is some risk in regards to finding out about the improvement. In the case study in the automotive, attention is paid to lateral information sharing and this should be another consideration for using this DSBP model.

Scenario C: The industrial network: The third scenario is a network-based approach where practitioners of common practice goals, form networks that nurture the development and sharing of best practice. Lateral information sharing is amplified and reaches people that may not be directly involved in projects or have any immediate shared interest. The network is supported by informal attitudes between its members

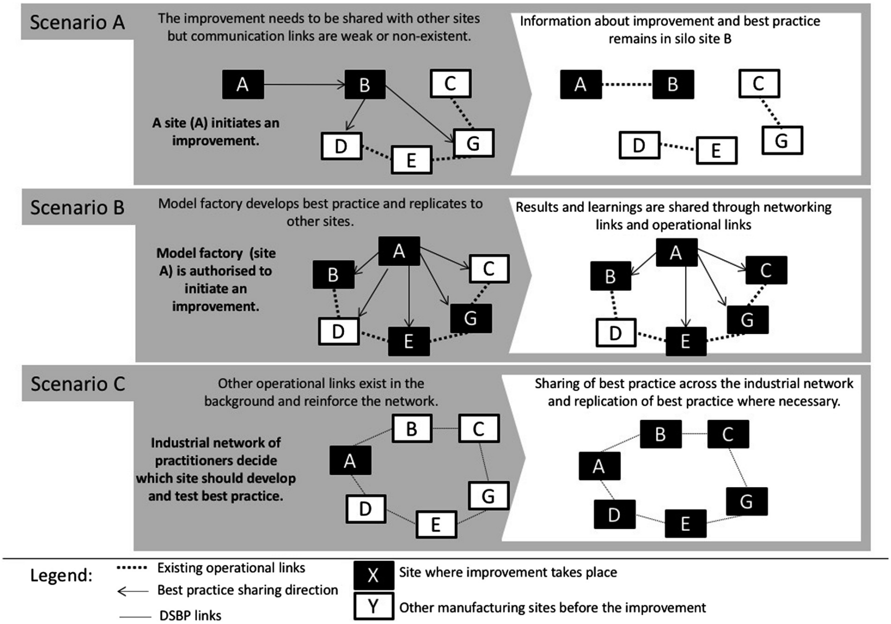

Fig. 1. Demonstration of SDBP models in three scenarios

and a sense of trust enhanced by common goals that the network promotes throughout the business. In this DSBP model, an improvement is identified by one site or brought forward by a networking activity (quarterly meetings). This is added to a collection of improvement projects and the network commonly agrees to prioritize the projects based on success factors, financial risk or urgency. Central budget may be raised with supporting procurement processes (i.e. economies of scale to introduce better equipment across many sites rather than just one). The network financially supports the implementation of the solution in one of the plants and the benefited plant feeds the knowledge and benefits gained, back to the network. All plants are informed and further actions are developed (this time, site D is being informed even though the solution was not relevant to its operations, as D is represented in the network).

The industrial energy efficiency network is not the only network that operates within the aircraft company. For example, in March 2015 a network to improve gender balance in the workforce was launched. It was confirmed from the energy network leader that this is a common practice in the company as it is a way of keeping all sites informed about new projects and maintain a level of harmonisation in practices. It is a practice that has been nurtured over the years and is used to promote collaboration and communication internally and across sites. It was confirmed from the energy network leader that he made a conscious choice not to choose an energy-model architecture. He saw the network as a better cultural fit for that activity instead of promoting the site he worked at as the energy efficiency model factory. Compared to the aircraft company, the automotive relies more on their core capabilities of standardisation and continuous improvement to sustain networking functions internally and across remote sites.

5 Conclusions

The authors observe that there are two distinct approaches to development and sharing of best practice in parallel to a more "business-as-usual" approach. The distinction aims to demonstrate the organizational design and the cultural differentiators between these two approaches. A manager may choose to use these models in different conditions. One of the managers in the automotive concluded that: *"…so I think there is a blend to it to be taken or where would we use the network approach as a principle way of sharing and where we use the model plant of sharing something and I think that is a distinction that I will probably make. The sharing and network approach we tend to use for things that are locally developed by members, they make some kaizen on the line or do some activity that reduces some environmental impact. That is recognised within the plant and it is brought to be shared in the committee or the working group meeting. The model plant idea is to say we are trying to go away from this small incremental change to go towards a more step-change."*

The manager illustrates that there are various possible routes to develop and share best practice and furthermore the DSBP models can be complimentary to each other and can interplay. The authors' contribution to theory and practice is founded on the observation that organizational properties and priorities may favour one approach over the other. Resource-based view theory supports the argument that companies tend to rely on system strengths to respond to new challenges. From the case studies here, this assumption seems to be verified. However, it needs to be noted that the companies examined are considered to be quite mature in terms of the practices they tend to employ in operations. Both "model factory" and "networks of practice" exhibited improvement potential. It is outside the scope of the study to examine the speed of the improvements achieved as this may vary across industries and whether low hanging fruits in terms of energy and resource efficiency have already been reaped. In summary, the key contributions of this study are:

1. Manufacturers may choose to utilise DSBP models to implement and share best practice in multiple manufacturing sites. These conceptual models can help companies reduce the risk of developing solutions to energy and resource efficiency.
2. Managers should align the choice of these models by considering not only the environmental and economic benefits but also the cultural fit with the organization. Enhanced fitness may enable a more efficient dissemination of best practice and thus generate more value for stakeholders.

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Simulation-Supported Verification of Methods for Controlling Disassembly Lines

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Abstract. In order to follow the principles of sustainability disassembly of end-of-life products is necessary for the re-use of their parts and sub-assemblies. In contrast to production control of assembly systems, disassembly lines feature some peculiarities: used components can be proven to be non-detachable or even missing, so that with increasing disassembling progress the desired components can no longer be gained, and there is a threat that the stations and workers assigned to them would remain idle. This paper describes a procedure for controlling division of labor-based lines, which follow the flow principle and are tailored to the specific features of disassembly control. It aims at maximizing the disassembly proceeds and the utilization of the disassembly stations, but it also considers the uniformity of their utilization. Thereby future disassembly lines can be operated in a way that efficiently counters the increasing volume of end-of-life products to be disassembled. The effectiveness of the procedure is verified by means of a simulation-supported application study.

Keywords: Disassembly line · Flow principle · Disassembly control · Staff deployment · Simulation

1 Requirements for an Economical Disassembly Process

Due to legal requirements, in particular due to the European Waste Framework Directive 2008/98/EG [1] and the principle of producer responsibility that goes along with the basis of changing values towards greater environmental awareness ([2], p. 7), an increase in the amount of end-of-life products to be disassembled can be expected in the future. At the same time disassembly processes are characterized by generally low value creation compared to industrial production. Disassembly inefficient operations often prevail, exacerbating the situation further. Moreover, disassembly is often characterized by poor working conditions (e.g. noise, dirt, muscular stress etc.).

Therefore it is firstly necessary to reduce disassembly costs through systematic planning and control of the related processes. Secondly, the cost-effectiveness of disassembling improves when it is of an increasingly industrial character. However, to a greater extent automation is only technically and economically feasible with special end-of-life products. Nevertheless, a combination of manual operations with automated

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sub-processes - featuring so-called hybrid and flexible automated systems - is seen as especially economical (e.g. [3], p. 290).

During disassembly, however, due to the uncertainty with respect to the properties of the end-of-life products, the operations to be performed are not fixed and therefore not deterministic (e.g. [4], p. 374). The selected disassembly methods must be chosen depending on the condition of the individual end-of-life product, from which the necessary processing times can possibly then be derived [5].

The scope of the used parts or sub-assemblies to be disassembled, i.e. the degree of disassembly, is also not necessarily specified. Instead, depending on the respective state of each end-of-life product this must be re-determined from an economic point of view ([6], p. 31). For this reason it is logical that the degree of disassembly should not be equated with the degree of assembly, because it is operation-based, not product-based.

2 State of the Art for Control of Disassembly Systems

According to Zülch ([7], p. 56) there are basically three possible measures by which the processes of a given production order program can be controlled appropriately. These are: changing the order size (for example, by combining orders A and B), changing of order sequences (bringing forward order B to before order A) as well as the initialization logic (e.g. splitting an operation or order). In principle, these control measures have been developed for parts manufacture and assembly.

However, such control measures are only conditionally suitable for disassembly orders, since they do not account sufficiently for their specific characteristics. In division of labor-based systems such as disassembly lines, the control problem is complicated by the diversity of end-of-life product types and by the various usage states of the individual product. The latter in particular must be considered during disassembly control. Especially in manual systems compared to conventional production systems advanced or more detailed control measures are needed in manual systems in order to achieve efficient processes for disassembly.

As early as 1996 Geiger et al. [8] recognized that disassembly must be reactively controlled. The reason for this is that extraction of certain end-of-life components depends on the success of the disassembly of its previous components. Moreover, the state of these components determines the likelihood of successful disassembly (cf. ibid., p. 49).

Many literature sources regard the assignment of disassembly operations to stations, thus regarding the planning problem of line balancing (e.g. [9]). As a control task, the planning of the order sequence is considered. Some authors try to solve this problem analytically using methods of operations research [10, 11]. But these procedures solve only problems without any disassembly-typical disturbances.

Lee and Bailey-Van Kuren [12] investigate disassembly strategies with the help of the simulation using two end-of-life products as examples. The strategies are material-oriented and are carried out in robotic cells. Their contribution focuses on the mutual blocking of components; other disassembling difficulties are not considered.

As part of the planning of a hybrid disassembly system, Kim et al. [13] developed reactive control measures. Their application, however, also involves a robotic automated disassembly system, but not the manual systems considered in this paper. There is no evidence of the effectiveness of the developed method, as it is the case here using simulation. In a further study of this procedure, Kim et al. [14] use the simulation of another hybrid system to select from the possibilities of alternative disassembly operations a feasible one. Whether this procedure is also valid for an entire order program, as it is the case in our paper, is not checked with the aid of the simulation.

As a result, the control concepts proposed in the literature do not take into account disassembly specific difficulties, or if so then only partially - that is if such a concept considering a disassembly order program consisting of different end-of-life products exists at all. A dynamic, reactive control that takes into account available human and technical resources has not been carried out with any of the previously presented methods.

3 Development of a Novel Disassembly Control Procedure

In order to respond to difficulties or disturbances during disassembly it is not enough to manage these short-term changes to the order sequence with so-called re- sequencing or re-scheduling measures. Rather, the novel disassembly control procedure must be capable of much more, namely a re-configuration of the existing flow principle. In the sense of reactive control short-term scheduling should be feasible (e.g. a re-assignment of individual disassembly operations to line stations). Moreover, the control procedure must allow for a re-distribution of operations in conjunction with an adaptive-dynamic work plan ([6], p. 29). Consequently, what is sought is a short-term work schedule taking the given additional constraints into account (e.g. limited resources, cycle time) and as much compliance with the objectives as possible (e.g. high utilization of disassembly stations).

The following assumptions determine the initial situation that is the basis for the novel disassembly control procedure: It is assumed that there is a pre-existing balanced disassembly line with one worker at each station and an order program whose end-of-life products initially shall be disassembled in a pre-defined sequence. This order program can consist of different variants of an end-of-life product type with individual product states.

In terms of economics, the objective of the procedure developed here is, on the one hand, to ensure a high and most uniform utilization of the existing disassembly stations. On the other hand, the proceeds or contribution margin of the initialized disassembly order program for a defined planning period is to be maximized.

In the following, control measures are discussed that can react to disassembly specific difficulties or disturbances in an adaptive-dynamic manner (cf. also e.g. [15, 16]). In this approach, priority is given to a manual disassembly system ([17], p. 101):

– Variation of disassembly operation sequences
– Variation of disassembly operations
– Variation of disassembly tools

- Variation of the disassembly order sequence
- Variation of the disassembly depth
- Re-assignment of disassembly operations to stations.

Figure 1 illustrates the general flow of the newly developed disassembly control procedure: For each disassembly station the remaining time for the current order program is determined. Taking into account the available control measures the one is then selected, that on the one hand maximizes the disassembly proceeds and on the other hand maximizes the utilization of the disassembly stations, but also considering the uniformity of their utilization.

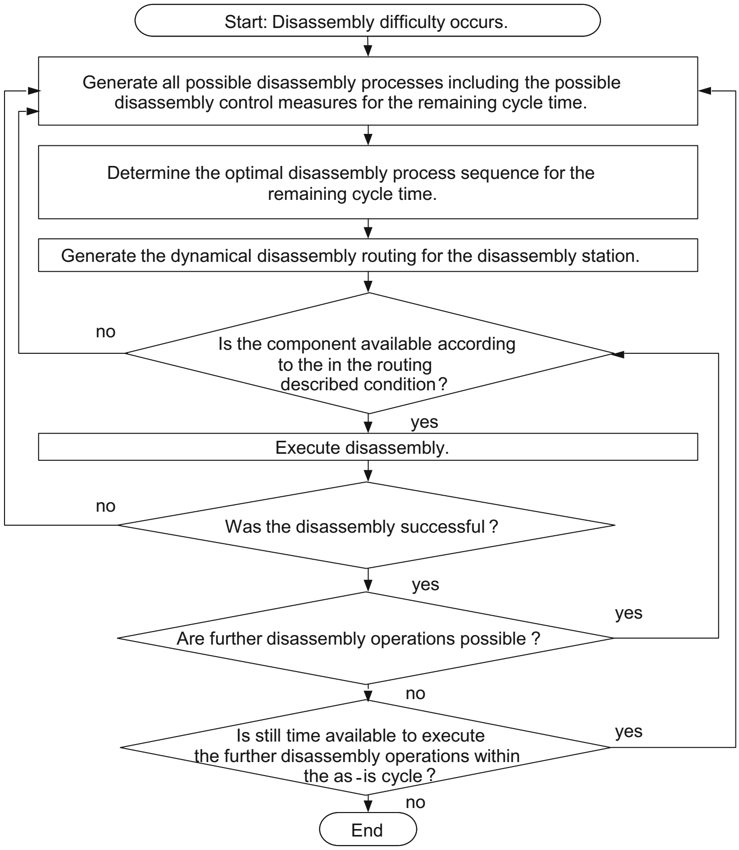

Fig. 1. Disassembly control procedure by re-assignment and operation-related measures for a disassembly station (according to [16], p. 404)

4 Verification of the Effectiveness of Developed Control Measures

4.1 Aim and Scope of the Study

Below the effectiveness of the developed algorithm and control measures is shown with the aid of the simulation using an application study: In a disassembly line an order program that consists of three different variants of an end-of-life product is executed in a defined order period. The end-of-life products are disassembled at four stations in a line with one employee at each station.

Three variants of an end-of-life product type with beta distributed activity times with respect to the applicable tools are available as well as the associated potential proceeds. Furthermore, the feasibility probability, the damage probabilities and the probability of depreciation due to damage associated with the respective tool are considered. Of the examined different control scenarios, only two are presented here, the initial solution as well as the most favorable improvement solution.

The following scenarios were conducted with a simulation period of 8 h. Included here were end-of-life products to be disassembled with the order sequence Variant A, Variant B, Variant C, Variant A etc. with the setting batch size 1.

The simulation results are shown in the following. The presented figures illustrate the Gantt chart representations, stating the workload of staff (and thus implicitly of stations). In addition, the tables contain the disassembly proceeds generated (shown here simply as 1 currency unit - CU - each per disassembly operation). To reduce the randomness of the results obtained, 10 simulation runs were carried out with different seeds for random numbers. Both, the respective results of the simulation runs as well as the average over all runs are listed.

4.2 Situation of the Initial System

The initial situation in modelled with the following assumptions: In the case of workflow disturbances, the workers select randomly a control measure or an alternative disassembly operation. The disassembly stations have an average workload of 83.0% (Fig. 2 and Table 1). Disassembly Station 4 is particularly poor with 77.2%; Disassembly Station 1 on the other hand has already achieved relatively high workload at 89.4%. The aim of the disassembly control procedure is to achieve high proceeds as well as a uniform utilization of all disassembly stations. In the initial situation, the difference between the busiest and least busy disassembly station is 12.2%. The disassembly proceeds amount to 7,854 CU.

4.3 Possible Control Improvements

The improvement solution is run under the following assumptions: Through buffers, staff can access the operations of the previous disassembly stations, and thereby help each other during processing. Determination of the disassembly proceeds is achieved

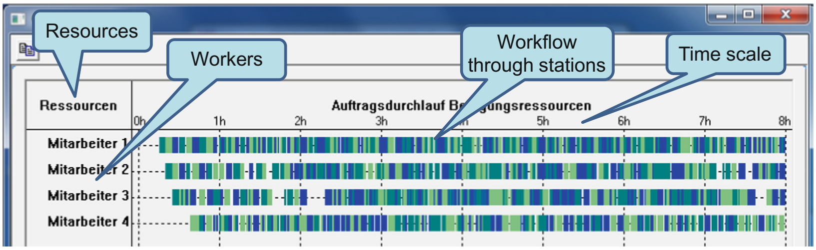

Fig. 2. Gantt chart representation of the initial situation (following [17], p. 146)

Table 1. Proceeds and utilization of the initial situation (cf. [17], p. 147)

Simulation run	*Proceeds in CU*	*Workload in %*				*Average*
		s=1	*s=2*	*s=3*	*s=3*	*s*
1	7.982	90,3	83,1	82,9	79,7	84,0
2	7.805	89,3	84,1	82,2	75,2	82,7
3	7.810	89,6	80,5	77,2	78,6	81,5
4	7.682	88,5	83,9	81,4	74,1	82,0
5	8.010	89,9	84,8	85,4	77,4	84,4
6	7.924	89,0	87,2	82,5	77,9	84,1
7	7.718	89,0	82,5	82,6	74,7	82,2
8	8.022	89,0	83,1	79,8	80,7	83,2
9	7.982	89,1	84,7	85,0	77,5	84,1
10	7.606	89,8	85,9	75,3	76,5	81,9
Average	7.854	89,4	84,0	81,4	77,2	83,0

by the developed control algorithm, whereby a re-assignment of disassembly operations to stations can be carried out if this is appropriate.

