EcoProduction
Environmental Issues in Logistics and Manufacturing

Paulina Golinska *Editor*

EcoProduction and Logistics

Emerging Trends and Business Practices

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Environmental Issues in Logistics and Manufacturing

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Preface
On the Way to Environmental Friendly Production

Environmental consciousness is nowadays playing a growing role in production and logistics. Planning, developing, and controlling of manufacturing processes and technologies should not only support the goal of high productivity but should also respond to the need of resource and energy conservation and pollution prevention. Environmental awareness is driven mainly by the scarcity of natural resources and by more strict legal regulations. The modern enterprise policy should look at the relations between economic actions and ecological consequences.

Ecoproduction is a new business approach which focuses on the most efficient and productive use of raw materials and natural resources in order to minimize footprints on the natural environment. This book aims to provide the state of the art as well as new ideas of the environmental conscious operations management. The contributors present in the individual chapters problems related to: eco-friendly production technologies; recycling and waste reduction. Scope of the topics discussed in this book also covers pollution prevention, and energy efficiency. Authors describe problems of information management in complex systems.

This book presents both emerging theoretical methods as well as business practices. It might be interesting both for researchers and practitioners. Contributors present and discuss the tools, methods, and applications to make manufacturing operations environmentally friendly and conform to environmental regulations. Case studies are provided to guide readers in areas outside their expertise.

In this monograph the emphasis is placed on three main areas:

- sustainability and life cycle management;
- environmental friendly resource management in production;
- information systems and information management supporting sustainability.

The aim of the first chapter is to examine the various challenges of requirements management regarding the challenge of Product Life Cycle Management. Authors present an interesting integration framework explaining how to manage requirements information throughout the whole product life cycle.

The second chapter is dedicated to sustainability issues in different countries in Asia and Oceania region. Author compares a number of criteria to identify the risks and opportunities of innovative development of these countries. An integrated sustainability model based on Sustainable Development Index and Developmental Risk Index is described.

The next chapter aims to introduce the concept of strategic eco-controlling. Applying the strategic planning and controlling systems to support decision making concerning sustainable development and environmental protection. The potential of business intelligence application for supporting eco-controlling is examined.

Environmental proactivity is one of the key aspects related to corporate social responsibility of companies. In the two subsequent chapters authors analyze whether through a higher environmental proactively orientation companies might generate added value. Two industries (ceramic industry and food industry) are taken in consideration to examine the theoretical concepts. Authors perform quantitative analyses to find out main obstacles and benefits of proactive approach.

In the second part of this book emphasis is placed on effective resource management. Increasing scarcity of resources and high energy costs have led to an increasing importance of the utilization level monitoring. Despite the big number of projects and research in this area, there is still a lack of practicable support for small and medium enterprises (SME).

The opening chapter in this part aims to prove relevance of environmental problem in production management and to propose indicators to assess the efficiency of environmental friendly production.

The subsequent chapter highlights the problem of waste management on the shop floor. Authors present the organizational and technological conditions influencing the waste generation. The detailed case study of medium size company from packing sector is provided.

The next two chapters describe the problem of sustainable orientation in maintenance management. Sustainable maintenance is a new challenge for industrial companies. It requires continuous development and constant improvement of maintenance processes, increasing operational excellence and safety of operations, and infrastructure. The theoretical studies are concluded with case study in glass processing company.

The problem of energy efficiency is described in the chapter “Framework for Controlling Energy Consumption of Machine Tools”. Authors present the results of research project focused on communication mechanisms in production systems and working machines in order to asses energy consumption values automatically and coherently on all required levels.

The problems of energy management are continued in the chapter “Mobile assistance for energy-efficient production—Scenario parameters and system impact”. It describes scenarios to integrate mobile and stationary devices for energy-efficient operation within the framework of order-related manufacturing. Authors identify stakeholders, who may influence energy-efficiency measures in a manufacturing system.

The chapter "Scheduling a Single Mobile Robot Incorporated into Production Environment" focuses on mobile robots which will automate extended logistics tasks in production facility. Mobile robots are more flexible to perform certain tasks such as transporting and feeding materials, pre-assembly, or quality inspection at different workstations. Using such mobile robots can lead to increase in production efficiency. Authors present the benefits of better resource allocation by application of mobile robots.

The topic is continued in the next chapter "Declarative approach to cyclic scheduling of multimodal processes" where authors present a novel approach for scheduling analysis employing the declarative modeling.

The last part of this book covers information systems and information management supporting sustainability. In the opening chapter authors present the research related to the applicability of software technologies for simulation in green production and logistics. Six specialist simulation packages are evaluated in detail regarding defined "green criteria". The chapter is concluded with case study in medium size food company.

The next chapter considers an organization's environmental impact assessment with respect to a water resource. It investigates formal approaches to temporal monitoring design. The focus is on efficient data collection and analyses. Authors explain how the proposed approach can be incorporated into an organization's environmental information system.

In the subsequent chapter the conception of interactive information and decision support system for urban and industrial air quality management is presented. The emphasis of the project AirWare system developed within Eureka WEBAIR is on real-time analysis and multi-media information. The proposed solution integrates meteorological data and forecasts, air quality, and emission monitoring from distributed mobile sources via the Internet.

The chapter "Organizational Learning and Environmental Engineering with Special Focus on Health Care" combines research on environmental engineering, environmental management systems and learning organizations in context of hospital organizations. The author explains how the implementation of environmental engineering could be a possibility to extend organization's environmental awareness.

The last chapter describes complementary information systems on research in Europe on ICT for environmental sustainability. The authors explain the result of EC financed project ICT-ENSURE regarding its goal, contents, functionality, and mutual interaction of the information systems.

This monograph provides a broad scope of current issues important for the development of Ecoproduction. It is a composition of theoretical trends and practical applications. The advantage of this book is presentation of practical application from number of different countries and industries.

Paulina Golinska

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Part I
Sustainability and Life Cycle Management

Supporting Product Lifecycle Management with Requirements Information

Jorma Papinniemi, Lea Hannola and Michael Maletz

Abstract Consistent definition, categorization and operation of products delivered to global markets and customized for different buyer segments is one of the major challenges for Product Lifecycle Management (PLM). Customer requirements with all related product requirements need not only be integrated with each other, but with all processes and stakeholders involved through the related business functions of product lifecycle. In this chapter we examine the various challenges of requirements management, especially related to Product Lifecycle Management. We introduce an integration framework, according to which challenges at different levels are categorized. In order to illustrate the specific integration challenges of requirements information with PLM, a case study of automotive industry is introduced. As a conclusion, the study shows the core points where and how the concepts of PLM and requirements management should be developed to create requirements-integrated solutions for extended products and systems through the product lifecycle.

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1 Introduction

Manufacturing companies are facing more and more comprehensive challenges when coping with customer requirements related to product requirements. In order to produce new competitive products and innovations, companies should pay more attention to managing requirements information throughout the whole product lifecycle.

Product Lifecycle Management (PLM) is an integrative information-driven approach comprised of people, processes/practices, and technology to all aspects of a product's life and its environment, from its design to manufacture, deployment and maintenance. Product Data Management (PDM) is a systematic, directed set of tools by which to manage and develop an industrially manufactured product. Information systems of PDM and with wider frame -oriented PLM systems are based on a data model enabling accessing, updating, manipulating and reasoning about product information in a fragmented and distributed environment (Grieves 2006; Saaksvuori and Immonen 2008).

Customer requirements management is generally not a part of current PLM systems. Because today's product development process is very fast-moving and products have become more customer-oriented, it is very important not only to collect but also track customers' voices and feedback to satisfy the demands of the markets. According to Schulte (2008), the classical customer-oriented approaches can be classified as solutions for the identification and evaluation of customer requirements, measurement of customer satisfaction, and customer integration into value-added processes.

Requirements management is a critical activity, which ensures that the voice of the customer is heard throughout the product development process, and it is not restricted to a single phase only, but takes place in all phases of the product lifecycle. Requirements are not only significant at the front-end phase of the innovation process, but are essential through the whole lifecycle, covering all life cycle activities associated with understanding a product's necessary capabilities and attributes (Maletz 2008a). According to Jiao and Chen (2006), it appears to be difficult for engineers to translate customer requirements, i.e. the voice of customers, into concrete product and engineering specifications. In addition, the requirements for products typically change during new product development, products are becoming increasingly complicated and the customer segments more fragmented (Möttönen 2009). Thus, requirements management has become a critical activity throughout the PLM.

In this chapter we examine what kinds of challenges are met when linking requirements management with Product Lifecycle Management, with emphasis on the early phases of the product lifecycle. In addition, the aim of this chapter is to find out how product-related information on customer requirements could be utilized better and integrated with PLM. We focus on some of the most important challenges and capabilities of requirements management (RQM) and on the integration of RQM and PLM. The theoretical part consists of a literature review to outline firstly the definitions and features of PLM, and secondly to introduce the processes, methods/tools and challenges of RQM. As a result we categorize the challenges of integrating RQM with PLM, by combining literature results and earlier research in the manufacturing industry. The integration framework introduced in this study is utilized in the categorization of the challenges. In the case study, company-specific challenges are identified when integrating requirements management with PLM in the case company operating in the automotive industry.

2 Features of PLM Concepts and Systems

The term Product Lifecycle Management emerged in the late 1990s after nearly twenty years of market and technological evolution. With the advent of Computer Aided Design (CAD) solutions as the means of creating a geometric model of products, engineering design entered a new era. Product Data Management systems appeared during the1980s, focusing originally on solving the problems of CAD file management by providing a data vaulting facility, and being typically limited to the engineering aspects of products.

2.1 Definitions and Processes

According to Grieves (2006), PLM is an integrative concept for managing products and product-related information throughout the whole product lifecycle, from design to manufacture, deployment and maintenance - culminating in the product's final disposal. PLM systems, as an extension of PDM systems, are based on a data model. They enable accessing, updating, manipulating and reasoning about product information produced in different phases of the product lifecycle and is usually scattered in a fragmented business network.

CIMdata defines PLM as a strategic business approach that applies a consistent set of business solutions in support of collaborative creation, management, dissemination, and use of product definition information across the extended enterprise, from concept to end-of-life, integrating people, processes, business systems, and information (Maletz et al. 2008b).

PLM can be considered as a holistic business concept for managing and controlling the product and product-related information. PLM does not refer to any particular software or method. PLM is a large functional system, built of the PLM concept and a group of systematic methods used to control the product information; it combines data, technologies, methods, tools, processes and people together in different phases of the product lifecycle. Product information means (1) the product definition data, (2) the product life cycle data and (3) metadata, which describes the product and lifecycle data (Saaksvuori and Immonen 2008).

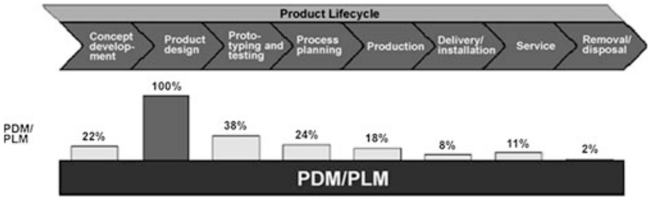

Fig. 1 Use of PDM and PLM throughout a product lifecycle; normalized to the product design phase (Lee et al. 2008a, p 298)

A typical PLM process with different stages has been introduced by Lee et al. (2008a) (see Fig. 1). The adoption of PLM systems in industry started primarily in the automotive and aerospace industry, followed by the machinery industry (Lee et al. 2008a). There are several vendors, including Windchill, IBM, Dassault Systems, SAP, UGS, etc. offering PLM solutions. Although PLM is meant to manage product information throughout the entire lifecycle of a product, an international study revealed that the adoption of PLM is still mainly limited to product design (Lee et al. 2008a), as can be seen in Fig. 1. The figure shows the relative intensities of PLM and PDM adoption in several stages of the product lifecycle. It can be seen that PLM has so far been used nearly ten times less frequently in the service phase than in product design, and that the use of PLM and PDM in the retirement phases is insignificant. Today's PLM applications are more than 5 years behind state-of-the-art solutions. The trend in the next few years is expected to focus on product lifecycle stages in general and on an improved support of engineering collaboration functionality.

2.2 Typical PLM Objects

The major benefit of PLM lies in seamless integration with other fields of product processes. This is done by bringing together e.g. product data, functions, processes, project tasks, costs etc. in direct correlation with related PLM objects (parts/items, documents, bill-of-material structures, change forms, requirements, resources, facility, equipment). These objects may be authored and managed in e.g. different PDM systems and other software tools used in product development (Maletz et al. 2008b).

2.3 Use of Typical PLM System Functionalities and Capabilities

As a software application, PLM is an extension to PDM systems. PLM systems are distributed technological information systems for archiving, administrating and providing all product information at the right time and place. Almost all modern

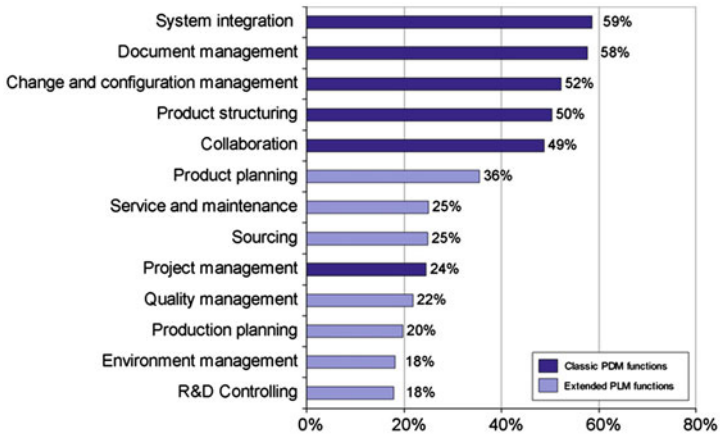

Fig. 2 Average system profile (survey with 17 PLM vendors by Schuh et al. 2007, p 215)

PLM systems provide the basic features for product information management: data (file) vault management, document and object management, release and change management, product structure management, viewing, mark-up and image service, classification and retrieval, and configuration management.

A vendor-neutral software requirements catalogue was used in a survey of Schuh et al. (2007) to assess the PLM solutions available on the market. The use of typical PLM system functionalities and capabilities was examined. The data analysis (see Fig. 2) showed that the fulfillment level was higher for the classic PDM functions, except for project management. The lower fulfillment degree for project management can be explained by the widespread use of stand-alone solutions (e.g. MS Project) integrated with project management modules from ERP. The analysis of extended PLM functions indicated a trend of enhancing product planning and service, and maintenance system capabilities in the next years. The average fulfillment levels were still low (36 and 25 %, respectively). However, there were already three lead vendors in each of these groups, covering more than 70 % of the requirements. Additional qualitative data obtained in contacts with vendors confirmed this trend.

3 Requirements Engineering & Management

3.1 Requirements Engineering & Management Process

The concept of product lifecycle management can be seen to be connected integrally to requirements engineering (RE) (Möttönen 2009). RE as a field originates from software engineering, and it is a sub-discipline of systems engineering. Traditionally, RE has been seen as a front-end activity that forms a solid basis for the other activities

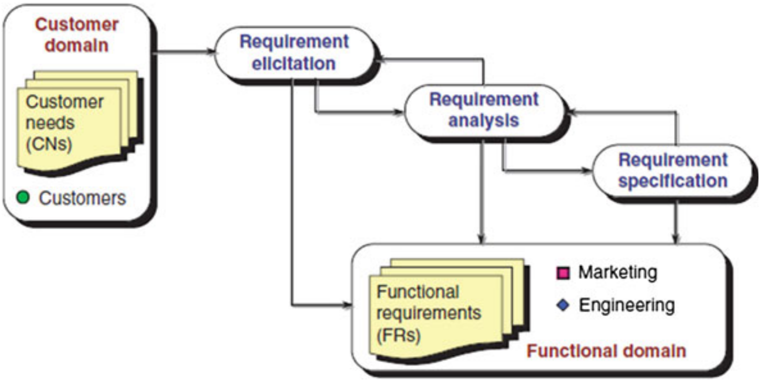

Fig. 3 Customer requirements management process (Jiao and Chen 2006, p 174)

of product development (Kauppinen et al. 2007). Wiegers (2003) defines RE as the domain that includes all project life cycle activities associated with understanding a product's necessary capabilities and attributes. According to Wiegers, RE can be divided into requirements development and requirements management (RQM). The requirements development phase focuses on developing baseline requirements before the actual product development, and it can be further subdivided into requirements elicitation, analysis, specification, and validation, and once the development is started, the requirements are managed through a requirements change process (Wiegers 2003). RQM is concerned with all of the processes involved in changing system requirements (Sommerville and Sawyer 1997), and it is a process that supports other RE activities and is carried out in parallel with them.

There exist several definitions of requirements management in the literature, however, and for example Tseng and Jiao (1998), and Jiao and Chen (2006) define requirements management as the whole process of requirements elicitation, analysis, and specification, as depicted in Fig. 3. The evolution process of design requirements ends up with a complete specification of functional requirements, from which a successful design can follow (Jiao and Chen 2006).

Requirements elicitation is the first step in the requirements management process dealing with customer needs in the customer domain. According to Jiao and Chen (2006), the requirements elicitation phase has several activities, which include e.g. systematical extracting and making inventory of the requirements of customers and stakeholders, including the environment, feasibility studies, market analyses, business plans, and benchmarks of competing products. The second step is requirements analysis, where the customer requirements are analyzed and interpreted to derive explicit requirements that can be understood by marketing and engineering. This phase includes classification, prioritization, and negotiation of customer needs. The third phase, i.e. requirements specification, is about the definition of concrete product specifications in the functional domain, which includes continuous interchange and negotiation within a team regarding conflicting and changing objectives.

Table 1 Properties for requirements classification

Categorization			Attributes			
Dimension	Level	Type	Target	Source	Priority	Status
Features	Project	Product	Engine	End-user	Must have	Created
Costs	Product	-Functional	Transmission	Strategic	Important	Active
Scheduling	System	-Non-functional	Cab	Marketing	Not critical	Change
Reliability	Component	Process	Hydraulics	Customer supp		Obsolete
		Organizational	Axles/differential	Sales channel		
			Electronices	Legal		
			Stying	Standard		
			Other	Engineering		
				Production		
				Competitor		
				Envirolmental		
				Social		

3.2 Requirements Classification

The requirements for products can be set by the end-users, customers, other stakeholders, standards and technical and/or environmental constraints. The diverse definitions of the term requirement suggest that there is no universally accepted definition of what a requirement is (Kauppinen 2005). On the other hand, Kauppinen discloses that researchers seem to agree relatively widely on the division of requirements into functional and non-functional ones, and many researchers also classify constraints as one of the requirement types. In addition to the different requirement types, Kauppinen points out that there are different levels of requirements as well, and requirements can be defined from the business, user and development perspectives. Wiegers (2003) defines

1. *business requirements* as a high-level business objective of the organization that develops a product, or of a customer who produces it,
2. *user requirements* as user goals or tasks that users must be able to perform with a system, or statements of the user's expectations of system quality, and
3. *functional requirements* as a statement of a piece of required functionality, or a behavior that a system will exhibit under specific conditions.

According to Hansen et al. (2008), different levels of requirements may be discovered, specified and managed across stakeholders or organizations, and ensuring consistency across different levels creates a complex set of challenges.

For example, Table 1 presents some categorization and attribute examples for creating requirements classification in the commercial vehicle industry. By using dimension information as categorization, impacts can be analyzed from the perspectives of features, costs, scheduling, and reliability. Also hierarchy levels (project, product, system and component) can be used for requirements categorization. In addition, a requirement type can be added, such as functional, non-functional or organizational requirements. However, if more information is needed for specifying the requirements, this can be done by adding attributes related to the target, source, priority and status of a certain requirement. Documenting and linking the attributes related to a certain requirement ensures that e.g. a certain component level requirement can be traced back to the initial customer need. When utilizing the classification of Table 1 in other industries, the target elements and possibly some other elements must be adapted to the technology base of the company.

3.3 Challenges Related to Requirements Management

Understanding and fulfilling customer requirements has been recognized as an urgent challenge for companies across industries (Jiao and Chen 2006). According to Möttönen et al. (2009), the more complex and abstract a product is, the more vital RQM becomes for a successful new product development process, and especially for embedded systems containing both hardware and software. The requirements for products typically change during new product development, products are becoming increasingly complicated and the customer segments more fragmented, and thus requirements management has become a significant challenge for especially high tech companies (Möttönen 2009).

According to Tseng and Jiao (1998), requirements have the tendency to be vague, fuzzy and difficult to manage. Furthermore, requirements are derived from different perspectives of the product lifecycle, including such issues as manufacturing, reliability, maintainability, and environmental safety. Jiao and Chen (2006) point out that different stakeholders use different semantics and terminology, requirements are often poorly understood, and they are expressed in abstract, fuzzy, and conceptual terms. Valenti et al. (1998) discovered that several users may evaluate the same information need differently, or may present requirements raising either conflicting or competing use of limited resources, according to their role in the organization, background or mindset. In addition, there may be problems when mapping the customer requirements and relationships in the customer domain into functional requirements in the functional domain (Jiao and Chen 2006).

In general, requirements change, new requirements will appear or requirements can be removed at any phase of a product's lifecycle. One primary cause for requirement volatility is the fact that the user or customer needs evolve over time. Another cause for changing requirements is that requirements are a product of the contribution of many individuals, and these individuals often have conflicting needs and goals. Requirements may also emerge from new stakeholders who were not originally consulted at the early phases of the product lifecycle (Sommerville and Sawyer 1997). Furthermore, according to Ovaska (2009), the understanding of the requirements changes during product development. Preconditions, attitudes and expectations among stakeholders change the participants' interpretation and understanding of the requirements. In addition, the priorities of requirements may change. The importance of a particular requirement may change during the development, as people often find it difficult to assign priorities during the requirements elicitation phase, because they do not have a complete picture of their needs and product requirements at that time.

Requirements management is a multi-disciplinary effort, where requirements come from several domains, such as mechanics, software, and/or electronics. Although several tools exist to support requirements management in each of these domains, the integration of domain-specific requirements is still a huge challenge. Changing requirements in a certain domain may affect also other domains, and the dependencies between domain-specific requirements have to be ensured. Among others, systems engineering addresses this challenge.

3.4 Methods and Tools

Several methods and tools have been developed to help organizations to obtain a better understanding of customer requirements (Wang and Ji 2010). In the following paragraphs, some methods and tools are presented, especially related to the classification of customer requirements.

3.4.1 QFD

Quality function deployment (QFD) is a widely used customer-driven design and manufacturing approach developed in Japan during the 1960s, and it has been used in the manufacturing industry for several years. Generally, it utilizes four sets of matrices called the house of quality (HOQ) to translate customer requirements into engineering characteristics (Li et al. 2009). An HOQ is a conceptual map used by a cross-functional team to identify the customer and user requirements, and how best to develop systems (Karlsson 1997). According to Wiegers (2003), QFD provides an analytical way to identify those needs and requirements that will provide the greatest customer satisfaction. The QFD technique classifies requirements as

1. *expected requirements*, where the requirement might not be even stated by the customers, but who will be disappointed if they are missing,
2. *normal requirements*, and
3. *exciting requirements*, which provide high benefit to customers if they are included in a product but little penalty if not (Wiegers 2003).

3.4.2 Kano's Model

Kano's model is a widely used tool for understanding the voice of customers, and the model categorizes different customer requirements based on how well they are able to achieve customer satisfaction (Wang and Ji 2010). Thus, the model suggests that there are three main types of customer requirements, must-be, one-dimensional and attractive attributes (Wang and Ji 2010):

1. customers take must-be attributes for granted if they are fulfilled, but are dissatisfied if the product does not meet these requirements sufficiently,
2. the fulfillment of one-dimensional attributes is positively and linearly related to the level of customer satisfaction, and
3. the fulfillment of attractive attributes will lead to greater than proportional customer satisfaction, but the absence of these attributes does not mean dissatisfaction because they are not expected.

In addition, Kano's model also proposes another set of three categories of customer requirements, which are indifferent, reverse and questionable. A Kano questionnaire has been designed to help in categorizing customer requirements into the six Kano's categories (Wang and Ji 2010).

3.4.3 Extensions of the Original Kano's Model

The analytical Kano model (A-Kano) extends the traditional Kano model by introducing

1. Kano indices, which are quantitative measurements of customer satisfaction,
2. Kano classifiers, which consist of a set of criteria to classify customer requirements,
3. Configuration index, which provides a decision factor for selecting the functional requirements, and
4. Kano evaluator, which is a performance indicator leveraging upon both the customer's satisfaction and producer's capacity (Xu et al. 2009).

Xu et al. (2009) propose a comprehensive process model to integrate these techniques for customer need analysis. Further, Lai et al. (2004) have combined the Kano model and QFD to meet customer requirements in product design, and to provide a product design optimization method. This method uses the Kano model to analyze the customer requirements and QFD to translate customer requirements into product design. Lee et al. (2008b) have presented an integrative approach by incorporating the Kano model with a fuzzy mode into the matrix of QFD and adjusting customer requirements weights. In addition, Li et al. (2009) have introduced an integrated method, which combines the rough set -theory, Kano's model, the analytical hierarchy process (AHP), and the scale method in order to obtain the final importance of customer requirements in the product planning house of quality.

3.4.4 Tools for RQM

The challenges related to requirements classification and management have raised an absolute need for requirements management tools. According to Maletz (2008a), a great number of requirements management tools are available in today's market, and most of them are developed and used in the field of software development. The International Council on Systems Engineering (INCOSE) and the Tools Database Working Group (TDWG) have gathered information on requirements management tools since the 1990s, and publish a comparison of the features of many RM tools, updated periodically (INCOSE 2011). INCOSE divides the tools into *requirements management* and *requirements generation tools,* and further the requirements management tools into three different categories (INCOSE 2005):

1. *Requirement Classification Tools.* These tools help the engineer classify the requirements based on work to be done, so that the requirement analysis activity can be scheduled and tracked. They help an engineer to classify requirements based on how the requirements will be used in modeling so that completeness of traceability can be monitored.
2. *Requirements Capture & Identification Tools.* Requirements capture tools accept text information from heritage sources, users, customer requirements and customer operations concepts. They assist an engineer in finding relationships among entities in the information and in moving among the entities, whereas requirement identification tools aid the engineer in separating requirements in the information before him from extraneous information. Modern versions of these tools use natural language processing to identify statements containing imperatives of any kind in the information.
3. *Requirement Traceability Tools.* enable the engineer to link requirements to their source, to changes in requirements, and to modeling elements that satisfy the requirements. They provide traceability among the successive documents that are used to review the system development.

Commercial tools especially for requirements management are e.g. IBM Rational DOORS, MKS, or Teamcenter Requirements.

4 Challenges and Capabilities in integrating RQM with PLM

One of the most holistic approaches to integrate requirements management with product lifecycle management found in the literature is the concept for integrated requirements modeling (Maletz et al. 2007). Integrated requirements modeling is a consistent concept allowing continuous integration of requirements into every phase of the product lifecycle. The concept combines the different aspects to be taken into consideration. Starting with the requirements specification document, ontology with requirements is the basis for classification and traceability. Mapping and verifying requirements structures with other product structures through

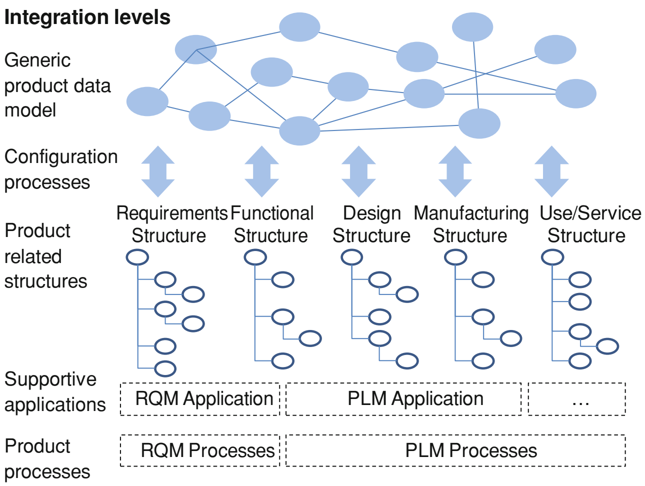

Fig. 4 Product structure integration through product lifecycle (adapted from Maletz et al. 2007)

lifecycles is one point of integration needed. Also different representation formats and tools are needed for better understanding of different stakeholders (Maletz 2008a; Nilsson and Fagerström 2006).

In order to achieve better understanding of the different integration challenges, we have developed a framework for product structure integration. In this framework, the recognized challenges are categorized on different integration levels. As a result, we have categorized the challenges of integrating RQM with PLM by combining literature results and earlier research in the manufacturing industry.

4.1 Integration Levels of RQM and PLM

It is important to have a master concept capable of collecting a variety of engineering information and providing the lifecycle processes with consistent product data information. The generic product structure, which can serve as a central information pool, is such a concept. All relevant structures, including the requirements net, functional net etc. are derived dynamically and linked bidirectionally with the generic product structure. These structures can consist of general terms (i.e. placeholders) which serve as universal carriers of information (Maletz et al. 2007). This means that specific configuration processes are needed for realizing vertical integration between the generic product structure and product-specific domains, such as functional, design, manufacturing, use and service domains, as presented in Fig. 4.

In this study we concentrate mainly on horizontal integration challenges at the three lowest levels: product-related structures, supportive applications and product processes. Moreover, capabilities required for integrating RQM with PLM are introduced.

4.2 Product-Related Structures

Product structuring describes the manner in which objects are arranged to form a product. These objects are managed in PDM systems, where they are viewed as central data-building blocks capable of describing structures from the part level upwards. Mapping requirement structures to product structures, updating the requirement structures, and linking other structures, such as functional or manufacturing structures can lead to arduous manual process (Maletz et al. 2007).

Consequently, the next type of challenges are probably met and coped with by integrating the requirements with product-related structures

- Structure management does not cover all phases of the product lifecycle: customer requirements, product features, functionalities, design, manufacturing & supply, delivery, implementation /use, service, disposal;
- Inconsistent conformance of requirements slows down rapid development and change management of interrelated structures;
- Tracking and tracing of requirements to other product-related structures may not work bidirectionally (upwards or downwards derivation);
- Configuring product instance structures according to specific requirements/ options by customer;
- One requirement can exist in several places in the product structure, and traceability must be ensured to all equal requirements.

4.3 Product-Related Processes

Typical integration challenges between the RQM and PLM processes occur due to the following reasons:

- Different terminology and concepts of the RQM and PLM process domains may cause communication problems;
- Coordination and collaboration between RQM and PLM processes is not easy to manage;
- Different lifecycle scopes: RQM is mostly seen as a project-oriented task (project lifecycle), PLM is a product process (product lifecycle), and ALM is an application process (application lifecycle);
- Change management processes of intangible requirements and physical products have completely different time frames;
- Challenges related to the processes of RQM and PLM are often tried to be solved with commercial tools, even before the process itself is managed;
- Commercial tools often guide RQM and PLM processes. When these tools are separate applications and follow different processes, the integration of product processes becomes challenging.

4.4 Supportive Applications and Tools

Typical integration challenges between RQM and PLM applications occur due to the following reasons:

- Interoperability of RQM tools and PLM systems;
- Separate applications exist for RQM and PLM;
- Only a few PLM applications include some features of requirements management;
- The functionalities of applications do not cover all the required needs of product and business processes;
- The requirements are collected and scattered to several different systems;
- The requirements specification phase for a new product can be outsourced to another company, which has its own tools for RQM.

4.5 Capabilities Required for Integrating RQM with PLM

Requirements management meets not only horizontal product integration processes through the lifecycle, but also a complete set of capabilities that establish a strong vertical link across diverse engineering activities (Abramovici and Bellalouna 2007). The capabilities needed for vertical integration between RQM and PLM can be described as follows:

- Capturing the needs and searching for available requirements for re-use
- Refining, flowing down, and validating requirements;
- Allocating requirements, e.g. to support and optimize the overall product quality requirements in the lifecycle (Tan and Yun 2008);
- Ease of use for broad adoption;
- Verifying the design and product against the requirements;
- Managing and tracing the changes impacting the requirements;
- Representation and transformation of requirement data.

5 Case Study

Many companies are facing technical changes in terms of moving more and more towards the development of integrated mechatronic products with a strong interaction of systems. The case company AVL has moved over the last decade from a specialized combustion engine development company into a "whole powertrain" company. Close to portfolio enhancement, additional "interlocking boundaries" address product-related structures, processes, methods and tools, as well as organizational aspects.

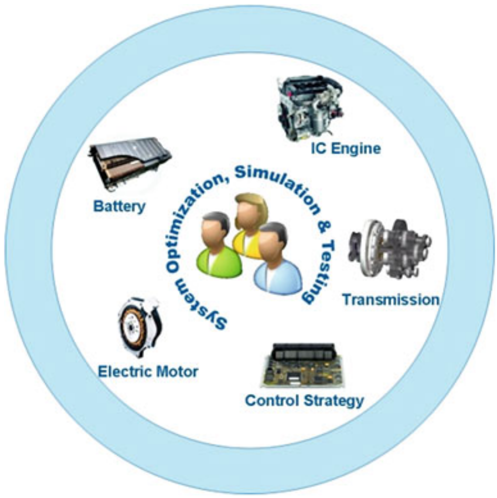

Fig. 5 The five elements of the powertrain

The goals of addressing the interlocking boundaries are related to optimizing the overall system function, increase development efficiency, as well as to raise quality of work. Additional aspects, next to business goals, are driven by upcoming standards and regulations, e.g. safety (ISO 26262).

An integrated systems engineering approach is seen as a methodical fundament within this scope. Some specific integration challenges related to requirements information management throughout the lifecycle, utilizing the integration approach of Fig. 4, are introduced in this section.

5.1 Product-Related Structures

Offering solutions to today's market demands for vehicle electrification and hybridization, AVL develops and validates entire powertrain solutions, including all individual elements forming a powertrain (see Fig. 5).

Whereas in e.g. traditional internal combustion engine (IC Engine) development project requirements are usually stated by customers, hybrid powertrain projects have often a different approach. Based on vehicle properties and goals (e.g. drivability, performance, etc.), requirements engineering activities are performed to develop advanced powertrain technology concepts that fulfill customer needs concerning e.g. decreased fuel consumption or emissions. Among others, this requires a methodical approach including defined structures to document and communicate requirements throughout the organization, to customers and suppliers.

Furthermore, the structuring and cascading of requirements has to be addressed by a multidisciplinary approach including the creation of different views. Here, a challenge is to combine different structures such as product structure (Bill of

Material) and functional structures based on requirement structures. Some goals hereby are to reach full traceability, to identify and communicate interdependencies, as well as to perform specific analysis.

5.2 Product-Related Processes

Taking know-how from experts of all five powertrain elements into consideration, leads to an optimal electrified or conventional powertrain, and furthermore to specified requirements for the element development.

The goals are to develop best-in-class engineered products with outstanding quality, in a minimum of time and by optimized cost. State-of-the-art development processes are a necessity for this. Increased simulation and testing efforts require efficient development methods such as frontloading, systems engineering or requirements management embedded into an integrated engineering environment.

Development processes are often based on tasks rather than delivered information in terms of task output. This is due to a close integration of methods within processes. In order to e.g. allow adequate tool support of processes, it is seen as a necessity to move towards information based processes. Furthermore, the anchoring of requirements engineering as a value adding core process, as well as requirements management as a main supporting process is seen as a challenge to be faced.

5.3 Supportive Applications and Tools

Integrating requirements management into an overall information management strategy is a necessary step in order to support efficient product development. However, there are also some challenges that come along with such steps. Taking a closer look at the elements of a powertrain shows that several domains are involved during the development. Whereas the software domain has experience of the structured methodology of requirements management and the use of supporting tools, (e.g. ALM & RQM including requirement structures), the hardware domain is more centered on methodologies and tools around the product structure (e.g. PDM). From the system point of view, the functional interaction (function structure) of elements under certain driving maneuvers is an additional view as a basis for the deviation of hardware and software requirements. Therefore a proper methodology for the classification of requirements that clearly defines interactions and relations between the requirements, function and product structure is a necessity. Since requirements engineering is performed within distributed development teams, the challenges concerning the consistent formulation of requirements, as well as simple and user-friendly representation are additional needs to be considered. This is seen as one of the core functionalities of a tool environment to efficiently support engineering development processes.

5.4 Organization

Last but not least, the above-mentioned challenges also require an adequate level of organizational aspects to be addressed. In the end, PLM is not only a software but a strategy that combines methods, processes and tools by putting the human resource in the center of adding value to product development—to optimize the product function, increase efficiency and raise quality.

6 Conclusions

As a major result of this study, we comprised an organized picture of the various challenges of customer-oriented requirements management (RQM) and the integration of RQM with product lifecycle management (PLM) in the environment of manufacturing industry. To categorize the challenges, we introduced a table of requirements classification and a framework for product structure integration through the lifecycle.

Implications for facilitating and solving the problems of integration can be defined at different managerial levels: product-related structures, product processes, supportive applications for lifecycle directed integration, and capabilities for vertical integration of diverse engineering activities. To illustrate the specific integration challenges of RQM with PLM, a case study of a power train company acting in the automotive industry was introduced.