Thus, those disassembly operations are selected which promise the highest possible proceeds. Through a re-assignment of disassembly operations to stations in conjunction with the instruction which end-of-life product is to choose those alternatives that promise the highest proceeds, the following results can be obtained: The proceeds now achieve 8,411 CU. The difference between the busiest (91.6%) and least busy disassembly station (82.4%) stands at 9.2%, while the average workload is 87.2% (Fig. 3 and Table 2).

4.4 Conclusion of the Application Study

With the help of the application study performed here, it has been demonstrated that the disassembly processes can be improved with the help of the developed control procedure. Although the disassembly line is already highly utilized in the initial situation, as the static workload across all disassembly stations shows with an average of 83.0%, and relatively high disassembly proceeds, the system can still be improved. Through the use of the developed disassembly control procedure in the improvement solution, utilization of all disassembly stations can be further increased. The proceeds will improve by 557 CU or 7.1%.

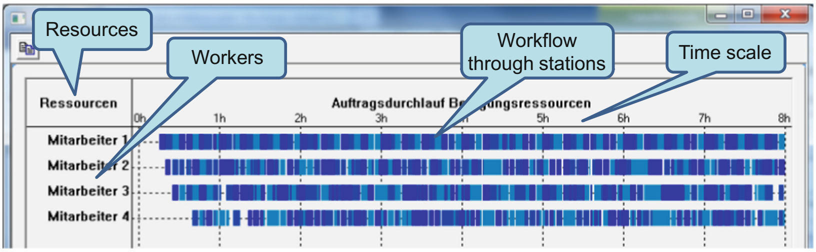

Fig. 3. Gantt chart illustration of the improvement solution (following [17], p. 151)

Table 2. Proceeds and utilization of the improvement solution (cf. [17], p. 151)

Simulation run	Proceeds in CU	Workload in % s=1	s=2	s=3	s=3	Average s
1	8.218	91,7	86,2	87,4	79,3	86,1
2	8.233	91,0	87,5	88,5	83,2	87,6
3	8.344	91,0	86,5	89,6	84,1	87,8
4	8.667	92,2	85,1	88,9	81,4	86,9
5	8.430	91,4	86,0	89,5	83,5	87,6
6	8.487	90,4	85,5	89,6	81,0	86,6
7	8.348	92,2	85,2	89,4	81,5	87,1
8	8.460	91,0	86,2	87,5	83,5	87,0
9	8.559	92,8	87,0	89,6	82,7	88,0
10	8.369	92,2	85,0	86,9	83,4	86,9
Average	8.411	91,6	86,0	88,7	82,4	87,2

Thus, the effectiveness of the disassembly control procedure is verified. In particular, the combination of the developed control measures can improve processes for division of labor-based disassembly systems.

5 Summary and Outlook

In this paper, a reactive control procedure has been developed that allows division of labor based disassembly systems to be controlled so that an existing order program can be as economically performed as possible. For this purpose, adequate disassembly-specific control measures have been developed and brought together in an overall concept. In addition, the effectiveness of the procedure has been demonstrated.

For further improvements of the developed control procedure, the control measures must be communicated to staff in an appropriate form. In order to respond to specific situations, interaction between staff and control management should be facilitated by means of staff communicating current disassembly difficulties or disturbances to a control management system (e.g. using an earlier approach suggested by Schiller [6], p. 231). Staff then receives new operating procedures for the purpose of an updated selection of the end-of-life products and their components to be disassembled, as well as an updated work plan.

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A Novel Knowledge Repository to Support Industrial Symbiosis

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Abstract. The development of tools and methods supporting the identification of Industrial Symbiosis opportunities is of utmost importance to unlock its full potential. Knowledge repositories have proven to be powerful tools in this sense, but often fail mainly due to poor contextualization of information and lack of general applicability (out of the boundaries of specific areas or projects). In this work, a novel approach to the design of knowledge repositories for Industrial Symbiosis is presented, based on the inclusion and categorization of tacit knowledge as well as on the combination of mimicking and input-output matching approaches. The results of a first usability test of the proposed tool are also illustrated.

Keywords: Industrial Symbiosis · Mimicking mechanism · Knowledge repository · Industrial synergies · Resource efficiency

1 Introduction

Industrial Symbiosis (IS) is nowadays one of the most prominent sub-disciplines of Industrial Ecology (IE), a discipline advancing sustainable industrial ecosystems through paradigms that support interactions and exchanges between industrial flows and their surrounding environment [1]. It is, even if still a relatively new field, a growingly accepted paradigm for processing waste into material, energy and water with benefits to participants measured by economic, environmental and social gains [2]. In practice, it means that manufacturers can make better use of all inputs to their processes through exchanges of waste, by-products and energy with other companies/sectors [3].

However, in spite of the potential benefits of IS, there is still an evident implementation gap, with practitioners failing to fully exploit its possibilities [4]. Part of this gap is certainly given by the high degree of characterization needed for the design of IS in different contexts, as well as by the huge number of factors influencing its development, such as technical, political, economic and financial, informational, organizational and motivational [5]. In addition, unlike commodities such as recycled metals, waste materials are typically nonstandard or highly variable in composition, thus the process of exchanging them can be more challenging [1].

It is well acknowledged in literature that IS opportunities identification can benefit from the creation of knowledge repositories [1, 6, 7]. Thus, over the last years, IS researchers and practitioners have made several efforts in order to create knowledge

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repositories for IS [6], and the present work builds on related literature to create a novel knowledge repository combining main pros and addressing main cons of existing ones.

The main research question addressed in this paper is therefore: *How to effectively design a knowledge repository to identify new ideas and opportunities for IS?* In the following paragraphs, a review of main approaches to the design of knowledge repositories to support IS opportunities identification will be presented, aimed at identifying strengths and weaknesses for each of them. Then, the design of a novel repository based on these premises is described, first of all defining the design process and then illustrating main outputs of its application. Finally, some planned future developments to improve the proposed repository will be discussed.

2 Literature Review

The development process for IS, as it is described in literature [6], usually starts with a first, fundamental phase in which opportunities for IS implementation are identified. Opportunities identification can occur in different ways: (i) the company can focus on a specific waste material and develop a new process to transform it into a by-product; (ii) the company can get in touch with neighboring companies and look for potential synergies (this approach is usually facilitated by a third party); or (iii) the company can learn from business cases in which similar companies were involved and replicate successful practices [6]. Especially considering the last two approaches, in which gathering and analyzing data from other companies is fundamental, several tools have been developed over the last years trying to facilitate opportunities identification and to partially fill the implementation gap. These tools are generally either based on workshops (as described for example in [8]), or on Information and Communication Technology [6, 7, 9]. Anyway, the effectiveness and general applicability of these tools is often still unclear [6], one of the main shortcomings being the fact that they do not address contextualization issues. The opportunities identification phase is in fact one of the most influenced by contextual factors and, being a very early one, can condition the whole development process. Thus, the creation of tools designed ad hoc to facilitate this stage is of utmost importance, since it can potentially enable and ease following phases, contributing to face the contextualization challenge. There are two main approaches usually followed to design knowledge repositories for IS: the first one is based on the mechanism of "relationship mimicking", while the other one is based on the mechanism of "input-output matching" [1, 6].

The "relationship mimicking" mechanism involves mimicking successful relationships employed by similar organizations. Triggering mimicking mechanisms by the means of knowledge repositories is a process that has proven to be positively practical and easy to implement [6]. In fact, this requires enabling information exchange by matching companies from similar industrial sectors, a process that is supported by existing standardized classifications for industry. These classifications, as for example the statistical classification of economic activities in the European Community [10], are already well known and widely used. A successful linkage can therefore be explicitly designated by two codes, one for each of the industries it connects [6].

The creation of such explicit linkages is not as easy in the "input-output matching" approach. This approach builds on the definition of available resources for one organization, and on the identification of complementary resource requirements for another organization [1]. It usually leads to the creation of new exchanges in a much more straightforward way compared to mimicking approach, as it directly links the demand and offer for a specific material. Nevertheless, it is generally successful only when applied to closed systems (one famous example of a closed system is Kalundborg, Denmark [11, 12]) and/or to facilitated systems, where synergies are established, by third parties among pre-selected industries, basing on their geographical proximity or on their existing relationship and mutual trust [1]. A knowledge repository designed with an input-output matching approach tends to fail when not strongly supported by waste management experts and when not applied to closed systems, mainly because the definition of a common and standard classification of waste is still a challenge. Nowadays, the development of open IS models enabling unrestricted and wider participation of partners as well as competitive terms in exchanging materials and energy is becoming more and more common, as it is considered to be consistent with the dynamic nature of IS networks [1]. Therefore, the input-output matching approach needs to be improved and potentially combined with the mimicking approach, creating a sort of new, hybrid approach, in order to still be considered effective.

Existing knowledge repositories for IS, both designed using a mimicking approach and an input-output matching approach, have two main limitations. The first one is that they are generally lacking tacit knowledge content and the second one is that they often only include synergies created within a specific project or in a specific geographical area, losing general and trans-contextual validity [6, 7, 13].

Tacit knowledge is the kind of knowledge residing within individuals or a company, difficult to express in written forms [14] (e.g. expertise and roles of people to involve in the IS development process, factors determining the success of IS implementation, effort needed to implement IS exchanges, etc.). It is opposite to explicit knowledge, which is defined as information that is easily communicated, codified, or centralized using tools such as statistics [6]. Tacit knowledge transfer offers tremendous opportunities to enable Industrial Symbiosis networks, as it specifically addresses contextualization challenges [15, 16]. Thus, it could help avoiding practitioners' biases towards their own expertise or particular industries they wish to serve, informing them about new and unexplored potential synergies as well as required associations, know-how, expertise and engineering solutions [1].

In the present work, the design of a knowledge repository based on the mimicking approach, but trying to integrate positive features of the input-output approach as well as a substantial tacit knowledge content, without losing simplicity in use and effectiveness is presented. This work represents the first step towards the creation of a repository of potential opportunities for new symbiotic exchanges.

3 Methodology for the Design of a New Knowledge Repository

A preliminary review of IS case studies presented in literature set the basis for the tacit and explicit knowledge to be included in the knowledge repository, taking into account main knowledge transfer needs highlighted from previous IS development experiences. The tacit knowledge content has then been classified, while the explicit knowledge content has been codified (mainly associating existing and widely adopted codifications to relevant pieces of information, i.e. industrial sector of companies taking part in symbiotic exchanges and materials exchanged) in order to improve the repository usability and to make the content easily accessible to final users. Thus, a first design of the repository's structure has been defined.

After that, the structure of the knowledge repository has been shown to a group of researchers and industrials already familiar with IS topics, ad their feedback has been used to consolidate it as well as to define potential use processes.

A further literature review has been performed and the knowledge repository has been populated with a set of 46 different case studies set in 16 countries across the world (28 in Europe, 12 in Asia, 4 in America and 2 in Australia), providing a wide overview of different contexts in which Industrial Symbiosis has emerged so far (426 symbiotic exchanges are described within the considered cases). It is important to mention that both scientific and non-scientific literature have been considered for database population. This has allowed taking into account also whitepapers and industrial presentations other than scientific papers, thus including in the knowledge repository also simple but effective forms of Industrial Symbiosis that are usually left out of academic research.

Eventually, data collected in four different industrial companies have been used to perform a first usability test of the knowledge repository, evaluating its ability to inform companies on potential IS opportunities.

4 Results

The main output of the design process illustrated in the previous paragraph is a knowledge repository structured in two different and connected sections: a library of case studies and an exchanges database.

Within the library of case studies, each case is described according to a precise structure: a brief narrative of the case description is followed by five sections gathering the related tacit knowledge content, which are the results of the tacit knowledge content classification. *Triggering and precondition* factors are identified to describe the main business challenge that was addressed (the starting point for the search of a solution) and the antecedents that made the symbiotic exchange feasible under the described business context. Antecedents are here intended with the same meaning as illustrated in [17], i.e. inputs to understand and analyze the dynamics of Industrial Symbiosis. The main *barriers* encountered in the specific Industrial Symbiosis implementation are described, as well as the *approach* used by the individuals/organizations involved in order to overcome those barriers. Then, the *discovery process* (the process initiated by the triggering factors and finalized by the realization of the symbiotic exchange) is explained, highlighting the main steps and efforts made by the involved individuals/organizations. This includes the description of role of facilitators, whenever applicable.

The description of the discovery process within the library of case studies is meant to help companies fully understand the activities necessary to deliver progress towards the IS vision, as it might not be so clear at this stage, resulting in failed or even dissuading implementation attempts.

Each case in the library is identified by a numerical ID, as well as each source (paper, whitepaper, industrial presentation, etc.) used for library population. A combination of these two numerical IDs plus an additional sequential number univocally identifies each synergy described in each case. This numerical identifiers allows to link the library of case studies to the database of exchanges. This database is a spreadsheet, mainly containing explicit knowledge content, in which each row corresponds to an exchange occurring between two different companies.

For each synergy, the industrial sector of the companies involved is identified using the NACE (Nomenclature générale des Activités économiques dans les Communautés Européennes) code [10], while the exchanged material is identified using the European Waste Classification (EWC) [18]. These two codification systems have been chosen due to their wide diffusion among companies, so as to improve the usability of the repository also for users with no or little background on IS topics, and also according to previous research results [1, 7]. The use of the NACE code specifically allows the triggering of mimicking mechanisms, as companies can search the database to find out what exchanges other companies from their own industrial sector have already implemented. The use of the EWC code is instead twofold: on the one hand, it contributes to supporting the triggering mechanism, as companies can search the database to find out what exchanges other companies have implemented with their own waste, while on the other hand it can be considered as a first step for input-output matching, as it suggests potential partners for each exchange.

Eventually, a description of the waste treatment is given wherever applicable, as well as some additional details regarding the synergy (final use of the exchanged flow, availability of flows' quantities and payment details in the original source, level of completion of the synergy).

5 First Validation

In order to perform a first usability test of the designed knowledge repository, two initial standard queries have been identified, representing two possible use processes of the library of case studies and exchanges database. Nevertheless, it is important to highlight that additional searches are enabled in both the library and the database, e.g. keyword searches, but have not been considered as standard queries for this first test phase due to their intrinsic variability and higher degree of customisation. They will, however, follow a similar logic as query type A and B (described in the followings).

The two standard queries defined for the usability test are:

- Standard query type A (in red in Fig. 1), looking for similar companies (same NACE code);
- Standard query type B (in green in Fig. 1), looking for exchanges of similar waste materials (same EWC code).

The last three steps of the two standard queries are identical (in blue in Fig. 1), as they are referred to the identification of the case studies within the library that corresponds to the exchanges in the waste database, and to the extraction of tacit knowledge contents.

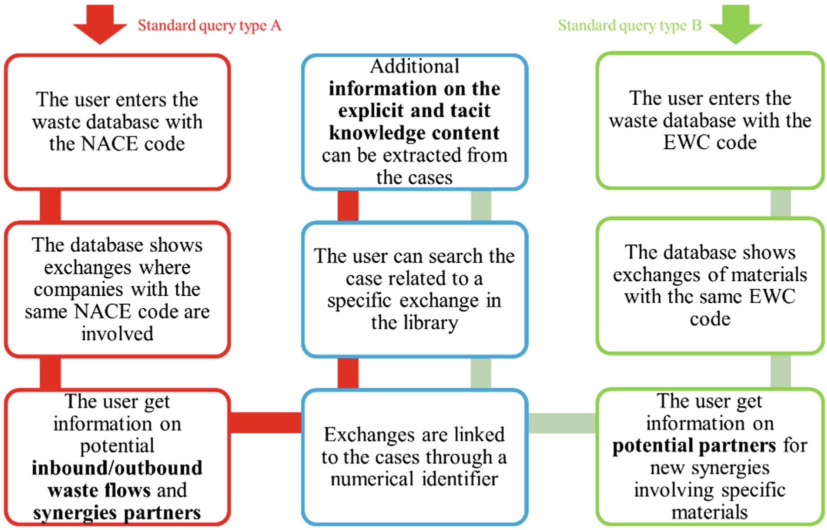

Fig. 1. Standard queries type A (in red) and type B (in green) (Color figure online)

The usability test has been conducted using NACE codes and EWC codes provided by four different companies from the process industry (two chemical companies, a metal parts and a plastic components producer). As a means of example, the following table provides some extracts of the results obtainable from one search using standard query A and from one search using standard query B. Due to confidentiality issues, data presented in the table do not belong to any of the four companies used for testing (Table 1).

The database provided examples of flows corresponding to the search criteria for 20% of the analysed codes. Multiple examples of flows have been found for single codes in several cases. The test resulted in the identification of 38 relevant flows, 19 related cases and 26 potential types of partners for exchanges.

Table 1. Example of results obtained using standard query A (in red) and B (in green).

Code used in the query	*ID of exchange identified in the database*	*NACE of companies involved in the exchange*	*Brief description of the exchange*	*ID of corresponding case in the library*	*Brief description of the case*
17,11 (NACE)	17,27,2	17,11 (donor); 20,15 (receiver)	A pulp producer sends ashes derived from a combustion process to a fertiliser's manufacturer that uses them as raw material.	17	Relvao industrial park, Portugal. The park has been created with the support of regional authorities. Symbiosis is a means to reduce environmental impact and increase competitiveness [19].
01 03 09 (EWC)	23,21,12	24,42 (donor) 23,51 (receiver)	An alumina refinery sends red muds to a cement producer.	23	Spontaneous synergy in the Gladstone industrial district in Australia. Symbiosis is a means to reduce environmental impact and face resource scarcity [20].