Academically, this chapter provides a larger picture of various types of a multifaceted requirements bundle which should be integrated with many stakeholders along the product lifecycle. It also adds to the understanding of the many linkages between requirements and their inconsistency.

As a final conclusion, the study shows the core points where and how the concepts of PLM and RQM should be developed, from the requirements point of view of the customer, design, manufacturing, use /service, and environment etc., to support the whole lifecycle process better. Further, on the basis of this study, future work will be focused especially in finding solutions for integrating product- related requirements completely as an embedded part of extended products and systems.

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Sustainability Discussion with an Example of Selected Countries in Asia and Oceania

Victoria Bakhtina

Abstract A systemic approach to innovative development, creation, and implementation of efficient mechanisms for innovation policy, sustainable financial sector reform, and ultimately, sustainable, balanced, and harmonious development of countries based on investment innovative models, calls for the creation and implementation of an innovative product to support strategic decision-making based on integrated indices and risks in a triune concept of sustainable ecological, social, and economic development in the global, regional, and national contexts. This chapter seeks to illustrate one approach to the indicated model, using the examples of South East Asia and Oceania, and taking into consideration the risks and opportunities for innovative development in these countries. This research incorporates the Environmental Performance Index (EPI).

1 Introduction

The new Millennium brings cardinal changes to defining the direction of economic progress, shifting the focus to solving problems of innovative development acceleration and the transfer to an economy of knowledge firmly rooted in intellectual resources. Intellectual capital, science, education, and transformation of knowledge to creation of material goods via innovation tools, play a special role in this process. The ultimate goal is to improve quality of life and increase people's opportunities, for a sustainable, balanced, and harmonious development of society.

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The modern vision of systematically advancing sustainable development joins three main components—economic, ecological, and social. All three aspects are interconnected, and the economic component is more and more often linked with the concept of human development. The human, or social, dimension becomes a defining factor for harmonious sustainable development under ecological and resource constraints while material well-being becomes a condition of development.

Transition to a regulated model of a market economy may be required, with a significant part of direct and indirect state influence, and the establishment of close synergies between the public and private sector, while maintaining a continuous dialogue with investors. This approach entails devising an investment innovative policy based on a sound, objectively justified methodology. It necessitates the development and implementation of a priorities system and the creation of concrete mechanisms to ensure the formation of national and international innovative systems. To achieve this, it is necessary to facilitate systematic information-analytic support, and to provide a foundation for strategic decision-making with respect to investment and technical assistance activities, structure recommendations based on priority risks, and the monitoring of progress in the context of sustainable development (global, regional, and national).

The concept of Sustainable Development was first introduced by Vernadsky (Vernadsky 1926) at the beginning of the twentieth century, and attracted a great deal of interest after the Brundtland Commission published its report in 1987 (Our Common Future 1987). Ecological, economic, and social components are closely interrelated, and call for the creation of integrated assessment studies which would analyze the three aspects of sustainable development jointly. Historically, starting in 1972, numerous studies were devoted to the simulation of sustainable development, looking jointly at such factors as economic growth and human and environmental systems (Meadows et al. 1972; Hughes 2006; Forrester 1971), modeling the three domains of sustainable development, and estimating the relations among the components and possible outcomes for various scenarios. Some efforts also focused on operationalizing the concept of Sustainable Development and utilizing the existing models to analyze the relationship between environmental change and human development (Boumans et al. 2002; Hilderink and Lucas 2008). The difficulties in implementing such approaches are the links and compatibility of all underlying models and their assumptions. Moreover, the synchronization of data dependencies among models with no circular reference is a clear challenge. This is why approaches utilizing integrated indices are becoming more and more popular.

Since the late nineties it has become customary to view sustainability in the perspective of Environmental, Social, and Corporate Governance (ESG) constituents. Currently more and more banks and corporations incorporate ESG metrics to their practices.

The year 2006 became a milestone in project financing, featuring the introduction of Equator Principles by the IFC (Equator principles 2006), which facilitated socially and environmentally responsible project financing.

Sustainability is complex to measure, and requires extensive statistical data and a broad range of indices. One of the best known and most broadly used indices is the

Human Development Index (HDI), first introduced in 1990. This index for the first time both enabled an innovative approach to the evaluation of Human Development from an alternative perspective, emphasizing that development encompasses a much broader area than economics and income, and emphasized human-centered development. It integrates such aspects as longevity, literacy, and income, and ranks the world's countries based on their integrated assessment. The HDI ranks countries based on their level of Human Development, but does not directly include an ecological component. Subsequently, a sustainable development index, incorporating an ecological component and the concept of developmental or sustainability risk, were introduced (Bakhtina and Zgurovsky 2008), allowing for the transfer of the research to the regional level and analysis of concrete examples, using data for Africa, Latin America and Asia to illustrate the model.

There is a clear gap between interpreting and using the output of the existing models for the decision-making process and policy development. The goal of this publication is to propose a structure for an integrated sustainability model which would utilize the results derived from the two types of indices: Sustainable Development Index and Developmental Risk Index (Bakhtina and Zgurovsky 2008), focusing on a subset of countries from different regions.

Every year climate change and environmental deterioration effects become more and more severe and "will result in net costs into the future, aggregated across the globe and discounted to today; these costs will grow over time." (Parry et al. 2007). Climate change is a defining developmental issue, as affirmed in a United Nations development report. In comparison to Bakhtina (2011), the current research aims to incorporate environmental aspects into sustainability risk modeling more extensively. It is supplemented by the Environmental Performance Index (EPI)—the result of research by the Yale Center for Environmental Law & Policy and the Center for International Earth Science Information Network, Columbia University (Environmental Performance Index, http://epi.yale.edu/).

Using publicly available statistical data, the author has created tables and graphs to demonstrate the structure of the application, illustrating the model with the help of Principal Components Analysis. References to all the databases are given at the end of the publication.

2 Structuring an Integrated Sustainability Model

It is suggest structuring an information-analytic support for innovative development covering the following segments and steps:

(a) Create and utilize holistic sustainability risk models and respective systems;
(b) Devise methodology facilitating prioritization of sustainability risks in the regional and national context;
(c) Integrate existing resources and knowledge to perform forecasting, sensitivity, and scenario analysis for investment activities and technical assistance;

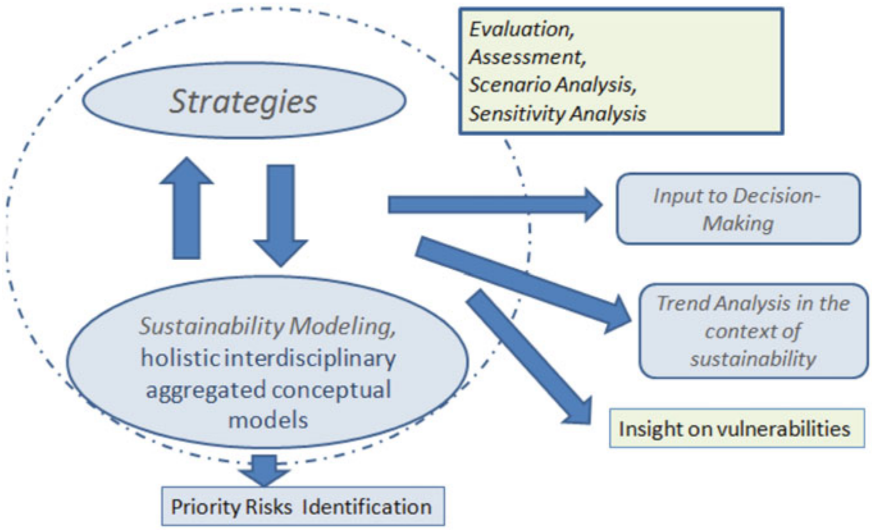

Fig. 1 Integrated sustainability model

(d) Adjoin trend analysis and evaluation of investments in a global sustainability context;
(e) Suggest approaches to further help in detecting integrity gaps and vulnerable spots;
(f) Provide active input to qualitative knowledge management.

Figure 1 explains how an integrated sustainability model operates, required inputs, and results.

In Fig. 2 is presented one of the ways of structuring the process of information-analytic support.

3 Sustainability and Global Risks Modeling

In the current research, sustainable development measurement is performed jointly using economic, social, and ecological components. Ideally, each of the components takes into account as many comprehensive indicators as possible. The research is based on a methodology of global sustainability processes modeling (Zgurovsky et al. 2008), and integral sustainability risk[1] models in a regional context (Bakhtina and Zgurovsky 2008). Sustainable development measures shall ideally incorporate as many comprehensive characteristics encoded in the

[1] "Sustainability risk" will be used interchangeably with "developmental risk". This definition is in line with the approach used in the finance, risk management, and insurance industries.

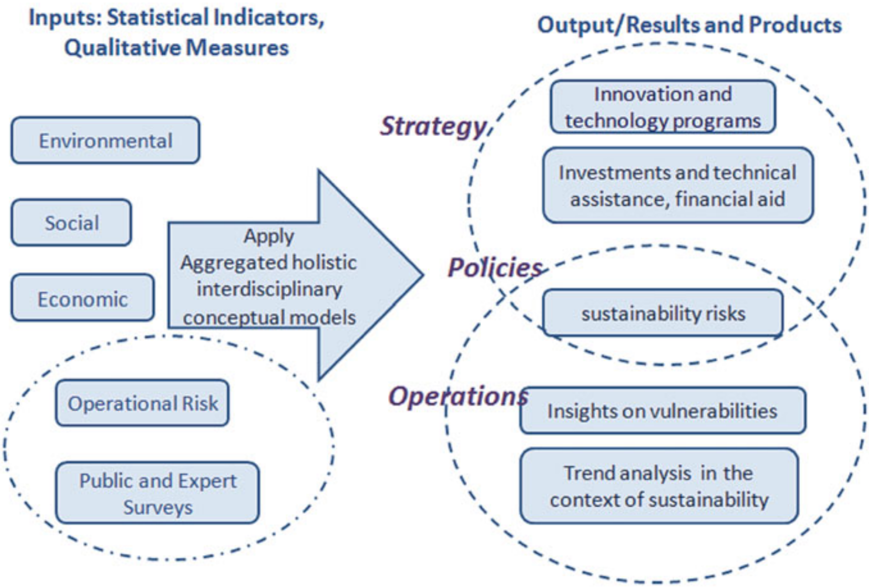

Fig. 2 Schema of information-analytic support for decision-making in the context of global sustainability

sustainability dimensions as possible. The most widely used indicators for the three domains are GDP, economic freedom, human development, business environment, ecosystems, and ecological footprint. Review of countries in South East Asia and Oceania allowed us to conclude that it would be sufficient to use a socio-economic index supplemented with the ecological component.

The sustainability index is structured as follows. Two indicators are considered: HDI (UN Human Development Report 2009) and carbon intensity. HDI belongs to the socio-economic category. It comprises three indices: an education index, which shows relative achievement in adult literacy and involvement in tertiary education, a life expectancy index, which shows life expectancy at birth, and a GDP index, which reflects the relative level of well-being in the country. It is presumed that the GDP index represents a complete measure of the economic component, and that the combined education and life expectancy indices are measures of the social component.

In 2010, the Human Development report changed the methodology of computing the HDI index and provided two new indices: Inequality adjusted HDI, which reflects inequality in the three major areas of development, and the Multi-Dimensional Poverty Index and Gender Inequality Index. As a result, the index computation methodology was fine-tuned and additional dimensions were added to a global comparison of information, making the reports more insightful. Conversely, this novelty requires more data points to measure inequality, so there is no adjusted HDI measure for many countries. This makes it impossible to analyze trends in adjusted HDI for many countries under consideration. For this reason, this analysis is limited to only the HDI index.

Carbon intensity is one of the most broadly used measures of the countries' CO_2 (Carbon intensity, http://www.eia.doe.gov/emeu/international/carbondioxide.html) pollution relative to the economy activity[2]; it can be reduced by using cleaner fuels and reduced fuels consumption via innovation. An ecological component is represented by carbon intensity and the Ecological Performance Index (EPI).

In addition, specifics of the indicated region allow for separating the following risks to cover all three domains of sustainable development: (1) disbalance between economic and human development, (2) lack of education, (3) low life expectancy, (4) lack of access to potable water and sanitation facilities, (5) HIV epidemics, (6) greenhouse gas (GHG) emissions, (7) political instability and corruption, (8) natural disasters, (9) unsustainable business environment and (10) poor environmental performance.[3] The next step is to select proper measures for each risk, and subsequently analyze the risk for each country.

For each country, it is possible to get insight into the question of how balanced and sustainable the country's development looks relative to its peers, as well as the remoteness of the country from crisis, based on the series of risks considered.

Correlations between the components suggest a strong relationship between GDP, Education, and Longevity. A strong correlation between GDP, Education, and corruption perception shows that countries where the economy is performing well and the education system is well designed are generally perceived as less corrupt. A strong correlation also exists between an enabling business environment and education.

4 Sustainability and Risks for South East Asia and Oceania: Empirical Evidence

The current research reviews 27 countries from South East Asia and Oceania,[4] excluding Japan, North Korea and Kiribati. The set of countries is chosen with the focus on emerging economies. Only 27 countries are covered due to data limitation. Japan is ranked 10 in Human Development, which is significantly over-

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[2] CO_2 intensity reflects the emission intensity, or the average emission rate of CO_2 from a given source relative to the intensity of a specific activity. Carbon intensity of the economy can be observed in two main relationships: energy intensity and carbon intensity of energy use.

[3] Completeness and integrity of environmental information is essential for the efficiency of the decision-making process related to global climate change adaptation and the application of innovative approaches to optimize use of the bio-capacity at a national level. In a modeling process unavailability of EPI information is considered as a penalty.

[4] The countries include Bangladesh, Bhutan, Cambodia, India, Laos, Maldives, Mongolia, Myanmar, Nepal, Papua New Guinea, Samoa, Solomon Islands, Sri Lanka, Timor-Leste, Tonga, Vanuatu, Vietnam, Brunei Darussalam, China, Fiji, Hong Kong SAR, Indonesia, Malaysia, Philippines, Singapore, South Korea, Thailand.

performing the rest of the region. In spite of one of the highest risks of natural disasters in the region, implied by the Disaster Risk Index (DRI), Japan has the most advanced social and economic components, making the country significantly different from the set of 27 countries under consideration. After the devastating earthquake and tsunami in March 2011, unprecedented efforts were made to move the country towards recovery. Such measures comprised the April 2011 creation of the Reconstruction Design Council, which produced a report with recommendations to facilitate full scale national disaster response. Historically, Japan has faced many earthquakes, and the nation has always lived both with and against natural disasters. "The reality of the disaster is catastrophic. However, the history of Japan shows time and again that the country has been devastated by disasters only to bounce back with formidable power of reconstruction, displaying a very strong degree of resilience. Such clout of rebirth ought to happen again. That is what people in stricken areas would want. The spirit underlying the report is that the entire people of Japan, rallying around the Government, are going to support just such resilient power," stated Dr. Makoto Iokibe, Chairman of the Reconstruction Design Council (Ministry of Foreign Affairs, Japan 2011). In October 2011, we observed signs of Japan's economic recovery. The disaster response and commitment of the nation once again demonstrated that the Human dimension defines the sustainable future of any nation and the planet.

For each risk factor discussed in part 2, a representative measure is assigned, based on publicly available statistical information. The following measures were selected for each of the risks indicated: (1) GDP Rank—HDI Rank (DEHD)[5]; (2) education index (EI) (see footnote 5); (3) life expectancy index (LI) (see footnote 5); (4) access to improved water supply (AWS)[6]; (5) HIV infected population % (see footnote 6); (6) carbon intensity (CI); (7) corruption perception (CPI),[7] political stability and absence of violence (PSAV) indices[8]; (8) disaster risk index (DRI), covering number of deaths from natural disasters; (9) doing business indicators (EDB)[9] and (10) Environmental Performance Index (EPI). For each country, a global risk resilience index[10] is built using a formula:

$$RR = \sqrt[p]{\sum_{i=1}^{k} Xi^{p}} \tag{1}$$

Here k is a number of risks, Xi is a respective quantitative index, normalized to the scale [0; 1], and p represents the sensitivity of the global risk resilience to

5 UN Human Development Report (2009).

6 World Bank (2008).

7 Transparency International (2009).

8 Kaufmann et al. (2007).

9 Doing Business Report (2009).

10 All underlying risk indicators are normalized to the scale [0; 1], where 0 indicates the weakest performance, and 1 the strongest performance.

relative impact of each of the separate risk components. Generally, $p = 3$ gives enough sensitivity and provides good practical results [3]. For convenience, RR is normalized to the scale [0; 1].

$$RR^0 = \frac{RR - RR_{min}}{RR_{max} - RR_{min}} \tag{2}$$

Here RR^0 represents a "distance" of each country to the totality of selected threats, which determines the risk resilience of the country. The shorter the distance, the lower the risk resilience for an indicated country. The countries are ranked from the shortest distance to the longest and clustered into groups with similar properties.[11]

The example of South East Asia and Oceania shows that resilience to global risks is higher for countries with a higher level of social component of sustainable development. High human development provides for a higher quality of education—a necessary condition for innovation—and opens new opportunities to combat risks.

The existing information is supplemented with an innovation index for the following countries: Singapore, South Korea, Hong Kong SAR, Malaysia, China, Thailand, India, Philippines, Sri Lanka, Indonesia, Vietnam, Mongolia, and Nepal (BCG 2009). The example showed that Human Development Index is also higher for countries with higher innovation potential. At the same time, the better the level of education, the higher the innovation potential. In cases where the level of education is low, the necessary conditions and a base for innovation are lacking. Earlier detailed research at a country (province) level shows that workers' tertiary education is significantly and positively related to provincial innovative activities in China (Chi and Qian 2009).

Innovative and well-balanced countries such as Singapore, South Korea, Hong Kong SAR, and Malaysia provided the highest level of human development in the region; all established specifically targeted programs for stimulating innovation. Figure 3 illustrates this approach.

5 Practical Applications

Using the derived indices of sustainable development and harmonization, all countries are clustered[12] into groups based on the level of sustainable development, its balance, and distance from the set of threats. The grouping is provided in Appendix 1. The countries with the highest level of sustainable development are Singapore, South Korea and Brunei Darussalam. These countries have the highest levels of human development, economy, and innovation. Singapore and Brunei have the most advanced social dimension.

[11] Due to underlying data limitation, Environmental Performance Index was not available for Hong Kong SAR, Samoa, Tonga, Vanuatu, Timor-Leste.

[12] Clustering is performed using the Ward agglomerative method.

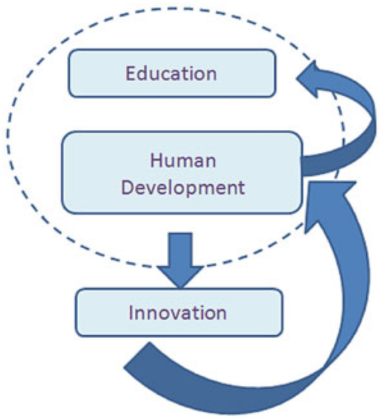


Fig. 3 Development chain: innovation stimulates human development

The next cluster includes Malaysia, Sri Lanka, Philippines and Maldives. Philippines, Maldives and Malaysia are balanced in social, economic, and ecological aspects. Timor-Leste and Mongolia are ranked lowest on the level of sustainable development index; Myanmar and India are among the lowest performers, with the lowest values in all three dimensions compared to other countries in the group.

Principal Components Analysis (PCA) applied to the risk results illustrates how the model input can be used to make investment decisions (Appendix 2). The first three components describe approximately 69 % of variance. The components can be interpreted the following way, based on their structure. The first principal component (F1) "Socio-Economic State with Accent on Education". The second principal component (F2) implies that imbalance between economic and social development may lead to a decrease in life expectancy. The suggested name: "Disbalance between Economic and Human Development and its Impact on Life Quality". The third principal component (F3) has the highest loadings on HIV, environmental performance, and natural disaster risk. The suggested interpretation: "HIV Epidemics, Environment Deterioration, and Natural Disasters".

The indicated interpretation suggests that the main direction for investments may be in social domain, specifically education, and in balancing economic activity with human development. The second suggested direction will cover healthcare, ecology, and natural disasters. Each country can be located on the axis of principal components, and compared to the other countries. Figure 4 also shows the class each country belongs to, from the highest risk, to the lowest risk.

Timor-Leste, Myanmar, Bangladesh, Nepal, Cambodia, and Papua New Guinea are among the countries which may require significant investment in the social sector. Nepal, Sri Lanka, Indonesia, and Philippines are the least politically stable and are perceived as the most corrupt in the region. The illustration suggests that India, Solomon Islands and Laos may benefit from infrastructure investments. Tonga, Mongolia, and China are among the countries with the highest disbalance between economic and social components, and at the same time, the highest carbon intensities. Timor-Leste and Myanmar are excluded from the display as

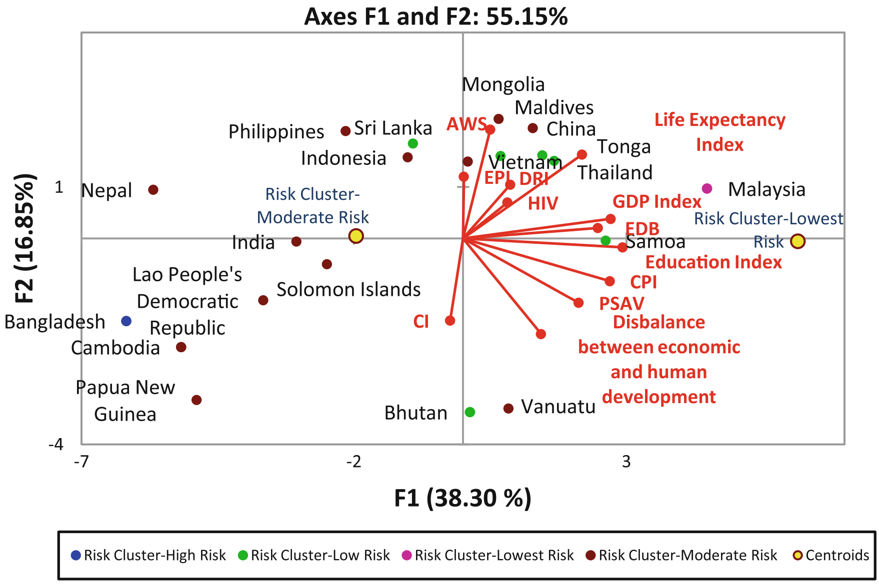


Fig. 4 South-East Asia and Oceania countries and the main risks factors

they show the lowest resilience to global risks, and may be very close to the state of crisis. Hong Kong, South Korea, and Singapore are excluded as they significantly over-perform the rest of the countries.

Figure 4, derived by the author with the help of Principal Components Analysis, shows the countries under consideration and their resilience to the main risk factors.

Similarly, the Principal Components Analysis applied to sustainable development dimensions shows that the main principal component is significantly correlated with social and economic factors. The second component is closely related to the ecological component.

Each quadrant shows countries with different properties. The upper part of the right quadrant and the right part of F1 axis is the most prominent in relation to sustainable development nations: Hong Kong, South Korea, Singapore, and Brunei. The lower left quadrant shows the countries with the lowest values of social, economic, and ecological indices. The analysis, similar to the risk results, implies that India, Myanmar, Papua, and Timor-Leste may require more investments in infrastructure, social sectors, and environmental technologies.

Correlations among main key risks and Principal Component Analysis details are provided in Appendices 2–4 (Fig. 4). Figure 5 illustrates clusters of countries of South East Asia and Oceania in relation to Economic, Ecological and Social components.

Interpretation of sustainable development indices shall always be considered in conjunction with the risks. In cases where both the level of development and risks are high, as in Brunei, Philippines, and Fiji, efforts may be directed to address natural disasters and social sectors.

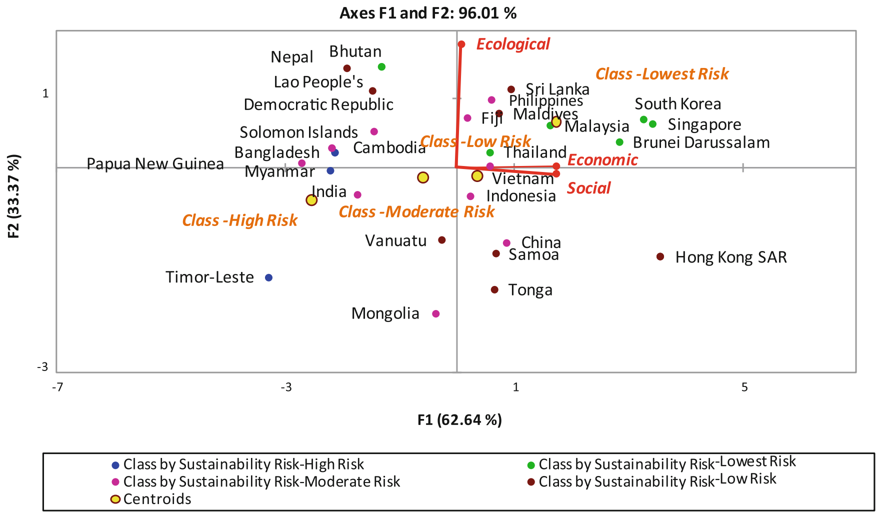


Fig. 5 Clusters of South East Asia and Oceania countries

6 Conclusion

This chapter illustrates a potential implementation of sustainability models for information-analytic support and input to the investment decision-making process, and presents research based on the results of such a model for 27 countries in South East Asia and Oceania. It shows that sustainable development, its harmonization, and resilience to global risks are higher for the countries with a better developed social sector, which articulates the social factor as a defining component of sustainable development. An interpretation of derived results is provided from the perspective of sustainability and from the perspective of sustainability risk using principal component analysis. The conclusions of the two models should be reviewed jointly. Based on this analysis, among the countries which may benefit from aid in social sectors are Timor-Leste, Bangladesh, Nepal, Papua New Guinea. Furthermore, we separated sets of countries with high human development that are prone to the risks of natural disasters, such as Brunei Darussalam.

Mongolia and China stand out in average human development, but are strong underperformers in the ecological dimension. A balanced combination of the two directions of investments: social and environmental, possibly focusing on the innovative technologies of clean fuels utilization and efficient fuel consumption, is implied by the model.

There is much to be done in the direction of sustainability modeling. The set of indicators can be expanded and extended to more countries, and particular sets of innovative financial instruments or special types of technical assistance can be analyzed for the set of indicated countries with the main focus on a social dimension.

To achieve visible progress towards a sustainable, informed, and futuristic decision-making process, the issue of developing common data and reporting standards needs to be addressed: the extension and refining of models for sustainable investment decision making, their evolution to a new level, and their meaningful utilization, are only possible if there are accurate and high-quality data available for their fine-tuning, testing and calibration.

Acknowledgments The views expressed herein are those of the individual contributor and do not necessarily reflect the views of IFC or its management.

Appendix 1: Grouping of Countries by Sustainable Development Index, Harmonization and Resilience to Global Risks

Country	Harmonization (G)	Sustainable development index (SD)	Resilience to global risks	Class by G and SD	Class by sustainability
Bangladesh	0.83	1.09	0.23	Low	High Risk
Bhutan	0.78	1.29	0.82	Upper moderate	Low risk
Brunei Darussalam	0.93	1.50	0.84	Very high	Lowest risk
Cambodia	0.88	1.12	0.36	Low	Moderate risk
China	0.81	1.19	0.36	Upper moderate	Moderate risk
Fiji	0.94	1.34	0.47	High	Moderate risk
Hong Kong SAR	0.72	1.36	0.51	Upper moderate	Low risk
India	0.97	1.07	0.41	Low moderate	Moderate risk
Indonesia	0.92	1.22	0.34	Low moderate	Moderate risk
Lao People's Democratic Republic	0.82	1.25	0.54	Upper moderate	Moderate risk
Malaysia	0.99	1.43	0.78	High	Lowest risk
Maldives	0.95	1.38	0.59	High	Low risk
Mongolia	0.68	1.01	0.36	Very low	Moderate risk
Myanmar	0.92	1.08	0.13	Low moderate	High risk

(continued)

(continued)

Country	Harmonization (G)	Sustainable development index (SD)	Resilience to global risks	Class by G and SD	Class by sustainability
Nepal	0.73	1.23	0.56	Upper moderate	Moderate risk
Papua New Guinea	0.87	1.05	0.38	Low	Moderate risk
Philippines	0.92	1.39	0.45	High	Moderate risk
Samoa	0.79	1.16	0.63	Upper moderate	Low risk
Singapore	0.94	1.57	1.00	Very high	Lowest risk
Solomon Islands	0.87	1.18	0.39	Low	Moderate risk
South Korea	0.95	1.56	0.69	Very high	Lowest risk
Sri Lanka	0.91	1.42	0.56	High	Low risk
Thailand	0.95	1.32	0.71	High	Low risk
Timor-Leste	0.81	0.82	0.00	Lowest	High risk
Tonga	0.71	1.10	0.53	Very low	Low risk
Vanuatu	0.84	1.10	0.52	Low	Moderate risk
Vietnam	0.91	1.27	0.46	Low moderate	Moderate risk

Appendix 2: Principal Component Analysis. Application to Risks

	F1	F2	F3	F4	F5
Eigenvalue	5	2	2	1	1
Variability (%)	38	17	13	10	6
Cumulative (%)	38	55	69	78	85

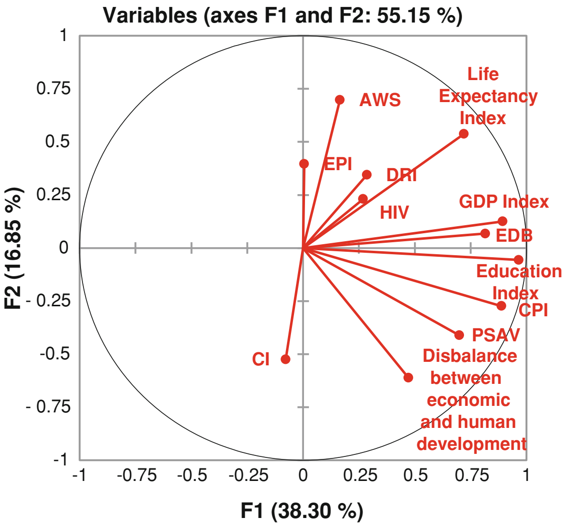
Factor loadings

	F1	F2	F3
GDP index	0.89	0.13	0.24
Life expectancy index	0.72	0.54	0.10
Education index	0.96	−0.06	−0.17
EPI	0.00	0.40	−0.55
Disbalance between economic and human development	0.47	−0.61	−0.46
AWS	0.16	0.70	0.06

(continued)

(continued)

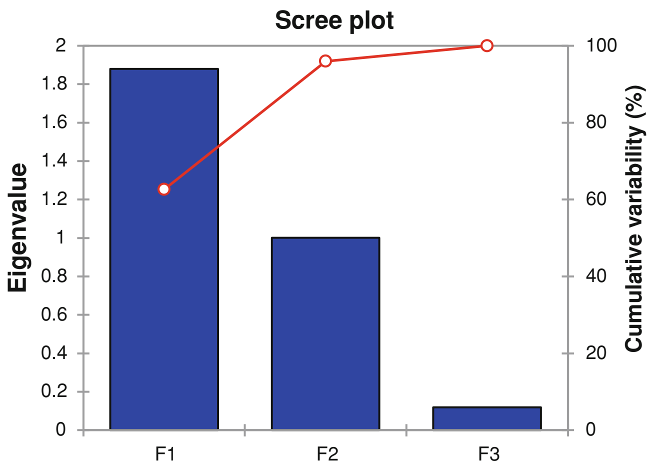
Factor loadings			
	F1	F2	F3
HIV	0.27	0.23	0.77
EDB	0.82	0.07	0.01
CI	−0.08	−0.52	0.28
CPI	0.89	−0.27	−0.02
PSAV	0.70	−0.41	0.11
DRI	0.29	0.34	−0.56

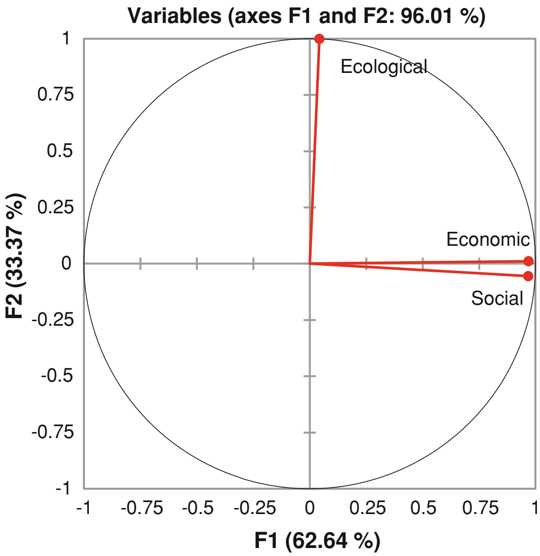


Appendix 3: Principal Component Analysis. Application to Sustainable Development and Harmonization Indices

Eigenvectors			Factor loadings		
F1	F2	F3	F1	F2	F3

	Eigenvectors F1	Eigenvectors F2	Eigenvectors F3	Factor loadings F1	Factor loadings F2	Factor loadings F3
Economic	0.71	0.01	0.71	0.97	0.01	0.24
Social	0.71	−0.06	−0.71	0.97	−0.06	−0.24
Ecological	0.03	1.00	−0.05	0.04	1.00	−0.02


Scree plot
Eigenvalue
Cumulative variability (%)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
100
80
60
40
20
0
F1
F2
F3


Variables (axes F1 and F2: 96.01 %)
Ecological
Economic
Social
F2 (33.37 %)
F1 (62.64 %)
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
-1
-0.75
-0.5
-0.25
0
0.25
0.5
0.75
1

Appendix 4: Correlations Among Key Risk Variables

Variables	GDP index	Life expectancy index	Education index	EPI	Disbalance between economic and human development	AWS	HIV	EDB	CI	CPI	PSAV	DRI
GDP index	1.00	0.72	0.86	0.04	0.24	0.22	0.44	0.69	0.03	0.77	0.47	0.10
Life expectancy I\index	0.72	1.00	0.65	0.03	−0.13	0.33	0.29	0.65	−0.30	0.41	0.31	0.42
Education index	0.86	0.65	1.00	0.11	0.60	0.13	0.14	0.73	−0.01	0.87	0.61	0.34
EPI	0.04	0.03	0.11	1.00	0.14	0.35	−0.14	−0.10	−0.14	−0.03	−0.28	0.20
Disbalance between economic and human development	0.24	−0.13	0.60	0.14	1.00	−0.19	−0.26	0.23	0.09	0.60	0.54	0.02
AWS	0.22	0.33	0.13	0.35	−0.19	1.00	0.24	0.14	−0.20	0.00	−0.14	0.08
HIV	0.44	0.29	0.14	−0.14	−0.26	0.24	1.00	0.03	0.03	0.20	0.24	−0.22
EDB	0.69	0.65	0.73	−0.10	0.23	0.14	0.03	1.00	−0.15	0.68	0.49	0.15
CI	0.03	−0.30	−0.01	−0.14	0.09	−0.20	0.03	−0.15	1.00	0.09	0.04	−0.26
CPI	0.77	0.41	0.87	−0.03	0.60	0.00	0.20	0.68	0.09	1.00	0.63	0.15
PSAV	0.47	0.31	0.61	−0.28	0.54	−0.14	0.24	0.49	0.04	0.63	1.00	0.10
DRI	0.10	0.42	0.34	0.20	0.02	0.08	−0.22	0.15	−0.26	0.15	0.10	1.00

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Introduction to Strategic Eco-Controlling to Support Strategic Decision-Making

Miada Naana and Horst Junker

Abstract Because of the consideration to the environmental issues in the last years it was introduced the concept (environment-oriented enterprise management). The ecological enterprise policy looked at the connections between the mutual effects from economic actions and ecological consequences and that required constant supervision and correspondence with the enterprise targets. Due to this situation, enterprise management shows its interest in sustainable resource management. That can be realized through applying the strategic planning and controlling systems to support decision-making concerning sustainable development and environmental protection. Because of business intelligence plays a role to support decision-making, we will describe in this contribution how business intelligence systems can be used to support Strategic Eco-Controlling.

1 Introduction

Environmental effects of production are coming from the application of raw materials and energy on the input side of a production process and on the output side by waste and undesirable products (Lang 2007). This has substantially positive as well as negative consequences to the environment. For this reason, the main focus in the environmental domain is resource reduction as well as a

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continuous decrease or avoidance of environmental impacts in all areas of producing enterprises (Rautenstrauch 1999). For that, management is required to analyze the environmental impacts of its products as well as production processes and to improve them (Schaltegger and Sturm 1993). Consequently, these environment-related perspectives receive the importance of corporate environmental management as a necessary area in enterprise. Moreover it promotes environmental management to an appropriate level coming from the rising importance of environment protection.

1.1 Corporate Environmental Management

To reach the enterprise goals, successful potentials are built up and used for the supply and the application of suitable resources and failure potentials are avoided (Souren 2008). The application of corporate environmental management supports realization of the enterprise purposes indirectly and directly, because it encloses the planning, control, supervision and improvement of all operational environment protection actions, as well as employee's management (Kamiske et al. 1995). It is applied exactly like the enterprise management at different planning levels for environment-related decision support for realizing the added value activities as well as the environment protection strategy. Therefore, corporate environmental management can be defined as a subsystem of the top management and can be specified afterwards.

The matters of corporate environmental management are environmental impacts as well as financial impacts. There are possibilities for using the available potentials for the environmental discharge and at the same time for cost reduction, which can be fulfilled by the reduction, optimization and reorganization of operational material usage. Therefore environmental achievements originate concretely through active environmental management by the recognition of the weak points which results in early-stage influence of environmental-relevant enterprise activities (Lang 2007). Accordingly the environment-oriented enterprise management has various tasks to improve on the supervision and management of the product life cycle. These tasks are concretized by application of eco-controlling.

1.2 Eco-Controlling

Because the operational activities are always connected with undesirable outputs, the compensation of this situation requires measurement applications and control systems for reducing the material and energy consumption as well as protection of natural resources. Hence, the concept of "eco-controlling" has picked up since the middle of the 80s to detect and improve the effects of economic action.

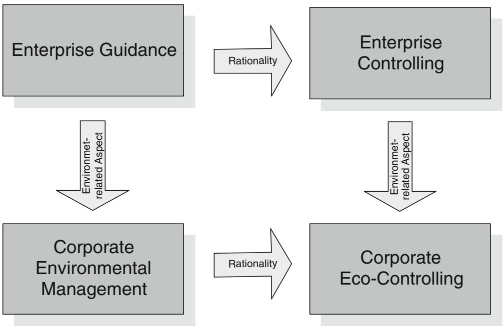


Fig. 1 Two stage deduction of eco-controlling. *Source* (Based on Rüdiger 1998, p 282)

The tasks of the strategic as well as tactical and operative management have led together with controlling to the formation of a specified management function (Dyckhoff 2000). Moreover, Weber stated that controlling is understood as ensuring management rationality (Weber 1999). With regard to the corporate environmental management, eco-controlling concentrates upon the relevant environment protection aspects of the enterprise management and shows as a subsystem of the corporate environmental management as well as the enterprise controlling (Dyckhoff 2000) as shown in Fig. 1.

Hence, it is an environment-related subsystem of enterprise controlling and has a specific structure und functions for operationalizing the tasks of corporate environmental management. Moreover, it has responsibility for many tasks and also implements many targets to record and assess the ecological impact of economic activities in order to (Schaltegger and Sturm 1993, p 229):

- reduce the negative ecological effects of existing products,
- set benchmarks for product development,
- enable the creation of an ecologically orientated product range on a rational basis.

1.2.1 Goal of Eco-Controlling

The objective of eco-controlling is derived of enterprise controlling goals which support the enterprise management (Dyckhoff 2000). Due to this situation, eco-controlling can be seen as a management support system and coordination system of the corporate environment protection.

In this case, it is seen as the difference between the exogenous and endogenous real target: the exogenous target covers merely adaptation to legal regulations. But endogenous target considers environmental protection and provides as a possibility for reaching an adequate investment program. For that, it is recognized that environmental protection and sustainability can contribute to operational success

(Faßbender-Wynands et al. 2008, p 104f). Hence, an endogenous target is a necessary condition for eco-controlling.

1.2.2 Tasks of Eco-Controlling

The tasks of eco-controlling represent all the activities needed for the realization of real targets (Bleis 1995 p 289). This means that it tries to find out the information to provide a basis for decision-making. According to definition of Bauermann et al.[1] the tasks of eco-controlling consist of the coordination and adaptation abilities, which are shown with system-building and system-coupling functions. The first one, the system-building function includes creation of an organization as well as process structure which contributes to the coordination of the tasks (Faßbender-Wynands et al. 2008, p 104). The second one, the system-coupling function, exists in forming up and compression of information for a basis to be used in decision-making (Bleis 1995, p 290). Hence, the system-building function can be seen as supposition to successful realizing the system-coupling tasks of the eco-controlling.

"The coordination and adaptation tasks serve the solution of problems which arise from the increasing complexity, dynamism and discontinuity of the environment"(Faßbender-Wynands et al. 2008, p 105). On the one hand, coordination task ascribe the coordination and exchange of information by different management subsystems (especially, planning, control and information care system) (Faßbender-Wynands et al. 2008). For that, the coordination area can be seen as the head of eco-controlling. On the other hand, the adaptation task refers to the possibility of adapting in environmental change (Bleis 1995). Due to anticipation ability, it can provide additional information about changes of the environment. Consequently, it is always possible to fix occurred environmental damages and to anticipate subsequent correction and certain interaction.

1.2.3 Modules of Eco-Controlling

Schaltegger et al. stated that eco-controlling envisages a strategic approach to environmental issues and proposes a systematic management procedure with various steps from target and strategy formulation to data management, decision support, control, implementation and communication (Schaltegger and Sturm 1995). The structure and tasks setting of eco-controlling are described as phase modules in Fig. 2.

[1] "Eco-Controlling is an additional subsystem that extends the overall controlling consisting of each planning, management, controlling and information supply components by both system building and system coupling coordination. These additional features support the system by means of an increased adaptability and coordination" (Bauermann et al. 1995 p 339).

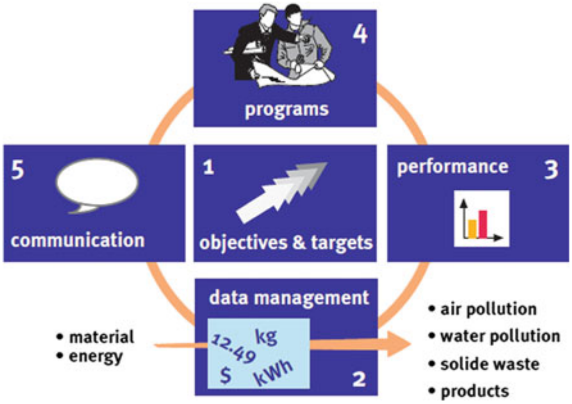


Fig. 2 Modules of eco-controlling. *Source* (Sturm and Müller 2000, p 4)

Objectives and Targets: It is already mentioned that the controlling goal is reaction, coordination and adaptation abilities in management. That is needed in order to realize the real purposes of the enterprise (Horváth and Partner 2009). Moreover, that has to be clear for a company to be a credible and an efficient environmental performer and to reap the benefits of being an environmental leader. The formulation of environmental objectives and targets starts with a commitment to comply with all relevant environmental regulations and to continuously improve environmental performance (Sturm and Müller 2000, p 6). Additionally, the ecological purpose is oriented to the question: how is the subject ecology influencing the economic success of the products/services and the production processes.

Data Management: The recording of environmental data and environmentally induced financial information is necessary as a basis for effective decision making (Sturm and Müller 2000, p 10). Both the financial and environmental data are imaged in information systems. These systems can gather the information in physical as well as in monetary units. It gets the data from different reference (e.g., environmental cost account, material and energy flows ect.) and then processes these data by different instruments. This means, these systems have to be adapted, because eco-efficiency has an ecological and an economic dimension (Sturm and Müller 2000).

Performance Management and Control: The reasons for collecting data about corporate environmental impacts as well as environmentally induced financial impacts are to calculate eco-efficiency,[2] and to measure how well the operations of the firm contribute to or detract from sustainable development (Sturm and Müller 2000). Moreover, in this stage the actual progress is compared to the goals set, with strong and weak points being identified. Hence, management

[2] Eco-efficiency is defined by the ratio of value added per environmental impact added, respectively, the ratio between an economic performance indicator and an environmental performance indicator (Schaltegger and Sturm 1990).

and control processes coordinate the distribution of all information in order to support the decision-making.

Decision Making Support: Many of the existing environmental management tools fail to consider the importance of the implementation process (Sturm and Müller 2000). The controlling function is basically understood as a support function for decision makers in view of purpose reaching (Bleis 1995). The task of eco-controlling lies in finding out environment-related information to support the basis of decision-making. This mean, those information systems delivers raw data which are processed decision-oriented. This is followed by taking into consideration equally ecological and economic identification numbers as well as environmental cost accounting as a helping instrument in decision support (Faßbender-Wynands et al. 2008).

Communication: The communication stage deals with the information exchange between the areas in enterprise, especially for strategic and operative decisions concerning ecological consequences. This is necessary for considering the requirements of internal and external stakeholders in the enterprise. Consequently, eco-controlling is assumed as a suitable help system in corporate environmental management to realize the environmental targets.

However, some questions come to mind:

1. How can relevant data be derived for the data management for realizing the objectives and targets.
2. To enable a long-term saving of resources and to keep the production ability continuously high, how can eco-controlling be improved in order to generate concrete effects?

The answer to these questions needs the usage of Business Intelligence system and its tools in order to improve eco-controlling functionality.

2 Business Intelligence

Today's companies are faced with the continuous increase of both data sources and data volume. These data is not only to be stored, but also needs to be collected, managed, filtered and analyzed to provide the best possible image of the business situation. In order to ensure correct strategic and operational decisions, the underlying knowledge must be gained and/or derived from the available data. These challenges prompted the development of business intelligence (BI) concepts, which today are frequently used both in science and in economical practice.

It's obvious that BI represents two major facets. The first one is defined by the technologies used in the field of BI. The second one, on the other hand, is merely based on concepts and methods and thus independent of technology. BI is platform which includes technologies, applications and methods to manage a large amount of data in order to facilitate decision making in a timely manner. It is carried out to gain sustainable competitive advantage, and is a valuable core competence in some instances. Every BI system has a specific goal, which is derived from an organizational goal or from the vision statement.

2.1 Requirements and Conditions

The support of strategic decision-making can be realized through using business intelligence tools and technologies in the field of environmental controlling. That can achieve many targets in the corporate environmental management. The implementation of BI solutions does not differ in this field from common applications. It can generally benefit in the following features (Berger et al. 2000, p 84):

Complexity, defined as the number and, respectively, the variety of relevant environmental stocks within various environmental segments. Applied to a system, this means that a large number of objects and dimensions as well as numerous interdependencies among the objects have to be taken into account.

Dynamics, defined in terms of each frequency, speed, strength, regularity and predictability of changes of environmental resources relevant for the company, in various environmental segments. As a consequence, systems need to be adjusted often.

The basics of holistic and integrated approaches can provide assistance, as these are used for both economic and ecological goals. A technology is available for the company that can identify and remove the environmental risks and vulnerabilities prematurely.

2.2 Technologies and Architectures

BI applications include various technologies; basically these are divided into three categories, as is shown in Fig. 3.

Data Generation: Both heterogeneity and huge volume of the data belonging to the source systems make it impossible to directly access the operational (internal and external) systems for analytic purposes. Therefore, the first step of the extract transform load (ETL) process is used for extracting the data from the various sources and loading them into the so-called staging area.

Data delivery and processing: Prior to their usage by appropriate business users, it is necessary to transform and load the data into a database. The transformation process (second stage of ETL) includes all activities to transform the operational data into data that can be interpreted in terms of business and economy. It is composed of several sub-processes, i.e., filtering, harmonization, aggregation and enrichment (Kemper 2004, p. 24). In large enterprises this data will be stored in a central multidimensional database, the so-called data warehouse (DWH).

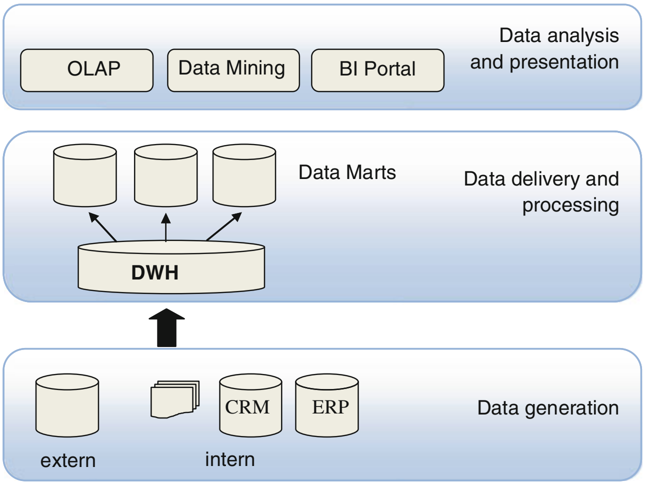


Fig. 3 Technologies and architecture of BI. *Source* (Based on Kemper et al. 2004, p 21)

In the context of DWH it is spoken about dimensions, facts, aggregations and hierarchies. Depending on business needs, the data model may be configured as a star, snowflake, or galaxy scheme. The data can be grouped into data marts that are defined in functional terms. They include each subject-specific, previously aggregated, historical, current and planned data.

Data analysis and presentation: In order to analyze the data and to transform them into a legible manner either online analytical processing (OLAP) or data mining are available as state-of-the-art technologies. Both of them offer the possibility to compare objectives and real performance. Furthermore, early warnings play a prominent role for executives.

3 Introduction to Strategic Eco-Controlling

Due to the ecological challenges (especially: damage by emissions on earth, water and air.) as well as the economic requirements for increasing margins and profits, this requires to support strategic decisions about the long-term balance between economic and ecological dimensions in the corporate environmental management. This situation needs to harmonize between environment-related strategic measures planning and control of the operative activities.

3.1 Strategic Environmental Management

Strategic environmental management receives a growing significance through the ecological and economic sustainable development in enterprises. That is not only because of increased legislations concerning environmental risks, but also the growing scarcity and costs of natural resources at the world market (Lang 2007, p 11). This generates, actually, the importance of strategic environmental management which leads to strategic tasks in the following aspect:

- Warning the enterprise for ecological long-term dangers,
- Supporting the objective of long-time survival of the enterprise,
- Ability to maximization of long-term profit,
- Identification of long-term social enterprise responsibility.

For that, through planning and management of enterprise activities the tasks of strategic environmental management include the consideration of:

- continuous sustainable development,
- ecological and economic future added value activities,
- definition of social and environmental responsibility,
- environment-related strategic decision support.

These tasks help avoiding and decreasing environmental impacts as well as long-term protection of the enterprise purposes. Moreover, it can appreciate ecological successful dimensions through the economic effects.

3.2 Strategic Eco-Controlling

With regard to concretizing and controlling the enterprise strategy, especially long-term environmental management strategy, a Strategic Eco-Controlling concept can be used. Due to significance of ecological and economic balance by application of voluntary or legal measures, this situation needs to fulfilling and condensing the information. For that, strategic eco-controlling is a good method to detect a suitable basis for long-term decision-making. Moreover, it can especially serve concretizing the sustainable strategy and its realization in enterprise action.

This system needs at first to improve the adaption area which can ascertain early-stage recognizing for strong and weak points as well as future chances and risks. Hence, the adaption area is an engine of eco-controlling, because it gives new suggestions, new knowledge of chances and risks, particularly being at hand from the ecological domain (Bleis 1995, p 312). Additionally, it reports the coordination area with important changes of the indicators or recognize about weak signals.

In order to improve the adaption and coordination functions in strategic eco-controlling, BI system can be used. This is relatively a new approach to using the benefits of BI in environment area. It is capable to recommend the best decisions of actions (based on past data), but it does so in a very special way.

3.3 Strategic Environment Model

Strategic environment model can support the requirements of the enterprise management and especially strategic environment management. In this model the economic and ecological requirements must be fixed as well as organizational and technical bases must be created. This requires the following considerations: definition of social, legal and environmental responsibility, clean production and recycling technologies, laws and orders as well as perception of environmental impacts and costs. On the base of the generated information, the strategic environmental management can define the long-term purposes, which have to take into consideration the enterprise strategy. The actual realization of the ecological and economical purposes can be handled by planning and control instruments, such as increasing the material efficiency and reduction of impacts and emissions. These purposes should be structured completely and presented to all stakeholders in the enterprise. In this situation, the measures are formulated, structures are defined and new trends and their enterprise-related consequences are derived. Furthermore it should be not only fixing the measure planning and achieving the activities, but also continuing the processes and avoiding negative impacts.

Hence, to realizing the strategic environment model the law-, technical-, organizational and information situations should be therefore described for defining the strategic targets. This exists in the condensation and aggregation of information for finding out the basis of long-term decisions, as is shown in Fig. 4.

In addition, in this model a strategic eco-controlling should be designed. Strategic eco-controlling, which has the adaption and coordination tasks, tries to achieve the goals of strategic environmental management. It could be used as a "supervision and correction instrument".

Hence, the strategic environment model concentrates clearly to describe the strategic decision-making starting from: definition of environmental targets till reaching to a suitable decision. This situation leads to using BI to applying strategic eco-controlling, which is shown in Fig. 5.

A business intelligence system is defined as "a broad category of application programs and technologies for gathering, storing, analyzing, and providing access to data" (Michalewicy et al. 2007, p 5). It can help controlling functions through: the aggregation and integration of environmental data with many dimensions in a data warehouse for particular purposes, and then analyze the integrated data concerning the environmental issues. As result of analyzed data, specific environmental indicators are produced about using the material and energy as well as the amount of wastes and emissions for a product. These environmental indicators can principally give a lot of signals and contrasts concerning the environmental issues.

Fig. 4 Strategic environment model

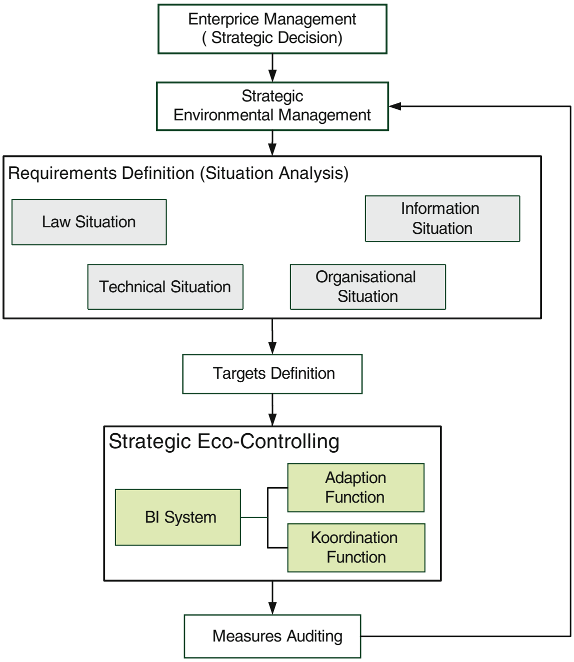
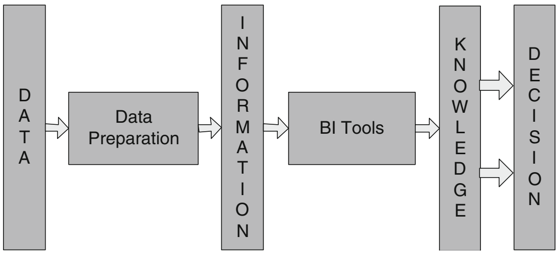


Fig. 5 BI system. *Source* (Based on Michalewicy et al. 2007, p 5)



Hence, by using BI, the functions of strategic eco-controlling can be realized. BI can create environmental knowledge, which help applying the adaption as well as the coordination tasks of strategic eco-controlling, especially regarding strategic targets, as is shown in Fig. 6. Strategic eco-controlling incorporates alerting, predication and optimization modules through many indicators for improving future decision. That can make signals for weak points, and then predicate a new chance and solution.

Within the scope of the adaptation task, the recognizing for new enterprise-relevant trend is understood as well as matching the adaptation decisions (Bleis 1995). To fulfil the adaption task, suitable instruments are required. Early warning and prediction functions are suitable instruments to recognize prematurely critical, economic and ecological developments and to timely generate suitable counter

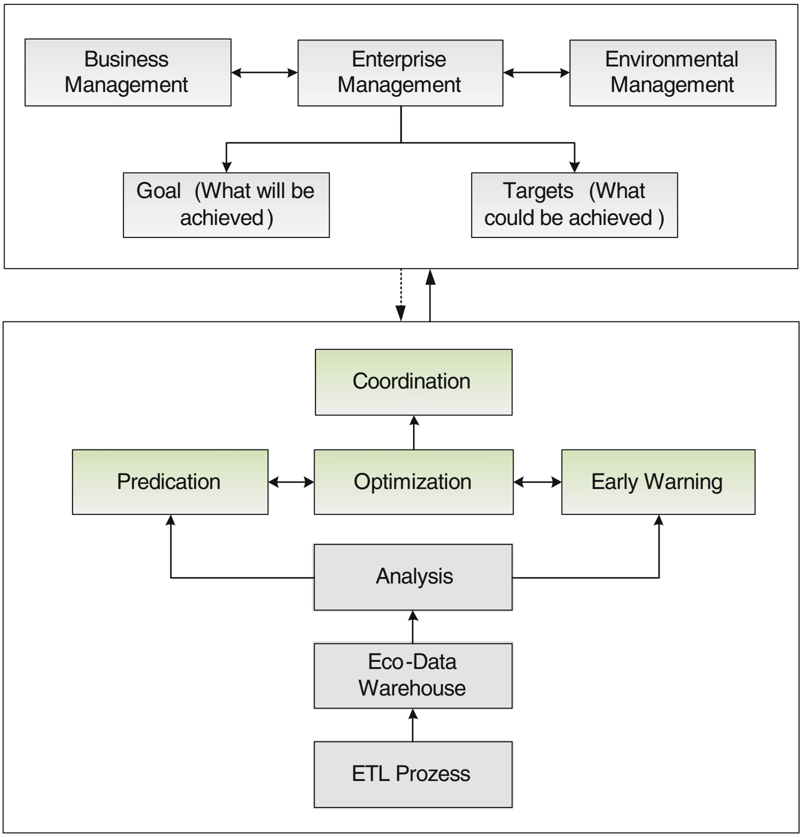


Fig. 6 Abstract strategic eco-controlling model

measures. On the one hand, early warning function can give signals about the weak points in production process and measures. On the other hand the prediction function gives information about new chances or ideas, which can bring better value and result. Therefore, the adaption task improves above all the forecasting of continuing changes in natural, technical, social, political, legal and economical domains. Moreover, Michalewicy et al. stated: “the discipline of using prediction and optimization techniques to build self-learning (decision system)” (Michalewicy et al. 2007, p 5).

Due to this situation, it carries out advances in relation on decision support. In all cases, the predicated information are optimized and transferred to the coordination task. In this stage, the information can be managed and controlled with the planning data. Consequently, this function can provide a suitable decision basis for managers.

4 Usages of Strategic Eco-Controlling

As it was already mentioned, the corporate environmental management supports on operative, tactic and strategic levels the enterprise management goals. For this, strategic eco-controlling system receives constantly and at an early stage the recent and integrated information. It is responsible for the support of strategic environmental management targets.

4.1 Decision Support System

Strategic eco-controlling supports decision-making in the corporate environmental management, because the task of business Intelligence tools is the collection, processing and representation of information for the decision support (Bange 2009, p 158). For example, OLAP processes analyze environmental information and generate environmental information concerning environment protection measures, and Ad-hoc-reports are afterwards created. Through the internal reports the corporate environmental management has a suitable basis to decision support. Hence, strategic eco-controlling can manage and control the long-time enterprise targets in relation on the material and energy efficiency as well as reduction of the environmental impacts.

4.2 Early Warning System

The application of BI tools makes the execution of strategic eco-controlling system on analysis, planning management and control processes easier. Such a system informs the environmental management with in time warnings and gives remarks for the present situation and fixes the weak points. **Performance Dashboard** (cockpit) is a tool in BI and serves clear and easy representation of aggregated information (Bange 2009, p 162). This tool improves the adaptation function of eco-controlling. On the one hand, it generates either positive or negative signals about the weak points in production process and measures. That can help the environmental management in the control of environment-related processes. On the other hand, it predicates new chances or ideas, which can bring better value and result.

For example, as shown in Fig. 7 analysis of emissions for a product refers that the production processes give more emissions from NO_x and SO^2 than from CO^2. This means, there are weak points in regarding to the emissions NO_x and SO^2, and that gives negative signals. Hence, this situation can be changed through using the predication and early warning tasks of strategic eco-controlling, and can be found a suitable solution in early time.

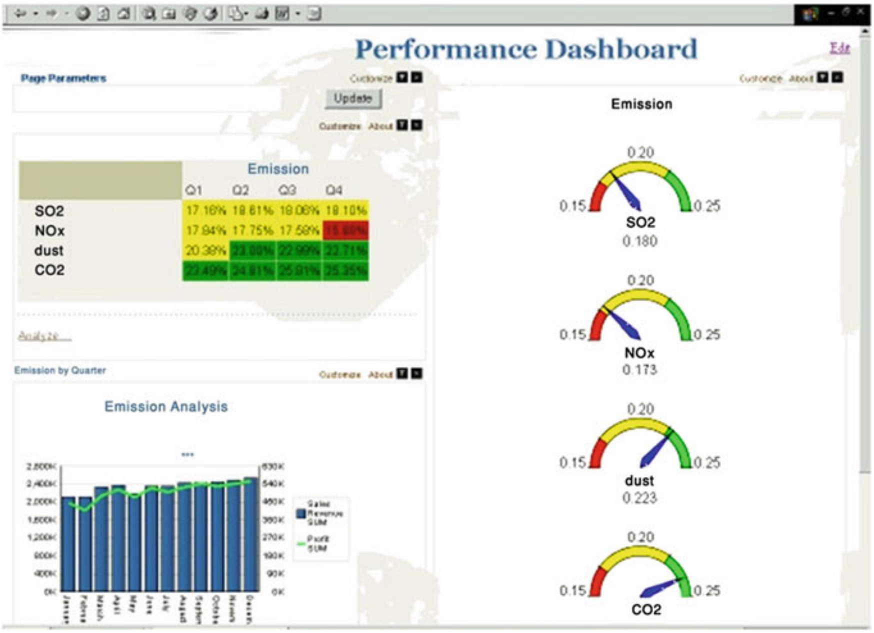


Fig. 7 ORACLE performance dashboard (BI Tool)

In addition, there is the **balance scorecard** (BSC). It creates other functions from key performance indicators. BSC as a management method of the strategic enterprise guidance propagates an integral and comprehensive look at the key performance indicators (KPIs) in an enterprise as well as a conversion of visions and strategies in concrete KPIs and actions (Bange 2009, p 162). BSC describes varied tasks of the planning, communication and inspection of KPIs and contains typical possibilities for the data analysis and report, and gives for that a lot of environmental information. Therefore it can be profited from this tool in strategic eco-controlling for the environment protection strategy (see Fig. 8).

So it could be found the relationship between many dimensions concerning environment protection strategy. For example, it can be created environmental performance indicators between cost accounting and production process. These indicators help the enterprise and especially environment management to find a suitable decision about which product makes profits and at the same time is environment-related. Moreover it can be also created environmental indicators between production management and investment management. They generate the information about which products have so much negative environmental effects. This helps the production management to choose the products that can be invested and developed.

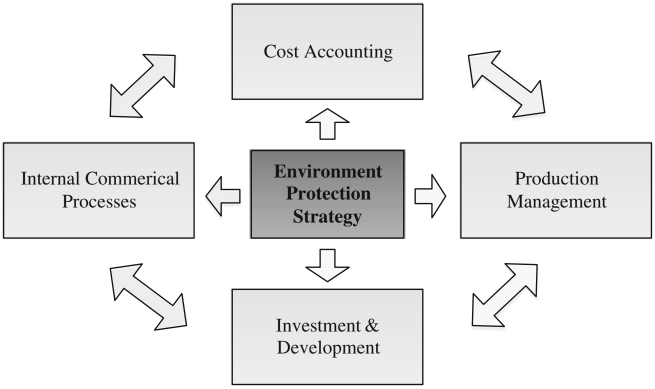


Fig. 8 Application of the balance scorecard

5 Conclusion

The strategic eco-controlling concept can be used in the industrial company. It is specifically developed to realize the requirements for decision-makers in strategic environmental management within the range of the environmental protection and sustainability improvements in an optimal way, as well as the realization of financial and strategic targets for the top management. Moreover, strategic eco-controlling can serve for realizing and implementing tasks of strategic environmental management by applying different functions: starting from the definition of targets and purposes as well as decision support, management and control of actions. All these are for the identification of weak points which results in early-stage influence of the environment-relevant enterprise activities. For example, there are the following points:

- Reducing the usage of raw material,
- Reducing the CO^2 emission,
- Ability to reproduce the waste of product,
- Ability to investment a new product or usage an alternative material,
- Support of strategic planning.

In order to improve the strategic eco-controlling concept a process model should be designed in the next step. This model can describe all processes and functions for realizing the tasks of strategic eco-controlling.

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Is It Possible To Generate Added Value Through A Higher Environmental Proactivity Orientation? A Practical Analysis of the Spanish Ceramic Industry

Conrado Carrascosa-López, María-del-Val Segarra-Oña, Ángel Peiró-Signes, Luis Miret-Pastor and Baldomero Segura-García-del-Río

Abstract Environmental proactivity is actually one of the key aspects considered in the strategic dimension related to corporate social responsibility of companies. The aim of this work is to analyze if it is possible to generate added value through a higher environmental proactivity orientation. The empirical application focuses on the Spanish ceramic industry allocated in Castellón. The objective of the research is to know which aspects determine company's environmental strategy, which are the barriers and facilitators that enable proactive environmental orientation of the industry studied and to verify what benefits companies can obtain from its application using a qualitative methodology.

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1 Introduction

Actually, it is crucial to evaluate the point to which the environmental factor is part of the business strategy of companies (Singh et al. 2008), how companies incorporate their environmental orientation is an emerging competitive priority in manufacturing strategy (Da Silva et al. 2009). Environmental proactivity offers a vision of progress that integrates immediate and longer term objectives as well as local and global action, and regards social, economic and environmental issues as inseparable and interdependent components of human progress (Porter and Van der Linde 1995).

A growing number of companies consider aspects tied to sustainable development, environmental attitude, eco-innovation or environmental management to be a first-class asset on a strategic level (Da Silva et al. 2009; Dubé and Paré 2003; Porter and Van der Linde 1995). In this context, management of sustainable development becomes a crucial process.

The industrial sector has repeatedly been responsible for assaults on the environment, which have been reduced over the years due to the growing environmental awareness of the sector and the implementation of laws and guidelines to control the level of pollution caused by industries (Fairchild 2008). These changes give rise to the implementation in companies of different environmental strategies (González Benito and González Benito 2006) from environmental responsiveness to environmental proactivity.

Several research papers have studied how environmental management tools affect firm competitiveness; Russo and Harrison (2005) found that incentives could be a valuable tool for improving environmental performance and, then, environmental promotion could be an opportunity to shape an organization's redesign to be more proactive. McKeiver and Gadenne (2005) analyzed both, the external and internal factors affecting the implementation of an environmental management system. Other authors studied how competitive advantages could be gained through environmental orientated activities (Segarra-Oña and De Miguel Molina 2009) or how firms' performance could be improved (González Benito and González Benito 2006; Noci and Verganti 1999).

Companies need to differentiate through sustainability is becoming more and more important, but there is still no scientific basis to carry out its measure. Consequently, it is necessary to analyze the environmental factor as a proactive aspect of company's management, as well as the determining factors encouraging a company to move towards environmental protection in what come to be called "corporate environmentalism" (Banerjee 2002; Banerjee et al. 2003). Several authors have analyzed the integration of the environmental factor in business strategy (Hitchens et al. 2005). On a general level, the influence of factors such as social pressure (Kalantari and Asadi 2010), environmental legislation (Segarra-Oña et al. 2011a), competitive advantages and management's commitment to the company's environmental focus (Russo and Harrison 2005) and also aspects as its strategies have been studied (Buil-Carrasco et al. 2005; Miret-Pastor et al. 2011; Walker et al. 2008).

1.1 Objectives and Structure

Several studies on business proactivity applied on industries can be found. On a Spanish level, Aragón-Correa et al. (2008) found that in the automotive repair sector, the economic performance of companies with more proactive practices was improved. In the work performed by Martín-Tapia et al. (2009), the food industry was studied and a correlation between advanced environmental strategies and the export level of the SMEs was found. Currently, there is a need to analyze the actual inclusion of environmental proactivity in the global strategy of organizations as a differentiating element and hence, creator of competitive advantages, by analyzing the extent to which the environmental factor forms part of the business strategy.

Taking these into account, the main objective of this research is to analyze the environmental factor as a proactive aspect of company management and identify the factors that help companies to move towards sustainable management; the specific objectives being the identification of the factors characterizing environmental performance and the identification of the facilitators and difficulties encountered by companies with respect to their environmental management (Walker et al. 2008).

The study has been performed on the Spanish ceramic industry by analyzing the companies' performance in order to identify improvement actions.

This research examines the existing literature on environmental proactivity, environmental strategy and environmental determinants in the industry in order to identify the most representative issues affecting the decisions made in companies in the ceramic industry. In this work, actions taken by a set of 14 ceramic companies, a heterogeneous group of national and multinational companies were considered; all of them have in common the location in the ceramic cluster located in the surroundings of Castellón.

A questionnaire to measure environmental integration (Peiró-Signes et al. 2011) was applied, used as a tool for guiding semi-structured interviews as case-study method can certainly contribute to the cumulative development of knowledge (Fundación Entorno 2003; Smith 2010). The results of the interviews conducted with the environmental heads of the companies studies were then analyzed, differentiating between the type of company (national, multinational and size). Findings were determinant since differences between companies belonging to the same industry were explained. Then, the analysis and discussion of the results are presented. The work finishes with a summary of the conclusions.

1.2 Literature Review on Environmental Strategy

Different classifications have been made according to their environmental strategy, however, in general, four groups have been defined in terms of endogenous and exogenous environmental risks: reactive, proactive, strategic and preventive (González Benito and González Benito 2005; Vastag et al. 1996; Winsemius 1992).

In order to identify those factors to be taken into account for classification purposes, *Fundación Entorno* (Fundación Entorno 2003) named companies as:

- leaders, those who see the environment as an opportunity to innovate and improve;
- enthusiasts, those that implement environmental management and prevention systems;
- proactive, those that integrate environmental aspects into their operations and are very attuned to and take advantage of opportunities offered by the environment; reactive, those that react to the environmental obligations and make decisions to comply with the law in force;
- indifferent, those that find it hard to take the necessary measures and do not feel committed but rather negative, seeing environmental concern as a threat hampering operations.

Several classifications have been made attending different criteria, Hunt and Auster (Hunt and Auster 1990; Peteraf 1993), as beginner, fighter, concerned citizen, pragmatist or proactivist, Winsemius and Guntram (1992) as reactive, receptive, constructive proactive, Roome (1994), as non-compliance, compliance, compliance plus, excellence and leading edge, Azzone and Bertelé (1994) as stable, reactive, anticipatory, proactive, creative, Vastag et al. (1996), as reactive, crisis preventive, strategic or proactive, Schaefer and Harvey (1998) as beginner, fighter, concerned citizen, pragmatic and proactive and González-Benito and González-Benito (2005) as reactive, pro-certification, pro-design, pro-logistics and pro-commercial.

The combination of the resource based theory, RBV as in previous studies (Peiró-Signes et al. 2011; Segarra-Oña et al. 2011b), with the adoption of environmental strategies has also been considered, through the development of an integrated framework for analyzing the relationship between environmental strategies and the development of the company's specific environmental capabilities (Dowell et al. 2000; Sharma and Vredenburg 1998; Singh et al. 2008; Verbeke et al. 2006).

Though they may appear to be different, they all have points in common in that they analyze the strategic positioning in different intermediate states between the most reactive and most proactive point of view. On the other hand, factors determining the proactive environmental orientation have been classified as internal aspects of the company (size, level of internationalization, position on the value change, attitude of the management as well as the motivation and strategic attitude of the company), external (sector and Geographic location) and as a determining factor, the pressure of the shareholders/owners (González Benito and González Benito 2006). Also, Murillo et al. (2004), classifies the factors as external (legislation, clients, vendors, companies in the sector, financial entities, insurers, media, ecologists and/or citizens or nearby communities; and internal (management, partners and shareholders and/or employees).

Trying to identify factors affecting the environmental orientation adopted by companies, some studies have been developed (Segarra-Oña et al. 2011c). In the consumer goods sector, factors such as the influence of external pressure forces, environmental orientation, corporate and marketing strategies, size, macro-sector and whether or not the company has a marketing department were found to have an influence on which environmental strategy is adopted (Christmann 2000; Peteraf 1993). Gonzalez-Benito and González-Benito (2005) identified several environmental proactivity strategies in three industrial sectors, electricity, chemicals and furniture, noting the multidisciplinary nature of environmental proactivity.

Although the studies performed to date are high quality and specialized works, there is not yet enough data which aids in identifying the aspects of environmental proactivity with an influence on business competitiveness nor is there sufficient scientific basis for carrying out its measurement.

The intention is to study particularly which is the influence of the facilitators of environmental proactivity in the ceramic sector and more particularly in companies of Castellón's cluster. The cluster is known as a model where the nearness of the companies and the support institutions promote important increases of competitiveness (Peteraf 1993), although the companies present an individual performance, which meets affected by its pull of resources and capacities (Kalantari and Asadi 2010). In this line and focusing on the evaluating of which concrete characteristics of the companies affect the environmental proactive orientation, we raise our hypotheses:

H1: Small size is a barrier to a company's environmental proactivity.
H2: The multinational nature of a company facilitates its proactive orientation.
H3: The direct implication of management is vital to facilitate proactive orientation.