6 Conclusions

The novel knowledge repository psroposed in the present paper has been tested in four different cases and has proved to be a very promising starting point for the identification of IS opportunities. It enables mimicking and represents a good basis for input-output matching approaches, and its rich tacit knowledge content, referred to different contexts and projects all over the world ensure its effectiveness. In addition, the classification provided for the tacit knowledge content allows an easy and effective usability of the proposed tool.

The main shortcoming of the proposed repository, emerged during the usability test, is the use of the EWC classification, which is sometimes too general when it comes to the definition of produced substances and therefore limits the potential uses of the tool. In fact, it happens that substances that could be reused in different ways are considered altogether as a unique entity by EWC, and the naming of the wastes itself does not always allows a clear matching.

In addition, the number of cases analyzed is still not enough to ensure the general applicability of the repository.

Next steps defined for the improvement of the designed repository are first of all to further analyze and overcome main barriers and limitations of the current configuration of the knowledge repository, related to codification issues, searching modalities and general applicability, and then to make it publicly available online to enable peers and users review and to perform further usability tests.

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Ecological Footprint in the Cotton Supply Chain: The Consumers' View

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Abstract. The ecological footprint estimates the impact of individuals in nature as they maintain their lifestyle. It can be used as an indicator of environmental sustainability applied to individual lifestyles, regions, and nations. This study aimed to assess the ecological footprint and the awareness of sustainability of consumers based mostly on their choice of consumption of cotton clothing. The estimation was based on the answers to an online questionnaire containing questions related to the subject lifestyle. The ecological footprint was calculated, and the results were analyzed using data mining, considering the cross-validation using 10% of the samples to obtain a decision. The results show that the better the index of the ecological footprint, the greater the awareness of the issue by the consumer.

Keywords: Textile supply chain · Sustainability · Cotton clothing

1 Introduction

The environmental impacts caused by human activities and the level of consumption of natural and industrialized resources are environmental concerns amongst the countries, governments, academia, companies, and citizens. Climate change is a consequence of the consumer lifestyle, and it represents a threat to the natural environment [1, 2]. Carbon footprint assessment (CFA) is an important approach for the control and management of noxious gasses - NG [3]. Sustainability indicators have been the item of study in several areas, with the objective of operationalizing sustainable development [2]. It is necessary to monitor consumption of natural resources in the various segments of production that meet the human needs of survival, and thus presenting proposals that can absorb the impacts and residues generated by such consumption to evaluate sustainability information. The Ecological Footprint (EF) method [6] was developed to estimate how much of the material is being used and waste generated by individuals, cities, countries, and worldwide, which draws attention to the unsustainable lifestyle that has spread since technological advances accelerated the consumption of natural resources. The model was quickly applied worldwide as a tool to assess sustainable development [6]. The methodology can be used on several levels for organizations, individuals, families, regions, national and worldwide [7].

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Cotton is an agribusiness product, and it is accountable for increasing the impact of the pollution. In Brazil, agriculture is responsible for 33% of the total emissions in 2014, and part of it comes from cotton production [1]. However, consumers are not conscious that by wearing clothes made of cotton they are harming the environment. Cotton processing integrates the fashion chain, known as one of the most polluting supply chains [8]. Scientific studies are scarce in the areas of ecological footprint in textile chains, specifically the use of cotton to make yarns for making fabrics. This study aims to show the consumer's view on sustainability, having as a parameter the Ecological Footprint, adapted for the consumption of cotton clothes.

2 Literature Review

Global climate change has been discussed lately in worldwide meetings since the Brundtland Report by the World Commission on Environment and Development (WCED) in 1987. In that meeting it was defined the expression 'sustainable development,' summarized as the capacity to use natural resources to the extent in which nature can recompose itself, making the planet habitable to the next generations [9]. In 1992, with the achievement of Eco-92 in Brazil, the governments of all parts of the world committed themselves to reduce the emission of noxious gasses (NG), and consequently the carbon footprint.

Agriculture, which includes cotton production, is one of the factors that elevate NG emissions. Brazil is self-sufficient in the manufacture of cotton, which is the fundamental raw material for the textile chain, with revenues of near US$ 4 billion in 2016, with the projection of producing 1,443.1 thousand tons in the 2016/2017 harvests [7]. Brazil is the world fifth largest producer of fiber, following India, China, USA, and Pakistan. The country also represents the last complete textile chain of the West, from fiber production and cotton planting to fashion shows, and going through spinning, weaving, processing, and retailing [10]. In 2016, the textile and confection production chain earned US$ 31 billion, which represented 8% of Brazilian GDP, with around 32 thousand formal companies. Textile production stood at 2 million tons, ranking fifth amongst world producers. The Brazilian garment industry, the fourth in the world production, produced about 7 billion pieces, including clothing, accessories, bedding table and bath linen. It represents 17% of jobs with 1.5 million direct employees, and nearly 8 million indirect employees, being the second largest employer in the manufacturing industry. Brazil is the world second largest producer and third largest consumer of denim [10].

The sector seeks differentiated products that use less non-renewable resources such as water and reduce energy consumption and chemical aggression in the handling of goods [1, 11]. The consumption of abundant water and effluents are a major problem in the sector. Effluent components use the common chemical dyes found in the textile industry [2], during the production phases iron, pre-ironing, bleaching, dyeing, stamping, washing and softening.

The developers of the ecological footprint concept in the early 1990s [6] at the University of British Columbia, Canada, presented the footprint as the land surface area needed to maintain natural resource consumption levels and to house the residues of this consumption. In the next step, a tool was built up to spread the concept worldwide, and individuals, companies, and organizations can calculate the carbon footprint. Each inhabitant of the planet, on average, has a carbon footprint of four tons per year [11]. In the United States, the production is 20 tons per person per year. In Europe, the UK has 20 tons and France, six. Governments and businesses are also aware of the world's carbon footprints [12].

The Global Footprint Network points to the availability of 1.8 hectares of productive land for each inhabitant, but the average has been on 2.2 ha, which makes it impossible for the land to replenish what has been consumed over a year. That points to Brazil in 59th place in the list of countries that consume more natural resources than the planet is capable of replenishing. The Brazilian ecological footprint presents the index of 3.1 ecological footprints per capita (GHA, global hectares) in 2012 [13]. The emission of greenhouse gasses (mainly carbon dioxide - CO_2) into the atmosphere is measured for obtaining the Ecological Footprint. It is also evaluated the presence of pollutants in the air, water, and soil.

Countries have responded to the Global Footprint effort. Switzerland has adopted the indicator as the basis for sustainability; Some European countries, such as Germany, Austria, France, Finland, Belgium, Scotland, and Wales, are reviewing their environmental accounting and presenting footprint initiatives. Canada, Ecuador and the United Arab Emirates work with the entity to reach a common denominator [9, 13]. Amongst the factors related to consumers' daily habits, the carbon footprint measurement analyzes various issues. They also include age, address location and size of household, monthly energy costs (water, light, gas), the quantity of household trash and their recycling habits, buying habits, what kind of food they consume and how they are produced, whether they travel a lot, and what modes of transportation they favor.

3 Materials and Methods

The Global Footprint Network has created a tool for citizens to measure their indicator, which has been used globally. In it, data on habits such as meat consumption, light spending at home, distance traveled by car per day, and some plane trips in the year, among others, is collected and can be performed on various websites [14]. In Brazil, the assessment can be made answering an online questionnaire.

Sustainability assessment tools still require adaptations for the various business chains. In this first phase of the methodology, a standard questionnaire was developed including questions about the consumption of clothes, and also questions related to the level of knowledge about sustainability by the consumer. Questions were designed aiming to evaluate the Ecological Footprint (EF) [14].

The sample was chosen based on the size of the Brazilian population (nearly 200 million inhabitants). The sampling error adopted was 10%, and the estimated sample size was 97 participants applying Eq. 1 [15] that was rounded to a minimum of 100 participants.

$$n = \frac{N Z^2 p(1-p)}{(N-1)\varepsilon^2 + Z^2 p(1-p)} \quad (1)$$

n = sample; N = population of each region; Z = confidence interval (95%); p = homogeneity degree (split 50/50); ε = sample error (10%).

The online questionnaire, developed using the Google Docs was distributed using the internet tools (e-mails and social media networks) obtained 209 answers, and all were employed in the analysis.

To determine the carbon footprint of each participant the scores of each subject was calculated. Each question had 2 to 5 alternatives, and each alternative was given value as described in Table 1. Subjects with a total of points from 50 to 70 had a good footprint. A total of points from 35 to 49 had a moderate footprint, and a total of points less than 35 had a bad footprint. For the analysis, the data were processed in the machine learning software WEKA® (3.5), using the algorithm J48, considering cross-validation with samples of 10% (10-fold cross-validation).

Table 1. Weight attribution for each alternative and the question related to the carbon footprint.

Alternatives	Questions													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	5	5	5	5	5	5	5	1	1	1	5	1	5	4
B	5	5	1	4	4	2	4	4	2	5	4	3	4	0
C	4	4	–	3	2	0	2	5	4	5	2	5	3	5
D	1	3	–	1	1	–	1	5	5	2	1	–	1	–
E	0	1	–	–	0	–	–	–	–	–	–	–	0	–

Source: [16].

A total of 14 questions is related to the lifestyle of the subjects, with emphasis on means of transportation, diet, energy consumption and production and disposal of garbage. The results present an idea of the individual's lifestyle, which was submitted to the table of weights available in [16] (see Table 1).

4 Results and Discussion

Table 2 presents the profile of the participants in the research. The majority of the subjects are between 26 and 60 years of age, female, with a minimum of college education and monthly income between US$ 550.00 and US$ 2,750.00. Although the questionnaire was largely distributed in the social media 95% was answered by subjects living in São Paulo State, which is the wealthier and most developed state of the federation, establishing a limitation to the research.

Amongst the answers, 74% of respondents believe that it is important to buy products from companies that are sustainable and 21% believe that it is indifferent to choose companies for this purpose. Almost 60% of the respondents could not say if the company from which they made their purchase is sustainable, and 30% stated that the

Table 2. Summarized description of the profile of the subjects who responded to the questionnaire

Age	25 (6.1%)	26–40 (43.3%)	41–60 (44.3%)	>60 (6.1%)	
Gender	Male (27.4%)	Female (72.6%)			
Education	Primary education (0.9%)	Secondary education (9.4%)	High educ. incomplete (8.0%)	High educ. incomplete (35.8%)	Post-grad. (45.8%)
Monthly income	Up to US$ 550.00 (14.2%)	From US$ 550.01 to US$ 1,162.50 (34.4%)	From US$ 1,162.51 to US$ 2,750.00 (34.0%)	From US$ 2,750.01 to US$ 5,500.00 (13.7%)	$\geq$ US$ 5.500.01 (3.8%)

business is not sustainable. More than half (56.6%) of the participants were not able to answer if the garment they wear contributed to the pollution or the sustainability of the planet. More than a third (33.6%) realizes that clothing contributes to pollution and 10.1% for the sustainability of the world. Near 70% of the respondents do not know how the industrial production of fabrics for the manufacture of clothes is done, 23.9% know, and they care about it. The total 5.6% does not know or do not care about this information. The values used for the income were adopted by the Brazilian criteria of socioeconomics scale [17]. The values were converted from Real to US Dollar (conversion rate = R$ 3.20 to US$ 1.00). Analyzing the data we found that these parameters, however, were not associated with the individual's ecological footprint, since they were not selected by the J48 algorithm to determine the model (see Fig. 1).

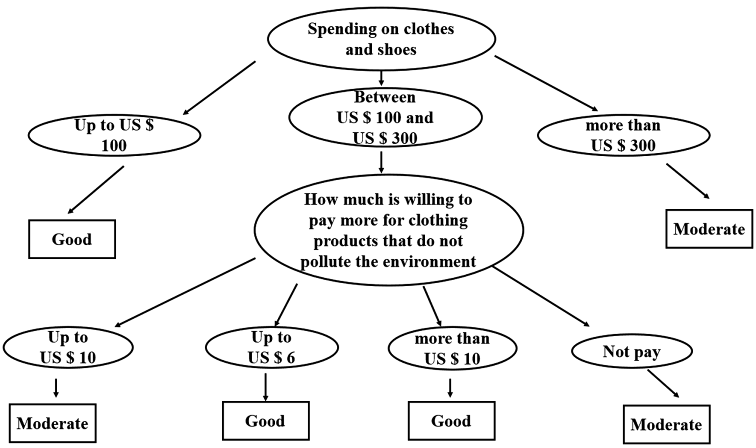

Fig. 1. Decision tree for the ecological footprint of the obtained answers.

Figure 1 presents the decision tree for the ecological footprint with 70.75% of accuracy. It is observed that in the present study, the parameter that is most related to the ecological footprint of the individual was the expenditure on clothes and shoes, followed by how much the individual is willing to pay for garments that pollute less the environment. According to the generated decision tree, persons who have bought clothes and shoes up to US$ 100.00 in the year are individuals who present a good footprint. The other hand, subjects who have spent over US$ 300.00 annually have a moderate footprint. When evaluating the people who spent between US$ 100.00 and US$ 300.00, we need to search for how much they are willing to pay extra for clothing products that do not pollute the environment. Those who are not prepared to pay anything or pay up to US$ 3.00 in the price of goods present a moderate footprint. Those willing to pay up to US$ 6.00 or US$ 10.00 or more show a good footprint.

The findings from the questionnaire were limited to São Paulo state population (95% of the responses were from São Paulo residents) characteristics, and it does not represent Brazilian society. The total answers were from women with a high degree of education, which also adds a limitation to the results.

In the Brazilian textile sector, suppliers seek to use some environmental indicators as a parameter in their cleaner production [10] that might be used to evaluate the consumer perception on this matter. The ecological footprint was employed by [18] to assess the environmental impact in a garment industry, dividing the data into three broad categories energy, resources, and waste. The results showed that the main contribution to the reduction of the footprint was the class of resources due to the high value associated with the cloth. The energy consumed was the second and the waste, the third. After this analysis, the final results were divided by the production rates for comparison by other areas. In the present study, it was found the same trend of the consumer worries regarding the energy and wastes.

When studying the Chinese textile chain [19] used the carbon footprint calculation system in a manufacturer of pure cotton shirts and found the average throughout the life cycle of the product in the country. According to the authors, the carbon footprint of global production, including agriculture and industry, accounts for more than 90% of the world's total carbon footprint, 96% of which is indirectly absorbed by the use of energy and materials. Thus, tissue production and its consumption refer to a highly polluting sector. Consumers need to be concerned with reducing the carbon footprint and thus contribute to the planet's sustainability. The carbon emissions are directly linked to personal habits (more walking or using public transportation than driving cars, saving energy resources, investing in an alternative source of energy among others) [12]. When comparing the data in the current study, it was observed that the consumer's lifestyle directly influence the ecological footprint, even when the consumer does not present the related consciousness.

Measurement has been applied to assess the impact of individual lifestyles, regions, nations and even worldwide on the planet's sustainability. A report with ecological data Footprints is annually available [11]. Other studies have been carried out for the EF of regions and cities all over the world, such as [20], who calculated the footprint in the town of Rio Claro, Brazil. Other authors calculated EF from cities, for instance Barcelona [21]. The continuation of the present study will be the calculation of the ecological footprint in the whole textile supply chain.

5 Final Remarks

Cotton production and the textile manufacturing process is one of the most polluting supply chains. The present study is the first initiative to assess the ecological footprint in the cotton chain and the Brazilian textile industry. The approach adopted in the research was to understand the perception of the consumer about sustainability in this cotton supply chain. One of the findings was that about 60% did not know if the supplier of the clothes they wear is sustainable. The same index was repeated regarding the issue on the clothes contributing to the pollution or for the sustainability of the planet.

It was also observed that the better the index of the ecological footprint, the more awareness for the subject the researched individual demonstrates since they have a willingness to pay more to get products that are less aggressive to the environment.

Although there are already manufacturing processes and ecologically correct raw materials (sustainable fibers, such as organic and colored cotton), awareness about the subject is still small. A detected limitation of the present study was that more than 70% of the answers were provided by women.

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Green Distribution – A Comparative Study of Sea and Road Transport Modes for a Norwegian Manufacturing Company

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Abstract. This paper presents a case study comparing sea and road transport modes for a Norwegian producer of plastic pipes for the construction industry. The study is based on three cases in which CO_2e emissions and transport costs were calculated and compared. The main research problem was to analyze whether sea transport is more environmentally friendly than road transport in terms of emissions of greenhouse gases (GHG) and cost-effectiveness. The results from the three analyzed cases show that sea transport is not always the most environmentally friendly and cost-effective mode. We suggest that in order to evaluate the environmental impact and cost-effectiveness of sea transport as an alternative to road transport, such factors as transport distances, load weight/volume ratios, ship load factors, number of port calls, ship sizes, and ship fuel types for each specific case need to be analyzed.

Keywords: SCM · Distribution · Sustainability

1 Introduction

The global economic growth in the last century has led to huge increases in the consumption of goods. However, the production, transportation, storage, and consumption of these goods have created environmental problems. Global warming is now a major environmental concern and there is consensus among most climate scientists that this is mainly caused by large-scale emissions of GHG [1].

According to Crum et al. [2], supply chain managers are in an advantageous position to impact environmental and social performance, both positively and negatively, through such means as supplier selection and supplier development, modal and carrier selection, vehicle routing, location decisions, and packaging choices. According to Hjelle [3], the issue of global warming receives wide attention on the global political agenda, mainly related to direct emissions of GHG from vessels and vehicles, but also to emissions related to the manufacturing of these means of transport.