2 General Perspective Ceramic Sector

Spain is the second European producer of ceramic tiles and the third world exporter, behind China and Italy. The Spanish ceramic sector produced in 2009 324, 4 million of m2 of ceramic tiles (37 % of EU-27). It employs 17,700 persons directly and more than 6,000 indirectly. It exports to 182 countries for a total value of 1,673 million Euros. Being the total sales of the sector of 2,591 million Euros.

In 2008, the Spanish ceramic sector invoiced 3,692 million Euros, which represents a decrease of 11, 37 % turnover of the previous year. This fall has been especially sudden on the Spanish market, where the decrease of sales has been near to 22 %, whereas on the international markets the fall has been much softer, with a decrease of the sales near to 4 %. The provisional information of 2009 shows an even more accused decrease in the domestic market (37 % respect 2008), and on the international markets (24 % respect 2008). The decrease of international sales is explained in Europe and the USA due to the economic crisis, which could not

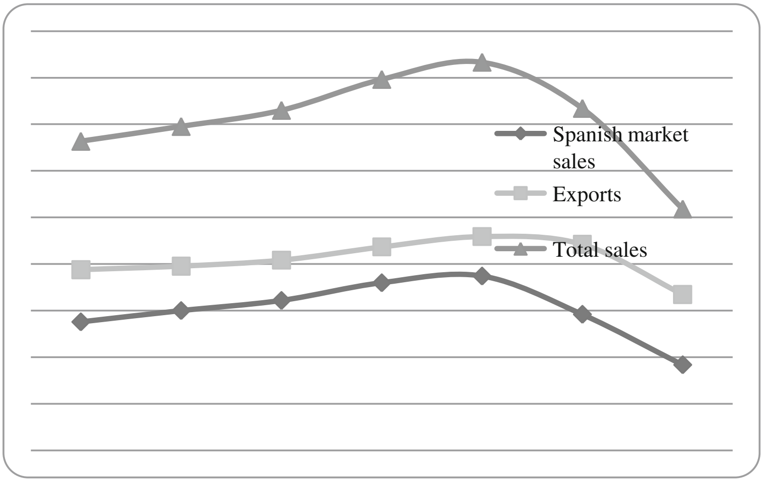

Fig. 1 Spanish ceramic sector sales (Million Euro). 2009*(Provisional date), *Source* Compiled by author with data from ASCER

have been compensated by significant increases in Africa, Eastern Europe and Middle East. In Spain the fall is major due to the strong contraction of the construction sector, and the most accused fall of the internal demand (Fig. 1).

A characteristic of the Spanish ceramic sector is the high geographical concentration in Castellón's province (Segarra-Oña 2009; Telle and Larsson 2007), since 94.5 % of the Spanish national output is concentrated in the area delimited in the northern part by Borriol and Alcora, in the western part for Onda, in the southern part for Nules and in the eastern part for Castellon de la Plana. His importance in the Valencian Community is very big, since it has been for many years the first investing sector and the second exporter (only behind car manufactures).

3 Methodology

We have developed an explanatory case study methodology Kaplan (Kaplan 1986) to try to figure out how the barriers and facilitators of environmental proactivity influence competitiveness. Fourteen cases were studied according to Rouse and Daellenbach (1999).

The method to be used in this study, i.e. in-depth interviews, is classified as direct data collection (Stake 1995). The type of interview used is called a structured open-ended interview (King 1994). This technique combines the advantages of closed questionnaires with those of qualitative research interviews. Following (Dubé and Paré 2003) to have high rigor level when using case studies as the methodological research, some considerations have to be taken into account. We have followed their three areas structure when designing our study:

- firstly, aspects related with the design, as identifying clear research questions, taking advantage of pilot cases in order to help refine the design and the data, the collection plans, to conduct more longitudinal case studies and, exploiting the richness of the various data collection methods;
- secondly, questions regarding with data collection as to provide detailed information with respect to the data collection methods, procedures aspects as number of interviews, and interviewees, use of an interview, guide, instrument validation etc., the effectively use of tables to summarize information about the data collection process or how to triangulate data in order to increase internal validity of the findings and provide clear explanations on how the triangulation process is achieved.
- finally, data analysis procedures in order to provide clear descriptions of the analytic methods and procedures, make greater use of preliminary data analysis techniques and tools and compare findings with extant literature (both similar and conflicting) in exploratory case research so as to increase the confidence in the findings.

Following Flyvbjerg (2006), when the objective is to achieve the greatest possible amount of information on a given problem or phenomenon, atypical or extreme cases reveal more information, for that reason we studied the company leader of the cluster, Porcelanosa among the chosen firms. Another tile manufacturer competitors and auxiliary companies all of them belonging to the ceramic cluster in Castellón.

A Likert scale questionnaire was prepared with five possible answers and an additional alternative answer indicating there is not enough criteria to answer. The questionnaire was filled in personally by the authors of the study in order to characterize the company in terms of its level of environmental proactivity and to establish a system for measuring the integration of environmental proactivity in the company's business strategy.

On the other hand, since the interview is conducted personally by one of the researchers, an attempt is made to gather qualitative information not directly related to the specific questions included in the questionnaire by means of informal talks with employees of the company, identification of information/internal training, and examination of the company's products and manufacturing processes (Stake 1995).

The questionnaire consists of a total of 42 questions focused on identifying the aspects enabling the company to be characterized in terms of its environmental proactivity, and also those aspects of organization enabling a system to be established for the measurement of the integration of environmental proactivity in the companies' business strategy.

Before its final circulation, the questionnaire was submitted to a pre-test to verify and discuss the appropriateness of the questions. The interviews are conducted by means of personal interviews with the directors or managers of companies rather than by post in order to make the results obtained more reliable. Proximity to reality, which the case study entails, and the learning process that it generates for the researcher will often constitute a prerequisite for advanced understanding (Flyvbjerg 2006).

4 Results Analysis

The group of studied companies is composed of 14 companies all of them belonging to Castellón's ceramic cluster. The sample is mixed, 50 % of the companies are multinational, and other one 50 % are national. They have been gathered in groups as for the size in small (less than 50 employees), medium (between 50 and 250), and large (more than 250 employees). 71 % of the companies of the sample have own environmental management department, and 29 % realize the tasks distributed between other departments. 71 % of the companies have environmental accreditation already gained or are in process of obtaining it. It is important to emphasize that even two companies have patents related to environmental actions.

4.1 Facilitators Identification

The internal company facilitators observed with the analysis of the realized surveys are three: The size of the company (small, medium and large company), the characteristic of the company as for his internationalization (international or national), and the degree of implication of executives and shareholders (high, major of 70 %, or low, minor of 70 %).

In the following table, the environmental behaviour of the companies is characterized, grouping them taking into account the facilitators before mentioned (Table 1).

The aggregation of the surveys and the grouping of the companies according to the different facilitators allow us to see the influence of each one in each of the behaviours that characterize the environmental proactivity, that are detailed in the left column.

4.2 Identification of Obstacles to Environmental Proactivity

The main obstacles faced by companies when attempting to adopt a more proactive environmental strategy are, lack of institutional support (65.71 %), short financial support (54.29 %), lack of tools information (51.43 %), lack of technical solutions (37.14 %), and lack of qualified human resources (33 %).

Table 1 Facilitator's identification (%)

	Company size facilitator			Internationalization facilitator		Management involvement facilitator		Environ. behaviour
	Small	Med.	Large	Internat.	Nat.	High	Low	Total
Energy saving	55	48	92	82.86	48.57	79.2	40	65.71
Usage of ecological products in production	55	40	56	65.71	34.29	53.6	45	50
Water saving	60	76	84	91.43	57.14	84.4	55	74.29
Waste managed	85	92	100	100	85.71	100	85	92.86
Recyclable products	30	64	80	71.43	48.57	78	20	60
Training in environmental matters	55	32	72	62.86	42.86	61.2	40	52.86
Ecological arguments used in marketing	15	68	84	80	37.14	76.4	30	58.57
Environmental costs and savings quantified	30	52	80	57.14	54.29	72	25	55.71
Information of measures taken externally reported	25	32	44	51.43	17.14	46.4	10	34.29
Information of measures taken internally reported	25	24	56	45.71	25.71	49.6	10	35.71

Table 2 Obstacles to environmental proactivity (%)

	Company size facilitator			Internationalization facilitator		Management involvement facilitator		Obstacles to proactivity
	Small	Med.	Large	Internat.	Nat.	High	Low	Total
Short financial support	65	64	36	45.71	62.86	41.6	75	54.29
Lack of institutional support	75	68	56	88.57	42.86	61.6	70	65.71
Lack of tools information	50	72	32	60	42.86	49.2	55	51.43
Lack of qualified human resources	25	44	28	45.71	20	30.8	35	32.86
Lack of technical solutions	15	52	40	57.14	17.14	46	10	37.14

In the following table, the obstacles to environmental proactivity of companies are characterized, grouping them taking into account the facilitators before mentioned (Table 2).

Again the aggregation of the surveys and the grouping of the companies according to the different facilitators allow us to see the influence of each one and the relation with each of the obstacles observed in the left column. This detailed info gives a deep and close overview of each group's needs.

Table 3 Benefits of environmental proactivity (%)

	Company size facilitator			Internationalization facilitator		Management involvement facilitator		Environ. proactivity benefits
	Small	Med.	Large	Internat.	Nat.	High	Low	Total
Long-term economic benefits	35	64	60	71.43	37.14	62	30	54.29
Long-term cost savings	35	72	68	68.57	51.43	70.8	30	60
Improvement of corporate image	40	68	92	88.57	48.57	83.2	30	68.57
New business opportunities	60	48	72	68.57	51.43	67.2	40	60
Increase of customers	25	52	52	51.43	37.14	55.2	10	44.29
Competitiveness increase	25	52	52	51.43	37.14	51.2	20	44.29
Short-term economic benefits	40	44	36	54.29	25.71	41.6	35	40
Short-term cost savings	35	44	64	71.43	25.71	58.4	30	48.57
Avoid sanctions	55	84	72	74.29	68.57	77.2	55	71.43

4.3 Identification of Benefits of Environmental Proactivity

The companies identify significant benefits arising from the implementation of proactive environmental management actions, the most important one is to avoid sanctions (71.43 %), followed by improvement of the corporate image (68.57 %).

Table 3 shows environmental proactivity benefits detected by the ceramic companies.

The aggregation of the surveys and the grouping of the companies according to the different facilitators allow us to see the influence of each one and the relation with each of the benefits observed in the left column.

5 Conclusions and Discussion

5.1 Modelling Results and Hypotheses Testing

The environmental proactivity of the ceramic industry cluster located in Castellón region was studied and the barriers and facilitators the companies consider as a key to the inclusion of proactive environmental actions in their business strategies were

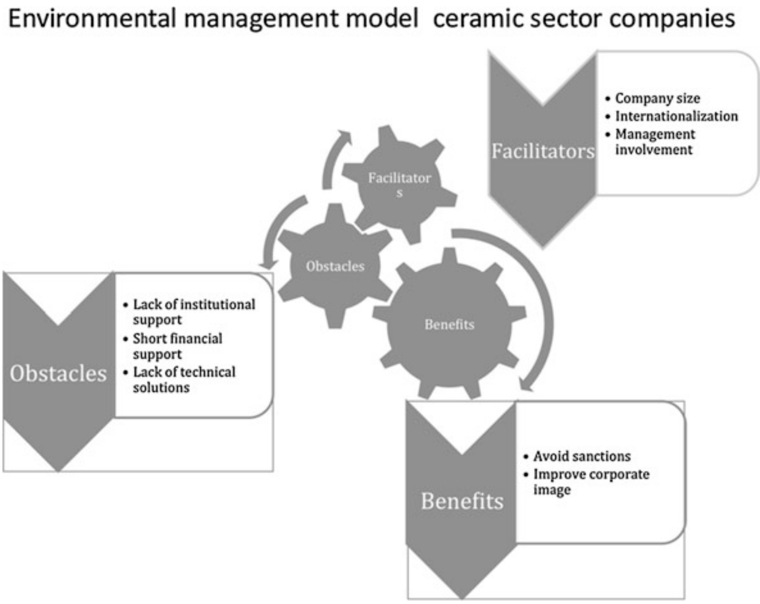

Fig. 2 Proactive performance model of the ceramic sector. *Source* Compiled by authors

identified. Figure 2 shows the model developed by authors based on the fieldwork performed.

With respect to the hypotheses made in the study, H1: Small size is a barrier to a company's environmental proactivity, this hypothesis is not verified. In table 1, several factors to identify and to characterize the environmental behaviour are observed, they show that there are small companies with a better environmental behaviour than medium companies, and even comparable to the behaviour of big companies. Evidently, the study is based on the companies of Castellón's ceramic cluster; due to this fact we can conclude that for these companies the size is not a barrier. What happens with our study is that the big size of a company is verified as a facilitator of environmental proactivity.

H2: The multinational nature of a company facilitates its proactive orientation. This hypothesis is fulfilled because all multinational companies (small, medium or large) have a better environmental behaviour than national ones.

H3: The direct implication of management is vital to facilitate proactive orientation. This hypothesis is fulfilled because all companies with high involvement of management have a better environmental behaviour than the other ones.

6 Conclusion

As for the obstacles observed for environmental proactivity, the major one is the lack of institutional support (66 %), followed by lack of financial support (54 %), and of lack of information of the tools (51 %). According to the observed company group, there are differences as for the perception of obstacles: The lack of institutional support is the major problem for small companies (75 %), international companies (89 %) and companies with poorly implicated management (70 %). The shortage of financial support is the major problem for the domestic enterprises (63 %) and for companies with poorly implicated management. The lack of information of the tools is the major problem for the medium companies.

As for the benefits observed of environmental proactivity, the major one is to avoid sanctions (71 %), followed by improving the corporate image (68 %), the saving of long-term costs (60 %) and obtaining new opportunities of business (60 %). According to the group of companies, there are differences in the perception of benefits of the environmental proactivity. To avoid sanctions is the major benefit waited for medium, national companies and with poorly implicated management. To improve the corporate image is the best benefit for big, international companies and with high implication of management. Whereas for small companies the major benefit is the possibility of obtaining new business opportunities.

To sum up, and according to the results obtained with the analyzed information, we can conclude that in Castellón's ceramic sector, many companies can be found that would be considered to be proactive, and even some as leaders. There are several indicators that show that environmental proactivity is a value taken into account in the strategic planning of companies. In this work we have highlighted the main actions that companies can work on to improve their environmental proactive orientation and improve their competitive resources set.

Nevertheless still possibilities of improvement are seen in the fields of institutional support and financial support basically. In the current circumstances of economic crisis, and seen the possible benefits that environmental proactivity can bring, its impulse might contribute with distinguishing factors to help companies exit of the crisis. These will lead our further research.

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Analysing the Determinants of Better Performance Through Eco Management Tools at the Food Industry: An Empirical Study

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Abstract This chapter exploits a data set of 6118 Spanish firms from 2008 SABI Database (Economic Register) to analyse if there is any relation between economic indicators and the use of the ISO 14001 eco-management tool. Using quantitative analysis techniques applied to the Spanish food industry we try to make a contribution, on one side, in understanding the role of proactive environmental management tools and incremental organizational eco-innovation in creating value in the Spanish food sector by means of an analysis of the effects of the ISO 14001, and on the other side, identifying the aspects that determine whether a food company minimises its environmental impact as a result of its innovative activity, and evolves from being innovative to eco-innovative. Results show significant differences in most of the analysed variables among studied groups.

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1 Introduction

All European countries have cultural traditions linked with specific food products, what represents that the European food market is developing as a large global market where huge commercial enterprises are created daily, distributing and selling food products in all markets (Jordana 2000), conscious that food quality and safety are central issues in today's food economics (Grunert 2005).

Food industry is the largest industrial sector in both, the EU and the USA, feature that persists in Spain where it accounts for 17 % of total industrial sales, 7 % of GDP, and employs over 500,000 people (Muñoz and Sosvilla 2010). However, different analysis (CIAA 2010; Wijnands et al. 2008; Fischer and Schornberg 2007) warn about the loss of competitiveness that this sector can suffer in the next years.

According to Matopoulos et al. (2007), a number of changes have occurred the last decade in the agri-food sector. The entrance of global retailers, industry's consolidation in most of the sub-sectors, the changing consumer consumption attitudes, as well as the existence of more strict regulations and laws regarding food production, have altered the business environment for most of the companies operating in the sector, encouraging collaboration attitudes among companies at all levels.

Moreover, the food industry operates in an economy and a society increasingly concerned with wide and diverse environmental issues (Mondéjar-Jiménez et al. 2011). Companies are being demanded an increasing environmental awareness (CIAA 2010), in the case of the food industry is increased by the continuing food security alarms.

In this context, many companies decide to go beyond the formal legal requirements and take a proactive stance on environmental issues (Segarra-Oña et al. 2011) although, there are still many authors that believe that it is a policy question and that, clearly, national policies on eco-innovation need to be underpinned by international agreements so that all countries will take action to reduce their environmental impacts (Ekins 2010).

Voluntary programs, in which participating firms adopt progressive environmental policies beyond the laws stipulations, are an integral component of the emerging environmental governance paradigm (Kettl 2002).In this regard, in recent years has been observed a significant increase in the number of companies with ISO 14001 environmental certification. In the case of the Spanish food industry has grown from three companies certified (with EMAS or ISO 14001) in 1997 to 298 in 2008, representing 3.45 % of total registered companies in Spain (Muñoz and Sosvilla 2010).

Business companies are giving more and more consideration to aspects connected with sustainable development, environmental awareness, eco-innovation or environmental management, a first-class strategic asset (Christmann 2000; Esty and Winston 2009; Hart 1997; Noci and Verganti 1999). Standardised environmental management can be classified according to the criteria of the recognised authorities (Oslo Manual 2005) as incremental organizational innovation.

In this context, management of sustainable development becomes a crucial process (Segarra-Oña et al. 2011), eco-efficiency is considered as one of the major challenges for R&D practice (Noci and Verganti 1999), as well as the need for implementation of quality control mechanisms that assure that products and services comply with stipulated standards of excellence related to the principles and practices of sustainability (Weaver and Lawton 2007) and value creation through environmental certification (Daviron and Vagneron 2011) and especially through the ISO 14001 (McKeiver and Gadenne 2005). Actually, the food industry has the opinion that eco-innovation has to be considered as a key for increasing their competitiveness (CIAA 2010).

2 Objectives and Chapter's Structure

Nowadays, as Europe has lost a great part of its price advantage in a global economy, innovation is one of the resources and strategies that can maintain or increase competitiveness (European Commission 2009). The aim of the present chapter is to make a contribution, trying, on one side, to understand the role of proactive environmental management tools and incremental organizational eco-innovation in creating value in the Spanish food sector by means of an analysis of the effects of the ISO 14001, and on the other side, identify the aspects that determine whether a food company minimises its environmental impact as a result of its innovative activity, and evolves from being innovative to eco-innovative.

Many studies can be found in the literature on business proactivity applied to specific sectors. For example, in Spain, Aragón-Correa et al. (2008) found that in the automotive repair industry, firms with the most proactive practices exhibited a significantly positive financial performance.

Martín-Tapia et al. (2010) studied the food industry and found a correlation between advanced environmental strategies and export intensity of SMEs. Among the studies dealing with the implementation of environmental management tools, McKeiver and Gadenne (2005) analysed both, the external and internal factors that influenced the implementation of an environmental management system.

At the present time, no studies have been found that link the implementation of management tools with economic performance, nor have any been found on the relationship between both concepts according to the type of firms involved as regards the importance of size.

Bearing in mind all that has been explained up to this point, the aim of this work consists, firstly, on evaluating the impact of the implementation of an environmental management tool, the ISO 14001, in food companies on the firms' business results. Our main hypothesis states that *Environmental management through the ISO 14001 in food companies is linked to economic performance*. From this line of study, we will determine whether it is possible to identify moderating factors that influence this link, considering the *size of the firm* as a variable.

The literature on environmental management tools at the food industry and its implementation will be reviewed, trying to identify the most important aspects that affect the economic performance of food companies. An analysis and evaluation of a food companies sample that have implemented the ISO 14001 will then be made, as compared to a sample of companies that have not done so.

Also, innovation positive impacts like productivity gains, cost reductions, and access to new markets (Crespi and Pianta 2008; Van Leeuwen and Klomp 2006) have increased the interest of academic literature in identifying the factors which contribute to (Mohnen et al. 2006) or hinder innovation (Baldwin and Lin 2002). Company size (Segarra-Blasco et al. 2008), market structure (Geroski 1990) and technological intensity (Albors et al. 2009) have been identified as facilitators or barriers to innovation and sustainable development while environmental management have become essential since Brundtland report (1987) highlighted the need for greater private, public and political environmental pressure to maintain acceptable social conditions.

Innovation and environmental sustainability are two concepts that have a separate impact on the competitive positioning of companies (Hitchens et al. 2005) and together act synergistically (Esty and Winston 2006) as the intersection both is transforming existing markets, creating new ones, and, increasingly promoting the principles of sustainability in business strategies (González-Benito 2010).

Companies have identified the benefits of innovative behaviour (Hidalgo and Albors 2008; Vega-Jurado et al. 2008), but aspects that characterize the shift from innovative to eco-innovative behaviour in companies should be detected in order to targeting industrial policies that aim promoting eco-innovation.

The financial and institutional efforts largely justify the recent interest of the academic and business community in eco-innovation. Eco-innovation studies have begun to appear alongside the abundant work on corporate innovation, although there is still a significant gap in the study of the connections and differences in the performance of innovative and eco-innovative companies. Various authors (Vega-Jurado et al. 2009; Molero and García 2008) have used the PITEC database to advance the understanding of innovation in firms as well as the relationship between different innovative strategies, but as yet there are no researches that analyse the eco-innovative behaviour of Spanish food firms.

Empirical relationships will be established between environmental management with the ISO 14001 and business performance and between environmental orientation and some company characteristics. After the statistical analysis and discussion of the results, the conclusions drawn from the study will be given.

Table 1 Certification versuss technological intensity industry classification

	EMAS	ISO 14001
Low	29.6	15.5
Medium-low	39.3	56.5
Medium-high	23.3	32.1
High	7.5	8.9

Source Compiled with data from Ziegler and Rennings (2004)

3 Environment, Certification and Food Industry

A voluntary checking process that audits and gives written assurance that a process, product or service meets a specific set of standards (Bhaskaran 2006; Miret-Pastor et al. 2011) is defined as certification. These standards, in regard to environmental management, provide guidance to implement an Environmental Management System (EMS).

In fact, there are several works that recommend the use of environmental certification as an instrument for measuring eco-innovation (Speirs et al. 2008; Kemp and Pearson 2008) taking into account the possibility of adapting what is already stated in the report of the OECD about Governance of Innovation Systems (Remøe 2005) for the use of certification indicators in innovation studies. In any case, the certification would not be indicative of radical eco-innovations, but called incremental eco-innovations. The ISO 14001 standard is the most widely used environmental management. From 1996 to 2008 rose from 1491 to 129,199 licenses worldwide. About 40 % of these certificates are produced in the European Union.

Classifying the project “Environmental Policy and Firm-Level Management”, environmental certified companies by industry were analyzed for Germany (Ziegler and Rennings 2004). Dividing the industries according to their technological intensity, we obtain data represented in Table 1.

Notice that it is in the medium-tech industrieswere much of the environmental certifications are concentrated althoughit’s not negligible the number of certifications in low and high-tech industries. In any case, it’s significant that in low-techindustries, food industry, had the greatest concentration (59’4 % of the EMAS and ISO14001 40 % of the total in the low-tech industries).

On the one hand, the literature has studied the impact of environmental certification in reducing pollution. Some authors minimize this impact (Andrews et al. 2003), but much of the literature finds that joining ISO 14001 reduced firm’s pollution emissions (Russo 2002; Potoski and Prakash 2005; Arimura et al. 2008). On the other hand, there are extensive literature that examines the economic impact of the companies that implement ISO 14001 system. Melnyk et al. (2003) or Montabon et al. (2000) found empirical evidence to say that the ISO 14001 improves both the environmental and the business image. Economic improvements occur through several pathways, such as cost reduction (Florida and Davison 2001; Hart 1997), improving the reputation (Esty and Winston 2009; Antweiler and

Table 2 Environmental impact of the EU food industry

	% of total manufacturing industries	% of total EU
Water consumption	12	1–1.8
Greenhouse gases emissions	7	1.5
Solid waste generation	12.5	3.25

Source European Environment Agency (2007)

Harrison 2003), or increases in productivity (Bleischwitz 2010; Segarra-Oña et al. 2012). Although the interest of the academic community about the issues of environmental management in food industry is still scarce (Galdeano-Gómez 2010) and despite the changes in preferences consumer and technology, different authors (Bellesi et al. 2005) lead to assert that the food industry is an industry where environmental issues and food safety will play a key role in the coming years, especially in developed countries. On the other hand, food industry has a strong environmental impact because it is intensive in resources use, produces high pollution levels, needs heavy and intensive transport and generates a considerable amount of waste (Gerbens-Leenes et al. 2003), as can be seen in Table 2.

In fact, there are some previous works focused on the food industry that relate the proactive environmental attitude to various aspects of management, as increases in export levels (Galdeano-Gómez 2010; Tapia et al. 2010) or productivity improvements and competitiveness (Carpentier and Ervin 2002; Managi and Karemera 2005).

In any case, at the food industry is particularly important to distinguish between eco-labelling and environmental certification (Delmas and Grant 2010). The numerous existing eco-labels are informing customers about specific environmental attributes in the product (general attributes as in the case of the European Ecolabel or specific product labels as organic food or sustainable fishing).

A feature of the literature on proactive environmental strategies is that it focuses on large firms, due to the commonly accepted idea that the larger companies maintain more proactive environmental strategies (Sharma 2000, Russo and Fouts 1997), arguing that the SMEs are less environmentally proactive due to lack of resources as by a lack of experience in Environmental Management. This idea has been extrapolated to the food industry and various reports such as that of the European Commission (2007) indicates the unwillingness of SMEs in the sector to go beyond the requirements of environmental legislation and justify it primarily based on the lack of information, the financial capacity to undertake major investments, to its small size and low pressure from consumers.

This vision has led much of the literature, that does not consider SMEs in their studies. However, excluding SMEs from the analysis of the food industry in Europe means to exclude the 99’1 % of existing firms, the 61’3 % of employment and 47’8 % of total turnover (CIAA 2010). In fact, in recent years, some studies are beginning to reconsider their position and to analyze the environmental attitude of small and medium enterprises (Martin-Tapia et al. 2010; McKeiver and Gadenne 2005).

This chapter studies the food industry from an aggregate level and also segmented by size, which will allow us to gain knowledge about the behaviour of firms in terms of size.

However, there is a lack of research on the correlation between ISO 14001 certificated firms and their economic performance in crisis situations and also between the different size in the same industry.

This is the direction in which we planned our work should go, with our principal hypothesis being, *H1: Eco-innovation in environmental management by the application of the ISO 14001 standard contributes to creating value in the Spanish food industry by improving economic performance*.

The second hypothesis is derived from the first, *H2: Organizational eco-innovation has an unequal influence on the economic performance and on the environmental orientation of Spanish food industry firms according to their size.*

4 Eco-Innovation Orientation

Eco-innovation is a key factor for achieving the objectives set out in the Lisbon Strategy (European Commission 2004, 2010). This commitment to specific eco-innovation is set out in the Action Plan for Environmental Technologies (European Commission 2004), and in the Competitiveness and Innovation Framework Programme 2007–2013 (European Commission 2006), which is complemented with other programmes that have environmental objectives such as the Structural and Cohesion Funds and the Seventh Framework Programme for Research which includes a specific allocation for environmental issues.

The E.U. has also promoted several think tank centres for analysing and promoting eco-innovation, such as the European Forum on Eco-innovation, and European Clusters and Regions for Eco-Innovation and Eco-Investment Network, as well as academic chapters which centre on the definition and measurement of eco-innovation (Kemp and Pearson 2008; Reid and Miedzinski 2008). Similarly, Eurostat (the E.U.'s statistics organisation) is working on developing an Environmental Goods and Services Sector (EGSS).

The role of environmental management in the value-creating process is critical (Wang et al. 2009; Hallstedt et al. 2010) since it involves taking decisions in areas indirectly involved in environmental decision-making such as purchasing, logistics, product design, and R&D, which have a relevant impact on integrated environmental management (Noci and Verganti 1999).

From a strategic management standpoint, sustainable business development refers to the integrated management that encompasses the entire management of the firm's value chain, from the origins of raw materials for production processes, finished products and services, to the end of the product's life (Sartorius 2006). Which aspects determine that companies which create value through innovation have a proactive environmental focus in the food industry? More specifically, what are the moderating factors that help innovative companies to become eco-

Table 3 Classification of firms studied according to its size

	With ISO	Without ISO	Total
<50 employees	69 (1,27 % of total)	5354	5423
50–249 employees	46 (8,07 % of total)	524	570
>250 employees	35 (28 % of total)	90	125
Total	150 (24,5 % of total)	5968	6118

Source IHOBE and SABI databases

innovative in the food industry? It's also an objective of this chapter is to identify the aspects that determine whether a company minimizes its environmental impact as a result of its innovative activity, and evolves from being innovative to eco-innovative. Then we have set our hypothesis, H3, as: *The more companies are focused on innovation, the more eco-innovation is supported.*

5 Methodology

5.1 The Sample

It is important to identify the characteristic of firms since this affects their environmental management practices. Although at first we had thought of adopting smaller and more homogeneous regions, we considered that analysing a broader scenario could help us to obtain better results. Given the strategic importance of the food industry in Spain, we included firms from all the Spanish regions in the study.

Data referring to food firms with environmental certification were taken from the IHOBE database, (considering CNAE codes 10, food industry and 11, beverage industry) which consists of a monthly updated comprehensive list of Spanish companies certified according to the ISO 14001 standard, with a search system by sector, National Spanish Activities Classification, CNAE, or province. Affiliate level information includes name of the affiliate; host-region and economic activity as defined by the CNAE codes, the address, and the certifying organization.

Of the 6.118 Spanish food companies identified, economic information was obtained from the SABI database for the year 2008. Of these firms, only 150 had ISO 14001 certification. Table 3 shows the data divided into total companies and companies with ISO 14001 certification.

Source: IHOBE and SABI databases.

Data in the table above confirm the relationship between size and environmental certification. Although in absolute numbers most certified companies belong to small and medium enterprises (115), these figures represent only 1.27 % of total existing small businesses in the industry and 8.07 % of medium, while 28 % of large companies are certified.

Table 4 Classification of firms studied according to its size (number of employees) and type of R&D

R&D investment/size	<50	50–250	>250	Total
Internal R&D	216	204	140	560
External R&D	16	8	0	24
No R&D	16	7	1	24
Total	248	219	141	608

Source Compiled by author from PITEC 2008 database

We can say that the percentage of certified firms goes up with size. Thus, only the 1.27 % of small firms was certified, a percentage that rises to 8.07 % for medium enterprises and reaches 28 % of large enterprises. According to the segmentation, four separate studies will be made, one for the food industry in general (analyzing first hypothesis) and one for each of the three segments in which we divide the industry by size of firms (which will serve to validate the second of the hypotheses).Company size is measured by number of employees (European Commission 2003).

Data from the Panel on Technological Innovation, PITEC (2007), a database for monitoring the technological innovation activities of Spanish companies, has been analyzed to identify the moderating factors (Anderson 1986) which influence the sustainable orientation of the firms while innovating.

The database was built by the INE (Spanish National Statistics Institute) with the advice of academics and experts. The first data came from 2004 and has been updated yearly to include a comprehensive list of Spanish companies which are characterised by the type of innovation (classified by the Oslo Manual 2005) that they undertake, by industry (in line with the Spanish National Activities Classification, CNAE) or by geographical location. A total of 255 variables were analysed. Affiliate level information was not available as data was taken from an anonymous macroeconomic survey.

Data from 2008 was used to analyse a total of 608 firms belonging to the food industry (CNAE-2009 food, beverages and tobacco). Table 4 shows the data divided into firms with internal investment, firms that only had external investment and companies without any investment. Data were also segmented by number of employees.

5.2 Data Analysis

To validate hypotheses 1 and 2, we applied the ANOVA test that can detect mean differences across variables comparing, ISO 14001 certified with non certified firms, using specific performance indicators such as Trading Income, (TI), Net Sales (NS), size by number of employees (SZ), Profit Margin, (PM), Earnings on

Table 5 Comparison of means (one-way ANOVA) for economic performance -all the sample

ANOVA	ISO 14001	Mean	F	Significance
	ISO	1.06E + 05	628.360	0.000*
TI	NO ISO	7050.68158		
	Total	9457.24156		
	With ISO	1.03E + 05	621.174	0.000*
NS	Without ISO	6969.42915		
	Total	9318.28039		
	With ISO	361.41	559.235	0.000*
SIZE	Without ISO	29.82		
	Total	37.89		
	With ISO	1.15E + 04	634.722	0.000*
EBITDA	Without ISO	4.68E + 02		
	Total	7.36E + 02		
	With ISO	5782.079	438.162	0.000*
OBIT	Without ISO	164.01035		
	Total	300.81248		
	With ISO	1.30E + 01	4.190	0.041*
PPE	Without ISO	2.79E + 00		

*Significance at the 0.05 level is shown in italics

Sales Before Interest, Taxes, Depreciation and Amortization, (EBITDA), Ordinary Incomes Before Taxes (OIBT), and Profit Per Employee (PPE).

The same indicators had previously been used to analyse financial performance in Spain (Albors et al. 2009). To construct the indicators, information was taken from the SABI database and was subsequently processed.

The ANOVA analysis seeks to break down the variability in a study into independent components that can be assigned to different causes. It is a statistical technique designed to analyse the significance of the mean differences of the different populations, and as such, it is considered as an extension of the means difference test, and is used to study the relationship between nominal, ordinal and interval variables (Hair et al. 1998). The ANOVA technique indicates whether or not we reject the null hypothesis that reflects the equal means value for each α level of significance. In this way we confirm whether the mean of the variable performance is significantly different for the firms according to their ISO 14001 environmental certification. The database was analysed using SPSS.17.0 (see Table 5).

After analysing the overall mean value of the six studied variables, it was found that all of them revealed significant differences between firms with ISO 14001 certification and those without.

It is interesting to observe how the mean values of all of them are considerably higher than those in non-certified firms. Considering the mean size gives some indication of the relationship between size, process organisation and economic performance. This indication is supported by the EBITDA and the PPE values.

Table 6 Comparison of means (one-way ANOVA) for economic performance. Small, Medium and Big firms

		Small			Medium			Big		
ANOVA	ISO	Mean	F	Significance	Mean	F	Significance	Mean	F	Significance
	ISO	10500	91.13	0.000*	37100	2.65	0.104	383000	25.86	0.000*
TI	NO ISO	2895			27233			135181		
	TOT	2992			28013			203885		
	ISO	226.8	7.95	0.005*	36400	2.49	0.115	373000	25.34	0.000*
NS	NO ISO	49.5			26926			133427		
	TOT	51.7			27676			199986		
	ISO	41.3	22.38	0.000*	107.1	0.81	0.37	1359	22.82	0.000*
SIZE	NO ISO	15.1			100.5			487		
	TOT	15.2			101.0			729		
	ISO	762.0	77.6	0.000*	3880	11.30	0.001*	42500	33.70	0.000*
EBITDA	NO ISO	193.0			1960			8020		
	TOT	201.0			2110			17600		
	ISO	226.8	7.95	0.005*	1883	3.9	0.049*	21747	25.99	0.000*
OBIT	NO ISO	49.5			911			2591		
	TOT	51.7			988			7912		
	ISO	9.2	0.86	0.354	12.9	0.80	0.372	20,5	7.85	0.006*
PPE	NO ISO	2.1			8.7			7.2		
	TOT	2.2			9.0			10.9		

*Significance at the 0.05 level is shown in italics

A total of four one-way analyses of variances were conducted on each of the different performance measures in order to examine differences among the three segment groups identified. The results analyses are shown in Table 6.

Small firms performed very similarly to the whole sample, with TI, NS, Size, EBITDA and OBIT revealed significant differences between small food firms with ISO 14001 certification and those without. Only PPE shows no difference between small food firms with ISO 14001 certification and those without, although as we can see in Table 3, mean values of certified firms are significantly higher (more than four times). As in the whole sample, values of most analyzed variables revealed significant differences between firms that had adopted this eco-innovation tool and the rest of the sample. We can notice that mean value of number of employees is double in certified firms than in non-certified companies. Here again, a relationship between size, organizational innovation and economic performance can be observed.

The data obtained from the ANOVA analysis of medium food firms shows significant results for the EBIDTA and OBIT values, although no differences in mean income or total sales can be observed in this industry segment. An explanation could, perhaps, be found in the size factor, due to its similarity between sizes in certified firms with those non-certified. Despite this, the main indicator of profitability due to ordinary incomes revealed significant for ISO 14001 certified firms.

Results obtained from the analysis of the bigger firms′ segment is very similar to the whole sample results, with significance difference between certified and not certified firms for all the variables studied. The mean size of big firms with the ISO 14001 standard (1,359 employees) is substantially higher of those without (487 employees).

Also an ANOVA test was performed to study if there are significant differences in the variable previously indicated between low/not environmental oriented firms versus medium/high oriented. For the 608 companies included, half of them (304) answer that reducing the environmental impact while innovating is not important or it has low importance, and the other half answer that it has medium or high importance.

Variables included in this study were selected according to theoretical statements. NS represents the total sales income in 2008, SZ represents the number of full-time employees in the company during 2008, total goods investment (INVER) represents gross investment in tangible goods in 2008.

Local, national, E.U and other market variables added build EXPORT variable. As each variable is a binary variable with 1 = Yes and 0 = No. EXPORT variable is indicating whether the companies operate on a local, national, European or global scale, ranging from 1 to 4, so the higher the number the more export oriented the company is. Number of patents (PATNUM), numbers of R&D employees (PIDCA) represents the number of full-time employees who work on R and D activities, and Total Expenditure in R&D (GTINN) which represents the total investment in R&D (internal + external) for the year 2008.

Table 7 Comparison of means (one-way ANOVA) for different variables depending on environmental orientation while innovating

		Media	F	Significance
NS	Low/Not	60624629	6.771	0.009*
	Medium/high	98232077		
	Total	79428353		
INVER	Low/NO	2478989	1.428	0.232
	Medium/high	3305350		
	Total	2892169		
SZ	Low/NO	161.74	7.762	0.006*
	Medium/high	246.13		
	Total	203.94		
PIDCA	Low/NO	4.3	27.2	0.000*
	Medium/high	8.46		
	Total	6.38		
PATNUM	Low/NO	0.04	13.612	0.000*
	Medium/high	0.27		
	Total	0.16		
GTINN	Low/NO	538685.95	6.377	0.012*
	Medium/high	1200852.55		
	Total	869769.25		
EXPORT	Low/NO	3.2007	5.81	0.016*
	Medium/high	3.3783		
	Total	3.2895		

*Significance at the 0.05 level is shown in italics

The variable of study is a modification of the variable OBJET11 in the PITEC database, which measures how essential it is for innovating firms to improve their environmental impact. Variable studied considers only a binary state, 0 for not oriented or low oriented that corresponds with companies answering no important or low important in PITEC survey (3, 4), and 1 for companies medium or high oriented that corresponds with companies answering medium or high importance. The results are shown in Table 7.

Results show that significant differences in all variables besides total investment (NS). Medium/high environmental oriented firms are larger as they have 62 % higher incomes and 52 % more employees than low or not oriented. Also it seems that innovative firms that have higher number of R&D employees, grater expenditure on R&D and bigger number of patents are more environmental oriented while innovating as they double R&D employees and investment and have six times more patents than low or not oriented firms. Also, firms with medium/high environmental orientation show significant grater export orientation.

6 Conclusions

First of all, our findings showed that the use of ISO14001 as an environmental management tool had a significant impact on several economic performance variables, which led us to conclude that there is a direct relation between ISO 14001 and corporate performance, thus validating our main hypothesis, which stated that eco-innovation in environmental management by the application of ISO 14001 contributes to value creation in the food Spanish industry by improving business results.

The ANOVA analysis revealed significant differences in economic performance in the total sample, composed of all food companies with ISO 14001 environmental certification.

In the analysis of the sample segmented by size it can be seen that size is a distinguishing factor, although in the three samples differences between firms certified and those non certified were important, number of firms certified increased in direct correlation to firm size and in the three segments studied mean size were higher in certified firms.

The second hypothesis is validated by the fact that the so-called organizational eco-innovation has an influence one way or the other on firm results according to their size measured by number of employees. The most important difference lays in size. Even in the small firms group we have found differences in economic performance between firms that have implemented ISO 14001 but the mean value of certified firms doubles size of non-certified firms (Mean value Size of non certified = 15,13, mean value size of certified firms = 41,29).

A large number of empirical studies have confirmed that the use of formal systems for achieving greater coordination characterises evolutionary periods (Greiner 1997). This could explain why there is a direct relation between applying innovative organizational systems and better business management and performance. The data analysed in this research seem to be in agreement with other studies. The results show that firms with proactive practices exhibited a significantly positive economic performance (Aragón-Correa et al. 2008, Martín-Tapia et al. 2010). In addition, as could be expected from the theory (Kroeger 1974), small firms need support systems to help managers in their development needs, while larger firms can afford to have a team of specialists.

On the parallel study done over PITEC, we can conclude that the more on innovation companies are focused, the more eco-innovation is supported, considering that both formal innovative activity (Patents) and total innovation investment (total expenditure in R&D and number of R&D employees) are good indicators of the level of innovation and there are significant differences between groups considered. Our second hypothesis is fulfilled, as company size determines the sustainable innovative proactivity of the firm. Also higher export orientation is a characteristic of eco-innovative firms.

To sum up, our analysis shows that the best performing firms in the Spanish food industry are those that have adopted the ISO 14001 proactive environmental management tool, considering size acts as a moderating factor. It has sought to provide an insight into identifying factors which affect the eco-orientation of innovative firms in the food industry by analyzing which are the aspects that determine whether companies behave in a sustainable proactive way.

The results indicate the options that can be used to address the problem and an analysis of the economic, social and environmental impacts of proactivity shows the way future eco-innovation policy-making should go (Kandel et al. 2007; Del Brío and Junquera 2003; Peiró-Signes et al. 2011).

Limitations of the research are due to the quantitative analysis perspective done. An in-depth case study will be necessary to obtain further information on the results obtained by the different food industry segments. Another line of research will consist of studying the performance of the same industry in other countries, such as France and Italy, in which food industry makes a considerable contribution to the GDP.

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Part II
Environmental Friendly Resource Management in Production

The Role of Production Efficiency Regarding Ecological Aspects

Adam Kolinski

Abstract Production efficiency is one of the most important problems for modern management, both at operational and strategic levels. Raising the level of production efficiency can be achieved in many ways. Ecological aspect is very often undervalued and even missed by the managers of a company, especially when they are small or medium sized. It needs to be mentioned that there is growing interest in environmental aspects not only in production companies or whole supply chains but also in policies of many countries in the world. The aim of this paper is to highlight the importance of environmental problem in production management and to propose indicators to assess the efficiency in eco-friendly production.

1 Introduction

Production activities of companies are dependent on internal and external conditions. Customers' requirements concerning products are growing and are being individualised all the time. Fast technological development leads to creating new technologies and shortens the life of products. Extensive utilization of the resources and power supplies in a production process causes not only economic

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but also ecological threats. Presented factors have a major impact on the efficiency of production process.

Production efficiency is a very important issue from the point of view of a single company or a whole supply chain. Improving the efficiency of a production process is therefore a very important factor in controlling actions. Nevertheless, it needs to be remembered that aiming at maximising production efficiency can entail numerous threats. The most dangerous traps of maximising production efficiency are:

- lack of coordination in realisation of operational aims of individual departments with strategic aims of a company or a supply chain,
- discrepancy between strategic aims formulated by individual companies which are elements of a supply chain,
- discrepancy between operational aims of different departments of a company and, finally,
- threat of a negative influence on the surrounding environment.

Ecological aspect is very often undervalued and even missed by the management of a company. It needs to be noticed that there is growing interest in environmental aspects not only in production companies or whole supply chains but also in policies of many countries in the world. Governments have changed the "end-of-pipe" environmental laws to more comprehensive ones, broadening the responsibility of producers towards a "cradle-to-grave" perspective. The European Union, for instance, has approved the Waste Electrical and Electronic Equipment (WEEE) directive, making producers responsible for their end-of-life products (Quariguasi et al. 2009). This growing interest can also be seen in policies of many companies which emphasise the importance of ecological aspects in managing the production. Nowadays, the final customer expects products which are environmentally friendly. Therefore production companies and supply chains face the challenge of analysing production efficiency regarding also ecological aspect.

2 Efficiency in Production

Production efficiency is a concept which is quite difficult to define. Generally efficiency can be defined as a measurement (usually expressed as a percentage) of the actual output to the standard output expected. Efficiency measures the performance relative to existing standards; in contrast, productivity measures output relative to a specific input, e.g., tons/labour hour. Efficiency is the ratio of (APICS 2004):

- actual units produced to the standard rate of production expected in a time period,
- standard hours produced to actual hours worked (taking longer means less efficiency),

- actual volume of output in value to a standard volume in a time period in value.

In economic aspect efficiency is the result of company's activity, which is a proportion of the achieved effect to expenditures (incurred costs):

$$E = \frac{e}{s} \tag{1}$$

key: E—efficiency; e—effects; s—incurred costs

Complexity of production management is supported by a number of managing concepts which are implemented in order to improve production efficiency. According to model (1) we can distinguish few methods of improving efficiency of actions:

- lowering costs and keeping the level of effects at the same time,
- lowering costs and raising the level of effects at the same time,
- keeping the constant level of expenditures and raising the level of effects at the same time,
- raising the level of expenditures and raising drastically the level of effects at the same time.

Figure 1 shows basic methods of improving production efficiency and attributing them to chosen concepts of managing.

The basis of the above picture is conviction that Lean Production concept concentrates on reduction costs. Agile Production concept, on the other hand, does not focus on costs optimisation. Theory of Constraints concentrates on two methods of improving efficiency:

- increasing effects and keeping expenditures at the constant level
- streamlining process and lowering costs (e.g. reducing the supply of work in progress).

According to the definition of production diversification (Kolinski 2010), raising effects is possible thanks to increasing costs (e.g. introducing new products or entering new markets).

There are definitions which can be analysed when assessing production efficiency. Table 1 presents chosen definitions of efficiency in the framework of production management.

Literature analysis only confirms the complexity of analysing production efficiency. Most organizations say they are continually trying to increase their productivity. There are really four ways of doing this (Waters 2002):

- improve effectiveness with better decisions,
- improve efficiency using fewer inputs to achieve the same outputs,
- improve performance in some other way such as higher quality, fewer accidents, less disruption,
- improve morale to give more co-operation and incentives.

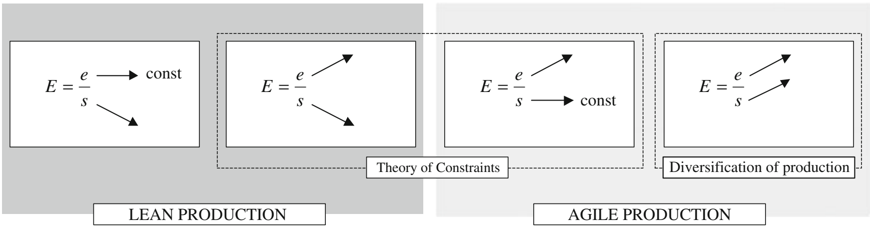

Fig. 1 Methods of improving efficiency regarding the production management concepts

Table 1 Chosen definitions of efficiency in the framework of production management

Allocation efficiency	The use of resources to produce those goods and services most wanted by consumers.
Efficiency variance	In cost accounting, the difference between the actual volume of a resource used and the budgeted volume, multiplied by the budgeted or standard price.
Line efficiency	A measure of actual work content versus cycle time of the limiting operation in a production line. Line efficiency (percentage) is equal to the sum of all station task times divided by the longest task time multiplied by the number of stations.
Manufacturing cycle efficiency	The ratio of value-added time to manufacturing lead time or cycle time. Manufacturing cycle time can be improved by the reduction of manufacturing lead time by eliminating non-value-added activities such as inspecting, moving, and queuing.
Materials efficiency	A concept that addresses the efficiency with which materials are obtained, converted, and shipped in the overall purchasing, production, and distribution process.
Operating efficiency	A ratio (represented as a percentage) of the actual output of a piece of equipment, department, or plant as compared to the planned or standard output.
Performance efficiency	A ratio, usually expressed as a percentage, of the standard processing time for a part divided by its actual processing time. Setups are excluded from this calculation to prevent distortion.
Productivity	An overall measure of the ability to produce a good or a service. It is the actual output of production compared to the actual input of resources. Productivity is a relative measure across time or against common entities (labour, capital, etc.).
Worker efficiency	A measure (usually computed as a percentage) of worker performance that compares the standard time allowed to complete a task to the actual worker time to complete it.
Labour efficiency	The average of worker efficiency for all direct workers in a department or facility.
Labour efficiency variance	Labour efficiency variance is (actual number of hours worked minus standard number of hours worked) times standard labour wage rate. The variance is unfavourable if the actual hours exceed the standard hours.

In the above considerations over production efficiency ecological aspects are not emphasised. Nowadays a production process which is environmentally friendly makes a product much more valuable. They are more valuable for a customer, therefore, they are willing to pay more for eco-friendly product. Ecologically produced goods increase sale which makes the whole supply chain to concentrate more on the environmental aspects.

The purpose of eco-efficiency is to maximise value creation while having minimised the use of resources and emissions of pollutants. Eco-efficiency is in most cases expressed by the ratio (Verfaillie and Bidwell 2000):

$$\text{Eco-efficiency} = \frac{\text{Product or servicevalue}}{\text{Environmental influence}} \tag{2}$$

The eco-efficiency is calculated using absolute values for the product value and environmental influence. The two most important applications for eco-efficiency are as an internal tool for measuring progress, and for internal and external communication of economic and environmental performance. The use of eco-efficiency indicators solves the problem that 'traditional' environmental performance indicators might fluctuate as a result of changes in production volume and thus hide real changes in environmental performance. (Michelsen et al. 2006, p 291). The idea of eco-efficiency in production is shown in Table 2.

Companies don't need to make tradeoffs between environmental impact and profitability. Sustainable supply chain management can be answer to problems that companies face, namely (Golinska 2010b):

- increasing cost of energy,
- increasing cost of raw materials,
- increasing cost of waste disposal.

Therefore, an analysis of production efficiency in ecological aspect should include an analysis of primary activities as well as secondary activities which create the so-called Closed-loop Supply Chain (Golinska 2010b). Primary processes mean all processes which have influence on producing a product, beginning with material purchase, transport, storing and production and finishing with distribution. Secondary processes, on the other hand, are connected with reverse logistics, meaning collecting used products and resources and their remanufacturing or recycling.

The concept of pro-ecological supply chain is based on 'no-waste' rule which is difficult to achieve in business practice. An analysis of production process in a pro-ecological supply chain is complex for the following reasons:

- data should be collected not only in the area of primary processes connected with manufacturing a product but also in the area of processes connected with recycling and remanufacturing a product,
- need for increasing the quality controls in order to minimise the amount of production waste.

Table 2 Idea of eco-efficiency in production

Eco–efficiency in production	
Problems	Requirements
Which volume of waste arises in a specific step of process?	Selection using of materials that are able to be recycled, remanufactured and reused.
Which emissions arise at specific locations?	Modularity using of products for remanufacturing.
How big are costs connected with emissions and wastes?	Minimization using of waste and remains.

Source own study based on (Golinska 2010b)

Production efficiency regarding ecological aspect must, therefore, include indicators of a traditional production process, detailed analyses of production quality and indicators connected with materials, energy and water utilization as well as emissions of greenhouse gases.

3 Indicators for Assessing Production Efficiency Regarding Ecological Aspects

An analysis of production efficiency should be based not only on operational indicators, which are directly connected with production process, but also on financial indicators. Aims and indicators used in an analysis of production efficiency should result from a company's vision and strategy. An analysis of production efficiency can be named complete when it does not only refer to indicators which apply to past results but also when it allows monitoring what affects future results. The problem of complete production efficiency assessment has still not been solved in the literature. Taking into account ecological aspect, the problem of production efficiency assessment can be based on the assumptions of Balanced Scorecard developed by R. Kaplan and D. Norton. The authors proposed the analysis of efficiency from four perspectives: financial, customer, internal business process, and learning and growth. Many companies already have performance measurement systems that incorporate financial and nonfinancial measures. What is new about a call for a "balanced" set of measures? While virtually all organizations do indeed have financial and nonfinancial measures, many use their nonfinancial measures for local improvements, at their front-line and customer facing operations. Aggregate financial measures are used by senior managers as if these measures could summarize adequately the results of operations performed by their lower and mid-level employees. These organizations are using their financial and nonfinancial performance measures only for tactical feedback and control of production process in short-term (Kaplan and Norton 1996).

Carrying out an analysis of production efficiency in discussed four perspectives, we have developed a set of indicators (Corbett 1998; Sliwczynski 2011; Twarog 2005) which take into account the basic characteristics of efficiency defined by

Table 3 Indicators for assessment of production efficiency from a financial perspective

No.	Name of indicator	Formula	Characteristic	Unit
1.	Return on investment (ROI)	$\frac{a}{b}$	a—net profit b—investment[a]	%
2.	Return on equity (ROE)		a—net income after tax b—shareholder equity	%
3.	Return on assets (ROA)		a—net income b—mode of total assets	%
4.	Return on sales (ROS)		a—net profit b—sales revenue	%
5.	Ratio of material inventory turnover		a—material consumption costs b—average stocks of materials	%
6.	Ratio of worker productivity		a—net sales b—salary costs	%

[a] Investment, means the money which were spend for buying things which will be sold (Goldratt and Cox 2004)

model (1). Table 3 presents the chosen indicators applicable for the assessment of the production efficiency in a financial perspective.

The table 3 shows only chosen financial indicators which, in authors' opinion, are most often used when assessing production efficiency regarding also ecological aspects. There are many more indicators which can be useful in business practice but it needs to be remembered that the more indicators, the bigger the threat of missing the main aim of carrying out an analysis.

Table 4 presents chosen indicators of assessing production efficiency from customer's perspective—applicable in environmental friendly production.

Some of the aforementioned indicators are very often compiled to one indicator-OTIF (On Time and In Full delivery). This indicator should be seen as the level of customer's service from customer's perspective (commercial network)—"on-time, in-full"—full orders, delivered on time. In practice we can meet the term OTIF developed by "error-free" element. OTIF has become the key driver for process improvement initiatives across the organization. Planning orientation and organizational integration resulted in process optimization across the supply chain resulting in a higher service level with reduction in inventories (Sehgal et al. 2006). Table 5 presents chosen indicators of production efficiency from a perspective of an internal process—applicable in environmental friendly production.

Encapsulation of efficiency in production is best apparent in collation of indicators from internal business process perspective. This state of things should not be surprising as these are processes which take place on an operational level that have the biggest contribution in assessing production efficiency in ecological aspect.

Table 6 presents chosen indicators of production efficiency in learning and growth perspective—applicable in environmental friendly production.

Indicators of production efficiency in learning and growth perspective are the most wanted form of assessing production efficiency. However, they are also the most difficult to develop. One needs to remember that indicators of development

Table 4 Indicators for assessment of production efficiency from customer's perspective

No.	Name of indicator	Formula	Characteristic	Unit
1.	Effectiveness of realization of orders	$\frac{a}{b}$	a—number of completed orders b—total number of orders	%
2.	Quantity or value market share		a—volume of the customers target group b—total market volume	%
3.	Average duration of delivery		a—lead time of deliveries b—number of deliveries	h
4.	Share of defective product delivery to customer		a—number of defective delivery b—total number of deliveries	%

Table 5 Indicators of production efficiency from perspective of an internal process

No.	Name of indicator	Formula	Characteristic	Unit
1.	Share of defective production	$\frac{a}{b}$	a—value of defective products b—total value of products	%
2.	Production capacity utilization		a—used production capacity b—total production capacity	%
3.	Ratio of waste in production process		a—value of raw materials that are classified as defects in the manufacturing process b—total value of raw materials	%
4.	Efficiency of electricity use by the machinery		a—unproductive time using electric energy b—total working time of machinery	%
5.	Duration of the production orders for assortment groups		a—overall duration of production orders b—number of production orders	h

Table 6 Indicators of production efficiency from learning and growth perspective

No.	Name of indicator	Formula	Characteristic	Unit
1.	Share of spare parts in a product	$\frac{a}{b}$	a—number of components that can be replaced b—total number of components in the product	%
2.	Flexibility of production		a—number of executed special orders b—total number of special orders	%
3.	Effectiveness of design for new products		a—number of projects for new products b—total number of projects for new products	%
4.	Share of defective deliveries of raw material		a—number of defective delivery of raw material b—total number of delivery of raw material	%

also entail different threats. The indicators can be inconsistent not only with pro-ecological business management and a supply chain but also with the basic strategic aims. When preparing a set of indicators for production efficiency assessment regarding ecological aspects one needs to have in mind the link between individual perspectives. Analysing and compiling indicators of efficiency assessment for each perspective individually can lead to the situation which is reverse to the expected effect. A risk exists that the set of indicators will contradictory, so that they would exclude one another.

4 Conclusions and Further Research

The problem of production efficiency does not only apply to companies but also supply chains in which a given company is a link. Efficiency is a key factor which should have influence on the whole supply chain integration on the operational as well as on the strategic level (Kolinski and Fajfer 2011). Sustainable supply chain management requires a continuous course of actions in order to decrease the environmental impact of products and technology used by a manufacturer and its pre-chain (suppliers) and post-chain (collection, inspection and reprocessing activities) (Golinska 2010a). An opening stage of pro-ecological supply chain management is the choice of materials which can be reused at the final stage of a product's life. Therefore, classification and assessment of suppliers (Dolinski and Kolinski 2011) is one of key stages of implementing pro-ecological management of a company and supply chain. However, a condition which must be fulfilled is choosing an appropriate criterion of material's quality. Lack of supply chain integration can cause the threat of 'wandering' ecological issue. Making production process more sensitive to ecological aspect can result in an increase in environmental harm done by the consecutive links of a supply chain. A reverse situation is strong ecological sensitization of supply processes which can affect efficiency in production process (e.g. less processed materials which have a positive influence on eco-efficiency indicator for supplies can enforce implementing additional operations which can, in turn, have a negative influence on this indicator for a production process). Therefore, production efficiency should be analysed in two areas: efficiency of a supply chain and efficiency of a company and its production process. A chance for coherence of the aims of production efficiency in both areas is adhering to the assumptions of Balanced Scorecard, which has been shown in the present chapter.

It needs to be considered that an increase in one department's efficiency does not have to result in an increase in whole company's efficiency. Only an increase in key processes efficiency will result in an increasing the indicators of efficiency of a company's business activity. A very important aspect is also coordination of operational and strategic aims. If operational aims do not reflect accurately strategic aims, then a result can be generating contradictory indicators which have a negative influence on production management efficiency.

The aim of the this chapter is to present the complexity of production efficiency issue, also taking into account ecological aspect which is another very important factor influencing competitive dominance of production companies.

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Production Waste Management: Case Study

Paulina Golinska and Pawel Majewski

Abstract The environmental friendly production management requires a constant reduction of waste being generated on the shop floor. This can be achieved by improvement of technology and also by higher environmental awareness of the employees. This chapter contains analysis of waste management system in a company from packaging sector. The system includes processes of collection, movement, storage and registration of all waste arising in the enterprise. The work covers organizational and technical aspects of waste management in the company involved in the production of corrugated packaging. Authors present improvements which might lead to the reduction of the production's waste being generated.

1 Introduction

Environmental issues meet a lot of interest among manufacturing companies. Due to the growing cost of raw materials acquisition and waste disposal the proper treatment of production waste is an important part of the materials management activities in an industrial organization.

An interesting framework for reduction of the level of waste provides the circular economy concept (see: Pearce and Turner 1990). This approach highlights four economic functions of the environment (Andersen 2007):

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1. amenity values—which are pleasures that the environment provides directly to humans without interference from the economic system;
2. resource base—the environment provides renewable and non-renewable resources which are inputs for the economy and industrial activities;
3. sink of residual flows—as a sink (waste bin) for the residuals of economic activity, whether the emissions are waterborne, airborne or solid;
4. life—support system—reflects the inherent biological character of the environment.

From a materials management perspective the most important are second and the third function. In the production system these circular economy functions can be translated into following actions:

- minimize waste streams (sink function) generated during executions of operations;
- minimize the usage of both renewable and non-renewable raw materials (resource based function);
- reuse and recover the materials which were already introduced into production system;
- recover the energy used for creation of the products and execution of the processes.

In times of economic crisis, efficient reverse materials management (re-supply) can be perceived as a new opportunity to lower costs. In order to effectively manage waste level companies need interdisciplinary knowledge of logistics, production planning and control and materials science. The legal regulations impose a number of duties regarding the protection of the environment. Effective waste management requires the process of continuous improvement all aspects of manufacturing system functioning.

In number of industries the possibility of the waste to be processed will increase. More and more groups of waste will be reused as secondary materials. An excellent example of such an industry is packing sector. Demand for reprocessing of the cardboard's waste is already big with a strong growing trend.

The aim of this chapter is to present the improvement approach which might lead to a reduction of the amount of the production's waste. At first it is discussed the theoretical background relating to waste management and the concept of reverse logistics. In next parts detailed case study description is provided including the analysis of waste streams and a description of the related information management. The emphasis is placed on the identification of conditions determining the size of waste production.

2 Reverse Logistics and Recovery of Materials

The waste management can be executed at the individual level (single entity) or intra-organizational level (e.g. in the community like city of region) and national/international level. The main strategic objectives of waste management at the national/international level are:

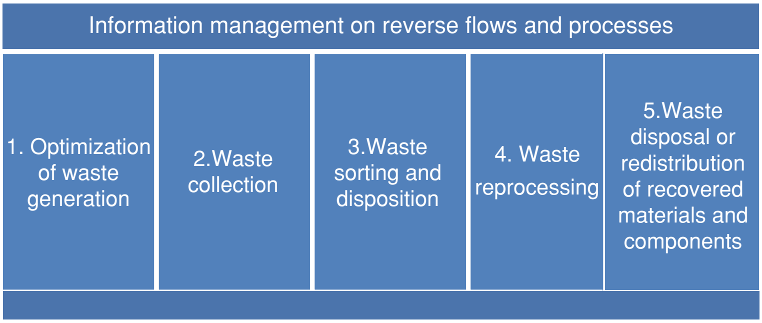

Fig. 1 Scope of reverse logistics

- increasing the levels of reuse and recycling,
- waste avoidance by burden the manufacturers with waste disposal costs,
- fostering the development of technologies associated with repeated use, and recycling,
- fostering the development of technology related to the disposal of non-reusable waste,
- minimizing the risks associated with the transport of waste.

At the level of individual entity (e.g. industrial company) the main goals of waste management are:

- waste avoidance,
- waste reuse and recycling or other recovery operations,
- disposal of production wastes in a safe and eco-friendly way,
- minimizing the cost of reverse logistics.

Reverse logistics covers all activities connected with collection, sorting and reprocessing of production waste, as well as end of life products. The efficient reverse flow management allows reducing the size of waste being disposed. The role of reverse logistics is growing every year, mainly because of the legislative regulations. The scope of reverse logistics activities is presented in Fig. 1.

Reverse processes are as follows:

- Optimization of waste generation covers all the activities regarding minimization of unrecoverable waste on the shop floor as well as application of such technologies which allow reusing the remains from the production process.
- Collection refers to all activities rendering used products available and physically moving them to some point for further treatment. Collection may include purchasing, transportation, and storage activities (adapted from Dekker et al. 2003).
- Sorting and disposition denotes all operations determining whether a given product or material can be re-usable and in which way, it results in splitting the flow of used materials to different recovery options.

- Reprocessing means the actual transformation of a used product into a usable product/component/material. This transformation may take different forms including recycling, repair and remanufacturing. In addition, activities such as cleaning, replacement and re-assembly may be involved.
- Disposal is required for products that cannot be re-used for technical or cost reasons. This applies, for example, to products rejected at the separation level due to excessive repair requirements but also to products without satisfactory market potential. Disposal may include transportation, landfilling and incineration steps (adapted from Dekker et al. 2003).
- Re-distribution refers to directing re-usable products to a potential market and physically to moving them to future users (adapted from Dekker et al. 2003).

In this chapter the emphasis is placed on the first phase regarding the optimization of waste generation.

Regarding the type of reprocessing activities (recovery options) waste can be classified as:

- waste to be remanufactured,
- recyclable waste,
- waste to be reusable,
- waste to be disposed with energy recovery,
- waste intended for long-term storage in landfills.

The recovery option depends on features of product or material. Remanufacturing is applicable for durable goods with high residual value. Remanufacturing is an industrial process in which a new product is reassembled from an old one and, where necessary, new parts are used to produce fully equivalent and sometimes superior, in performance and expected lifetime, to the original new product (Lund 1983). Remanufactured products conserve not only the raw material contents, but also much of the value added during processes required to manufacture new products (Seliger 2006).

Recycling is putting used materials back into the manufacturing chain at a very basic level. The output of the recycling process could be the same products, when the quality is good enough (e.g. steel, automotive plastics), or new ones in cases where used materials are not meeting the quality standards. Recycling has a large potential for conserving natural resources. Recycling processes besides giving up the energy that has been embodied in the initial products, need a lot of additional energy to arrive at the next products (Steinhilper 1998).

In cases when the remaining value is not high enough for remanufacturing, or the cost to obtain a product is high compared to the remaining value, then reuse is an option.

Reuse has the potential for raw materials and energy savings, due to the fact that it allows, in many cases, the replacement of single use products with reusable products and also reduces the number of manufacturing operations. Moreover, it allows a reduction in the disposal of waste.

3 Case Study

3.1 Company Characteristics

Packing & Co. is middle size enterprises which employs about 120 people. The scope of business covers the design, manufacturing and sale of packaging from corrugated paper. It is one of the leading companies on the polish market. Its manufacturing system is the most innovative in the polish packing sector. The company builds its competitiveness on quick response strategy. Any customer's order should be fulfilled within 48 h. Implementation of this strategy requires execution of the operations on the shop floor in three shifts and 6 days a week. The manufacturing technology is divided into three phases:

- cutting machines,
- printing machines,
- multipoint gluers.

Advantage over its competition, the company obtains through flexibility in fulfillment of customer needs. The system of caring out orders within 48 h is combined with the philosophy of the continuous cooperation with the customer by development of new packing. Continuous improvement of the quality of produced products is connected with reduction of the environmental impact. Constant reduction of the negative impact on the environment is achieved by regular reduction of production waste.

The Packing & Co. produces packaging mainly from corrugated cardboard three and five layered. Produced packing can be divided by their different shape, and color of the material from which they are made. Thus, they are divided into:

- cardboard packaging boxes,
- grey unilaterally bleached cardboard packaging,
- double-side bleached cardboard packaging,
- package with flexographic imprint method—up to four colors + varnish.

The company for all design and manufacturing activities has implemented quality management system complies with international standard ISO 9001: 2000 and in the field of environmental protection compatible with the international standard ISO 14001: 2004.

The production waste at Packing & Co. is classified as:

- cuttings,
- poor quality raw material,
- poor quality products,
- poor quality work-in-progress,
- trials lots for setups.

The waste from shop floor is mainly recyclable but the costs of reverse logistics regarding storage of the waste and its transportation to external recycling facility are high. The company is trying to lower the level of waste generated at the shop floor in order to reduce these costs.

3.2 Research Approach

The case study was conducted based on the following steps:

1. Identification of the technological conditions influencing waste generation,
2. Identification of the organizational conditions influencing waste generation,
3. Identification of parameters for optimization,
4. Simulations of production data.

The above presented research approach allows to simplify the problem through step by step analyzes of a complex manufacturing system. The data needed for analysis was collected in-field. The production reports for period of 6 month from year 2010 were collected and aggregated. In situation where the production reports were not consistent additional interviews with the production staff were conducted. The interviews covered both sift managers and machines operators.

3.3 Production Process: Identification of Technological Conditions Influencing Waste Generation

The quick response strategy gives company a big competitive advantage but it leads also to the higher production waste level. Short production series of customized products cause problems with machines setups.

The average time for machines setup times varies depending on type and shape of particular packing. In general the setup times are as followed:

- printing line—5–25 min, on average 10 min,
- cutters—on average 25 min,
- gluer—25–60 min, on average 35 min.

The technology of corrugated cardboard packing requires that each worker during setup operations uses or trials over 10–50 sheets of raw materials or semi-products.

Frequent machines setups for different customers' orders result in the increased level of operator mistakes. Moreover the machines that are often setup might lose the initial parameters during performing manufacturing operations. Both situations seriously increase level of production waste.

Moreover the structure of production requires application of more than one machine each time e.g. cutter, printer, gluer. The logic of production process for particular products requires usage of multiple setups at different machines. This situation increase level of the production wastes. In Table 1 the typical production routes are presented.

Table 1 Production routings for products

Products [%]	51%	12%	19%	5%	13%
Machine, its function, flow direction	M1	M2	M1	M2	M1
	Printing, rotated cutting, singlepoint gluing	Flat cutting	Printing	Flat cutting	Printing
			M2	M3	M2
			Flat cutting	Multipoint gluing	Flat cutting
					M3
					Multipoint gluing
	Final product				

The next reason for increased level of production waste is high speed of production operations. The particular production lines have following speed:

- printing line (M1)—150 pieces/min,
- cutting line (M2)—40 pieces/min,
- multipoint gluing line (M3)—80 pieces/min.

By production at such speed it is difficult to quickly identify the technological problems as wrong parameters or bad quality. The delayed problem identification leads to higher waste level.

The next factor that influences the average level of production's waste is the average size of the order. The smaller lot sizes the bigger setups frequency. The Packing & Co. fulfills orders bigger than 500 pieces. The average size of customers' orders is presented in Table 2.

In Table 3 is presented the calculation of the average number of setups per shift. The calculation is made based on data from subsequent production reports covering the half year period. Reports from 6 months were taken in consideration in order to exclude some periodical variations resulting from extraordinary orders.

Our calculation shows that the number of setups is very high and it is the main factor influencing the average level of production waste.

3.4 Identification of the Organization Conditions: Waste Management Registration System

The organizational conditions which are taken in consideration by this case study reflect mainly to the waste registration system. Company identifies two categories of production waste: real waste and virtual waste. The virtual waste is reported as a

Table 2 Average lot size for each production line/machine

Machine/line	M1	M2	M3
Average lot size [pieces]	1886	1689	5280

Table 3 Average number of setups per line/machine during shift

Machine	Setup time [min]	Speed [pieces/min]	Average lot size	Average working time [min]	Total working time [min]	Average number of setups
M1	10	150	1886	12.6	460.0	20.4
M2	25	40	1689	42.2	460.0	6.8
M3	35	80	5280	66.0	460.0	4.6

difference between the amount of raw material that has been declared in the previous phase of the production process and the real amount that is placed on the pallet. Identification of the virtual waste is a simplification which helps the company to exactly register the real waste.

In the company there are three typical documents for registration of production waste: daily balance for cardboard, operator's daily report, total record of cardboard's production waste.

The daily balance for the cardboard should be equal to zero. It takes into consideration:

- the amount of cardboard shipped to the production department from raw materials' inventory,
- the amount of cardboard received to the production department,
- the sum of production waste,
- the amount of finished products shipped to goods inventory,
- the amount of finished products received at goods inventory,
- differences in the work-in-progress inventory level between the current day and the previous production day.

The total record of cardboard's production waste is prepared in order to:

- monitor the level of waste at technological processes,
- monitor types of waste at technological processes,
- identified people responsible for establishing of waste,
- improve the environmental management system (update the environmental goals).

The last document in the reporting system is aforementioned operator's daily report. In this document every operator reports how much waste was generated during his shift because of cuttings, poor quality and setups' problems.

Figure 2 present the type of particular wastes, which are included in the company's reporting system.

The in-field research of the organizational conditions has showed that there are differences between the amounts of waste declared in the particular types of

<table>
<tr><th colspan="3">Type of report</th><th>Type of waste</th><th>Source</th><th></th></tr>
<tr><td colspan="2"></td><td rowspan="4">Total record of cardboard production waste</td><td>Cuttings</td><td>Flat cutting, rotated cutting, slotters cutting</td><td rowspan="4">Real waste</td></tr>
<tr><td rowspan="6">Daily balance of cardboard</td><td rowspan="3">Operator's daily report</td><td>Waste generated by quality checks</td><td>Raw materials control before production, quality control of finished goods at the end of production process (size & printing)</td></tr>
<tr><td>Poor quality of raw materials</td><td>Damaged raw materials</td></tr>
<tr><td>Poor quality of work-in-progress</td><td>Operator's error, bad setup's parameters, trial lots</td></tr>
<tr><td colspan="2" rowspan="3"></td><td>Non-conformity of work-in-progress</td><td>Deficit of work-in-progress amount placed on the pallet in comparison with amount registered on the machine's counter.</td><td rowspan="3">Virtual waste</td></tr>
<tr><td>Non-conformity of raw materials</td><td>Deficit of raw materials on the pallet declared by the suppliers comparing to the amount registered on the machine's counter.</td></tr>
<tr><td>Surplus</td><td>Surplus of raw materials or work–in-progress comparing with amount registered on the machine's counter.</td></tr>
</table>

Fig. 2 Complete classification of production waste

reports. The inconsistencies between particular reports make difficult the reliable evaluation of waste level for each period.

The incentives system in Packing &Co. for machine operators is based on the data placed in the daily report. In company there is a problem with operators who sometimes lower the reported level of generated waste in order not to lose their bonuses.