This paper is a part of an ongoing research project called Manufacturing Networks 4.0, conducted by Molde University College, NTNU, SINTEF and Møreforsking Molde, along with four industrial partners. One of the industrial partners was interested in analyzing whether changing from road to sea transport mode would reduce GHG emissions and simultaneously reduce its distribution costs. The case company is an

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international manufacturer of plastic pipes and fittings. The cases presented in this paper are related to delivery of pipes to road construction projects in Norway. Hjelle [3] pointed out that the efficiency of short sea shipping in a setting with small consignments and frequent port calls needs to be demonstrated relative to road transport alternatives.

The purpose of this study was to find out whether a manufacturer can reduce GHG emissions and transport costs by switching from road to sea transport.

2 Theoretical Background

Environmental issues related to road and sea transport are traditionally divided into environmental hazards that have local, regional, or global impacts [4]. Locally, the most severe effects are related to poor air quality from emissions of SO_2, NO_X, and particles. At the regional level, the concerns are emissions of SO_2 and NO_X, oil spills, and disposal of waste products such as ballast water. On the global scale, the issue of global warming has received the greatest attention, mainly related to emissions of GHG from vessels and vehicles [5]. International shipping contributes approximately 2.4% of global GHG emissions and this share is expected to increase in the future [6].

GHG emissions are defined as the total mass of a GHG released to the atmosphere over a specified period of time. GHG include such gases as carbon dioxide (CO_2), methane (CH_4), and nitrous oxides (NO_x). Each type of GHG has a different global warming potential and GHG emissions are usually reported in carbon dioxide equivalents (CO_2e). CO_2e is a unit used for comparing the radiative forcing of a GHG to that of carbon dioxide [4].

The CO_2e emissions can be calculated based on fuel consumption. The emission factors for different fuel types are presented in Table 1 [7, 8].

Table 1. CO_2e emission factors

Fuel type	Density (kg/l)	kg CO_2e/kg	kg CO_2e/l
Diesel	0.832	3.21	2.67
Marine diesel oil	0.9	3.24	2.92
Marine gas oil	0.89	3.24	2.88
Liquefied natural gas	0.42	2.83	1.18

Several factors affect the performance of sea and road transport mode with regard to fuel consumption. According to Hjelle [5], key performance indicators for sea transport are vessel types and operating speed, load factors, fuel, and engine types. In road transport, such factors as operating speed, road gradient, congestion, driver behavior, and vehicle characteristics affect the fuel consumption and GHG emissions [9].

The globalization of trade has resulted in the creation of worldwide shipping networks that make use of a limited number of large ports. This concentration of flows has produced a division between deep-sea shipping (DSS) and short-sea shipping (SSS) [10]. SSS is typically defined as the movement of cargo and passengers by sea between ports that does not involve an ocean crossing [11]. According to Hjelle [3], deep-sea and bulk operations are superior to other transport modes in terms of GHG emissions, while the superiority of SSS needs to be demonstrated relative to road transport alternatives.

3 Research Methodology

This paper presents a case study comparing sea and road transport modes for distribution of plastic pipes for road construction projects in Norway. The main focus has been to calculate GHG emissions and distribution costs for three cases. To collect the data needed for our analysis, such as price, fuel consumption, and number of port calls, we contacted a shipping agent, which provided us with information from three ship-owners.

In each of the cases, the calculations were based on the real-world data provided by the case company, ship owners, and shipping agents. GHG emissions were calculated using a method based on the European standard [7].

4 Case Study Analysis

4.1 Case Description

The case company, a manufacturer of plastic pipes, was interested in identifying whether it could reduce its GHG emissions and transportation costs by switching from road transport to sea transport.

In this context the sea and road transport costs and GHG emissions on three specific cases were calculated. Case 1 is a delivery to a road construction project in the North of Norway (Tromsø), Case 2 is a delivery to a project in the South-East of Norway (Fredrikstad), and Case 3 is a delivery to a project on the West coast of Norway (Haugesund).

The road mode includes transportation from the factory directly to the construction site. The sea mode includes transportation from the port closest to the factory to the port closest to the road construction site, as well as transportation by truck from the factory to the port of origin and from the destination port to the road construction site, assumed to be 10 km each way.

Table 2 shows the approximate distances for both sea and road transport modes for the three cases.

Table 2. Approximate transport distances from the factory to destination (km)

	Sea	Road
Case 1a, b – Tromsø	977	1272
Case 2 – Fredrikstad	1064	610
Case 3 – Haugesund	574	760

According to CEN [7], the CO_2 emissions from different fuel types are based on the fuel consumption. The trucks in road transport mode use diesel fuel, which has an emission factor of 3.21 kg CO_2e per kg fuel used. In our study, in sea transport mode, three types of fuel are used: marine diesel oil (MDO), marine gas oil (MGO), and liquefied natural gas (LNG). The fuels have different densities, but the emission factor for MDO and MGO is 3.24 kg CO_2e per kg fuel used, while for LNG the emission factor is 2.83 kg CO_2e per kg fuel used.

Plastic pipes have a high volume/weight ratio. Several methods can be used to calculate the share of GHG emissions that are caused by transportation of a specific load (plastic pipes in our case), which utilizes only a part of the ship's capacity. One of the methods is based on the ratio between the weight of the transported goods and the dead weight tonnage of the ship. However, in our case, because of large volume and relatively light weight of plastic pipes we chose to base the calculations on the ratio between the volume of the transported goods and the total utilized load capacity of the ship.

Cargo ships usually have a load factor of 50–70% [3, 12]. The load factor will have a significant impact on the final result of the CO_2e emissions that a specific load accounts for.

Fuel Consumption
The ships used in our study vary in terms of their size, fuel type, and load capacity. All of these factors influence actual fuel consumption.

The estimated fuel consumption in our cases is provided by the ship-owners and relates to a "normal" load for the ship. In Case 1, we look at two alternatives: transportation by a MDO-fueled ship and transportation by a LNG-fueled ship. In this case, for a direct route from Surnadal to Tromsø, ca. 11,700 kg of MDO will be used, while MDO consumption for the same route with 15–20 port calls is ca. 18,000 kg. In the other alternative, a LNG-fueled ship will use 40,800 kg of LNG from Surnadal to Tromsø with several port calls. In Case 2, the estimated fuel consumption for a route from Surnadal to Fredrikstad is ca. 13,350 kg of MGO. In Case 3, the estimated fuel consumption for a route from Surnadal to Haugesund is 9000 kg MGO.

For the road transport mode, we have calculated three different alternatives. The actual truck fuel consumption will vary, based on the weight of the cargo, the geography, driver behavior, etc. According to the case company's transport provider, the average fuel consumption is 0.45 L of diesel per kilometer. To be able to see the effects of these variations we have also calculated the GHG emissions based on an average consumption of 0.4 and 0.5 L of diesel per kilometer.

Load Factor
Load factors have a large impact when calculating GHG emissions in sea transport. A number of sources show varying load factors for short-sea shipping in Norway. A study by Hjelle [3] shows that there is a large difference in load factors between southbound and northbound transport routes in Norway. Southbound routes had a load factor of 66%, while northbound routes had a load factor of 47%. Oterhals et al. [12] found that an average load factor for ships operating on the Norwegian coast was 67%.

4.2 Results of the Analysis

Because of the variation in load factors, we chose to analyze the influence that different load factors (namely, 50, 60, and 70%) had on the GHG emissions a company will need to "pay" for. We also looked at different values for average fuel consumption for the road transport mode. The results of this analysis are presented in Table 3.

Table 3. Influence of different load factors on GHG emissions that transport of different volumes of plastic pipes accounts for

	Sea transport mode GHG emissions, kg CO_2e			Road transport mode GHG emissions, kg CO_2e		
	LF 50%	LF 60%	LF 70%	FC 0.4 l/km	FC 0.45 l/km	FC 0.5 l/km
Case 1a, Tromsø (MDO), 2253 m^3	45,913	38,261	32,795	33,972	38,218	42,464
Case 1b, Tromsø (LNG), 2253 m^3	32,068	26,723	22,906	33,972	38,218	42,464
Case 2, Fredrikstad (MGO), 1366 m^3	19,700	16,417	14,072	16,291	18,328	20,364
Case 3, Haugesund (MGO), 2253 m^3	17,037	14,197	12,169	20,297	22,835	25,372

Legend: LF – load factor, FC – fuel consumption.

Table 4 shows the results of the cost and GHG emissions calculations for the three cases. Case 1a (MDO) shows almost equal GHG emissions for sea and road transport modes, while the sea transport mode is ca. 30% cheaper than the road transport mode. In Case 1b (LNG) the GHG emissions are ca. 30% lower for sea transport mode than for the road transport mode, and at the same time sea transport mode is ca. 22% cheaper than the road mode. Case 2 shows approximately 10% lower GHG emissions for sea transport mode compared to the road transport mode, but the cost of sea transport mode is significantly higher (ca. 76%) than the road mode. The third case shows substantially lower GHG emissions (almost 40%) for the sea transport mode compared to the road transport mode, while the costs are only slightly (ca. 6%) higher for sea transport mode than for the road mode.

Table 4. Sea transport GHG emissions and costs as a percentage of road transport GHG emissions and costs on respective routes (LF 60%, FC 0.45 l/km)

	GHG emissions	Transport costs
Case 1a – Tromsø (MDO)	100.1%	69.6%
Case 1b – Tromsø (LNG)	69.9%	77.7%
Case 2 – Fredrikstad (MGO)	89.6%	176.4%
Case 3 – Haugesund (MGO)	62.2%	105.7%

5 Discussion

As this study is based only on three cases, its results are not generalizable. However, the findings create a background for discussion around the efficiency of sea and road transport modes in terms of GHG emissions and distribution costs.

Several sources present sea transport as a “by default” greener alternative in terms of emissions of GHG compared to road transport [5]. However, the results of the study presented in this paper show that this is not always correct when different factors are taken into consideration. Below we provide a discussion about the influence of such factors as number of port calls and load factors on GHG emissions and costs connected to transport of loads on relatively short distances. In addition, such factors as ship size and fuel type also influence the level of GHG emissions in each specific case. For instance, according to Hjelle [5], larger ships are more fuel efficient than smaller ones. According to a study by Burel et al. [13] conducted for a 33,000 DWT tanker ship, usage of LNG leads to a 35% reduction of operational costs and a 25% reduction of CO_2 emissions compared to usage of heavy fuel oil.

Port Calls

An example from Case 1a shows that the fuel consumption for a direct route between the factory and Tromsø is 13,000 kg MDO; however, for a more realistic route with 15–20 stops, the estimated fuel consumption is 18,000 kg MDO. Because the ship in this case is relatively small, the GHG emissions the case company accounts for would be lower if the company chartered the whole ship and shipped its goods directly. Although many ships run on regular routes up and down the coast, many ships make additional calls to other ports, and several ships only make port calls if they are notified of available goods.

Because of these variations, it can be difficult for companies to choose the “greenest” transport alternative.

Load Factors

Several sources show that load factors in short-sea shipping in Norway vary from 50 to 70%. The actual load factors are very important for concluding whether the sea transport mode is “greener” than road transport, as shown in Table 4. The achieved load factors will vary between northbound and southbound routes, between ship-owners, and will depend on the origin and destination of the transported goods.

The results of the present study show that there is no simple answer to the question of whether sea or road transport is more cost-efficient and environmentally friendly over relatively short distances. In order to determine this, each specific case has to be analyzed by comparing the alternatives while considering such factors as transport distance, number of stops, weight/volume ratio of load, load factors, fuel types, and ship sizes.

6 Conclusion

This paper has presented an analysis of GHG emissions and costs connected to distribution of plastic pipes by sea and road transport modes in Norway. The objective of the study has been to find out whether sea transport is more environmentally friendly in terms of GHG emissions and more cost-efficient than road transport, based on three specific cases. In each case, the calculations were based on the real-world data provided by the case company, ship-owners, and shipping agents. The results from the study show that the widespread opinion that sea transport is "greener" than road transport is not always correct when considering transportation of loads to relatively short distances. For example, loads have different weight/volume ratios; ships on different routes have different average load factors and use different types of fuels; road distances can be longer or shorter than sea distances in each specific case; and ships often have different number of stops on each route. All of these factors need to be taken into consideration in order to create a more realistic picture of which transport mode is cheaper and more environmentally friendly for each specific case.

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From SCM to Eco-Industrial Park Management: Modelling Eco-Industrial Park's Symbiosis with the SCOR Model

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Abstract. From a business perspective, initiatives are undertaken at both inter-company level and intra-company level to implement the concept of sustainable development. At inter-company level, Industrial Ecology uses natural ecosystems as analogies to design sustainable industrial systems such as Eco-Industrial Parks (EIPs). Similarly to a Supply Chain (SC), an EIP is a community of independent businesses that cooperate with each other to efficiently share resources (materials, resources and information). However, if the SC cooperation is focused on product manufacturing, the EIP cooperation intends to reap economic gains, improvements in environmental quality and equitable enhancement of human resources that would not have been achievable individually. In the extensive and multidisciplinary body of literature studying EIP, the lack of a framework to evaluate the performance and benefits of an EIP is repeatedly discussed. Having observed similarities between SCs and EIPs, the use of Supply Chain Management tools for the description of synergies among an EIP is motivated. A model inherited from SCOR model is proposed to map this symbiosis and is demonstrated in a case study. Even if EIPs and SCs do not share the same goals, we will conclude with the relevance of using the SCOR model for EIP management.

Keywords: Supply Chain Management · Eco-Industrial Park · SCOR model · Industrial Ecology · Industrial Symbiosis

1 Introduction

With the growing presence of environment and energy security concerns, it has become clear that human activities and business activities in particular are having a preoccupying negative impact on our planet. Rising population sizes and increasing urbanisation call for an efficient use of resources embodied by

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the concept of sustainability as introduced in the Brundtland Report, by the United Nations World Commission on Environment and Development in 1987 [28]. From a business perspective, initiatives dealing with sustainability are initiated at both inter-company level and intra-company level, those initiatives are regrouped within the spectrum of 'Eco-Industrial Development'. At inter-company level, 'Industrial Ecology', a subset of Eco-Industrial Development, uses natural ecosystems as metaphors to design sustainable industrial systems [15]. Industrial Ecology aims to transform traditional linear industrial ecosystems into cyclic, or quasi cyclic, ecosystems (where the output of a process becomes the input of another one). This instrument of Industrial Ecology is called 'Industrial Symbiosis'.

An Eco-Industrial Park (EIP) is a type of industrial or business park implementing a long term Industrial Ecology strategy through, among other initiatives, Industrial Symbiosis. The most famous definition of an EIP was proposed by the U.S. President's Council on Sustainable Development in the mid-1990s: "*a community of businesses that cooperate with each other and with the local community to efficiently share resources (information, materials, energy, infrastructure and natural habitat), leading to economic gains, improvements in environmental quality and equitable enhancement of human resources for businesses and the local community*" [25]. An extensive body of literature is available on the study of EIPs and, more generally, Industrial Ecology. A number of authors highlight the lack of a robust framework to evaluate the performance and benefits of an EIP and to support its sustainable development [7,24,26]. Indeed, it is a rather complex task to monitor an EIP's performance over time. A multidisciplinary and international community has been working on this topic over the last decades. As a way to contribute to this topic, we suggest the use of endorsed industrial practices and tools.

In parallel, since the 1980s, a lot of work has been done in the field of Supply Chain Management (SCM). The Supply Chain (SC) is also an inter-company organisation model that integrates increasingly sustainable development purposes. It is defined as *the life cycle processes comprising physical, information, financial and knowledge flows whose purpose is to satisfy end-user requirements with products and services from multiples liked supplies* [3]. Managing the Supply Chain leads to various contributions in terms of its design, scheduling, planning, performance evaluation, and operation of its processes for the satisfaction of the final customers [27].

As we can see from their definitions and management objectives, EIPs and SCs present some similarities: they are both communities where businesses collaborate to reach a common goal. Both definitions introduce the notions of physical and information exchanges: *shared resources* for an EIP and *flows* for a SC. Among its various goals, SCM aims to measure and improve the performance of the global SC, objectives that are also shared by EIP management. From these observations, the use of SCM tools for EIP management is proposed.

The objective of this prospective article tackles the first step of EIP management which is the description of its resource sharing with a SCM tool that addresses inter-company flows modelling, namely the SCOR model. This work is encompassed in a much larger task: the implementation of a performance evaluation framework for the management and development of EIPs.

This article is structured as follows. First, we introduce preliminary concepts supporting this article, showing links between EIP and SC. Then we present the use of the SCOR model as a management framework for EIPs through a case study on one of the most famous EIPs: Kalundborg in Denmark. Finally, we finish this article with concluding remarks and directions for future work.

2 Positionning of Eco-Industrial Parks and Supply Chains

2.1 Eco-Industrial Park as an Application of Industrial Ecology

The Eco-Industrial Park (EIP) paradigm relies on a very rational and intuitive idea: Industrial Ecology. Industrial Ecology, introduced by Frosch and Gallopoulos in 1989 [15], is a systemic approach that studies materials and energy flows. Jelinski proposed three development models for Industrial Ecology, starting from the linear and immature ecosystem (Type I) that is unsustainable to the semi-matured ecosystem (Type II) through to a mature materially closed ecosystem that is ultimately sustainable (Type III) [1,18]. These three development models are illustrated in Fig. 1. As we mentioned before, Industrial Ecology means to transform traditional type I industrial systems into type III, or at least type II, systems [21]. This concept, also called 'Industrial Symbiosis' uses natural ecosystems as analogies to design sustainable industrial systems.