4 Simulation

In the previous subsections were described technological and organizational conditions. The most of waste is arising from frequent machine's setups. The strategy of company is based on flexibility and quick response to customer needs. In our opinion it is possible to combine flexibility with more reasonable lot

Table 4 Classification of production waste

	Year n−2	Year n−1	Year n
Production volume (kg of raw material used)	19256254	20203309	18395031
Waste generated by quality checks QC (kg)	48054.95	26915.96	18106.84
Poor quality of raw materials PQRM (kg)	150354.08	202756.4	148095.9
Poor quality of work-in-progress PQWIP (kg)	97110.95	112967.3	106003.9
Inconsistencies INC (kg)	126111.95	151324.6	95492.05
Surplus	50695.97	41797.96	43012.59
Waste in total (kg)	370936.0	452166.4	324686.1
QC (%)	0.25	0.13	0.10
PQRM (%)	0.78	1.00	0.81
PQWIP (%)	0.50	0.56	0.58
INC (%)	1.29	1.56	1.38
Surplus (%)	0.39	0.54	0.29
Waste in total (%)	1.93	2.27	1.77

Table 5 Data analyzed for line M1

Number of production reports [pieces]	300
Number of products types [pieces]	1400
Number of analyzed production lots [pieces]	4347
Average amount of raw materials lot [pieces]	1886
Number of products [pieces]	8,200,207
Waste level [pieces]	109,058

size planning. The increase of average size of lot size allows reduction of number of setups per shift and per machine. Previously company has not analyzed the influence of lot size on the amount of waste for particular machines and processes. In Table 4 is presented the classification of production waste.

A number of simulations were run based on real life production data. The simulations have showed the preferable size of customer's order which generate the lowest potential level of waste. The results also show the range of reasonable lot size. The simulation was done separately for each production line/machine due to the different capacities of analyzed equipment. First the printing line M1 is analyzed. Table 5 presents the data characteristics.

M1 is used for production of over 80 % of products types offer by company (see Table 1). It is the most often setup machine in the whole manufacturing system. As indicated in Table 5 during 300 shifts there were 4347 setups. On average it gives about 14 times per one working shift.

Figure 3 shows the simulation results for printing line M1. It presents how the size of lot is connected with reduction of production waste. The lot size taken in consideration by simulation responds to following ranges:

- 200–500 pieces,
- 500–2000 pieces,
- 2000–5000 pieces,
- bigger than 50000 pieces.

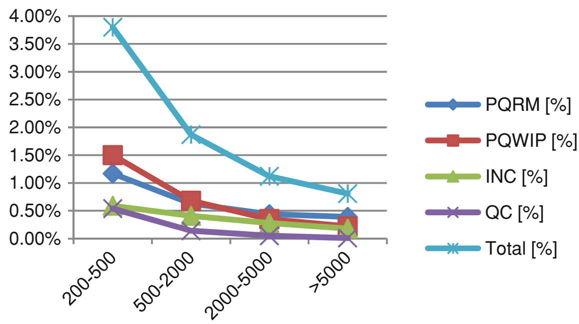

Fig. 3 Lot size versus level of the production waste for M1

Table 6 Data analyzed for line M2

Number of production reports [pieces]	447
Number of products types [pieces]	757
Number of analyzed production lots [pieces]	2828
Average amount of raw materials lot [pieces]	1689
Number of products [pieces]	4,776,384
Waste level [pieces]	25,496

Table 7 Data analyzed for line M3 data

Number of production reports [pieces]	200
Number of products types [pieces]	241
Number of analyzed production lots [pieces]	944
Average amount of raw materials lot [pieces]	5280
Number of products [pieces]	4,984,386
Waste level [pieces]	39,216

For cutting line M2 the data characteristics is presented in Table 6. The cutting line M2 consists of two separate cutters. The size of raw materials used is lower than on the others lines (1689 sheets). The line is based on unique technology with flat punches. The punch is individually designed for each customer's order. Its high customization and big working surface allows optimizing the cutting process from cardboard sheets (up to 16 pieces of packing from one cardboard sheet).

Figure 4 shows the simulation results for cutting line M2. It presents how the size of lot is connected with reduction of the production waste.

For multipoint gluing line M3 the data characteristics is presented in Table 7. For multipoint gluing line M3 the average size of lot is bigger than in the case of the two other lines. It is because this gluing technology usually is used for very small packing boxes. Company accepts for this technology only bigger orders or cumulate smaller orders, so in simulation different range of lots are used than in the previous cases. Figure 5 presents the simulation results for gluing line M3.

These results provide a framework for managers in the company. It gives in-depth insights into the relations between size of lot and amount of waste that is

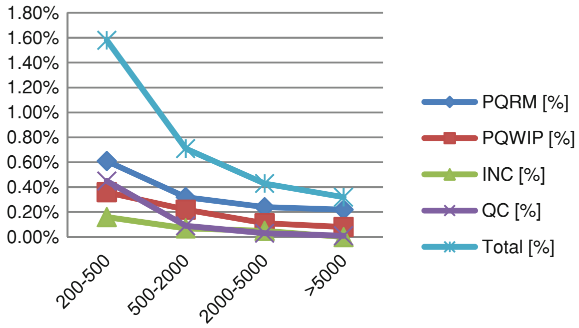

Fig. 4 Lot size versus level of the production waste for M2

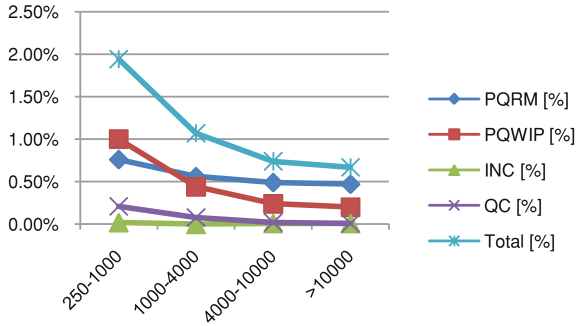

Fig. 5 Lot size versus level of the production waste for M3

generated in the company. They should be treated as a base for some trade-off between extreme flexibility that company is offering to its customers and some environmental and economic benefits which might be achieved by more careful lot size planning. At present usually one order is treated as one separate lot size. Only some exceptions from this rule appear at line M3.

5 Conclusions

The chapter presents case study of corrugated cardboard packing manufacturer. The aim of research was the optimization of production waste. The organizational and technological conditions of the manufacturing system were taken in consideration. The level of production waste decreases significantly with increase of lot size. It is connected mainly with setups which require many trials and generate waste. The strongest relation between lot size and level of generated waste can be observed at printing line M1, where the difference was 2.9 %. Moreover this machine is used for manufacturing of 83 % of all products, so the reduction potential is the biggest. For line M2 (cutting) and M3 (multipoint gluer) the differences were 1.26 and 1.27 %.

Company should include in the sale policy customers' incentives for placing bigger or aggregated orders.

Moreover the problem that appears by our analysis is the fact that operators report "qualify poor quality work-in-progress" (PQWIP) as "poor quality raw material" (PQRM). It is in fact shifting the responsibility on suppliers and shades the real picture of shop floor operations. This practice happens because high values of reported "poor quality of work-in-progress" PQWIP decreases the operators bonuses.

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Sustainability: Orientation in Maintenance Management—Theoretical Background

Malgorzata Jasiulewicz-Kaczmarek

Abstract New concepts and approaches to corporate management, such as Lean Manufacturing, new challenges connected with natural resources management (Green Manufacturing), and thinking in a sustainable way (Sustainable Manufacturing) resulted in developing new approach to maintenance management as well. Contemporary maintenance is not only a set of operations focused on dealing with breakdowns and failures and conservation of machines and devices. Nowadays, it is more like long term strategic planning which integrates all the phases of a product lifecycle, includes and anticipates changes in social, environmental and economic trends, benefits from innovative technologies. Thus, it is necessary to include sustainable development category into processes and activities realized in the area of enterprise's technical infrastructure maintenance.

1 Introduction

According to the World Commission of Environment and Development (1987) sustainable development is that which "meets the need off the present without compromising the ability of future generations to meet their own needs". Therefore, sustainable development is about reaching a balance between economic, social, and environmental goals, as well as people's participation in the planning process in order to gain their input and support (Sneddon et al. 2006). For company sustainable development means adoption of such business strategy and such actions that contribute to satisfying present needs of company and stakeholder, as

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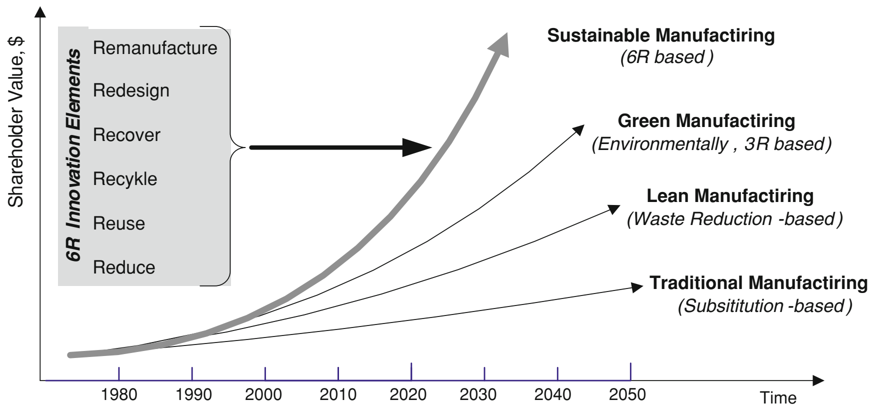

Fig. 1 Sustainable Manufacturing [adopted from (Jawahir 2007)]

well as simultaneous protection, maintenance and strengthening of human and environmental potential which will be great value in the future. Manufacturing businesses can contribute to this effort by designing products and production systems that have only a slight or optimally low impact on the natural environment in terms of resource depletion, waste emissions, energy usage, and other impacts (Michaelis 2003).

Since sustainable development is becoming an increasingly popular concept, there is a growing need to ensure the possibility of its implementation. The way to help companies improve their economical, environmental and social performance is by (Kopac 2009):

- minimizing production of waste—less waste generated and increase waste re-usage or recycle,
- using resources such as materials, water and energy efficiency,
- avoiding or at least improving management of metalworking fluids, lubricating oils and hydraulics oils,
- improving environmental, health and safety performance,
- adopting lean manufacturing and other sustainable engineering techniques,
- improving working conditions,
- using best practice in the process of producing and maintaining movement,
- training all employees about sustainable practices.

In the manufacturing sector, applying the “6R” concept of reduce, reuse, recycle, recover, redesign and remanufacture can enable improving on the lean (waste reduction-based) and green (environmentally benign) manufacturing strategies to more holistic, sustainable manufacturing to achieve exponential growth in stakeholder value (Jawahir 2007) as shown in Fig. 1.

This innovative solution which applies the principle of systemic approach allows the enterprises to look through a holistic prism at both the external relationships in a supply chain as well as the internal relationships in the context of

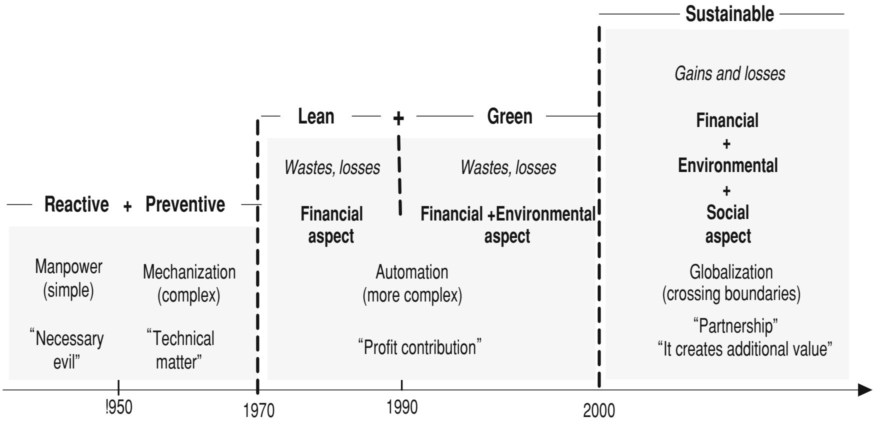

Fig. 2 The evolution of maintenance on a time perspective

implemented processes and resources used. The possibility to use the potential and full capacity of resources is a prerequisite for effective action and obtaining a competitive edge.

A company contains a large number of technical systems which all interact to achieve the pursued business objectives. Maintenance contributes more than ever to the achievement of these objectives. Proper maintenance does not only contribute to lowering the operating costs and extending equipment durability but also positively affects the overall performance of the company.

New concepts and approaches to corporate management, such as Lean Manufacturing, new challenges connected with natural resources management (Green Manufacturing), and thinking in a sustainable way (Sustainable Manufacturing) resulted in developing new approach to maintenance management as well (Fig. 2).

Contemporary maintenance is not only a set of operations focused on dealing with breakdowns and failures and conservation of machines and devices (traditionally the scope of maintenance activities has been limited to the production vs. operation chase). Nowadays, it is more like long term strategic planning which integrates all the phases of a product lifecycle, includes and anticipates changes in social, environmental and economic trends, benefits from innovative technologies (for example e-maintenance, e-diagnostic). Whereas the goal of maintenance is increasing profitability and optimization of total lifecycle cost without disturbing safety and environmental issues (aspects: loss, consequences, benefits).

Thus, it is necessary to include sustainable development category into processes and activities realized in the area of enterprise's technical infrastructure maintenance. Sustainable infrastructure maintenance is focused on prolonging assets use and providing high efficiency of technical systems at optimal resources use.

Hence, in declared and realized by enterprises sustainable development strategy, sustainable infrastructure maintenance is an important element supporting and necessary to achieve the "sustainable" status.

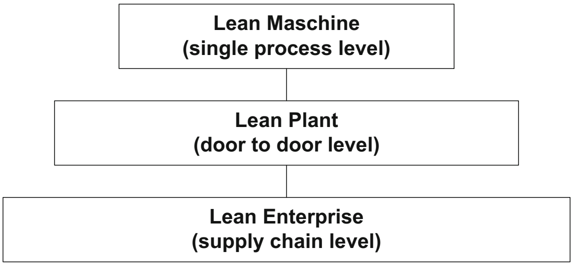

Fig. 3 Different levels of Lean manufacturing. *Source* (Simons and Zokaei 2005)

2 Lean Thinking in Maintenance Activities

Lean manufacturing (LM) is a multi-dimensional management practice including quality systems, work teams, cellular manufacturing, supplier management, etc., in an integrated system (Worley and Doolen 2006). The core motivation of lean manufacturing is that these practices can work synergistically to produce finished products at the pace of customer demand with little or no waste. Waste, in LM, is defined as anything that does not add value to the product or service from a customer's perspective (Taj and Berro 2006). To eliminate waste, LM uses tools such as workplace organization, visual communication and control, quick changeovers, pull system, error proofing, etc. (Seppala and Klemola 2004), (Olivella et al. 2008). Lean thinking tools are used at all levels of enterprise functioning (Fig. 3) and enable effective process improvement, providing a potentially greater value for customers with less effort.

The structure of a manufacturing company has changed from a labour-intensive industry to a technology-intensive, i.e. capital intensive, industry. Lean does not work without highly reliable and predictable machines and processes. A failure in equipment or facilities not only results in loss of productivity, but also in a loss of timely services to customers, and may even lead to safety and environmental problems which destroy the company image. This resulted in a rise of support processes including primarily the process of movement maintenance.

The characteristic of lean thinking, associated with maintenance to improve efficiency and reduce waste, is the use of total productive maintenance (TPM). It is a comprehensive strategy that supports the purpose of equipment improvement to maximize its efficiency and product quality (Willmott and McCarthy 2001). TPM is aimed at zero breakdowns and zero defects which deviate from the specialist maintenance function to improve global consideration, i.e., the operator, the process and environment. TPM tools such as autonomous maintenance, planned maintenance and cross training improve the *effectiveness* of the process (i.e. dealing with the reasons why things do not go according to the plan). This includes frameworks to release capacity, increase control and repeatability.

In many companies LM and TPM work together to provide a holistic approach to achieve continuous improvement driven by progressively removing inhibitors and tuning the complete supply chain (Table 1).

Table 1 The benefits of Lean TPM

Measure	Impact of TPM	Impact of lean thinking
Productivity	Reduce need for intervention Reduce breakdowns	Reduce non-value-adding activities increase added value per labour hour
Quality	Potential to reduce tolerance Control of technology Reduce start-up loss	Highlight quality defects early
Cost	Reduce material, spares	Lower inventories
Delivery	Zero breakdowns Predictability	Shorter lead times, faster conversion processes
Safety	Less unplanned events Less intervention Controlled wear	Less movement, less clutter Abnormal conditions become visible easily
Morale	Better understanding of technology	Less clutter
	More time to manage	Closer to the customer Higher appreciation of what constitutes customer value
Environment	Closer control of equipment Less unplanned events/ human error	No 'over-production' Systems geared to needs not theoretical batching rules

Source (McCarthy and Rich 2004)

Including the category of lean thinking in movement maintenance practices in literature is called Lean TPM (McCarthy and Rich 2004), or Lean maintenance (Smith and Hawkins 2004). Ricky Smith (Smith 2004), defined Lean Maintenance as a "proactive maintenance operation employing planned and scheduled maintenance activities through total productive maintenance (TPM) practices, using maintenance strategies developed through application of reliability centered maintenance (RCM) decision logic and practiced by empowered (self-directed) action teams using the 5S process, weekly Kaizen improvement events, and autonomous maintenance together with multi-skilled, maintenance technician-performed maintenance through the committed use of their work order system and their computer managed maintenance system (CMMS) or enterprise asset management (EAM) system". This promotes achievement of a desirable maintenance outcome with fewest inputs possible. Inputs include: labor, spare parts, tools, energy, capital, and management effort. The gains are as follows: improved plant reliability (availability) and improved repeatability of process (less variation).

Lean maintenance seeks to eliminate all forms of waste (Ghayebloo and Shahanaghi 2010). Ohno (1988) identified seven initial types of waste within manufacturing production (waste from overproduction; waste from waiting inventories; waste from unnecessary transport; waste from waiting times; waste from unnecessary motion (movement of people); waste from unnecessary processes; and waste from defected products) to which Bicheno (Bicheno 2000) added another seven (Fig. 4).

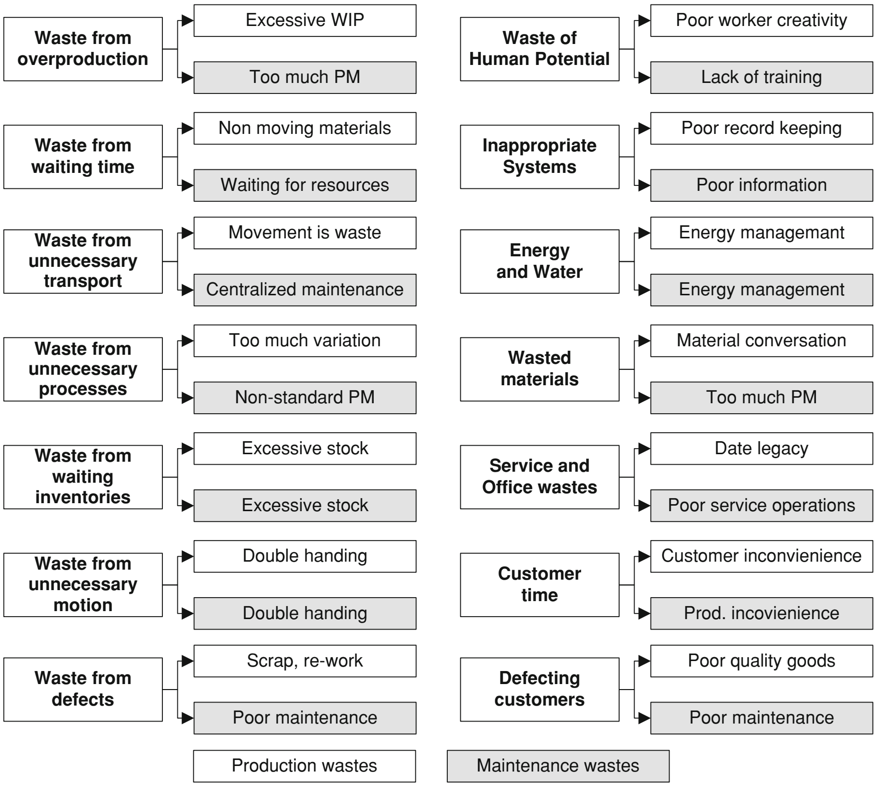

Fig. 4 Lean production waste and analogous waste within maintenance. *Source* (Davies and Greenough 2010)

One of the most important aspects of lean maintenance is developing an understanding of the maintenance processes and activities realized during maintenance processes. This involves evaluating whether each element of maintenance practice used adds value to the product and benefits the customer. In summary Lean maintenance:

- is the proactive maintenance role within the Lean Manufacturing never ending improvement process;
- transforms the role of maintenance from fixing breakdowns to quality improvement;
- raises maintenance standards to first stabilize and then optimize technology performance;
- releases maintainer time from routine activities to focus on long term solutions to technology problems;
- puts the maintenance function at the heart of Lean Manufacturing improvement process (lean maintenance is neither a subset nor a spinoff of lean manufacturing. It is instead a prerequisite for success as a lean manufacturer.

Lean manufacturing and maintenance are both essential and interconnected concepts. Maintenance must improve its ability to improve the value adding capability by delivering stabilized process and equipment performance to reduce unplanned events and waste and by delivering optimized performance to reduce quality defects, cost and delivery lead times. Lean thinking can help maintenance by the application of its proven tools and techniques to target the reduction of waste and non value added maintenance activities (Willmott 2010).

3 Green Thinking in Maintenance Activities

Green Manufacturing is defined by Allwood (Allwood 2005) as a method to "develop technologies to transform materials without emission of greenhouse gases, use of non-renewable or toxic materials or generation of waste" (the term "green", often used interchangeably with "environmentally-safe").

Manufacturing firms that have gone green are finding that it saves them money, because going green will cut down energy costs and can even save money on insurance rates.

By implementing LM companies can reduce wasted products and impact on the environment by 70 % or more. And though the main goal of Lean manufacturing is waste reduction by elimination of activities which are performed when manufacturing a product or providing a service and do not bring value to that product or service, it is close to Green Manufacturing when analyzing outputs and results of these two concepts (Table 2).

When implementing lean within organizations, equipment reliability is the predominant foundational element that enables lean operational performance. Embracing green manufacturing requires giving more focus to environmental and energy concerns during the implementation of reliability improvement projects.

Maintenance in manufacturing enterprise is a key issue and success factor, however in process approach it is usually classified as a process supporting core activity of production. Maintenance process has (or may have) an important influence on quantity and quality of production, but also on safety of people and environment. Because of all that, in enterprise benefiting from so called good engineering practices maintenance is not only a source of costs which should be avoided, but mainly activity which can be an effective input and contribution to enterprise development and be an integral part of green manufacturing called Green maintenance (GM).

In the early 1990s, the concept of GM was proposed, which required the aim of maintenance to be realized by using advanced technologies and equipment at the cost of the least resources and energy consumption, the least waste and environmental impact (Huiqiang and Yufeng 2008).

Practical realization of the concept in an enterprise depends on many factors, both internal (such as maintenance strategy, service performance planning, repairs

Table 2 Lean production losses and environmental aspects

	Overproduction (due to unplanned breakdowns etc.)
Lean production losses	More raw materials and energy consumed in making the unnecessary products Extra products may become obsolete requiring disposal Hazardous material use may result in extra emissions, waste disposal, worker exposure, etc.
	Extra inventory
	More packaging to store work-in-progress (WIP) Waste from deterioration or damage to stored WIP More materials needed to replace damaged WIP More warehousing costs
	Extra transportation
	More energy use for transport over production Emissions from transport More space required for WIP More packaging required to protect components during movement Damage and spills during transport Transportation of hazardous materials requires special shipping and packaging to prevent risk during accidents
	Defects
	Raw materials and energy consumed in making defective products Defective components require recycling or disposal More space required for rework and repair
	Overprocessing
	More raw materials consumed per unit of production Unnecessary processing increases wastes
	Waiting for maintenance
	Potential material spoilage or component damage causing waste Wasted energy from heating, cooling, and lighting during production downtime

technologies and materials, competences and awareness of employees) and external (such as service capability of equipment).

Service capability of equipment is developer at the design stage, thus machines and devices have to be designed from a holistic perspective benefiting and adding value for all participants, taking functions of technical object, safety, quality, costs and environmental aspects into consideration. Green maintainability should be considered in product design. The negative impacts of maintenance on environment are necessary to be eliminated or weakened by some measures in product design:

- materials choice: the requirements of environmental protection, energy-saving and materials-saving should be considered in materials choice (the reparability and recovery of valuable parts and parts made of rare materials are emphasized),
- structure design: the equipment or structure connections should be realized as possible as simple,

- the reliability study is recommended and the maintenance-free design is extended when the all cost of products in life cycle is considered (for example, the maintenance-free design is proposed to be used for the key equipment).

Realization of GM approach starts at the stage of taking decisions concerning new equipment as it should include environmental issues. Project assessment should be carried out with reference to overall lifecycle cost, thanks to which financial benefits or losses emerging from application of predefined practices in order to provide predefined reliability, accessibility and maintainability level.

The next factor influencing GM realization is maintenance strategy. Maintenance strategy is defined as an interrelationship description between maintenance echelons (on-site, in a repair shop, at the manufacturer, etc.) and indenture levels (subsystem, circuit board, component, etc.) including their maintenance actions (Shyjith et al. 2008). The maintenance echelon is characterised by the personnel skill, the available means and the location. When the indenture level depends on the complexity of an item structure, the accessibility to its sub-items, personnel ability level, test and measure means, safety considerations, etc. Miscellaneous strategies have been put forward for maintenance amongst which the most important ones are corrective, preventive, opportunistic, condition-based and predictive maintenance that considering each one's relevant industry and each of them has advantages and disadvantages (Al-Najjar and Alsyouf 2003; Coudert et al. 2002; Marquez 2005; Mechefske and Wang 2003; Saranga 2004; Sherwin 1999; Tan et al. 2011). The maintenance managers have to select the best maintenance strategy for each piece of equipment or system from a set of possible alternatives (reactive, preventive, proactive). They will not only be aware of the performance implications of the different strategies, they can understand some of the practices necessary to support each of the strategies (Jasiulewicz-Kaczmarek 2009).

Analysis of risk and decrease of uncertainty of assessment are the critical methods of strategic decisions concerning technical safety providing and cost minimization making. The most efficient methods are believed to be RCM (Reliability Centred Maintenance), RBI (Risk Based Inspection) and RBM (Risk Based Maintenance) (Arunraj and Maiti 2007). RCM can be defined as a systematic approach to systems functionality, failures of that functionality, causes and effects of failures, and infrastructure affected by failures. Once the failures are known, the consequences of them must be taken into account. Consequences are classified in: safety and environmental, operational (delays), non-operational, and hidden failure consequences. While RCM goal is to define level (class) of criticality of an analyzed object or element, in RBI and RBM (referring to identical ideas and ways of describing the system, similar classification of functional failures and types of failures as RCM method), attempts to calculate risk are taken.

Risk assessment integrates reliability with environmental and safety issues and therefore can be used as a decision tool for preventive maintenance planning. Maintenance planning based on risk analysis minimizes the probability of system failure and its consequences (related to safety, economic, and environment). It helps management in making correct decisions concerning investment in maintenance or related field. This will, in turn, result in better asset and capital utilization (Faisal et al. 2003).

In technical object exploitation stage, GM realization requires, except from traditional analysis, collecting and analyzing data with respect to their accuracy and environmental impact of service strategy implemented. Frequency of service performance, range of service provided, as well as material, parts, subassemblies applied should be analyzed with reference to their contribution to resources use, reuse, recovery and recycling of wastes (3R).

Technical service planning at strategic/high level can be successful only if it is supported by reliable data from operational level. It makes monitoring of condition of production equipment crucial for efficient GM (Emmanouilidis and Pistofidis 2010). Most machines can be monitored in a continuous manner, without stooping their work. Advance level in solutions available, in the area of vibration analysis, work stabilization analysis, balancing and thermographs helps in achieving perfect "health condition" of machines park. Application of the technical solutions above mentioned enables "listening" to what each machine "says" about its condition and thanks to that early diagnostics of a problem, before it leads to a serious breakdown. If there is a need to perform corrective actions, these tools provide fast and effective response, without any negative influences on production process performance.

Monitoring of a system includes also monitoring of condition of oils and lubricants as they are not renewable. Optimization of exploitation time and performance of oils and lubricants helps to decrease level of negative influence on environment, improves production process, decreases costs of energy, prolongs exploitation time of machines and devices and helps to achieve higher level of reliability. It is reasonable from business point of view. As experience and experiments show rationalization of lubricants management may lead to decrease of maintenance cost even by 30 %. Rational lubricants management has to include all the stages, from choosing the proper oil/lubricants, through its storing, supplying and using, proper machine equipment is important as well (air release, drainage), it should be adjusted to conditions of machine environment, and oil analysis system etc.

Despite maintenance department does not have a direct influence on energy and media use resulting from technology applied but it still can influence and decrease these levels. There are numerous opportunities, starting from implementation of simple services and repairs like for example alignment or balancing and including advanced technical diagnostics methods, purchasing policy or maintenance strategy. For example, problems with transmission shafts leads to 12 % higher energy use and used or inaccurate clutch May lead to 4 % of losses. Exchanging traditional passes in transmission with highly efficient new generation ones leads to energy savings by 2–4 %. The decision on application of EFF1 class engines allows to increase efficiency even by 26 % comparing to traditional electric engine. Application of energy-saving bearings in drives of machines and devices allows to decrease friction by 30 % and these machines reach maximum speed

Table 3 Examples of internal and external benefits from GM practices

Internal benefits	*Economic*
	Environmental fees decrease (for example by waste segregation, decrease of media use),
	Exploitation materials stock decrease (for example by maintenance planning),
	Decrease of CPU (cost per unit) (for example by decrease of energy use in manufacturing process)
	Environmental
	Waste generation decrease (for example by machine parameters control),
	Decrease of technological media use (for example by modernization of equipment),
	Decrease of lubricants use (for example by oils diagnostics)
External benefits	*Economic*
	Decrease of risk of serious failures and break downs by service and maintenance strategies selection based on risk analysis,
	Decrease of penalties caused by failures by developing scenarios and procedures limiting failures range,
	Increased competitiveness of organization (for example by decreased legal risk (coherence with law regulations))
	Environmental
	Elimination or decrease of penalties for improper practices
	Decrease of disturbances and harms for local societies (for example noise, emissions, pollution)
	Reduction of not renewable natural resources—gas, oil, fossil fuels

higher by 15 %. Elimination of leakiness in pneumatic installations, exchanging air system to accurate and high quality ones, using connectors and pipes of low flow resistance and optimization of compressed air system allows for saving up to 10 % of energy. Next factor is a correct choice and exploitation of compressor, especially in the context of compressing oils and pollution. Heat recovery is also important, as it can be used to warm the water in central heating system. In hydraulic systems losses are strongly connected with hydraulic oil flow resistance. Therefore new generation filters of low flow resistance can be used, like for example filters made of fibber glass or metallic net (Jasiulewicz-Kaczmarek and Drożyner 2011).

The areas of GM realization and some examples of practices applied in this area enable companies to achieve numerous benefits, both internal and external (Table 3).

One of the most import ant aspects of GM is introduction of new categories to analysis of service activities. The category is environmental issues. It is connected with assessment concerning influence of maintenance practices on natural environment and possible solutions to limit or eliminate negative influence identified. In summary, Green Maintenance:

- is a pro-active and integrating all the stages of product's lifecycle;
- includes environmental issues in planning and realization of maintenance practices;

- takes potential environmental hazards connected with equipment failures into consideration and introduces risk analysis tools into decisive processes connected with maintenance strategy choice includes maintenance in Green Manufacturing strategy realization (being "green" means realizing 3R in all the processes, main and supporting).

4 Sustainable maintenance

Sustainability in manufacturing is the new necessary paradigm which involves the integration of the economic, environmental and social perspective (known as the triple bottom line) at both operational and strategic levels. The operational level includes tools, techniques and methodologies to enable sustainability in product design and manufacturing, while the strategic level refers to organizational issues such as strategy, structure and culture of a company (Ioannou and Veshagh 2011).

The first step in transforming a company into a sustainable business is to develop a sustainability vision and sustainability strategies that include sustainability objectives. To provide ability of realization and success of the strategy, it has to emerge from resources available (including and stressing human resources), competences and experience of an enterprises as well as processes creating internal supply chain.

One of the key elements of internal supply chain in an organization is maintenance. Creating a sustainable production environment requires, among other things, the elimination of breakdowns and other sources of energy waste. The inadequate maintenance can result in higher levels of unplanned equipment failure, which has many inherent costs to the organization including rework, labour, and fines for late order, scrap, and lost order due to unsatisfied customers (Moore and Starr 2006). This has been one of the decisive drivers for changing the perception that people normally have maintenance from "fail and fix" maintenance practices to a "predict and prevent" mindset.

In contemporary maintenance not only financial aspects should be included. Also the balance between environmental (green) and social aspects of actions realized should be found and kept, and systematic approach to actions, their consequences, results and benefits expected should be applied (Table 4).

Economic, environmental and social dimensions of maintenance are interrelated and any change in the objectives of a dimension greatly influences the other two dimensions. Taking systematic approach as a key principle in building sustainable maintenance enables finding relations between dimensions (Fig. 5):

- economic: for example cost of technical services, investment in new machines, technical diagnostics tools, IT systems etc.;
- social: health, safety, ergonomics, working hours, salaries, satisfaction from work, etc.;

Table 4 The basics for assessing maintenance impact in term of gains and losses. Source (Liyanage et al. 2009)

Assessing impact in terms of *gains*	Assessing impact in terms of *losses*
What is the level of *financial impact* arising from excellent technical condition of systems/equipment of an asset due to effective and efficient maintenance practices?	What is the level of *financial impact* arising from poor technical condition of systems/equipment of an asset due to ill defined and/or poor maintenance practices?
What is the level of *social impact* arising from excellent technical condition of systems/equipment of an asset due to effective and efficient maintenance practices?	What is the level of *social impact* arising from poor technical condition of systems/equipment of an asset due to ill defined and/or poor maintenance practices?
What is the level of *environmental impact* arising from excellent technical condition of systems/equipment of an asset due to effective and efficient maintenance practices?	What is the level of *environmental impact* arising from poor technical condition of systems/equipment of an asset due to ill defined and/or poor maintenance practices?

- environmental: for example recycling, regeneration, minimization of energy, gas, water, waste, air pollution etc., and making optimal decisions from the costs and benefits point of view, hence understanding influence of stakeholders on business decisions and awareness not only of is done but also on how it is done.

The diagram introduced in Fig. 5 is general interactive presentation of relations and interdependencies between dimensions of sustainable maintenance. Thanks to that, both managers and operational level employees can understand better how decisions are made and how they influence dimensions of sustainable development. The decisions may concern for example:

- capital investment—to improve efficiency of employees, increase safety level and ergonomics in work environment;
- staff training—to provide high efficiency of employees and to continuously improve their awareness and qualifications;
- purchases of new machines and devices—machines differ with service capability, Mount of energy use, raw material consumptions etc.

Sustainable maintenance is a new challenge for enterprises realizing concepts of sustainable development. They can be defined as pro-active maintenance operations striving for providing balance in social dimension (welfare and satisfaction of maintenance operators), environmental (6R) and economic (losses, consequences, benefits). It requires introducing broad analysis concerning loss or putting into risk continuity of enterprise performance (in economic, environmental and social aspect), if maintenance strategy taken and actions realized do not provide required condition of technical infrastructure (machines, devices, installations). Therefore degradation-based anticipation (the pro-activity in maintenance) becomes essential, to avoid failing situation with negative impact on

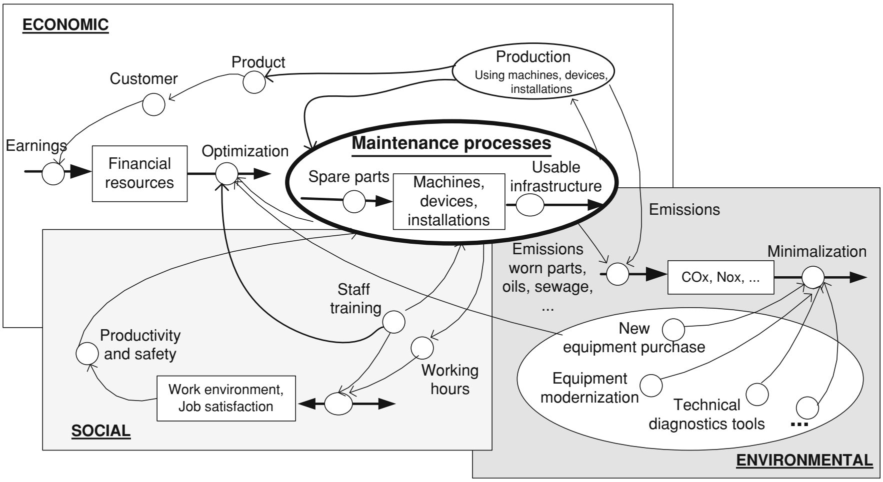

Fig. 5 General model of interdependencies in sustainable maintenance

product condition (zero breakdown maintenance). Pro-activity in maintenance make emerging the E-maintenance philosophy to support "predict and prevent" strategies while keeping maintenance as an enterprise process (holistic approach). E-maintenance is a sub-concept of e-manufacturing and e-business for supporting next generation manufacturing practices.

E-maintenance is emerging from the major changes in maintenance goal needed for supporting the new sustainable and eco-efficiency paradigms. This approach is the synthesis of two major trends in today's society: the growing importance of maintenance as a key technology and the rapid development of information and communication technology. E-maintenance seeks to implement maintenance management, wherein maintenance operations, planning and decisions data and tools to process and act upon them become available anytime, anywhere and to anyone at multiple levels of operation (Levrat et al. 2008; Muller et al. 2008; Gilabert and Arnaiz 2006) (Table 5).

Building sustainable maintenance requires not only considering technical but also social objects. Technical objects, employees and their work environment require keeping in good condition. The social dimension of the sustainable maintenance is very complex and contains many elements. The elements include: safety and health of employees, working hours (number of hours an employee works per week), payments, financial resources spent on training and investments in new equipment and software supporting people in their work.

Human mistakes which are emerging from the lack of knowledge and improper conditions of work and tools in machine work environment (setups, conservation, repairs etc.) might result in hazard to operator and employees in its environment. Many actions taken to support safety in an enterprise are taken after an incident happens. With other words, after injuries happen, actions are taken to prevent similar injuries in future (procedures are developed, trainings are conducted and

Table 5 E maintenance potential on various levels of maintenance management

E—maintenance	*Strategic level*
	It provides IT tools necessary to support decisions concerning maintenance, definition of maintenance policy and communicating it to lower levels of organization's hierarchy
	Tactical level
	It provides tools and information enabling and facilitating realization of maintenance policy defined at strategic level. It provides availability of resources to realize maintenance and service activities (CMMS data interface and ERP central system)
	Operational level
	It provides technology and tools to integrate functions connected with monitoring of degradation level and availability status of equipment and installations, supports decisions of supporting staff with diagnostics and prognostic information, supports assessment of efficiency indicators used in an enterprise.

preventions are implemented). However, it also refers to actions and events which already taken place, which is called reactive safety. Sustainable maintenance promotes pro-active safety culture based on safety awareness and responsibility for oneself and others (interdependent organization).

Safety and hygiene of work, including psychical hygiene (stress) result in high quality of work performed and high satisfaction on work. Satisfied (not only financially) employees feel more connected with an enterprise. If satisfaction from work decreases to a certain level, employees quit and leave an enterprise and an enterprise has to bear costs connected with recruitment and training new employees.

One of the most important aspects of Sustainable Maintenance is introduction of a new category, next to economic and environmental, to analysis of maintenance and service efficiency. The category is social issues and searching for balance between three dimensions: economic, environmental and social. It is connected with assessment of relations and interdependencies between them as elements of organization management system. In summary, Sustainable Maintenance: is a pro-active activity integrating all dimensions of sustainable development;

- includes social issues: working hours, salary, safety and health of employees, satisfaction on work;
- includes risk connected with keeping and using so called soft assets in organization (for example costs of developing proper competences), includes maintenance in Sustainable Manufacturing strategy (being sustainable means realization of 6R in all processes, both core and supporting).

5 Conclusion

In the hereby chapter evolution in approach to technical infrastructure maintenance issues was introduced with special respect to realization of sustainable manufacturing. In Lean Maintenance concept loss was the crucial aspect, and actions taken were analyzed mostly in financial aspects. Green Maintenance on the other hand introduces a new category for analysis of service and maintenance activities. The category is environmental approach. The consequence of such approach is assessment of the elements of practices applied in maintenance and their influence on natural environment, as well as analysis and development of solutions which enable limitation or elimination of negative influence of before mentioned practices on natural environment. Sustainable Maintenance completes the list of two categories used (economic and environmental) with the third one. The category is social issues and searching for balance between these three dimensions: economic, environmental and social.

Including the category of sustainable development to processes and actions realized in technical infrastructure maintenance area is a challenge but also a necessary support in sustainable manufacturing realization. The challenge, because it is not one, separate action but a process which requires building maintenance strategy and goals in consistency with sustainable development corporate strategy, as well as commitment and participation of all the employees, knowledge, experience and consequent performance (the process is evolutionary). Necessary support because maintenance is a crucial process in internal supply chain and if neglected or missed makes sustainable development corporate strategy only theoretical declaration of managers.

In order to understand complexity of sustainable maintenance it is necessary to apply systematic approach. All the dimensions, social, economic and environmental have to be analyzed simultaneously and not isolated as they are interconnected and changes in one dimension result in changes in the others as well. Further research on measures and indicators reflecting both static and dynamic character of the connections within maintenance itself and between maintenance and other processes should be realized in an enterprise.

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Sustainability: Orientation in Maintenance Management: Case Study

Malgorzata Jasiulewicz-Kaczmarek

Abstract Sustainability is the new paradigm for manufacturing which requires the integration of the economic, environmental and social perspective. Being good at balancing environmental and societal costs with financial success will no longer be a choice but instead will be a must. Sustainable maintenance is a new challenge for enterprises. It is a process of continuous development and constant improvement of maintenance processes, increasing efficiency, safety of operations and maintenance of technical objects and installations, focused on employees. This chapter presents case study in glass processing company. It highlights the challenges of sustainable maintenance introduction within industrial enterprise

1 Introduction

Sustainability in manufacturing is the new necessary paradigm for manufacturing which involves the integration of the economic, environmental and social perspective. Being good at balancing environmental and societal costs with financial success will no longer be a choice but instead will be required.

Sustainable maintenance is a new challenge for enterprises realizing sustainable development approach. It is a process of continuous development and constant improvement of maintenance processes, increasing efficiency (operational excellence), safety of operations and maintenance of technical objects and installations, focused on employees.

The following chapter presents glass manufacturing process as well as practices and initiatives of sustainable maintenance implemented in Gostyn glass

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manufacturing plant to realize the sustainable development strategy specified by Ardagh Glass Group.

2 Glassmaking Characteristics

Glass has been produced for thousands of years, dating from as early as 7000 B.C. The earliest makers of glass, the Egyptians, considered it to be a precious material, like gemstones. Today, glass has become an integral part of people's lifestyle. Glass industry is divided into the following sectors based on end products: flat glass, container glass, pressed/blown glass (specialty), glass fibber, products from purchased glass.

Glass manufacture, regardless of the final product, requires four major processing steps: batch preparation, melting and refining, forming, and post forming. **Batch preparation** is the step where the raw materials for glass are blended to achieve the desired final glass product. While the main components in glass are high-quality sand (silica), limestone, and soda ash, there are many other components that can be added. Another raw material used in glass manufacture is "cullet." Cullet is recycled glass obtained from within the plant (rejects, trim, waste scrap) and from outside recycling companies. Cullet can constitute from 10 to 80 % of the batch, depending upon the type of glass manufactured. Glass manufacturers use cullet where possible because it is less costly than virgin materials, and reduces the energy required for melting. Once mixed the batch is charged to a melting furnace. **Melting** of the batch may be accomplished in many different types and sizes of furnaces, depending upon the quantity and type of glass to be produced. The melting step is complete once the glass is free of any crystalline materials. The areas with most potential for melting improvement include batch and cullet preheating, a driven process to accelerate shear dissolution in the fusion process, and innovative means of reducing refining time. **Refining** (often referred to as fining) is the combined physical and chemical process occurring in the melting chamber during which the batch and molten glass are freed of bubbles, homogenized, and heat conditioned. After refining, the molten glass is sent to forming operations. **Forming** is the step in which the final product begins to take shape, and may involve casting, blow forming, sheet forming, fiberization, or other processes. Forming processes vary widely, depending on the type of glass being manufactured. Some products require **post-forming** procedures, and these vary widely depending upon the product. These may include processes which alter the properties of the glass, such as annealing, tempering, laminating and coating (container glass is annealed and coated). Example inputs and outputs of glassmaking process were presented in Table 1.

Glassmaking is a high-temperature operation, and thus is very energy-intensive. The energy needed to melt glass accounts for over 75 % of the total fossil fuel energy requirements of glass manufacture. Energy is also consumed in forehearths, the forming process, annealing, factory heating and general services. By using

Table 1 Example inputs and outputs of glassmaking process. Energy and Environmental Profile of the U.S. Glass Industry (2002)

Process	Input	Output
Batch Preparation	Sand/silica and other formers, limestone and other stabilizers, soda Ash/potash, cullet, colorants, water, electricity	Homogeneous batch, particulates, unusable raw materials, filter residues
Melting and Refining	Crushed cullet, glass batch, refining agents, natural gas, fuel oil, electricity, air/oxygen	Molten glass, flue gas, particulates/dust, furnace slag, refractory, wastes
Forming	Molten glass, glass marbles, electricity, lubricants, air, cooling water, nitrogen	Formed glass, cullet, contaminated glass, spent cooling water, particulates, organic condensable, volatile organics (VOCs)
Post-Forming	Formed glass, natural gas, electricity, air coatings and resins	Finished products, cullet, particulates, volatile organics, waste water

cullet, energy consumption can be reduced, partly because the chemical energy required to melt the raw materials has already been provided. As a rule, every 10 % increase in cullet usage results in energy savings of 2–3 % during the melting process (Rasmussen 2004).

Melting raw materials and combustion products created by producing glass generate air emissions consisting of particulates, nitrogen oxides, and sulphur oxides. Emissions are also generated during the forming and finishing of glass products as a result of thermal decomposition of lubricants, binders and coatings. Other emissions from forming and fabricating may include sodium fluoride, sodium fluorosilicate, silica, calcium fluoride, aluminium silicate, sodium sulphate, boron oxides, fluorides, boric acid, carbon dioxide and water vapour. These depend on the composition of the glass and the processes used for forming and post-forming. Dust particles may arise from various sources throughout the glass manufacturing process, but mostly from the preparation and sizing of the glass batch. Glass manufacturers often use baghouse filters to capture the particulate emissions. The baghouse dust is then typically recycled back into the furnace. Glass plants remove air pollutants through the use of aqueous media, filters, and precipitators. Air pollution control technologies used in the glass industry commonly transfer contaminates from one media (air) to another (water or hazardous waste). Sulphur oxides and nitrogen oxides are the primary air pollutants produced during the production and manufacture of glass products.

Waste generated in the glass industry can be categorized into the following three groups:

- Materials—handling waste includes the waste generated during the receiving and transfer of raw materials at the facility for storage or processing, including raw materials that are rendered unusable when spilled during receiving and transfer.

- Pollution—control equipment waste, residues from pollutants produced or captured during the melting, forming, and finishing steps; these may be hazardous or non-hazardous, depending on the process and type of glass.
- plant maintenance waste—include waste oil and solvents generated in the forming process, furnace slag, and refractory wastes.

The air emissions, effluents and solid wastes generated by glass manufacturing processes were presented in Table 2.

3 Practical Realization of Sustainability: Orientation in Maintenance Activities

Ardagh Group is a global leader in rigid packaging and producing metal and glass packaging solutions for most of the world's leading food, beverage and consumer product brands. It operates 88 manufacturing plants in 25 countries, employs 14,000 workers and has global sales of over 3.2 billion Euros.

Sustainability is part of Ardagh Group wider policy of managing Corporate Responsibility. The company pledges to be operating according to ethical principles and in full compliance with all applicable regulatory requirements. Sustainability, as defined by Ardagh, comprises three aspects:

- Minimising environmental impact;
- Maximising economic performance;
- Social contribution.

The created strategy of sustainable development is implemented in relation to both the external environment of Ardagh Group (supply chain activities and supply chain management) as well as the internal environment at the level of individual plants and implemented processes (Fig. 1).

When it comes to supply chain activities Ardagh Group declares and implements a sustainable approach, inter alia, through: the production of environmentally friendly packaging, reducing the weight of unit package, detailed LCA assessments for both glass and metal packaging, use and improvement of environmental management system.

Distribution of accepted commitments at the level of Ardagh Group plants is reflected in the implemented and improved management standards like: ISO 9001, ISO 14001, OHSAS 18001 and industry systems such as ISO 22000. Processes and activities related to production of goods are implemented and continuously improved through effective and efficient use of such methods as: TPM, Six Sigma, Lean Manufacturing and tools like: 5S, VSM, FMEA, RCA, BBS (Behaviour Based Safety), etc.

Gostyn glass manufacturing plant (GP—Gostyn Plant), a part of Ardagh Group, is a company with long-term experience in manufacturing glass packaging combined with the latest developments in technology, management and marketing. It offers its

Table 2 Glass manufacturing process emissions, effluents, by-products and wastes

Process	Air emissions	Effluents	By-products/solid waste
Batch Preparation	Particulates in the form of dust (raw material particles) (controlled)	Not applicable	Unusable raw materials, baghouse or filter dust residues (recycled)
Melting and Refining	Particulates, nitrogen and sulphur oxides, carbon monoxide, carbon dioxide, fluorides, formaldehyde, lead (mostly controlled)	Not applicable	Furnace slag, filter and baghouse residues (recycled), refractory wastes
Container Forming and Post-Forming	Particulates, organic condensable particulates, volatile organics	Waste oil and solvents, waste water (may contain dissolved solids, suspended so lids, heavy metals)	Solid residues from pollution control equipment, cullet

Source Energy and Environmental Profile of the U.S. Glass Industry (2002)

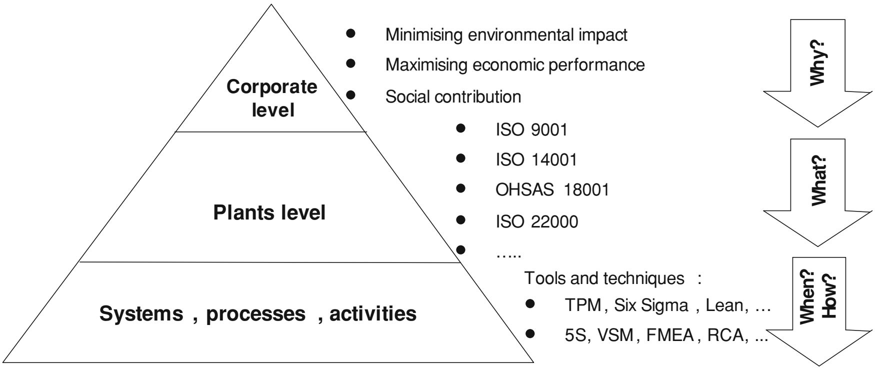


Fig. 1 Levels and tools of implementing strategy of sustainable development

customers a wide range of high quality products and support in the development of new packaging designs. The company currently employs about 400 workers.

Pursuing a corporate strategy of operational excellence in all areas of business activity, since 2002, GP has been implementing Total Productive Maintenance (TPM) infrastructure management strategy (in 2008, the company was awarded a Gold medal at the corporate level for maturity in using Lean tools strategies) supported by such methods and techniques as: Six Sigma and Lean. Moreover, GP applies and continuously develops pro-quality management systems: ISO 9001:2008, ISO 22000:2005, ISO 14001:2004, OHSAS 18001:2007.

Each of the corporate priorities of sustainable development strategy in GP is coupled with objectives and ways of their implementation. With regard to activities related to cost-effective management of natural resources and reduction of environmental impact, the objectives are a result of the analysis of external and internal threats characteristic for glass industry which are reflected in the processes, production technologies and resources used in the company (Table 3).

Movement maintenance service is actively involved in the process of achieving these objectives. The responsibility of the movement maintenance services in the company is not only maintenance of manufacturing equipment but also proper management of technological utilities and electric power.

The key elements of the manufacturing process of glass packaging in the context of environmental impact and costs are as follows (Giusti and Polo 2002; Hogetsu 2005; International finance Corporation & World Bank Group (IFC&WBG) 2007; McCloskey and Burgoon 2006): gas and electric power, raw materials constituting the batch charge and technological utilities (water, compressed air) (Fig. 2).

Glass manufacturing takes place on a continuous basis (glass furnaces operate continuously (only with minor repairs) for up to 12 years, before being rebuilt) (Rasmussen 2004). Due to high temperature that is necessary to heat the large mass of feedstock—glass manufacturing is a highly energy-consuming process and means of reducing energy consumption is critical for both production costs and

Table 3 Example objectives implemented in 2009–2011

No	Objective	Task
1.	Reduce CO_2 emissions	Renovation of glass melting furnace No. 1 Increasing the amount of cullet in the batch
2.	Reduce NOx emissions	Renovation of glass melting furnace No. 1 Increasing the amount of cullet in the batch
3.	Reduce dust within the batch house	Renovation of resources and batch transport
4.	Reduce noise emissions	Performing activities according to the schedule

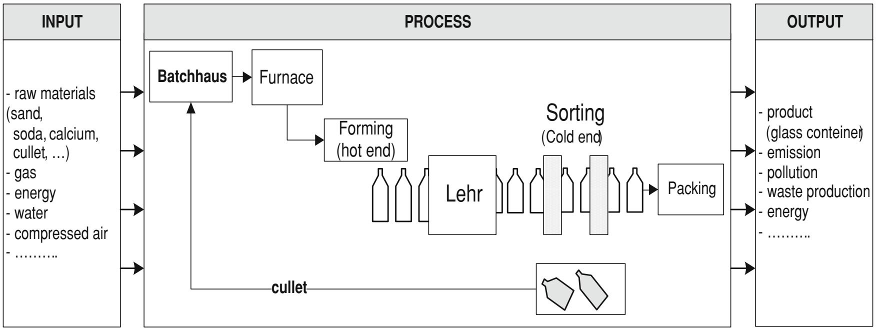


Fig. 2 The model of the manufacturing process of glass packaging

environmental impact. Therefore, it is necessary to continuously monitor fuel and electric power consumption and analyse energy efficiency of the various utilities.

The company designed and implemented an innovative system for monitoring performance of the manufacturing equipment and utilities: electric power, compressed air, water and gas. The idea is to control equipment operation in real-time, detect faults and send alarm information in the form of SMS to authorized personnel equipped with mobile phones. The system decides on the gravity of the problem and based on this decision informs the appropriate persons. The structure of the system is shown in Fig. 3.

The system is designed to immediately alert about failures, locate them, perform proper diagnosis (in some cases even removal) and ultimately shorten the time of machine downtime. The system also controls the working time of machines and equipment, and through the ability to set technically optimal performance parameters affects the efficiency of managing gas, electric power, water and compressed air and facilitates inspections, maintenance and repairs.

The system includes the following groups of equipment and installations:

- strategic technological equipment with fans, annealing lehr and technological waste transportation system,
- pumping station with drinking and circulating water networks,
- compressing with compressed air and vacuum networks,
- gas regulating and metering station (Fig. 4).

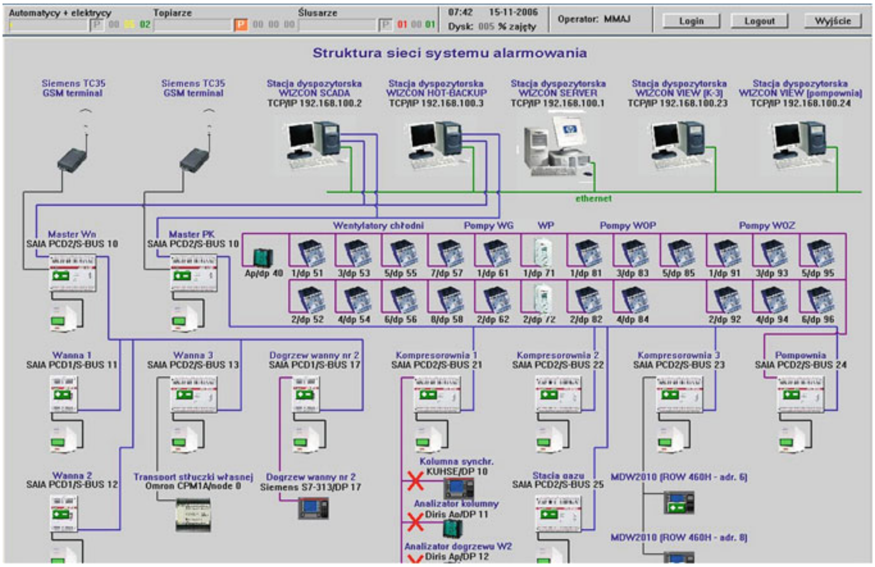


Fig. 3 Alarm system structure

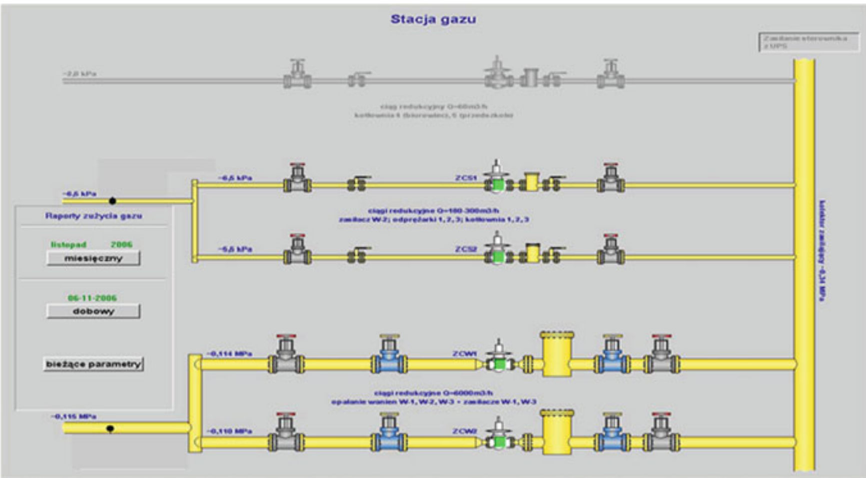


Fig. 4 Gas regulating and metering station

The alarm and equipment protection system is an open system, meaning that you can easily connect it to other witness points or devices (currently the company monitors around a thousand witness points). The key benefits of the implemented and continuously improved system are the following:

- on-line measurement of parameters such as voltage, current, power, pressure, temperature, vibration, utilities consumption,

- greater precision in regulation of compressed air pressure, which brings substantial economic benefits with regard to energy savings and is a part of the company's sustainable development strategy,
- control of machinery and equipment operation status (well developed industrial network), built-in GSM module which in case of failure sends an SMS message with a brief description of the situation to authorized persons,
- inspection control based on hours of operation (the system reminds about the inspection after a specified number of operating hours)
- possibility of machinery remote control (switching pumps, compressors, fans, etc.),
- significant reduction of failure response time,
- building a knowledge base concerning the efficiency of the implemented processes (all measurements are recorded in the database by the system, which allows for traceability and analysis).

Virtually all areas of company's activity, from financial planning to monitoring results and reports are supported by the SAP system.

All machinery and equipment are entered into the system and marked. For each of the machines the system performed an analysis of impact on: safety (threats to people and the environment), production (impact on the production line efficiency, on the production process variability, on the failure frequency and the time lost for repairs), quality (quality loss), costs (spare parts costs, repair costs), and classified the results into one of four classes of validity: AA—critical, A—very important, B—important, C—negligible (validity classes determine the choice of maintenance strategy). Depending on the validity class (AA, A, B, C), the specific requirements defined by the manufacturer and the history of performed maintenance, frequency and scope of planned works have been specified (inspection, maintenance, repairs). The computer system automatically generates recommendations to perform a particular maintenance work resulting from the plan and sends them to the personnel responsible for a given machine.

Every area of production (such as a hot end, cold end, etc.) is fitted with terminals which contain a detailed description of works to be performed for technical services defined in the plan. All executed works, both those arising from the plan and those outside the plan, are minutely described and recorded in the system. This creates a "machine history"—a complete database of all maintenance activities that have been performed. "Machine history" enables to check the amount of maintenance services, removed failures, implemented modifications, adjustments, machine performance observations and determine how long it took to perform these services.

Thanks to the registration system which is linked to SAP system containing information about spare parts give out, control of movement maintenance costs including the type and extent of executed work can be easily performed (Fig. 5)

In the decision-making process regarding maintenance management, the company uses measurements of reliability, e.g.: MTTR (Mean Time To Repair), MTBF

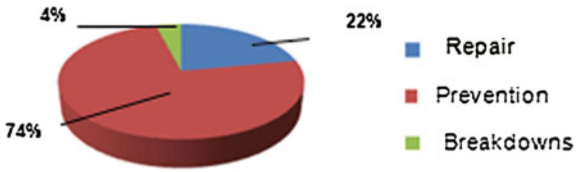


Fig. 5 An example analysis of movement maintenance costs 001 area

(Mean Time Between Failures), etc. (Fig. 6). They provide a basis to optimize the decision-making process and improve the quality of maintenance work.

The systematic recording of information in the system enabled the company to accumulate knowledge that allows people in charge of a given area to make rational decisions based on facts, to plan new investments and anticipate their consequences. Moreover, the availability of information to operators and workers of maintenance service (e.g. manuals, procedures, OPL, SOP) enables them to execute scheduled tasks and interpret work results in a more effective way. All activities related to maintenance in the glass manufacturing plant in Gostyn, complement the advanced techniques for early failure detection. The main task of technical diagnosis is to detect quickly and precisely the sources of poor operation of machinery and equipment, prevent failures, and in consequence losses, from occurring. Understanding the physical phenomena occurring during the operation of the machine allows specifying the qualitative relationships between the destructive processes taking place and the machinery condition and making decisions on how to proceed with the machine. This may be a decision about its further use, about some preventive actions (adjustments, replacement of parts or whole units) or changes in design, technology or service. Diagnostic actions allow for machine evaluation both from the point of view of the user (e.g. operator) or the maintenance department employee. The user is focused on determining whether the object is functioning (or can function) properly. The user is also interested in the expected life of the machine. The operator has to be able to locate each fault, to determine the cause of damage, to specify the data needed to determine the basic parameters of the repair process (the average repair time, the probability of repair at a specified time, the expected cost of repair) and to designate the data to estimate the parameters of recovery process (mean time to the next damage, the expected time for subsequent inspection and preventative actions) (Kurowski 2007; Niziński and Michalski 2002; Starr et al. 2010). Technical diagnostics, next to tribology, reliability, security and operation theories, is one of the fundamental sciences of rational machine exploitation (Żółtowski 2008).

GP applies, inter alia, the following diagnostic techniques:

- vibroacoustics,
- thermography,
- oil tests,
- vibration measurements.

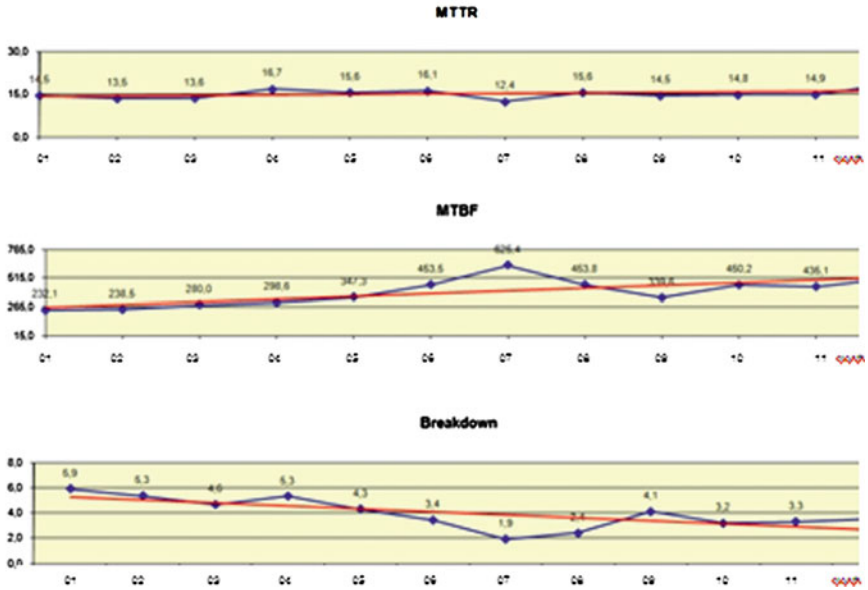


Fig. 6 Examples of MTTR, MTBF charts and breakdowns

Table 4 Cost of air untightness (for pressure of 6 bars)

Leak opening diameter [mm]	Air loss [l/s]	Leaking air cost [PLN/year]
1	1.24	1,800
3	11.24	16,400
8	72.15	106,000

3.1 Vibroacoustic Tests

Vibroacoustic tests are carried out regularly according to the preventative plan supervised by the SAP system. Compressed air management is not only about the optimal operating parameters of compressors, but also about installation tightness control. Lack of installation tightness causes financial losses (Table 4). GP carries out diagnostic tests on installation tightness on a regular basis. These tests involve specialized equipment for acoustic measurements.

3.2 Vibration Measurements

Vibration measurements are carried out particularly in the areas of glass furnaces, automated forming machines/IS machine (depending on what machines are used) and selected motor-reducers. Some machines (e.g. fans of automated glass forming

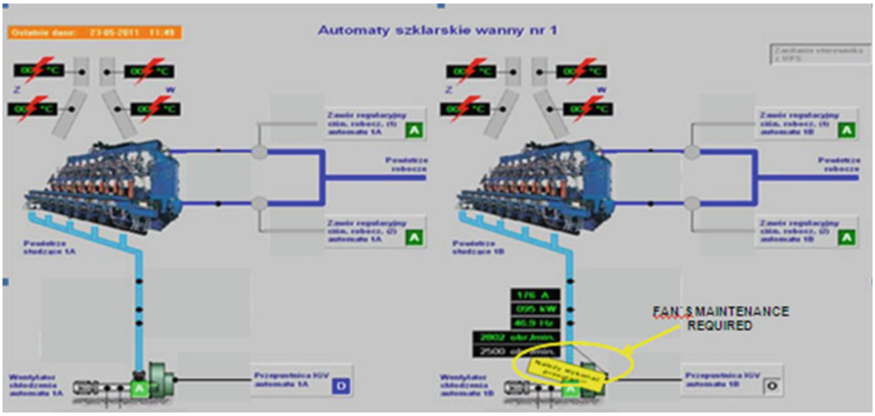


Fig. 7 Machine cooling fans

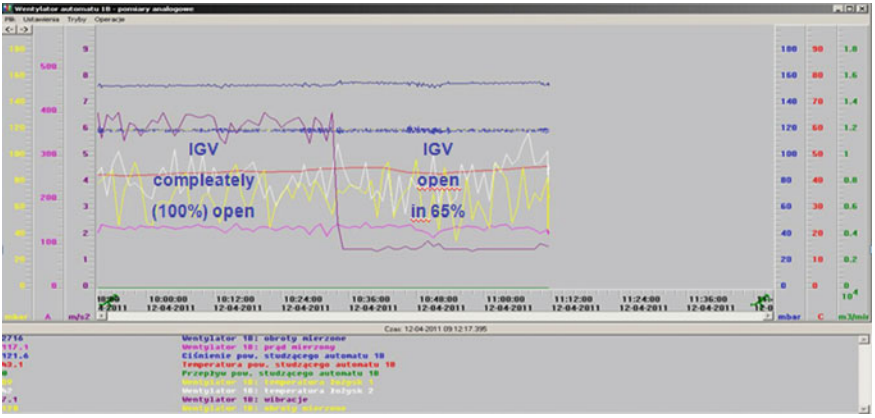


Fig. 8 Adjustment of cooling fan

machines) are connected to the alarm system and vibration measurement is conducted on-line (Fig. 7), while for other machines, relevant to the manufacturing process, vibration measurement is conducted with specialized instruments.

A very important performance parameter, for example, for fans cooling automated glass forming machines, is the appropriate setting of fan inlet guide vane (IGV). For example, if you open the vane 100 % it will induce vibrations at level of 6–7 m/s^2 and compressor stall phenomenon. After shutting the vane down to 80 %, vibrations decreased to 1.7 m/s^2 (Fig. 8). Optimal fans use is to reduce electricity consumption by about 20 %.

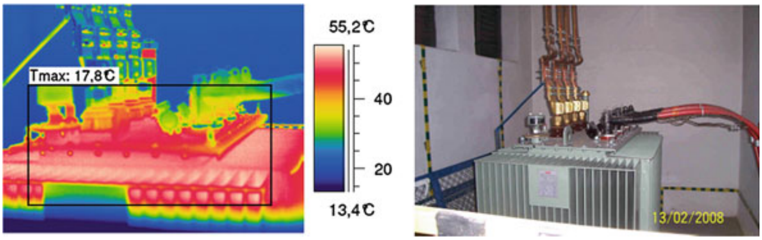


Fig. 9 Transformer thermographic analysis

3.3 Thermographic Tests

Thermography and thermovision are research methods deploying remote and touchless evaluation of surface temperature distributions of the examined objects. These methods are based on the observation and recording of invisible infrared radiation emitted by each body, whose power depends on the temperature, and converting this radiation to visible light. Modern thermovision systems equipped with the latest miniaturized infrared cameras allow non-contact measurement of temperature distributions on the surface of objects, which guarantees high accuracy and does not require liquid nitrogen to cool the detector. This increases considerably the possibilities of using such equipment in extreme conditions occurring in the glassmaking process. Using this method is primarily of great importance in the area of glass furnaces (overheating of any of the furnace walls can have disastrous consequences) (Osiadły 2009), control cabinets (contactors, relays, inverters), and the area of power utilities (Fig. 9).

3.4 Oil Tests

Oil tests are carried out for selected machines and equipment. The aim of the test, on the one hand, is to determine oil usability, on the other, to verify that there are no metallic particles that would prove certain equipment wear and tear (Szafrański 2011). By reducing the frequency of oil changes and unifying the types of used oils (with a very large variety of machines and equipment the company currently uses three types of oils) the annual oil consumption decreased by 30 %. It can, therefore, be said that GP maintenance service has at their disposal and uses a huge knowledge base, actively supporting the implementation of corporate strategy of excellence in the field of sustainable development.

A very important environmental issue for GP [as well as the entire glass industry (Bingham and Marshall 2005)] is to reduce emissions of COx and NOx in particular (in Polish conditions sulphur dioxide emission depends mainly on the batch and is not a very significant problem). Burning large quantities of gas is a source of carbon dioxide emission—which belongs to the so-called greenhouse gases affecting global warming and climate change (the process of carbonates decomposition which comprise the feedstock is also the source of the emission of large quantities of carbon dioxide—so apart from emission from burning of fuels we are also dealing with so-called process emission, which is included in the European Emission Trading Scheme both for the allocation of emission permissions, as well as for plans to reduce national emissions limit (National Emission Reduction Plan).

Since glass melting is a vastly power-consuming and high-temperature process it is undoubtedly a potential source of high heat losses. The main factors affecting energy consumption of fossil fuel-fired furnaces are the following (Minimising the Environmental Impact of Glass, Layman's Raport 2009; Rasmussen 2004; Worrell et al., (2008):

- glass furnace capacity (large furnaces are more energy efficient due to the lower area to volume ratio),
- operating lifetime (usually furnace thermal efficiency decreases with operating lifetime increase, even up to 20 %),
- addition of cullet (this may cause reduction in energy consumption, every 10 % of cullet addition saves 2–3 % of the energy required for melting).

The above factors also affect emissions, per tonne of melted glass, of those substances which are directly related to the amount of burned fossil fuel.

Therefore, the company pays special attention to the rational gas usage and reducing its consumption as far as possible. Every year the company increases the amount of cullet comprising the batch. Using larger quantities of cullet enables (Isa 2008):

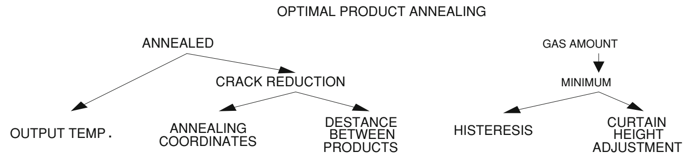
- significant savings in natural gas consumption, which is directly reflected in the reduced emission of nitrogen oxides, sulphur dioxide,
- glass melting at lower temperatures which also reduces emission to the atmosphere (cullet is an excellent flux).

Currently cullet comprises about 55 % of batch in the company. Another activity carried out in the company to reduce gas consumption is the modernization of glass furnaces and their thermal insulation. As a consequence, the consumption of gas was decreased by about 25 % per month.

Loss search and optimization of processes are key issues for continuous improvement. Continuous improvement is a process that is structured, formalized and systematically evaluated based on performance measurement matrix. Employees' teamwork and continuous awareness and competence rising play a significant role in this process. The plant uses Lean and Six Sigma methods and tools in a very methodological and consistent manner. An example of a project, aimed at reducing gas consumption, implemented by the company and attended by representatives of the maintenance service is presented in Table 5.