A large body of symbioses has been documented and studied, such as Kalundborg EIP (further described in Sect. 4); the Austrian province of Styria; the Jyväskylä region in Finland [19]; the petrochemical complex of Sarnia [10]; and the Burnside Cleaner Production Centre in Canada [8]. These prosperous symbioses, and other varyingly successful attempts to realize Industrial Ecology, resulted in different criteria defining an Eco-Industrial Development. Chertow [6] proposed the following taxonomy of different material exchange types:

Material exchanges taxonomy from Chertow [6]:

- Type 1: through waste exchanges
- Type 2: within a facility, firm, or organizations
- Type 3: among firms co-located in a defined eco-industrial park
- Type 4: among local firms that are not co-located
- Type 5: among firms organized "virtually" across a broader region

Types 3–5 offer approaches that can readily be identified as industrial symbioses and this paper will be restricted to EIP, precisely corresponding to Type

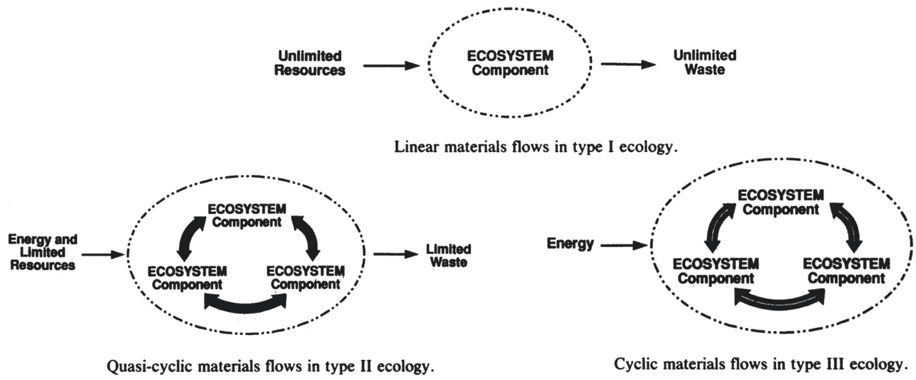

Fig. 1. The three types of ecology, from linear to cyclic industrial systems [18]

3. The symbiosis in an EIP is built around two main types of collaborations: substitution synergies (bilateral materials or energy exchanges) and mutualisation synergies (pooling of resources between two or more companies)

Recent work on the concept of EIP deals with the evaluation of its performance through the definition of new indices [23,26] and the use of multi-criteria decision making approaches [29,30]. Researchers in Industrial Ecology are increasingly moving away from the natural ecosystem metaphor towards more complex, dynamic and systemic approaches [11,14]. Indeed, the design of industrial symbiosis was investigated through optimisation methods [5], the use of system engineering [16] or the use of agent-based modelling [9].

2.2 Supply Chains and Supply Chain Management

The network of relationships between companies from the first supplier to the final customer is called Supply-Chain (SC). As we have mentioned before and according to Huan et al. [17], SCM research can be classified into three categories: Operational, Design and Strategic. Operational SCM is concerned with the daily operations along the main functions of the SC; Design SCM focuses on the location of decision spots along the SC and the achievement of the objectives of the chain; and Strategic SCM intends to understand the dynamics of a supply chain and development of objectives for the whole chain in order to help decision-makers in the evaluation of alternative SC configurations and partnerships. The SCOR model has emerged as a standard tool in Strategic SCM.

Another area in SCM that is close to EIP management and that has gained a lot of interest in the last two decades is Green SCM. Green SCM aims to minimise or eliminate wastages including hasardous chemical, emissions, energy and solid waste along SC [2,13,22].

2.3 EIP and Supply Chain

From the definitions in Sects. 2.1 and 2.2, we observe that EIPs and SCs show some similarities. The parallel between SC and Eco-Industrial Parks has been exploited by Zhu and Cote with their study of the evolution of the Guitang Group, a Chinese sugar complex, towards an eco-industrial development by applying integrated Green SCM [31]. Li et al. support the idea that green SC should be built inside EIP to create a "green economy" [20].

We propose a non-exhaustive comparison of both concepts in order to demonstrate the pertinence of using SCM tools for EIP's symbiosis management. We inventoried the differences and similarities in Table 1.

Table 1. Comparison between an EIP and a SC

Similarities	
Both are groups of companies	
Companies involved are production companies (of goods or services)	
Both concepts are based around the organisation of a collaboration between the involved companies	
All involved companies are working towards a common goal (but their goals are different)	
Exchanges of flows exist in both organisations (physical or information)	
The exchanges are based on long term deals (several years in most cases)	
Both concepts show a strong interest in logistics issues	
Differences	
SC	EIP
If the SC don't involve a vertically integrated firm, it will be organised around a focal company, the primer manufacturer	An EIP can be organised around a focal company but it will likely be managed by an external observer
Well defined roles for each company	Each company's role depends on the chosen perspective
The output of a SC is focused on common products	The output of EIP is the collection of each member's products
Geographical proximity is not mandatory	All the companies are co-located in a defined area

SCs and EIPs were created around different philosophies and motivations. SCs are focused on the production of a common product and the satisfaction of a final customer. Their management goal is to improve quality, productivity and security. Members of an EIP do not collaborate for the production of a product but for the reduction in costs and environmental impacts, and the improvement of their employees' work conditions.

The outcome we draw from this comparison is that there are no real arguments against the use of SCM tools to model the industrial symbiosis of an EIP. A SCM tool that addresses inter-company collaboration modelling is the SCOR-model, hence we proposed the use of the SCOR-model for the description of EIPs' flows.

3 Supply Chain Management Applied to EIP

3.1 Presentation of the SCOR Model

The Supply-Chain Operations Reference-model (SCOR) is a cross-industry standard for SC management developed by the Supply-Chain Council (SCC). It is a diagnostic tool for practitioners describing the processes of a SC from the first supplier company to the last customer company. SCOR model integrates the well-known concepts of business process re-engineering, benchmarking, and process measurement into a framework which includes [17]:

1. standard descriptions of management processes;
2. a framework of relationships among the standard processes;
3. standard metrics to measure process performance;
4. management practices that produce best in class performance;
5. standard alignment to software features and functionality

As we can see in Fig. 2, in the most recent version of the SCOR model, the processes are of six types:

1. *Plan* describes the activities associated with developing plans to operate the supply chain
2. *Source* describes the ordering (or scheduling of deliveries) and receipt of goods and services.
3. *Make* describes the activities associated with the conversion of materials or creation of the content for services.
4. *Deliver* describes the activities associated with the creation, maintenance and fulfilment of customer orders
5. *Return* describes the activities associated with the reverse flow of goods.
6. *Enable* describes the associated with the management of the supply chain.

The processes can be approached at four levels of abstraction, from the most generic (level 1) to the most particular (level 4). Level 1, or 'Top Level', defines the scope and content for the SCOR-model (performance targets). At level 2, or 'Configuration level', companies implement their operations strategy through the configuration they choose for their SC. At level 3, or 'Process Element level', companies 'fine tune' their operations through process elements definition, process performance metrics and advice on the best practices. The last level, called 'Implementation level' is not included in SCOR's scope.

As SCOR model provides this well equipped cross-functional framework, we believe that it would be beneficial to use it for the evaluation, benchmarking and decision making for the development of an EIP.

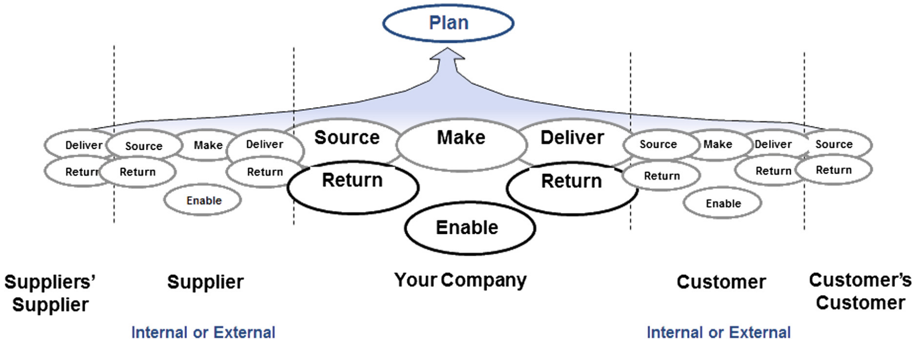

Fig. 2. The SCOR overall Supply Chain processes structure (APICS, SCOR 11.0 Overiew Booklet, 2014)

3.2 The SCOR Model Transferred to the EIP

The interactions between two members of an EIP can be of two different types: a bilateral exchange called substitution synergy or a pooling of resources called mutualisation synergy.

Substitution Synergy. A substitution synergy is a bilateral exchange of energy or materials. Using SCOR's process structure, a substitution synergy is the link between the *Source* process of a company and the *Deliver* process of another. Since one of EIPs' goals is to optimise their inputs in a circular way, a material exchange could be of various ancillary products. The materials emitted by a company can be of four types [31]:

1. *Products*, the desired output of the process;
2. *Co-products*, which represent substantial value even if they are not the intended product of the process;
3. *By-products*, unintentionally produced, that represent a lesser, but positive, value than the original raw material;
4. *Residual products*, or waste, with a negative value.

For example, a sugar refinery's product is sugar, two co-products are molasses and bagasse, and a residual product is filter sludge. The bagasse can be used in a pulp plant. The emissions of the pulp plant are the pulp (product), black liquor (by-product), and waste-water (residual product).

Because of these different types of materials, the *Deliver* process can sometimes be coupled to an ancillary *Make* and *Deliver* processes (*Make'* and *Deliver'*) to either tailor them for their next use (co-products and by-products) or to treat them to respect regulations (by-products and residual products). Therefore, we propose to represent the members of an EIP as shown in Fig. 3. Because substitution synergies are focused on materials, we ignore the processes *Plan* and *Enable*. Moreover, for this first modelling, we neglect the *Return* process.

Mutualisation Synergy. Using SCOR's process structure, a mutualisation synergy is the pooling processes between two, or more, companies. In theory, all the processes can be shared, but in practice, the most common pooling will likely be the *Deliver* and *Source* process. For example, two, or more, companies can come to an agreement to be delivered by the same carrier at the same time to minimise the shipping cost and environmental impact. In a similar fashion, the carrier importing materials in the EIP can be used to export finished products outside the EIP. With a bit more planning, the *Return* process can be organised in a collaborative way. Companies can share resources used in the *Make* process, such as quality control or information systems. A very common collaboration inside a EIP will be residual product treatment at the *Make'* process.

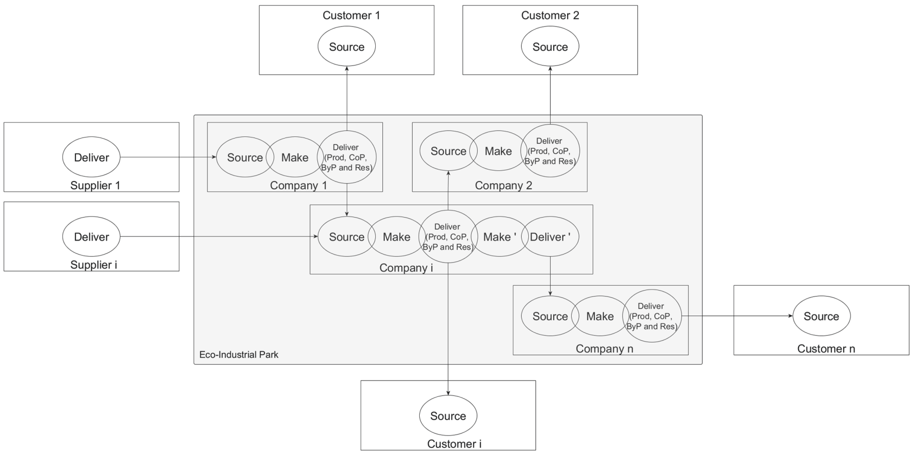

Fig. 3. Processes structure of an EIP of n companies inherited from the SCOR model (*Prod = Product, CoP = Co-Product, ByP = By-Product and Res = Residual Product)*

4 Case Study

4.1 Some Elements About Kalundborg EIP

The most famous and documented industrial symbiosis is located in Kalundborg in the Denmark [12]. Kalundborg's industrial symbiosis was built spontaneously, its development was progressive and with no planning. Since 1972, more than thirty materials or energy exchanges were established between the members of the symbiosis: six processing companies, a waste handling company and the municipality of Kalundborg. These bilateral agreements allowed to avoid production of waste and saved a consequential amount of resources. Only seeking economic profit, the members also reaped non-negligible environmental benefits and, following on from this success, Kalundborg has become the exemplary model for Eco-Industrial Development.

4.2 Application of the SCOR-Inherited Model to Kalundborg EIP's Symbiosis

As an example of the application of the SCOR model to an EIP, we chose to represent Kalundborg Symbiosis with the process structure described in paragraph 3.2. Information on Kalundborg's EIP were provided by Kalundborg's symbiosis official website[1] to obtain the most up-to-date data. Indeed, Kalundborg's symbiosis is dynamic: new substitution synergies are sometimes created or broken. With the data gathered, we mapped Kalundborg's symbiosis, as can be seen in Fig. 4. Except for Lake Tisso's surface water, we chose to only represent co-product, by-product and residual product flows within the EIP and their recovery outside the EIP. For the sake of clarity, the EIP members' products and imported primary materials are excluded of the figure and we differentiated energy, water and materials flows. The members of Kalundborg's EIP are:

1. Novo Nordisk, the world's largest producer of insulin;
2. Novozymes, the world's largest producer of enzymes;
3. Gyproc, producer of gypsum board;
4. Kalundborg Municipality, which handles the water and heat supply for Kalundborg's 50,000 inhabitants;
5. Dong Energy, owner of the Asnæs Plant, the biggest coal fuelled power plant in Denmark;
6. Statoil, owner of Denmark's biggest oil refinery;

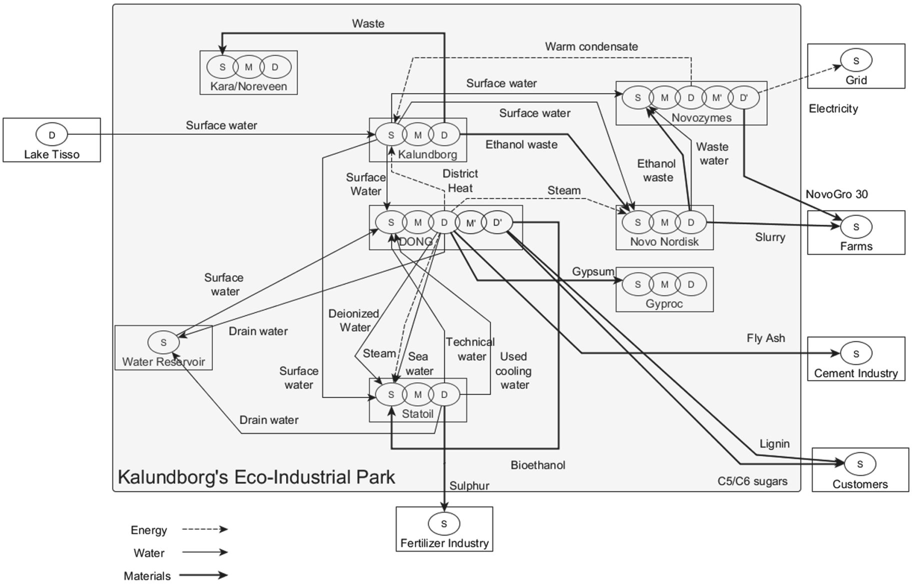

Fig. 4. Kalundborg symbiosis represented with the inherited SCOR process structure

[1] http://www.symbiosis.dk/en/diagram.

7. Kara/Novoren, a small waste treatment company;

As we can see in Fig. 4, DONG Energy and Novozymes both have ancillary *Make'* and *Deliver'* processes. Besides Asnæs Plant, DONG Energy owns Inbicon, a world leading lignocellulosic biomass conversion technology that uses Asnæs Plant surplus steam. Novozymes also owns a waste water treatment facility that uses Novozymes' biomass and Novo Nordisk's ethanol waste to produce NovoGro 30, used as a fertilzer by the farms nearby. Finally, since Kalundborg EIP is not focused on mutualisation synergies, our SCOR-inherited model only offers a mapping of the substitution synergy network.

The SCOR model is shown to be a standard enabling the mapping of EIP symbiosis. This first work addressed the use of the SCOR model as a descriptive model, but the SCOR framework offers other services such as benchmarking and performance metrics. Knowing that the SCOR can be adapted to describe an EIP is a first promising step towards the use of all its utilities. Since the philosophy and the goals of an EIP and a SC are not similar, additional work should be done to tailor the SCOR model for the performance evaluation of an EIP.

5 Conclusion

Owing to growing environmental concerns, the concept of Industrial Ecology has gained a lot of attention through its concrete application: EIPs. Observing some similarities between EIPs and SCs, we proposed the use of a SCM tool to describe an EIP's symbiosis. The SCOR-model, is Strategic SCM tool helping with the description and performance evaluation of the processes along the SC, was adapted to map the substitution synergies among an EIP. Applying our SCOR-inherited model to Kalundborg EIP, we have shown that it offers a standardised and original way to represent the processes inside an EIP. In the near future, we wish to apply our SCOR-inherited model to other EIPs: Savoie Technolac, a French Technopole with a philosophy close to the EIP's; Pomacle-Bazancourt EIP in France, one of the most successful example of bio-refinery in Europe; and the developing EIP of Victoriaville in Quebec.

This prospective work introduces the possibility to use the SCOR model at its fullest, for the evaluation, benchmarking and decision making for the development of an EIP. It also allows the use of other SCM tools associated with the SCOR-model such as performance measurement systems, multi-criteria decision making tools, and aggregation operator, such as the Choquet Integral [4]. Finally, this work means to inspire further research using tools endorsed in the industrial sector for the management and performance measurement of EIPs.

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An Integrated Supply Chain Model with Excess Heat Recovery

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Abstract. Energy efficiency is gaining increasingly attention from industries and from several other stakeholders since energy costs cover a significant share of the industrial total cost for manufacturing companies. The improvement of the performances and the consequent reduction of energy consumption lead to multiple extra benefits in addition to cost savings, for instance improved competitiveness, profitability and quality. For that reason, energy efficiency should be considered as a strategic advantage instead of a marginal issue. The relevance of this issue is particularly significant in energy intensive processes such as the metal industry (e.g. steel and aluminium producers), where usually high temperature processes present a remarkable opportunity to save energy through the excess heat recovery. The aim of the present work is to study a single-vendor single-buyer integrated production-inventory system with the opportunity to recover energy from the excess heat at the vendor production site. The chance to incur in larger savings thanks to a wider integrated network of heat exchanges across various actors along the supply chain (integrated heat recovery) is analysed.

Keywords: Supply chain · Joint economic lot sizing · Heat recovery · Energy efficiency

1 Introduction

The manufacturing sector is responsible for the majority of the energy consumed in industry which covers about 30% of the final energy consumption [1]. To reduce greenhouse gas emission and to send significant signals to the market, in 2012, the European Commission set a target of a 20% increase by 2020 of the energy efficiency compared with amount used in 2005. Recent studies [2, 3] claimed that making sustainable use of energy resources is becoming more critical for industrialized economies not only for the stringent targets imposed, but also for the geographic concentration and the huge prices of fossil fuels, and for the increasing customers' awareness. Improved energy efficiency represents one of the most remarkable way for industries to reduce energy costs and to allow additional multiple benefits for the business such as enhanced productivity and competitiveness, reduced costs for environmental compliance, O&M and waste disposal and extended equipment lifetime [4]. These costs represent a relevant concern for companies, especially for energy-intensive processes (e.g. steel and

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aluminium industries) mainly because of the growing use and the high prices of fossil fuels. Since a noteworthy amount of wasted thermal energy is generated by these production processes, heat recovery presents a huge potential in the improvement of the energy efficiency [5]. Excess heat can be used by the same company for core processes or auxiliary services or transferred to other users with a demand for heat. Moreover, excess heat can also be converted into electricity through different technologies. Among these several technologies, the one that presents the best conversion efficiency is the organic Rankine cycle (ORC). However, to identify the real potential of the energy recovery it is important to undertake the implementation of other energy efficiency measures [6]: i.e. production planning, investment in energy-efficient equipment and recycling of energy in the industrial production process. In addition, since the coordination among different companies of the supply chain lead to different production planning, supply chain management can affect the effect of heat recovery. The coordination among different members of the supply chain generates positive impacts on the performance. A joint economic lot size (JELS) model with variable production rate was presented in [7]; while [8] proposes an analytical model representing a two-stage production system introducing the energy implications. However, these works do not consider the opportunity represented by heat recovery. Excess heat and controllable production rates were considered in [9] but in this study a two-stage production system was analysed while not the integrated decision-making among different actors of the supply chain, and the focus is on the only ORC technology. Hence, the aim of the present work is to model a single-vendor single-buyer integrated production-inventory system through a JELS model with the opportunity to recover energy from the excess heat through the investment in additional equipment. The chance to export the energy obtained from the heat recovery to other companies along the supply chain is also considered to represent the opportunity to incur in larger savings thanks to the wider integrated network. The remainder of the paper is organized as follows: Sect. 2 introduces the notations, assumptions and the analytical models development for the considered scenarios, Sect. 3 presents the solution of the models, Sect. 4 provides a numerical example to illustrate the behavior of the proposed models and, in conclusion, Sect. 5 summarizes the main findings and provides suggestions for future research.

2 Model Development

2.1 Notation

α	[kW]	Constant of the power required by the vendor's production process
A	[€/order]	Order cost
β	[kW/unit]	Coefficient for the contribution of the power required by the vendor's production process function of *P*
c_{HR}	[€/kWh]	Levelized cost of electricity for heat recovery equipment
δ	[kW/unit]	Coefficient that links the variable energy consumption contribution to the lot size at the buyer's site
D	[unit/h]	Demand rate

ε	[kW]	Constant of the energy required at the buyer's site
e_j	[€/kWh]	Cost of energy for actor j
$\dot{EC}_B$	[kW]	Power required by the production process at the buyer's site
$\dot{EC}_V$	[kW]	Power required by the production process at the vendor's site
η_{HR}	[%]	Conversion efficiency of the heat recovery technology
h_B	[€/unit·h]	Buyer's holding cost
h_V	[€/unit·h]	Vendor's holding cost
$\dot{HR}_B$	[kW]	Recovered heat at the buyer side
$\dot{HR}_V$	[kW]	Recovered heat at the vendor side
$\dot{HR}$	[kW]	Flow rate of waste heat recovered through the technology considered
n	[shipments]	Number of shipments
P_{min}	[unit/h]	Minimum value for the production rate
P	[unit/h]	Vendor's production rate
P_{max}	[unit/h]	Maximum value for the production rate
Q	[unit]	Lot size
S	[€/setup]	Setup cost
TC_B	[€/h]	Total annual cost of the buyer
TC_V	[€/h]	Total annual cost of the vendor
TC_S	[€/h]	Total annual cost of the supply chain
ω	[%]	Percentage of the required for the production process that is sent in input of the heat recovery technology as waste

2.2 Problem Description and Assumptions

This work analyses the coordination of a single-vendor single-buyer supply chain. The vendor manufactures a lot of size nQ at a set production rate P with a single setup which is delivered to the buyer in n shipments of equal-sized lots of Q units. The vendor incurs setup cost at the beginning of each production cycle, production costs continuously during production and revenues from selling the lot to the buyer at every shipment. In addition, it is assumed that the vendor must invest a capital amount in the equipment to allow the recovery of wasted heat. For the buyer, ordering and purchasing costs occur each time a shipment is made, while the continuous demand leads to continuous revenues over the entire cycle. As an extension of the traditional inventory theory, in this paper the two-stage supply chain is extended by introducing energy requirements and the opportunity to convert recovered waste heat into electricity.

The following section develops formal models to study the problem described above and considers different scenarios with regard coordination and heat recovery opportunity:

- Decentralized scenario without heat recovery (D.0) and with heat recovery at the vendor site (D.1)
- Centralized scenario without heat recovery (C.0) and with integrated heat recovery (C.1)

In addition to the properties already described, the following assumptions are made:

1. The inventory system involves a single item with an infinite planning horizon and shortages are not allowed
2. Production/purchasing costs and revenues are not differential
3. The demand rate (D) is constant
4. The vendor's production rate is limited to the interval [P_{min}, P_{max}], but it is always greater than the demand rate. As in [9], a 'rigid case' is considered: i.e. due to technological reasons, the production rates can be varied only before the start of the production
5. Cost of generating electricity from the heat recovery technology is defined by the levelized cost of electricity (LCOE) and includes the initial investment, operation and maintenance costs, cost of fuel and other accessories costs [10]
6. It is also assumed that the waste heat in input of the heat recovery system is proportional to the power required to run the production [9], $\dot{Q}^{in} = \omega \cdot \dot{EC}_V$.

2.3 Energy Model

Several alternative technologies exist for the recovery of industrial excess heat [6], such as thermoelectric generator, Organic Rankine cycle (ORC), phase change material engine system and so on. All the technologies are characterized by a specific conversion efficiency, η_{HR}, depending on different factors (e.g. temperature of the heat source). According to [11, 12], the power requested for the production process consists of two contributions: one component is fixed and defined through a constant which usually comes from the equipment features required to support the process; while, the other is function of the current production rate, since, it depends on the physics of the process and on the quantity of product to be processed. The power request formulation is the same for both the actors but it is defined by different parameters.

$$\dot{EC}_V = \alpha + \beta n Q \tag{1}$$

$$\dot{EC}_B = \varepsilon + \delta Q \tag{2}$$

2.4 Economic Models

Decentralized Scenarios (D). In the decentralized scenarios, the vendor and the buyer take decisions separately to minimize their own total cost. The buyer should decide the size of the order quantity that minimizes the sum of order costs, inventory cost and energy cost. Thus, the buyer total cost TC_B is given by:

$$TC_B(Q) = A\frac{D}{Q} + h_B\frac{Q}{2} + e_B\dot{EC}_B \tag{3}$$

In the first scenario D.0, no waste heat recovery ($\dot{H}R = 0$) is considered, thus, the vendor does not incur into the additional cost of generating electricity from the recovery technology. Consequently, the vendor's total cost TC_V consists of the setup cost, inventory cost and energy cost; while the decision variables are identified by number of shipments, n, and the production rate, P.

$$TC_V(n, P) = S\frac{D}{nQ} + h_V\frac{Q}{2}\left[\frac{D}{P}(2-n) + n - 1\right] + e_V\dot{E}C_V\frac{D}{P} \tag{4}$$

In scenario D.1, the waste heat recovery is admitted at the vendor side. Hence, the annual total cost of the buyer remains unchanged (Eq. (3)) while the one of the vendor becomes:

$$TC_V(n, P) = S\frac{D}{nQ} + h_V\frac{Q}{2}\left[\frac{D}{P}(2-n) + n - 1\right] + \left[e_V\left(\dot{E}C_V - \dot{H}R_V\right) + c_{HR}\dot{H}R\right]\frac{D}{P} \tag{5}$$

where the heat recovery is given by the conversion efficiency and the amount of heat flow while the real recovery at the vendor site is given by the minimum between the power required for the production and the power recovered through the specific technology considered:

$$\dot{H}R = \eta_{HR} \cdot \omega \cdot \dot{E}C_V \tag{6}$$

$$\dot{H}R_V = min\left\{\dot{E}C_V; \dot{H}R\right\} \tag{7}$$

Centralized Scenarios (C). In the centralized scenarios, the different actors cooperate in the decision-making process, to minimize the total cost of the supply chain reaching the global optimum instead of multiple local optimums. Also under coordinated decision two scenarios have been considered: in the first (C.0), no waste heat recovery is allowed; while, in the second (C.2), the case of integrated heat recovery is studied. The supply chain's annual total cost, TC_S, without heat recovery is given by the sum of Eqs. (3) and (4):

$$TC_S(Q, n, P) = \left(A + \frac{S}{n}\right)\frac{D}{Q} + \frac{Q}{2}\left\{h_V\left[\frac{D}{P}(2-n) + n - 1\right] + h_B\right\} + e_B\dot{E}C_B + e_V\dot{E}C_V\frac{D}{P} \tag{8}$$

If integrated heat recovery is considered, the buyer incurs in extra-savings ($e_B\dot{H}R_B\frac{D}{nQ}$) due to the lower energy purchased from the grid. While, the vendor presents the same annual total cost as in scenario D.1 (Eq. (5)). Hence TC_S becomes:

$$TC_S(Q,n,P) = \left(A + \frac{S}{n}\right)\frac{D}{Q} + \frac{Q}{2}\left\{h_V\left[\frac{D}{P}(2-n)+n-1\right]+h_B\right\} + e_B\left(\dot{EC}_B - \frac{\dot{HR}_B}{n}\right) + \left[e_V\left(\dot{EC}_V - \dot{HR}_V\right) + c_{HR}\dot{HR}\right]\frac{D}{P} \tag{9}$$

where the heat recovery transferred to the buyer, $\dot{HR}_B$, is given by the minimum between the energy required at the buyer's side and the energy recovered by the waste heat still not used by the vendor:

$$\dot{HR}_B = min\left\{\dot{EC}_B; \left(\dot{HR} - \dot{HR}_V\right)\right\} \tag{10}$$

3 Models Solution

In the decentralized scenarios, the total cost of the buyer in the decentralized setting is the same with and without heat recovery. From the analysis of the objective function of the buyer, Eq. (3), it is possible to demonstrate its convexity in Q and thus an optimal value for the lot size can be deducted:

$$Q^* = \sqrt{\frac{2AD}{h_B + 2e_B\varepsilon}} \tag{11}$$

For what concern the vendor, the objective functions, Eqs. (4) and (5), present a convexity in n for given value of P and the optimal number of shipments is given by Eq. (12) and (13) respectively for scenario D.0 and D.1.

$$n^*_{D.0} = \sqrt{\frac{2SD}{Q^2\left[h_V\left(1-\frac{D}{P}\right)+2e_V\beta\frac{D}{P}\right]}} \tag{12}$$

$$n^*_{D.1} = \sqrt{\frac{2SD}{Q^2\left\{h_V\left(1-\frac{D}{P}\right)+2[e_V(1-min\{1;\eta_{HR}\omega\})+c_{HR}\eta_{HR}\omega]\beta\frac{D}{P}\right\}}} \tag{13}$$

Since the number of shipments should be an integer, the optimal value $\tilde{n}^*$ is obtained comparing the total cost of the vendor rounding up and down the result of Eqs. (12) and (13). Substituting $\tilde{n}^*$ in Eqs. (4) and (5), it is possible to study the convexity of the function in P. However, the obtained derivatives are quite complex and since the production rate should assumed an integer value between the two limits, $[P_{min}, P_{max}]$, it is possible to use the following algorithm to find the optimal value of P.

Step 1. Set $Q = Q^*$, $n = \tilde{n}^*$, $P = P_{min}$ and $TC_V(\tilde{n}^*, P_{min}) = 0$.
Step 2. Calculate $TC_V(\tilde{n}^*, P)$ from Eqs. (4) and (5).

Step 3. If $TC_V(\tilde{n}^*, P) > TC_V(\tilde{n}^*, P-1)$ then $P^* = P-1$ otherwise set $P = P+1$ and repeat step 2, in the range from *Pmin* to *Pmax*.

In the centralized scenarios, to find the optimal solutions, it is necessary to study the objective functions defined in Eqs. (8) and (9) for scenario C.0 and C.1. Analysing the derivatives, it is possible to observe the convexity in Q of both the equations and the optimal values for the lot size of C.0 and C.1 are defined by Eqs. (14) and (15) respectively.

$$Q^*_{C.0} = \sqrt{\frac{2\left(A+\frac{S}{n}\right)D}{h_V\left[\frac{D}{P}(2-n)+n-1\right]+h_B+2e_B\delta+2e_V\beta n\frac{D}{P}}} \tag{14}$$

$$Q^*_{C.1} = \\ = \sqrt{\frac{2\left(A+\frac{S}{n}\right)D}{h_V\left[\frac{D}{P}(2-n)+n-1\right]+h_B+2e_B[\delta-\min\{\delta;\beta(\eta_{HR}\omega-\min\{1;\eta_{HR}\omega\})\}]+2\beta n\frac{D}{P}[e_V(1-\min\{1;\eta_{HR}\omega\})+c_{HR}\eta_{HR}\omega]}} \tag{15}$$

Substituting Q^* in Eqs. (4) and (5), it is possible to study the convexity of the function in n and P. However, the obtained derivatives are quite complex, hence, it is possible to use the following algorithm.

Step 1. Set $Q = Q^*$, $n = 1$, $P = P_{min}$ and $TC_S(Q^*, n, P_{min}) = 0$.
Step 2. Calculate $TC_S(Q^*, n, P)$.
Step 3. If $TC_S(Q^*, n, P) > TC_S(Q^*, n, P-1)$ then $P^* = P-1$ otherwise set $P = P+1$ and repeat step 2, in the range from *Pmin* to *Pmax*.
Step 4. Set $n = n+1$ and repeat step 2 and 3.
Step 5. If $TC_S(Q^*, n, P^*) > TC_S(Q^*, n-1, P^*)$ then $n^* = n-1$ otherwise go to step 4.

4 Numerical Analysis

In the present section, a simple numerical example is presented to analyse the behavior of the model proposed. The data used for the analyses are presented in Table 1.

The results in Table 2 show that the lot size is reduced through the centralization and also shifting from scenario C.0 to C.1; while, in decentralized scenarios, the lot size is the same since it does not depend on the presence or absence of heat recovery

Table 1. Parameters used for the numerical analysis

α	10 kW	D	1000 unit/h	c_{ORC}	0.05 €/kWh
β	2 kW/unit	P_{min}	1000 unit/h	e_B	0.2 €/kWh
δ	0.5 kW/unit	P_{max}	2000 unit/h	e_V	0.15 €/kWh
ε	25 kW	S	400 €/setup	h_B	1.5 €/unit·h
η_{HR}	25%	A	100 €/order	h_V	3 €/unit·h
ω	80%				

initiatives. Conversely, the integrated scenario with heat recovery presents an increased production lot size (nQ); in this way, it is possible to incur in greater benefits.

Table 2. Results of the numerical example proposed

	D.0	D.1	C.0	C.1
Q [unit]	131.88	131.88	200.40	206.46
n [shipment]	9	9	5	6
P [unit/h]	1000	1000	1000	1000
TC_V [€/h]	€892.40	€844.72	€1,020.16	€955.97
TC_B [€/h]	€875.38	€875.38	€650.30	€664.85
TC_S [€/h]	€1,767.78	€1,720.10	€1,670.46	€1,620.82

The impact of the heat recovery in the reduction of the supply chain total cost is enhanced by the centralization of the joint decision-making: −2.97% shifting from scenario C.0 to C.1 against −2.70% from D.0 to D.1. At the same time, also the centralization allows greater reduction of the total cost if the excess heat recovery is allowed: −5.51% without recovery against −5.77% with recovery. In Fig. 1 the share of the cost components on the total cost of the supply chain is shown to observe the different impacts in the scenarios considered.

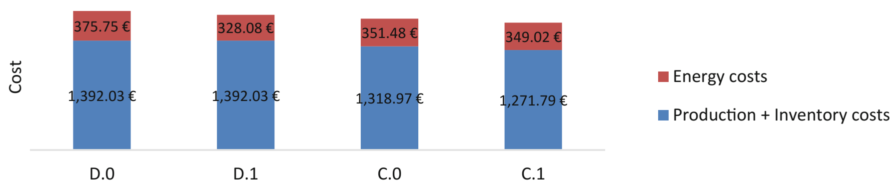

Fig. 1. Impact of the different costs components on the total supply chain cost

5 Conclusions

In the industrial sector, especially for energy intensive processes such as the metal industry, the recovery of the excess heat represents a great opportunity to increase the energy efficiency and thus to incur in relevant costs savings. The aim of the present work is to propose a model for studying a single-vendor single-buyer integrated production-inventory system with the opportunity to recover energy from the excess heat. The numerical example proposed shows that the centralization enhances the benefits introduced with the heat recovery and, at the same time, the presence of the recovery technology allows to increase the cost reduction obtained through the integrated decision-making. Future research could study more in details the behavior of the different heat recovery technologies, for example considering a conversion efficiency that depends on the power at which the technology works. Additional analysis should investigate the effect of considering a variable production rate at the vendor side which may lead to a trade-off between production-inventory costs and energy costs. Other extensions can be represented by the analysis of financial sharing and profit sharing mechanisms to make the centralization advantageous for both the supply chain members and by the integration of the thermal energy flow from the vendor to the buyer.

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Environmental KPI Selection Using Criteria Value and Demonstration

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Abstract. Determining key performance indicators (KPI) is a first step in achieving environmental sustainability of manufacturing operations. KPI selection is a multi-criteria decision making problem, because of various criteria that must be considered. Intuitively, one can rank candidate KPIs by specifying a numerical value indicating the effectiveness of a KPI in satisfying each criterion. However, linking selection criteria to KPI objectives, ranking how well a KPI satisfying a given criterion, and assigning a value to each rank lead to better KPI rankings. Values for each score are crucial. This paper shows steps to capture values to derive a criterion value function that is used to rank candidate KPIs. Selected KPIs can be used for assessing and monitoring sustainability performance, which must be considered together with including traditional (e.g., throughput) measures. A machine shop is used to show how an objective of reducing emissions from energy use in manufacturing can be pursued by monitoring the energy used to produce a unit product.

Keywords: KPIs · Sustainability · Selection criteria · Value function

1 Introduction

Achieving sustainability of manufacturing processes requires efficient and effective methods for defining, selecting, deploying, and monitoring key performance indicators (KPIs). Selecting KPIs is a multi-criteria decision making problem for which several methods are available. One approach is to let stakeholders assign a score of a KPI in satisfying a selection criterion. This process is repeated for each candidate KPI and final KPI ranks are obtained from aggregation of these scores.

Ezell (2007) and Collins et al. (2016) showed enhancement to this approach by capturing stakeholder "value" for each score point on the Likert scale. Our previous research also used a multi-variate value model where stakeholders score (and provide value of) each candidate KPIs against each selection criterion (Kibira et al. 2017). The score represents the degree to which a KPI satisfies a criterion. Each selection criterion is linked to a KPI objective. This way, each KPI is evaluated for its contribution to the defined environmental objective. The developed procedure has been submitted to the

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American Society for Testing and Materials (ASTM) as a work item to become a standard guide for identification and selection of environmental KPIs for manufacturing processes (ASTM International). This procedure requires an in-depth understanding of developing and using value functions for selection criteria. This process and the linking of criteria to KPI objective are discussed in this paper within the context of environmental assessment of manufacturing processes. This paper also demonstrates KPI deployment and performance monitoring in a machine shop.

Typically, value functions capture experts' assessment of the value of each score of a KPI against a criterion. To develop a value function, Duarte et al. (2006) first defined the minimum and maximum possible measures of the score but assumed a linear relationship between assigned score and value. Keeney and Lilien's (1987) developed a method of assigning value at salient points on a common probability distribution. This paper derives criteria value functions using a combination of above-mentioned approaches.

The rest of the paper is organized as follows. Section 2 presents concepts of the value model and shows steps to develop a value function. Section 3 presents examples of developing and using value functions. Section 4 presents a demonstration of implementing KPIs for performance monitoring. Section 5 is a discussion and conclusion of the paper.

2 Criteria Value Based KPI Ranking and Deployment Process

Figure 1 shows our proposed approach for selecting and implementing KPIs for a manufacturing system based on value. This section overviews the steps and the process from identifying selection criteria to ranking the candidate KPIs.

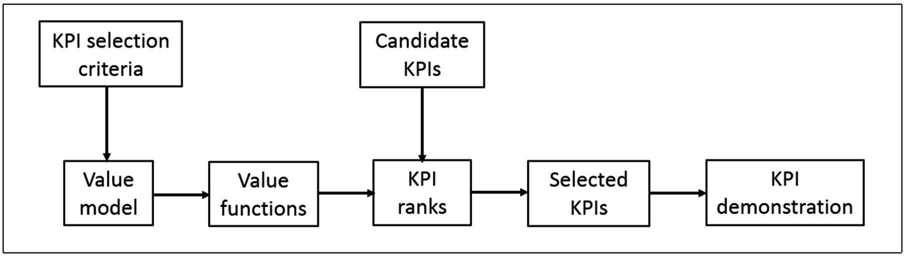

Fig. 1. Process and steps of KPI selection and demonstration

Identifying KPI Selection Criteria: Selection criteria should be fundamental to the KPIs as opposed to being a means to another criterion (Keeney and Lilien 1987). For example, a criterion such as "quantifiable" can be a means to ensure that a KPI is "calculable." Therefore, these two may not need to appear in the same criteria set. KPI objectives are used to identify criteria and are obtained from sustainability goal(s). For example, if reducing energy use by, say, 20% is the target, it implies that KPI should be measurable and/or computable. To obtain a complete representative list, criteria groups, e.g. financial-oriented or management-oriented criteria. To keep the analysis manageable, a decision can be made to select the best 5–10 criteria to make up the set.

Candidate KPIs: Typically, candidate KPIs are proposed by top management and presented to organizational units responsible for KPI implementation so they can be evaluated. However, the candidate KPIs can also be identified if there is a gap between KPIs currently in use and those that are needed to achieve environmental objectives.

Value Model for KPI Ranking: For a value model, (1) each criterion is weighted for its contribution, and (2) each candidate KPI is measured against each measure criterion. Most previous researchers used the additive model to compute total value of a candidate KPI (Keeney and Lilien 1987; Duarte et al. 2006; Ezell 2007; Collins et al. 2016). Thus:

$$v(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{n} w_i v_i(x_i) \quad (1)$$

where v is the overall value function, and $v_i(x_i)$ are the individual criteria values at measurement level x_i, w_i are the scaling constants (weights), whose total should equal to 1.

$$\sum_{i=1}^{n} w_i = 1, \ w_i > 0 \quad (2)$$

Value Function Development

Horizontal Measurement: This measurement scale is used to indicate the degree to which a KPI satisfies a criterion. After identifying this scale, the minimum and maximum possible values are specified. For example, Table 1 shows measurement scales as well as minimum and maximum values for three of the criteria described in Kibira et al. (2017).

Table 1. Measurement scale of sample KPIs

Criterion	Designation	Measurement scale	Minimum	Maximum
Quantifiable	x_1	# of metrics and data	0	Total # of metrics and data
Cost effectiveness	x_2	$ (or max/min)	$0	$ max savings (or 1)
Calculable	x_3	# of variables and data	0	Total # of variables and data

Vertical measurement: Values for each level on the horizontal scale are determined by analysts and subject matter experts (or stakeholders). KPI values increase with degree of satisfaction of each criterion by the KPI. Therefore, value functions for KPI selection would in general exhibit an increasing trend. Alarcon et al. (2011) proposed four relationships (i.e., linear, convex, concave, and S-shaped) that a value function can take, as seen in Fig. 2.

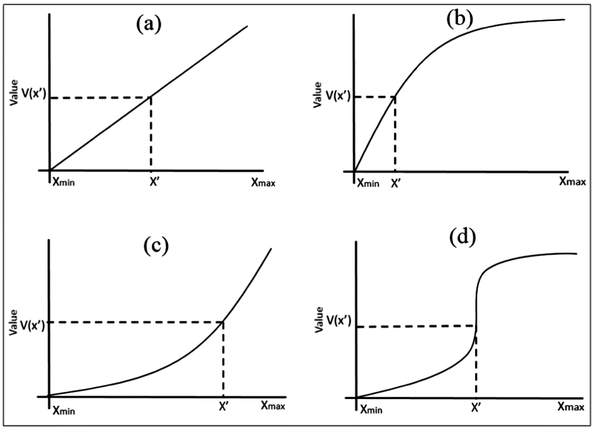

Fig. 2. Common shapes of the value function

To determine the actual values, let the minimum measurement be designated x_{min} and maximum be x_{max}. On a 0–1 scale for value, $v(x_{min}) = 0$ and $v(x_{max}) = 1$. Keeney and Lilien (1987) preferred to start with the mid-value (designated x'). The subject matter expert or stakeholders determines this value, where $v(x') = 0.5$. Other points between x_{min} and x' and between x' and x_{max} can be determined to yield additional points on the function v. If sufficient points can be garnered using experts, a sketch can complete the graph of the function.

KPI Ranking: Next, for each KPI in the candidate set stakeholders independently assign a score showing agreement that the KPI satisfies the criterion. A value is obtained from the value function for each score. An average is calculated for the values obtained from all stakeholders for each criterion for each KPI.

3 Examples of Applying Steps in Criteria Value-Based KPI Selection

This section presents examples to illustrate how the steps may be applied. Some of the processes illustrated in Fig. 1 are demonstrated in Kibira et al. (2017). Discussion will be on KPI selection criteria, value function development and KPI demonstration.

Selection Criteria: These are specified by production managers, supervisors, and shop floor workers. Lower-level KPI objectives for reducing material consumption include reduction in virgin material use and increase in use of recycled materials. The KPI objectives are used to identify criteria that would meet these objectives.

Value Function for "Cost Effectiveness" Criterion: This criterion implies the degree of perceived cost benefit of implementing the KPI. Let the measure for this criterion be expressed as the "savings" measured on a scale from 0 to 10, which is the difference between the income (or saved costs) and expenditure of implementing a KPI. Let the minimum savings, S_{min}, be 0 and the maximum, S_{max}, be 10.

The next step is to determine the shape of the value function. If savings through monitoring KPIs is a new strategic approach, any efforts in that direction are greatly encouraged. Therefore, initial measures are highly valued. A concave shaped value function, where the increase in value is maximized at the point of minimum measure, is suitable. See Fig. 2b. As you progress towards the maximum, the curve is more horizontal as the decision maker would generally assign less value to additions to high-level savings.

Once the general shape is established, what follows is to determine salient points on the curve. The expert is asked to express "How much savings, say *y*, such that the value from the minimum to *y* is equal to the value from *y* to the maximum?" Let this savings be labelled S' and x_1 designate the cost effectiveness criterion. On a scale from 0–1, $v_1(0) = 0$, $v_1(S') = 0.5$, and $v_1(S_{max}) = 1$. Proceeding from this point, mid-value assessments are made for additional pairs of cost effectiveness levels to generate other data points.

Ranking KPIs: Stakeholders independently assigned a score on the measurement scale for each KPI against each criterion. The value corresponding to this score was obtained from the value function. The final value of a KPI was a sum of values obtained from all stakeholders for all the criteria. The values (obtained from the value function) are scaled to the 0–10 range. All three stakeholders perform the same process and their results averaged. The final ranking in an example used in (Kibira et al. 2017) is summarized in the chart in Fig. 3. This chart shows that the "energy per part" KPI has the highest rank. This is used for monitoring energy performance in the demonstrated machine shop.

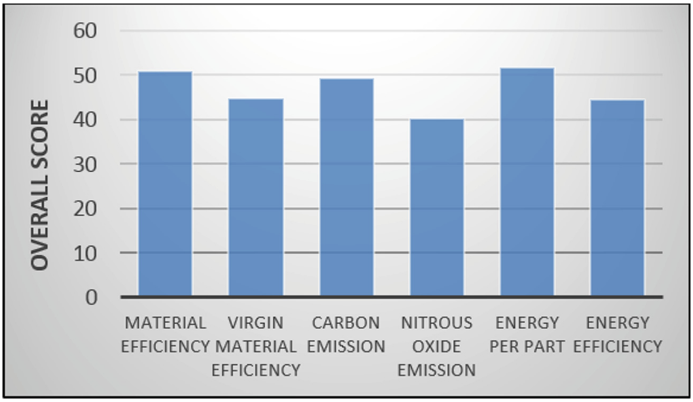

Fig. 3. Final assessment of individual KPIs (Kibira et al. 2017)

4 KPI Demonstration

This section shows the monitoring of performance using the highest ranking KPI, i.e., energy per part. Let us assume that the high-level goal was "to reduce global warming potential due to energy consumption in the manufacturing process without compromising throughput." To evaluate achievement of the above goal, it is necessary to break down energy consumption into lower level objectives and to monitor the energy use.

We use a case study of a small machine shop that manufactures metal products. The shop comprises of a foundry, one milling machine, one lathe machine, a drilling machine, and an ultrasonic inspection center. There are two classes of products: A and B. Figure 4 shows the work flow. Production starts when the parts are loaded onto the shop. After casting, A requires turning operations while B requires milling. Final process is drilling although some of A do not use it. All parts pass through the inspection station.

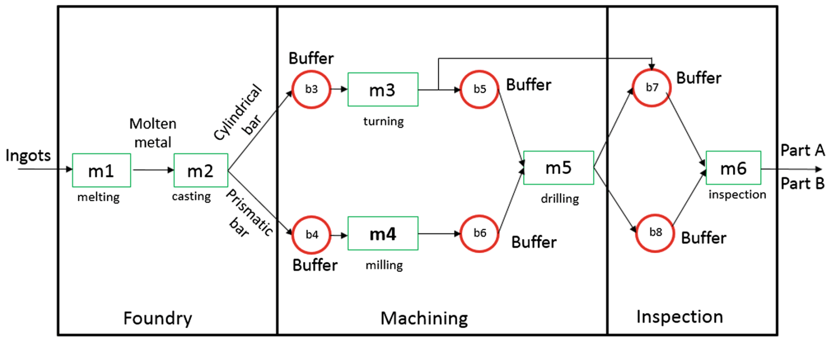

Fig. 4. Workflow through the shop

Energy Modeling and Simulation: A discrete event simulation model of the shop was constructed using AnyLogic simulation software tool. To attribute energy to a unit part, we use a framework such as that developed by Seow et al. (2011). Two types of energy are distinguished: direct and indirect. Direct energy is the type used in the actual production process, e.g., heat to melt metal. Indirect energy is that used in the ambient working area such as heating, ventilation, and air-conditioning (HVAC), and lighting.

Direct Energy: The direct energy for the casting process is obtained by combining energy used to bring the metal from room temperature to melting temperature and the fusion energy required. Machining energy is related to machining time. Both these quantities are calculated using empirical expressions for machining of mild steel products (Sonmez et al. 1999; Sardinas et al. 2006). For product inspection, the energy consumed is equal to the energy rating of the ultrasonic tester multiplied by duration of the inspection.

Indirect Energy: Indirect energy consumed in each section of the shop depends on the type of manufacturing activity. Indirect energy is calculated by considering HVAC and lighting rating requirements for manufacturing activities carried out in these sections. Energy per part is obtained by dividing the result by the total of parts produced.

Simulation Output: Simulation experiments are carried out to investigate the impact of batch size on both energy consumptions per part. Batch size is the variable used because it affects many factors including setup time and setup cost, inventory levels, lead times, safety stock, and order fulfilment. In general, small batch sizes are associated with higher overall set-up time while large batch size, without lot-splitting, can lead to increased idling and thus, reduced throughput. The effect of batch size is investigated for its effect on energy consumption and throughput in the multi-stage production environment. *Note* that set-up time for casting is not a constant for all batch sizes.

The energy consumption is shown in the graph in Fig. 5. For each experiment, Parts A and B are loaded alternately onto the shop in batches of equal size. Batches are varied from an initial size of 5 units. For a batch-size less than ten units, there is significant increase in energy use per part while any batch sizes exceeding 20 units, the decrease in energy use is not significant. On the other hand, the total number of units produced falls almost evenly with increase in batch size. The decision maker can use this graph to balance energy per part and throughput for each situation.

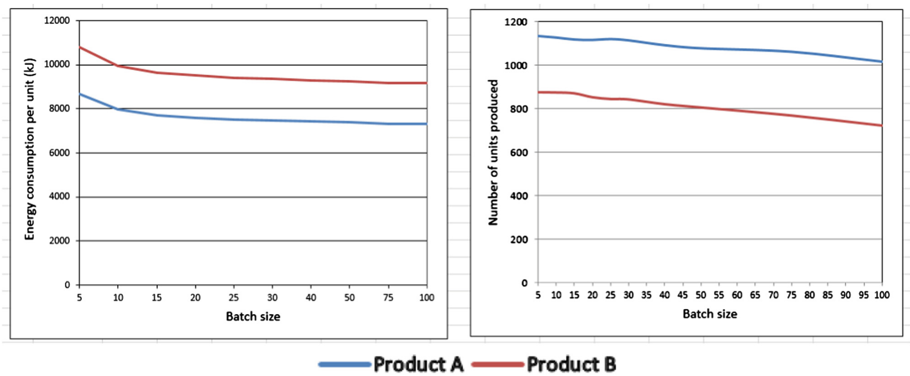

Fig. 5. Variation of energy consumed per part with batch size

5 Summary and Discussion

This paper has discussed using value of a score for a KPI against a criterion to evaluate a candidate KPIs. This approach was adopted after realizing that the relationship between such scores and benefit from the score is not always linear. Thus, the concept of value of each score, as a basis for decision-making is relevant to the KPI selection process and largely hinges on constructing value functions for each criterion.

Expert knowledge and stakeholder contribution is crucial for deriving value functions used for ranking candidate KPIs. Selection for KPIs is based on the resulting ranks. Selected KPIs can be used for assessing and monitoring environmental measures such as energy consumption. Analysis and tradeoff can be made between different measures. Simulation modeling may be applied to further investigate performance due to decisions made at different control levels as well as possible interactions between different KPIs.

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Simulation Method for Evaluation of Productivity and Energy Consumption Concerning Production Line for Injection Molding Machines

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Abstract. Methods for evaluating productivity and energy consumption simultaneously have been getting significant interest in the industry. In particular, although injection molding machines are important system components for production in plastic molding, a method for simultaneously evaluating their productivity and energy consumption has not been established. Therefore, we propose a simulation method that is based on a state transition model containing state transitions and states of machines in an injection molding production line.

Keywords: Manufacturing system simulation · Injection molding machine · Modeling · Energy consumption · Productivity

1 Introduction

In the industrial world, on account of the revision of the "Act on the Rational Use of Energy" which was implemented in Japan in April 2014, a decrease of more than 1% of the annual average energy consumption was systematically implemented. In the plastics industry, more than 90% parts are produced using injection molding machines. An injection molding machine involves processes that consume large amounts of energy, such as material plasticizing, part cooling, and opening and closing of molding die with high-pressure clamping. Therefore, the energy consumption per a part in manufacturing tends to be high. Moreover, the production line includes, in general, injection molding machines and several auxiliary machines that are used to improve productivity or maintain the product quality. Since injection molding and auxiliary machines work in series, the relations among processes in the production line are complicated. Currently, the relations between the states of machine and their transitions are not well organized. This causes difficulties in improving the productivity and energy consumption of the machines in injection molding lines. To address these matters, as first step, it is necessary to appropriately evaluate the productivity and energy consumption in production lines. Concerning studies on evaluation of energy consumption of injection molding machine, there were three types of the studies. The first type is to focus on evaluating

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energy consumption of physical phenomenon in injection molding processes such as plastic resin dissolution phenomenon, plasticization phenomenon and so on [1–4]. The second type is to focus on considering the life cycle Assessment (LCA) in injection molding processes using real measurement data [5, 6]. The third type is to focus on simulation methods. Concerning the simulation method, several studies have focused on evaluating productivity and energy consumption in production lines including machining and industrial robot [7–9]. As the relations among processes in the injection molding production line are complicated, the simulation methods for production lines did not often consider the injection molding machine. Concerning the simulation method for injection molding processes, there are two studies [10, 11]. The first study proposed considering the influence of production conditions and part shape [10]. However, this method focused on only single injection molding machines and did not consider auxiliary machines and multiple production lines to calculate the productivity and energy consumption of the whole production system. The second study proposed a simulation modeling method that defined a relationships among injection molding processes, necessary machines, and auxiliary machines, and defined states and transitions of each machine [11]. However, this simulation modeling method was not implemented in manufacturing system simulation.

In this research, a simulation method for pre-evaluating the productivity and energy consumption is proposed by using the simulation modeling method of the relationship between the machine states and the transitions in the injection molding production line. The proposed simulation method is implemented in manufacturing system simulation. Case studies to evaluate the effectiveness of the proposed simulation method were examined.

2 Proposal of the Evaluation Method of Productivity and Energy Consumption of an Injection Molding Production Line

Productivity and energy consumption of a production line can be calculated by integrating the work time or energy consumption of each system constituting the production line. The work time and energy consumption in each system changes over time, often in response to the state and state transitions in each system. Therefore, the evaluation of productivity or energy consumption requires a model linking the state, state transition, and energy consumption for each process. The production line of injection molding consists of material supplying processes, material drying processes, material plasticizing processes, producing processes, and product removing processes. These processes are executed by material loaders, material dryers, injection molding machines, and product take-out machines. In previous research, a state transition model was proposed for organizing the relations between the machine states and state transitions in an injection molding production model constituting these five processes. In the proposed state transition model, the state in each process, the state transition, as well as the inter-process sub-states' relations are organized as shown in Fig. 1.

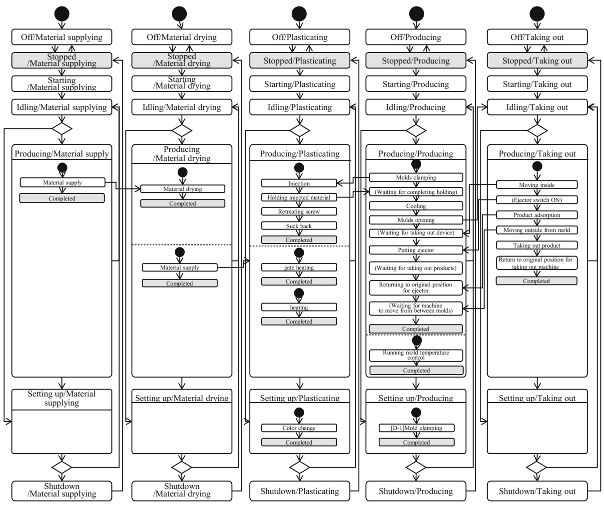

Fig. 1. Injection molding production line's state transition model.

To evaluate the productivity of a production system, we use discrete simulation. In particular, we simulate the flow of material and information in the production line through a discrete-time progression. In this case, the machine states and the state transition in a production system is modeled, and the productivity of the production system is evaluated by grasping the working and non-working states in the system states.

By implementing the state transition model of an injection molding production line that was previously proposed in our present simulation and modeling the state transition over time, it is possible to calculate the production time and throughput amount. Moreover, by assigning energy consumption to each of the system states, the total energy consumption over time can be calculated. Furthermore, by simultaneously evaluating the throughput amount and energy consumption, we are able to calculate the specific energy consumption, which is a representative index for evaluating the productivity and total energy consumption.

The specific energy consumption is an index evaluating the amount of energy consumption per product, and it is calculated from the amount of throughput P [product] and the energy consumption amount E [J] using Eq. (1).

$$U = E/P \tag{1}$$

We will explain the method of applying an injection molding production line's state transition model to a simulation.

First, we implement a state transition model of each process. For every process, a computer model based on a simulation is implemented, and information regarding state transitions at each state and sub-state is programed in the model. Overall, we implement this model for five processes.

Next, the constraints for the state transitions of each process are implemented. Since an injection molding machine and auxiliary machines in the production line work together, the proposed state transition model has procedural relations and constraints relating to the defined state transitions. In the procedural relations of state transitions, there are state and sub-state transitions in each process that serve as constraints for the generation of state transitions in other processes. Hence, with simulations, by implementing an imaginary signal for the state and sub-state transitions in each process and establishing a program for the process and other processes' states and sub-states to incorporate those signals, the procedural relations and restrictions in the state transitions are modeled.

Furthermore, a program for managing the input and output of information at each state is implemented. For each state of a process, the energy consumption is provided as input data. Moreover, a program that provides information related to productivity and energy consumption as output by simultaneously generating information on energy consumption and state transition over time is used.

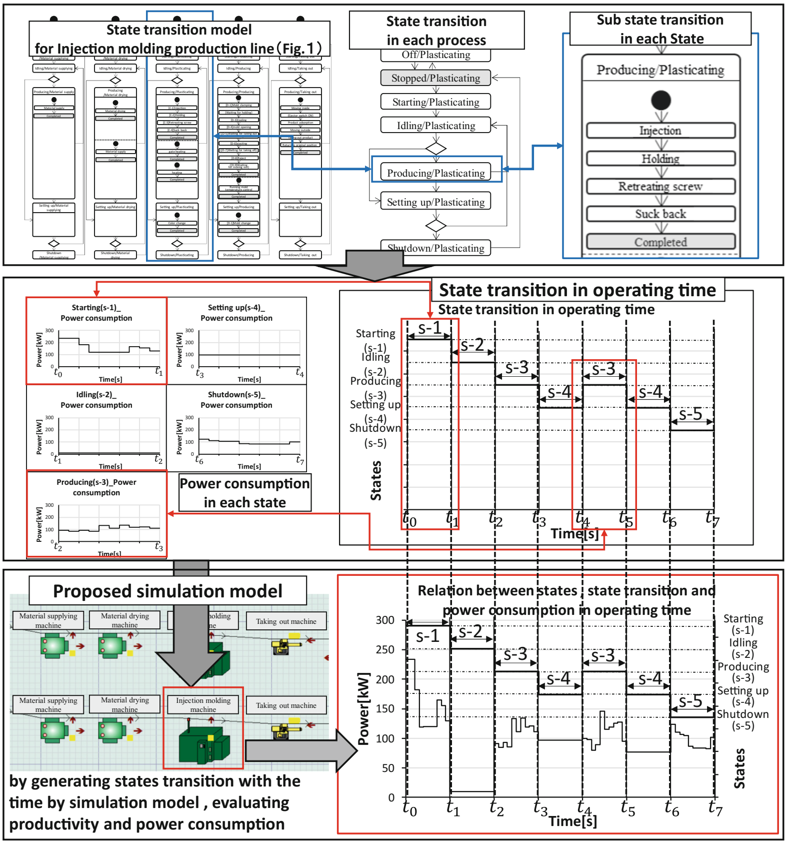

Fig. 2. Summary of the proposed evaluation method.

Based on the above procedures, a state transition model is implemented in a simulation. The implemented simulation simultaneously generates time-labeled state transition information as well as time-labeled state and energy consumption information, and it evaluates productivity as well as energy consumption. A summary of the evaluation method based on the implemented simulation is shown in Fig. 2. The state transition model in the production line is implemented in WITNESS which is a modeling tool for production system based on a discrete event simulation. WITNESS comprises basic models to represent machine behavior and can be extended using Visual Basic to create the required production system models.

3 Case Study

In this chapter, the proposed simulation method is used to assess whether the method successfully yields evaluation indicators regarding productivity and energy consumption. To verify the performance of the proposed method for different sys-tem boundaries, the following three cases were studied. Case study 1: single injection molding machine, Case study 2: one injection molding line including a single injection molding machine with auxiliary machines, and Case study 3: two parallel injection molding lines.

The following assumptions are made in this case study: six product items are processed in each production line, the lot size of each item is fixed, a production line produces one lot for each of the six product items every working day, changeover of molding die or material occurs during lot switching, and the simulation period is one-day operation from machine turn on to machine shutdown, i.e., about 10 h.

The energy consumption of each machine state was measured. The measured da-ta were different for each product item owing to changing production conditions, such as the cycle time and the amount of material usage.

In this case study, we confirmed reproducibility of the proposed method. When we applied the simulation model to a product item whose lot size was one, the model correctly yielded the state transition times and energy consumption of the machines. In addition, by adopting similar approaches not only for different product items but also for different lots, we could confirm reproducibility of the proposed method.

In this case study, the measured production time and energy consumption values were input to the state transition model in the injection molding production line. For simulation model validation, we examined whether the results of the evaluation indicators were in accordance with the results of manual calculations.

3.1 Case Study 1

In this section, the material plasticizing and manufacturing process attempted by the injection molding machines are targeted to access the proposed evaluation method. The simulation results are shown in Table 1 and Fig. 3.

Table 1. Calculated evaluation index for consumption energy and productivity.

classification	evaluation index	unit	Case study 1	Case study 2	Case study 3	
			Machine No.1	Machine No.1 & auxiliary machinery	Machine No.1 & auxiliary machinery	Machine No.2 & auxiliary machinery
For Productivity	Total output	product	442	442	442	602
	Operating time	s	33084	33084	33084	30799
	Total time from start time of "starting state" to finish time of "Shutdown	s	31682	31682	31682	28204
	Producing time	s	25082	25082	25082	25204
	Total time to Start-up and Shutdown	s	1402	1402	1402	2595
	Total time to Set up	s	6600	6600	6600	3000
	Throughput per unit time	product/s	0.01	0.01	0.01	0.02
	Utilization ratio	%	79.17	79.17	79.17	89.36
	Specific energy consumotion	kWh/product	2.32	2.61	2.61	1.88
For Energy consumption	Energy consumption in producing time	kWh	816	816	816	895
	Energy consumption in waiting time	kWh	207	207	207	113
	Total energy consumption	kWh	1023	1155	1155	1135
	Maximum instantaneous power consumption	kW	248.00	259.25	259.25	242.34
	Maximum demand power	kW	146.62	159.63	285.00	*Maximum demand power in two product line

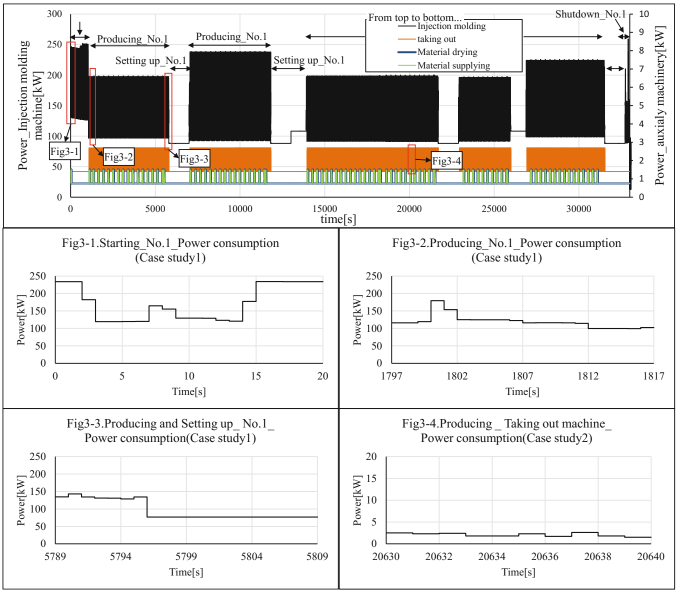

Fig. 3. List of the computed results for electricity consumed in case study.

3.2 Case Study 2

In this section, we verify the evaluation method with respect to the injection molding production line of case study 1 incorporating the material supplying process, material drying process, and product taking-out process. The implementation conditions are the same as in case study 1. The results are shown in Table 1 and Fig. 3.

3.3 Case Study 3

In this section, we verify a production system with two injection molding production lines, such as those used in case study 2. The results of the simulations are shown in Table 1.

In addition, Case study 3 also attempts change the production lot sequence so that a better production plan takes into account both the productivity and electricity consumption can be considered. The lot sequence in the production line with injection molding machine No. 2 is fixed. On the other hand, the lot sequence in the production line with injection molding machine No. 1 is changed. The original lot sequence in the line with injection molding machine No. 1 is item Nos. 1, 2, 3, 4, 5, and 6. The better sequence is item Nos. 5, 6, 4, 3, 1, and 2. By changing the lot sequence in the production line, the specific energy consumption reduces from 2.19 kWh/product to 1.93 kWh/product. The maximum electricity demand, which is defined as the mean electricity consumption in 30-min intervals in the two production lines, decreases from 285 kW to 249 kW.

3.4 Results of the Case Study

In case study 1, we evaluated whether the proposed simulation-based evaluation method can evaluate the productivity and energy consumption of the material plasticizing and producing processes conducted by the injection molding machines. The state transition in each process can be modeled as the simulation progresses, confirming the fact that the proposed method can be used to evaluate productivity. Moreover, it was confirmed that the energy consumption in each state can be calculated. Furthermore, by generating the system state and the energy consumption simultaneously over time, the specific energy consumption, which is a representative index for simultaneously evaluating productivity and energy consumption, could be calculated. Therefore, in case study 1, the effectiveness of the proposed simulation-based evaluation method could be confirmed.

In case study 2, whether the proposed simulation-based evaluation method can evaluate the productivity and energy consumption of a production line constructed with the addition of three auxiliary machines to case study 1 was verified. As with case study 1, the state, state transition, and energy consumption vary with time. Moreover, the state transition generation in other processes following the state transition of each process could be modeled. Hence, in case study 2, the effectiveness of the proposed simulation-based evaluation method could be confirmed.

In case study 3, whether it is possible to evaluate the productivity and energy consumption of a production system with two production lines constructed from injection molding machines and three auxiliary machines was verified. Even when the number of production lines increased, evaluations of productivity and energy consumption were possible, as in case study 2. Therefore, in case study 3, the effectiveness of the proposed simulation-based evaluation method could be confirmed. Furthermore, we confirmed that the proposed simulation method could evaluate energy consumption of the entire production system, which is one of the important matters of concern when we consider production plans. Thus, the proposed method can be useful for production planning in terms of energy consumption of production systems.

According to the above, the usefulness of the proposed method for simultaneously evaluating productivity and energy consumption by implementing a state transition model for an injection molding production line through a simulation was confirmed.

4 Conclusion

This research presented a method for simultaneously evaluating the productivity and energy consumption of an injection molding production line. The method proposed method involves application of the state transition model of an injection molding production line to a simulation. Different case studies were examined, and the effectiveness of the proposed evaluation method was confirmed. The proposed method could efficiently evaluate the productivity and energy consumption using different system boundaries of the production system, such as a single injection molding machine, single injection molding machine with auxiliary machines, and multiple production lines. In future, we will attempt to develop a method for reducing the electrical cost of maintaining specific energy consumption in an injection molding production line.

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Erratum to: A System Maturity Model for Supply Chain Management

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Due to a mistake during the uploading process the originally published article proposed a methodology for a performance sensitivity analysis. As this is not in alignment with the intended content of the paper, the following changes have been made in the updated version:

- Exclusion of the chapter *Scenarios and Models*
- Exclusion of the chapter *System Sensitivity Analysis by Using Simulations*
- Inclusion of the chapter *Supply Chain Maturity Model: SCMM*
- Inclusion of the chapter *Supply Chain Maturity Model with business management problems*
- Inclusion of the chapter *Supply chain management problems and investment problems on information technologies*
- Alignment of the introduction and the conclusion to the new content

The updated online version of this chapter can be found at https://doi.org/10.1007/978-3-319-66926-7_1

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