Table 5 A part of the project charter

Project's aim	Optimization of annealing process			
Project's objectives	Standardization of actions and reduction of gas consumption			
Project's participants	Representatives of forming, annealing, quality control and maintenance departments			
Actions				
1. QFD matrix was constructed				
2. SIPOC diagram was prepared (work flow)				
Suppliers	Inputs	Process	Outputs	Customers
Technology forming department	Gas containers	Annealed	Annealed glass	Packaging quality control
Chief engineering department	Gas compressed air		Containers cullet	Melting department
3. Critical-to-quality (CTQ) tree and matrix was constructed				



	OUTPUT TEMP.	ANNEALING COORDINATES	DESTANCE BETWEEN PRODUCTS	HISTERESIS	CURTAIN HEIGHT ADJUSTMENT
Providing product			X		X
Annealing	X	X		X	X
Cold refining	X		X		X

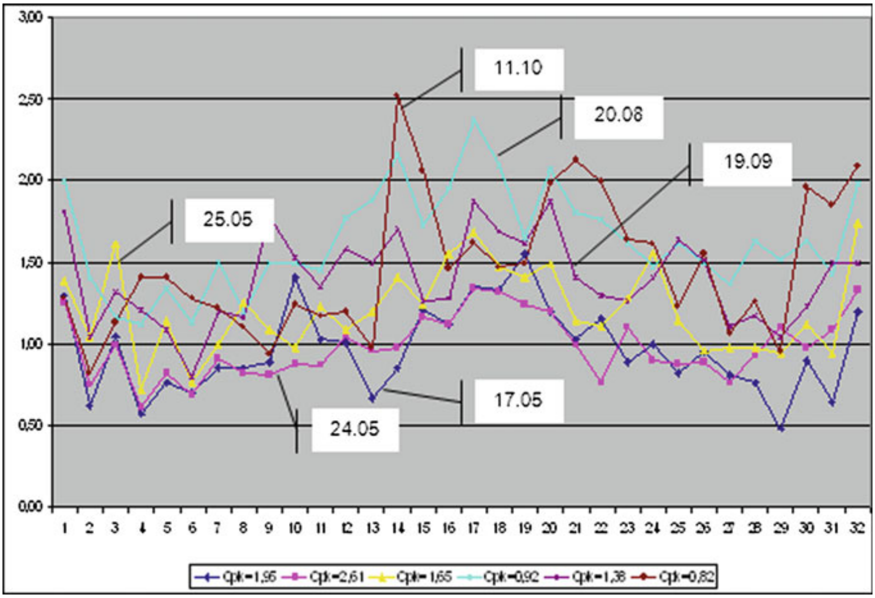
4. CTQ matrix was constructed

Key Values								
CTQ features of output effect	Temp. in the last zone	Assembly Line speed	Product mass	Input curtain height	Output curtain height	Tem. in the annealing zones	Bottom thicknes s	Gas burner setting
Temperature	H	L	L		M			
Annealing		M	L			H	M	M
Gas amount			L	L	L	M		H
KEY	High	H		Medium	M		Low	L
Only one indicator H specifies final Y								

5. FMEA analysis was carried out

6. Data was collected and analysed (below an example of analysis of annealing process stability is presented)

No	17.05	24.05	25.05	20.08	19.09	11.10
	Stress	Stress	Stress	Stress	Stress	Stress
1	1,29	1,25	1,39	1,99	1,81	1,28
2	0,62	0,75	1,04	1,40	1,04	0,82
3	1,05	0,99	1,61	1,16	1,31	1,13
30	0,90	0,97	1,12	1,63	1,23	1,96
31	0,64	1,09	0,94	1,43	1,50	1,85
32	1,20	1,33	1,74	1,98	1,49	2,09
x	0,97	0,98	1,21	1,63	1,40	1,47
s	0,26	0,19	0,26	0,31	0,27	0,42
Cpk	1,95	2,61	1,65	0,92	1,38	0,82



Implemented changes	Replacing polariscope with StrainMatic (annealing process measurements reproducibility)
	Introducing unified measurements of curtain height settings on each production line
Effects:	Environmental—reduction of gas consumption by about 5 %
	Customers relations—reduction of clients' complaints
	Implemented processes—process stability
	Financial—annual savings of about 250,000 PLN

An important element of efficient energy consumption is the production and management of compressed air. The literature research suggests that usually about 20–60 % of compressed air is used efficiently (oszczędności 2006). A considerable amount of compressed air is consumed inefficiently or for the installation, e.g.:

- inefficient management of compressed air, such as: blowing and spraying,
- leaks: 10–35 %,
- uncontrolled or artificial raising of pressure above the production requirements: 10–20 %,
- losses associated with air resistance or bad condition of filters and nozzles, etc. 3–10 %.

Due to the high demand for compressed air in the process of glass manufacturing, the company used vane compressors equipped with efficient multi-stage air filtration system (reduction of oil content in the air below 3 ppm), which are highly durable and reliable (e.g. metal parts of the compressor allow for non-contact operation). These compressors are equipped with modern microprocessor control

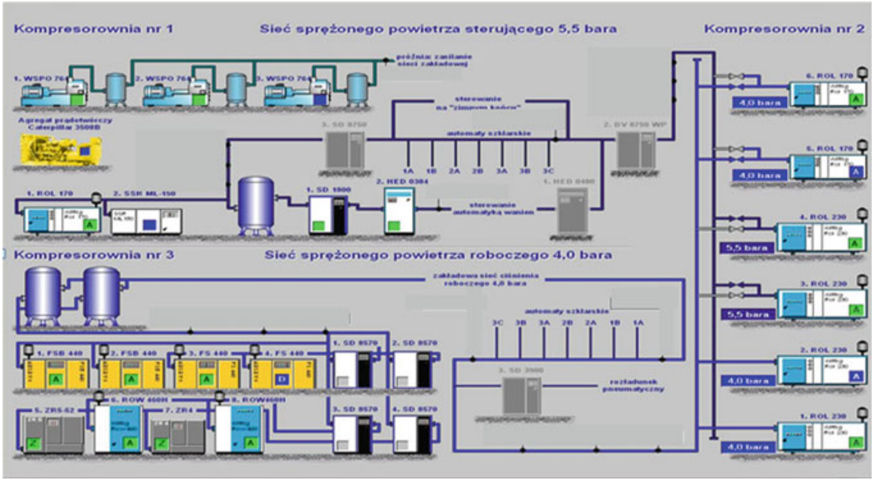


Fig. 10 GP compressed air system diagram

systems with possibility of smooth compressor speed (performance) adjustment. The company owns a system of several Witting compressors in sizes ranging from ROL 170 to ROW 460 and several high-power compressors from other manufacturers. Compressors have been put together under one control and monitoring system (Fig. 10).

Compressors' communication links were used to connect to PLC controllers into a remote controlling, monitoring and work balancing system. Some compressors were incorporated into the control system using analogue and digital inputs and outputs of their own controllers.

The fundamental task of the control system is to stabilize the pressure in essential points of the compressed air network, optimize system's energy consumption, minimize starts and stops of equipment, and balance their work time. The analysis of compressed air system's performance parameters, carried out by the maintenance service, confirms the effectiveness of solution implemented by the company (high pressure stability at network essential points, optimization of energy consumption and balancing compressors load). Company's monitoring system analyses parameters in the compressed air network, monitors compressors' condition, and provides information to designated employees via mobile SMS messages.

The uniqueness and innovation of the pressure control system resides in its ability of simultaneous control of all networked compressors of different capacities (from 18 to 60 m^3/min), depending on the operation place and current demand for compressed air (reducing pressure by 1 bar gives about 8 % of electric power savings). Flow and temperature meters along with reporting option and performance charts have been connected to the system (Fig. 11).

Reducing air pressure in the network (adjusting the machines to work at lower pressures) and liquidation of excessive stock (equipment can be operated at a

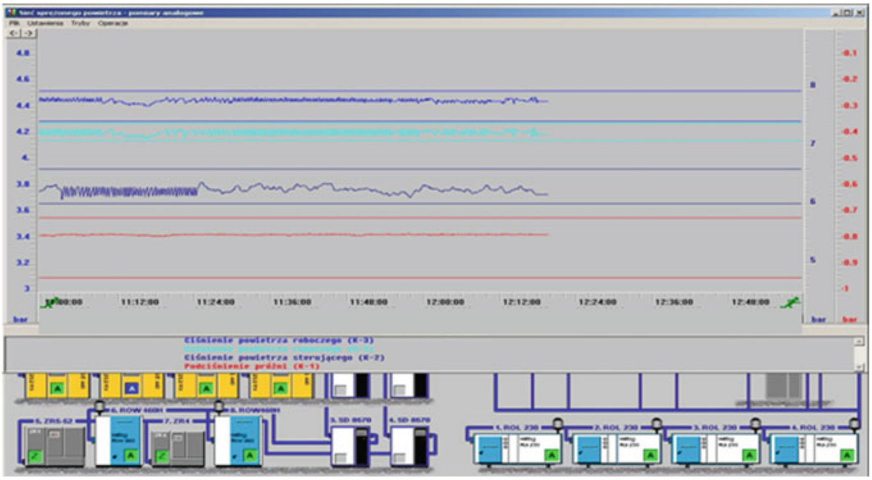


Fig. 11 Compressed air flow chart

pressure of e.g. 3.5 bar but due to other machines, which require to work at higher pressure, it works on higher pressure) resulted in savings of 132 kW.

Glass manufacturing consumes large quantities of water for cooling purposes. Even with closed circuits—evaporation causes non-retrievable losses requiring refilling cycles. Therefore, the process demands a continuous supervision of water consumption, both in the main production process as well as in the associated operations. Maintenance service employees, by incorporating the circulation of process and drinking water to the alarm system (Figs. 12 and 13), conduct an analysis of current water consumption and evaluate opportunities to minimize its contribution per production unit.

The use of closed water circulation, constant monitoring of its quantity and actions taken to reduce unjustified and inefficient use, resulted in fall in company's water consumption by about 70 %.

Presented examples of good practice and measures applied in Gostyn glass manufacturing plant in the field of environmental management, indicate priority significance that is attached by the company's management to environmental issues. Clearly defined and communicated goals, building relations based on teamwork and open communication, and company's culture based on knowledge comprise a firm foundation of company's integrity and accountability for "today and tomorrow."

4 Conclusions

Traditionally, Lean and Green Manufacturing were addressed as separate solutions applicable for various types of waste. Referring to approach of sustainable

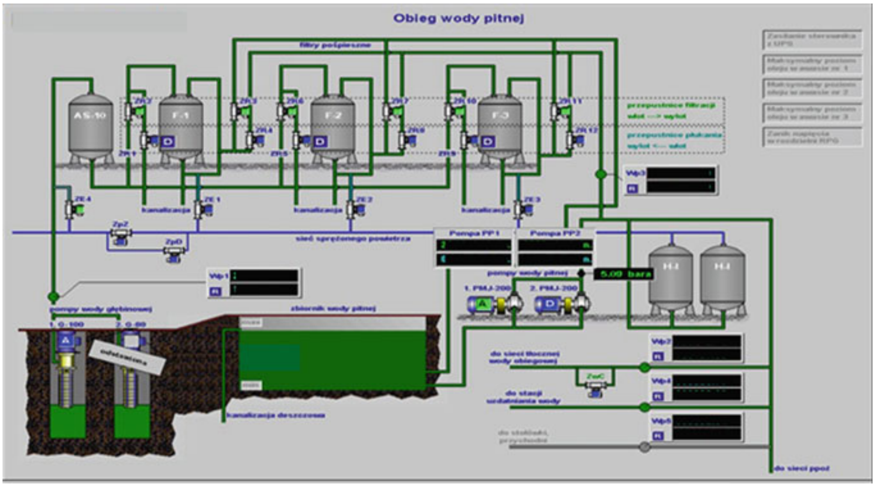


Fig. 12 Pump station—drinking water

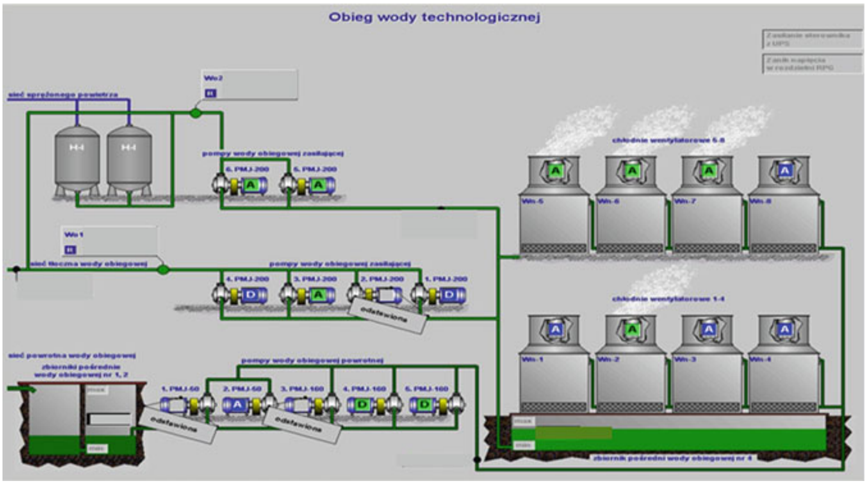


Fig. 13 Pump station—process water

manufacturing represented by Ardagh Group in its strategy these two concepts are integrated. Observation and analysis of activities realized in Gostyn glass manufacturing plant leads to the conclusions that every actions and activities performed both, in the aspects of Lean Manufacturing and the set of tools it encompasses, and in the aspect of Green Manufacturing and sustainable development are coherent, and supported by deep analysis. Relations and interdependencies are analyzed and tools and techniques supporting optimal decisions making terms of sustainability are used in a strict and methodologically structured way. The systematic approach to problem solving and searching for opportunities to improve actions and processes performed is a result of knowledge, experience and attitude of managers and employees at all the levels of organizational structure.

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Framework for Controlling Energy Consumption of Machine Tools

Jan Schlechtendahl, Philipp Eberspächer, Holger Haag, Alexander Verl and Engelbert Westkämper

Abstract Guaranteeing energy-efficient operation of production systems through a priori optimization is an extremely complex task. Therefore an alternative approach is necessary where controls can decide locally if an energy reduction is possible and set components to energy-optimal states. In this chapter results from the research group ECOMATION are presented, describing the information flow that generates energy control loops on different levels based on model information and an appropriate communication and control infrastructure. The communication mechanisms in production systems and working machines are presented which allow using energy consumption values automatically and coherently on all required levels of detail and abstraction.

1 Introduction

Production efficiency is an important element for the lifecycle balance of many products. Studies have shown that the ecological impact of modern machine tools is dominated by the energy consumption during its operational life (Zulaika et al.

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2009), and that the consumed electrical energy and pressured air often contribute with over 20 % to the total lifecycle cost (Dervisopoulos and Abele 2008). Being responsible for one-third of the total primary energy consumption in developed nations (UBA 2007), industrial production companies are looking for energy saving techniques to reduce their ecological impact and cost.

Optimizing the product, the supply chain, the production process chain and steps as well as the structure and components of manufacturing systems can contribute to resource- and energy-efficient production. It has to be kept in mind, though, that these strategies yield to an "average optimization". The operation in an energy-optimal state is not considered.

In this chapter, results from the research group ECOMATION are presented, describing the mechanisms in communication that are required to operate in an energy-optimal state.

In Sect. 2 an energy-based classification of components and machines depending on the ability to provide energy consumption values and mechanisms to influence the energy consumption are introduced.

Mechanisms describing how components in a working machine can provide their energy consumption in standardized manner are presented in Sect. 3, along with mechanisms that influence the energy consumption of components.

Section 4 describes an interface between a working machine and the plant floor which enables an optimized flow of energy-relevant information and influences the energy usage.

Section 5 displays how the energy information collected from different working machines and periphery systems can be used to determine the energy-optimal state of the factory and the strategies that can be used to reduce energy consumption through the adjusting lever described in Sect. 3.

2 Classification of Components

Different machine tools consist of different components and even in machine tools of the same type, some components can differ. In Fig. 1 the components of an Index V100 turning machine and their connections to power supply and control can be seen. The power consumers have been associated to four colour-coded classes regarding their ability to be controlled by the machine control:

1. always on;
2. switched on/off commanded by machine control;
3. continuous state commanded by machine control;
4. switched on/off or continuously controlled independently.

Components that are always active are, for example, the electronics in the control cabinet, the HMI, the PLC, the NCU and some fans or cooling devices. The consumption of these components constitutes the basic power load of the working machine.

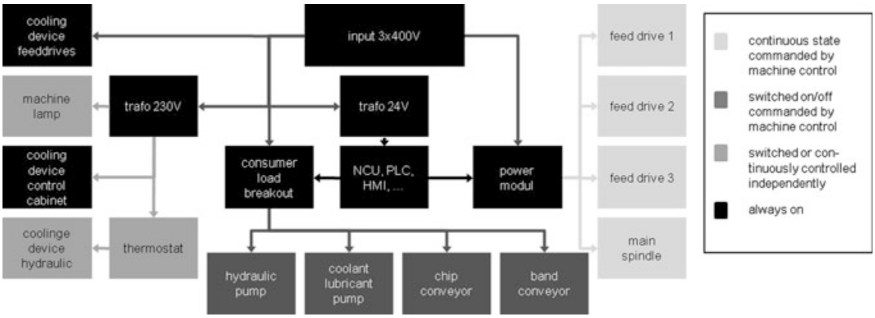

Fig. 1 Connections of the components of an Index V100. *Source* (Verl et al. 2011)

Some components are switched on and off by the machine control based on the current program e.g. the chip conveyer, the hydraulic pump or coolant lubricant pump.

Other components commanded by the machine control are the feed drives and the main spindle. These have a continuous state, depending on the requirements of the process on the machine tool. But the current process can also influence the power consumption of switching components, e.g. the coolant lubricant system.

The states of the switching components without connections to the machine control are unknown to the machine control. For these, the state either has to be estimated by a mean value or a behaviour model for the component is necessary, in addition to the energy consumption model. This is possible for components like cooling devices, which are switching based on temperature, but impossible for components like machine lamps, which are switched on and off by the user.

3 Working Machine-Based Control of Energy Consumption

3.1 Strategies for Accessing Consumption Values of Components

In order to enable a detailed consumption monitoring in a machine control, consumption values of all components have to be present.

Today continuous state-commanded components like main spindle drives, for example, are typically connected over an automation bus with the control. These components often have the ability to provide their energy consumption via the automation bus, through standardized communication parameters (see Fig. 2), in case the component can measure the consumption value itself.

Components that are switched on/off commanded by the machine control are normally controlled by the PLC. The PLC controls components like hydraulic pumps which will be simply switched on or off depending on the process dependencies. For these components the machine control only knows the actual

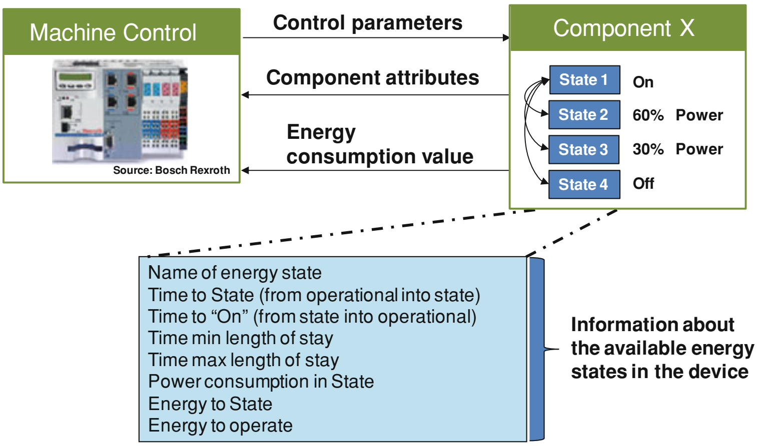

Fig. 2 Provision of energy consumption via automation bus

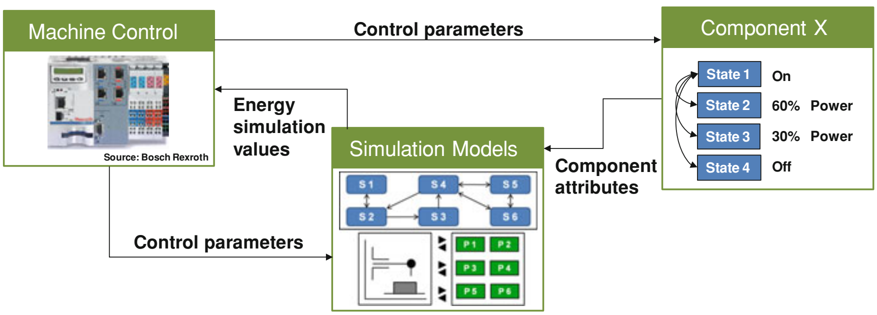

Fig. 3 Simulation models with control information

state but not the energy consumption itself. To calculate the energy consumption, models for these components have to be created, which use the state of the component as input parameter and provide the actual energy consumption as output (see Fig. 3).

Components that are categorized as "always on" can also provide their energy consumption via models (see Fig. 4). Compared to "switched on/off components" these component models have no input values. Therefore a previously measured average value is used as simulation value.

For components that are switched on/off independently or continuously, independently controlled, it is difficult to provide an energy consumption value to the control. To enable a consumption value provision, additional measurement equipment has to be installed in the working machine. The measurement equipment can either measure the energy value directly or can determine the state of the component (e.g. measure if a fan is running through a current measuring); both cases shown in Fig. 5.

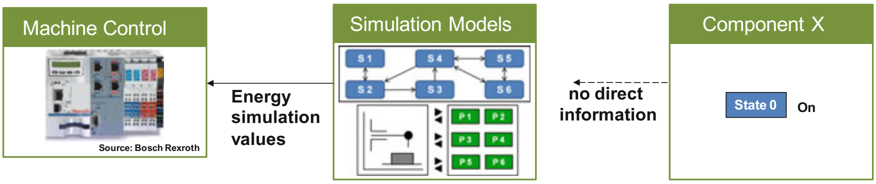

Fig. 4 Simulation models for "always on" components

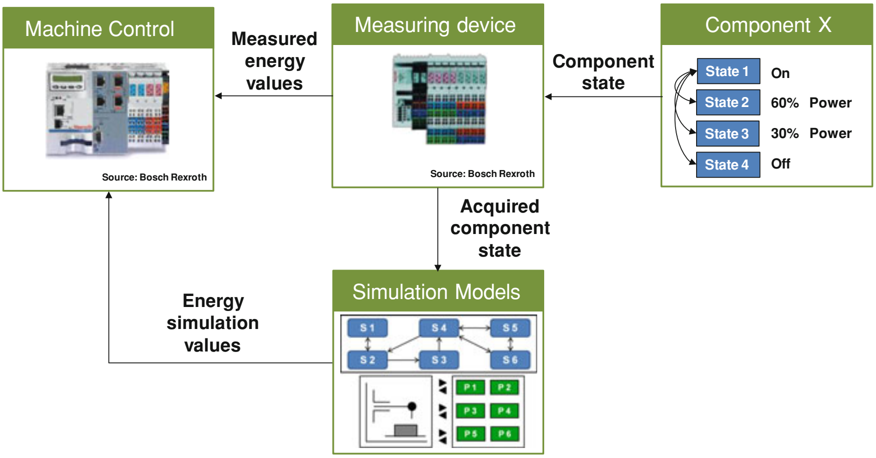

Fig. 5 Additional measurement equipment for either state or energy consumption

The measuring of the state of a component or the energy consumption can be realized through the following two approaches.

The first approach is to integrate the measurement system into the existing communication infrastructure. This will result in a reconfiguration of the machine control as new components have to be added to the automation bus. Depending on the machine type and the process the machine is used for, this can have an impact on the cycle times in which data is transferred from the control to the components, resulting in changes on the surface quality. On the other side, the energy measurement values can be transferred to the control in constant cycle times, only limited through the automation bus cycle time, which will enable a high resolution of the energy consumption measurement.

The second approach for providing measured energy values to the control is through the Ethernet interface most control units are equipped with today. By means of a standardized communication protocol like OLE for Process Control (OPC) information can be read from the measuring unit by the machine control without the need to integrate additional components into the machine infrastructure. The disadvantage of this approach is that the cycle time cannot be as high as with an automation bus for data provision due to limitations by the OPC and Ethernet protocol.

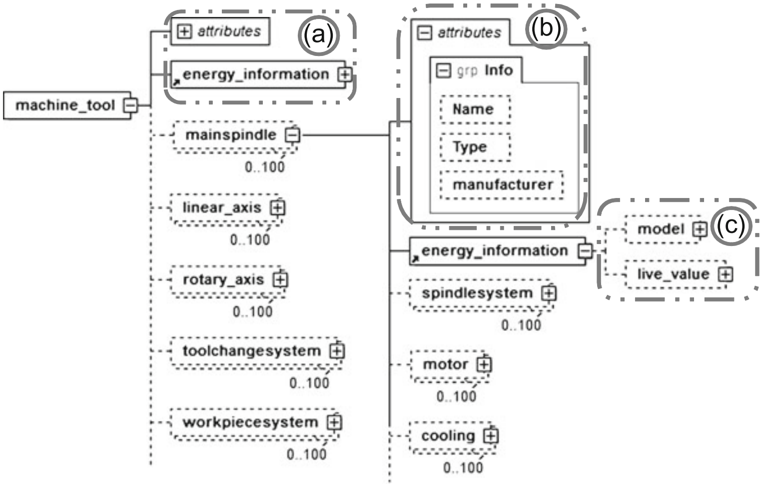

Fig. 6 EIDL's main frame

Based on these approaches the overall energy consumption of a working machine can be monitored by the machine control in every state the machine can be operated in (except the "machine off" state). The problem in monitoring all components in a machine control is that the control does not know which components are present in a machine. All components have to be added manually to create an energy consumption map of the whole machine. How the energy consumption can be calculated automatically is described in the following subchapter.

3.2 Automatic Provision of Component Information

To enable the use of the strategies described in Sect. 3.1 an automated approach for the exchange and the provision of energy information of all the machine tool's components is necessary. The approach has been implemented as energy information description language (EIDL) within the research group ECOMATION.

EIDL's main structure is based on the components and component-groups within a machine tool. The structure is built up as tree-like with different levels of detail considering the components and component groups. The machine tool itself represents the root node. Each attached sub node contains one component of the machine tool on the same level of detail. Depending on this level of detail, each sub node can contain further sub nodes with further components or component groups. An overview of EIDL's main frame is given in Fig. 6.

To provide the necessary energy information each node within EIDL's main frame is equipped with two information nodes: 'attributes' and 'energy information' (see Box A in Fig. 6). The node 'attributes' (see Box B in Fig. 6) contains

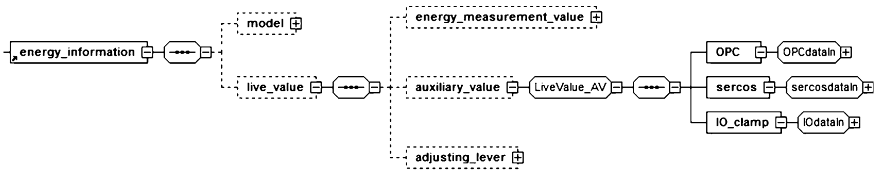

Fig. 7 Contents of the node 'live value'

data concerning the component that has to be specified with e.g., Name, Type, Manufacturer.

To enable the use of strategies to access consumption values of all components, the second information node 'energy information' (see Box C in Fig. 6) contains data that support the use of models and the available live values, which are present and accessible for the machine tool's control. The node 'model' consists of e.g., the model type, required inputs and outputs with data types and essential configuration for the use of each model. Information about the available live values within the machine control is described in the node 'live value' (see Fig. 7). It includes available energy measurement values, either from intelligent components or from additional measurement equipment, auxiliary values like current spindle speed or feed rates of drives and adjusting levers, meaning available control outputs that can manipulate the current energy consumption.

EIDL is implemented in XML language as XML schema, which is widely supported on different operating platforms. By defining the specific components and including the modelling and live value information the user derives an energy description of a machine tool. This derivation process is shown in Fig. 8. With software already on the market, it is possible to check the resulting machine tool's description conformity to the define EIDL XML schema.

3.3 *Control of Energy Consumption*

The behaviour of most milling machines can be described via state models similar to the one illustrated in Fig. 9.

In certain states (e.g. idle) energy is consumed, even if no process is in progress. Regarding former research of the ISW this can amount to 30 % (Dietmair and Verl 2009). In order to reduce the amount of energy consumption, the control needs to switch off consumers not needed in the current state or at least shift them to an energy-optimal state.

For shifting components in energy-optimal states the control has to know which energy states are available in the component and through which adjusting lever components can be sent into the energy-optimal state. Two approaches are possible.

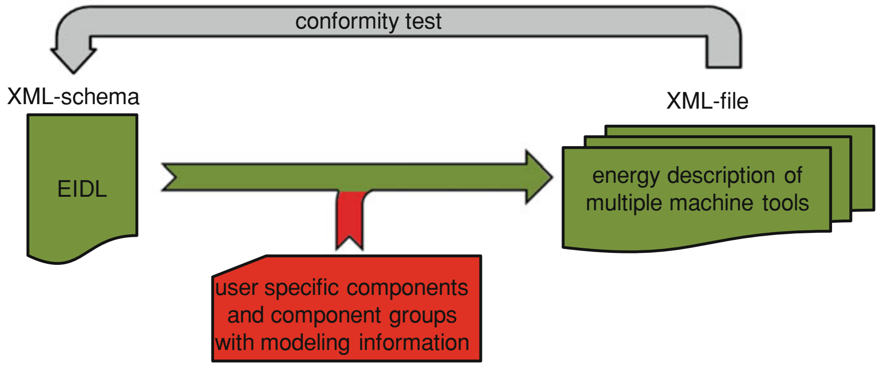

Fig. 8 Process of derivation of a machine tool's description with EIDL

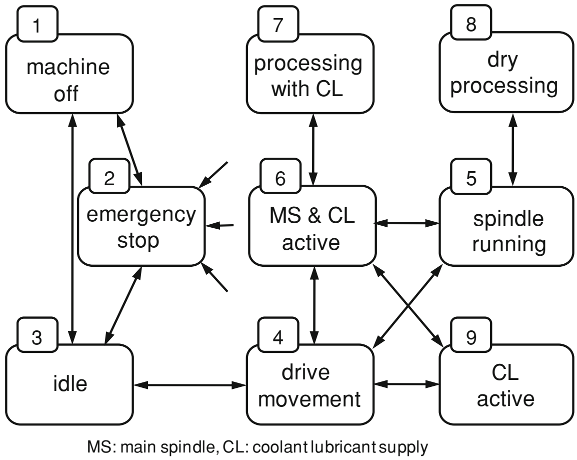

Fig. 9 Energy states of a milling machine

Firstly, if the component is continuously state commanded like a main spindle drive, automation bus mechanisms can be used to inform the machine control about the energy states within the machine. In order to decide which energy state is the optimal state, attributes of the energy state need to be provided by the component to the control (see Fig. 10). This information is as follows (PROFIBUS Nutzerorganisation e.V. 2010):

- How much energy is necessary to switch to the energy state and how much energy is required to bring the component back into an operation mode.
- The time required to send the component into the energy state and the time necessary to move the component into an operating mode.
- Furthermore, some components which can be shifted really fast to an energy-saving state might have some construction-related restrictions that do not permit a continuous shifting between the energy state and the operating state. In this case, a "minimum time of stay" needs to be available so that the control can be

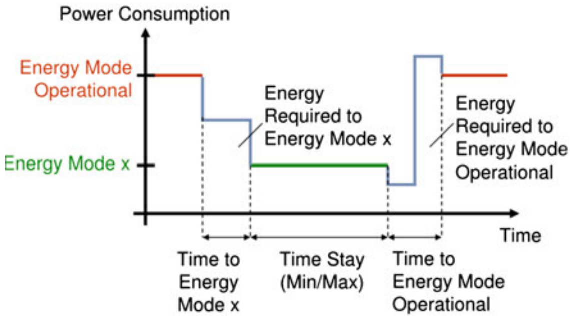

Fig. 10 Attributes of energy states. *Source* SERCOS International e.V. 2011

informed about these limitations. It is also possible that a component can only stay for a maximum amount of time in a certain energy state before it has to switch back to the operating state. An example could be: If a fan is switched off over a long term period this would result in the destruction of the cooled unit.
- Further the energy consumption of the energy state has to be available to the machine control for calculating whether switching to the energy state is useful.

For shifting the component into the energy-optimal state an adjusting lever like an automation bus command is required.

This dynamic approach can only be used in components that have some intelligence and can be addressed via an automation bus like Profinet or sercos. For all other components this approach is not usable.

A second, more static approach that can be used for informing the machine control about energy consumption values and mechanisms to control the energy consumption is through the energy information description language (EIDL, refer to Sect. 3.2). Through EIDL information about the origin of consumption values (e.g. by means of models, live values or a combination of control information with models) can be provided. In addition, the adjusting levers of every component can be made available for the machine control. This means, for example, which output in a PLC has to be switched off for shifting a pump into an energy efficient state. All adjusting levers should have attributes similar to the ones described in the automation bus approach.

Based on a dynamic and/or static approach a machine control knows how to influence energy consumption, even though the control has no strategies to do so yet.

4 Interface Between Working Machine and Plant Floor

For the development of efficient strategies, information from the plant floor is required. This information includes multiple criteria like "product to produce", "quality", "time", "energy consumption" and the relation between them. This

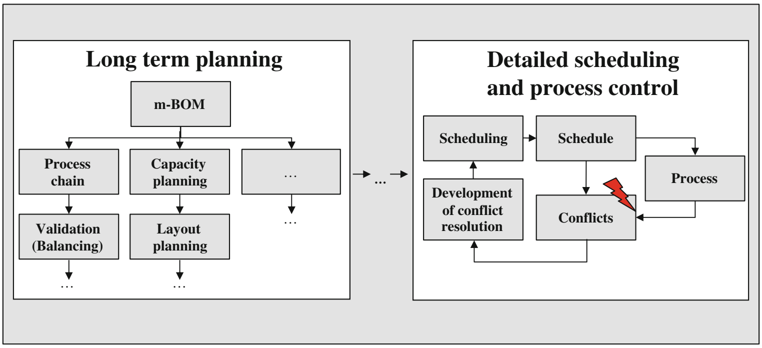

Fig. 11 Long-term planning and detailed scheduling. *Source* (Verl et al. 2011)

information needs to be generated in the plant floor and transferred to the machine control.

Furthermore, a single manufacturing resource is not able to detect disturbances in the flow of material, in a peripheral system, or at an upstream station. Thus, the manufacturing resource cannot initiate measures, and a central management system is needed. On this level, the energetic optimization of the entire process chain including possible peripheral systems can be realized. In view of an overall planning, it is important to distinguish between the tasks "detailed scheduling and process control" and "long-term planning" (Fig. 11).

Detailed scheduling and process control is usually a functionality of the Manufacturing Execution System (MES) and consists of the anticipatory consideration and the reaction to unexpected occurrences. Supervisory control could e.g. switch downstream stations into a standby mode based on upstream machine states and a model of the temporal and causal relationships between the stations. Here the real-time capability is a central feature (VDI 2007).

The long-term planning considers a longer period of time and is a prerequisite for a detailed scheduling and process control. For this, real-time capability is irrelevant. Based on the required product properties, processes and resources are selected. In a further step, capacity and layout planning will be executed. A first approach for a model-based energy efficiency optimization for production planning was presented in (Dietmair et al. 2010). The approach is to link the material flow simulation of the process chain with state-based energy models of manufacturing resources. This makes it possible to optimize various organizational aspects of production in relation to low energy consumption. In a first step, various (basic) parallel and serial production system topologies and patterns for job scheduling have been investigated. It turned out that an enormous energy-saving potential lies in the organizational optimization. Details of the long-term planning including the peripheral systems were presented in at ICPR 2011 (Haag et al. 2011).

The focus of the following approach is on the main level-based detailed scheduling and process control. The aim is to exchange energy-relevant data with the machine controller or model-based.

Implementation can take place based on the standardized software interface OPC, which fulfils all the conditions necessary.

To carry out a detailed scheduling and process control on the main level two features are required in particular:

- The time-discrete, quasi-continuous capturing of readings on a monitoring system
- The event-discrete data collection and communication in a messaging system.

The monitoring system is needed to monitor the continuous energy data collection and expanded by a time stamp in the production management system (e.g. MES).

Much more important is a functionality of a messaging system. This is the core functionality of the communication architecture. It enables bi-directional communication between the models or machine PLCs and the management system on the main level. A differentiation must be made between bottom-up messages and top-down messages.

In bottom-up messages all communication of a hierarchically lower level to a higher level are summarized. Typically, this corresponds to the communication from the machine to the higher-level management system.

Top-down messages are defined as all communication, which escalated from a hierarchically higher level to a lower level. Typically, it is therefore the communication from the management system to the machine.

To keep the data volume low, transparent communication is an important precondition. Here, the exchange of the following information seems to be useful:

- Timestamp (date on which the message was issued);
- Station (recognition of the sending respectively the receiving facility);
- Status (optional) (current status of the machine—only in bottom-up messages);
- Message (message in the form of an identification number);
- Time span (optional) (suspected fault time or time in which the information is valid).

Communication follows a mailing principle which allows a cross-level communication. OPC items are stored on the OPC Server. Each participant can access their own inbox and output.

At first, a prototype of the system-wide communication architecture is being developed in ECOMATION. It is currently being tested for suitability for multi-level Monitoring and Control of Energy Consumption of a process chain including the peripheral systems.

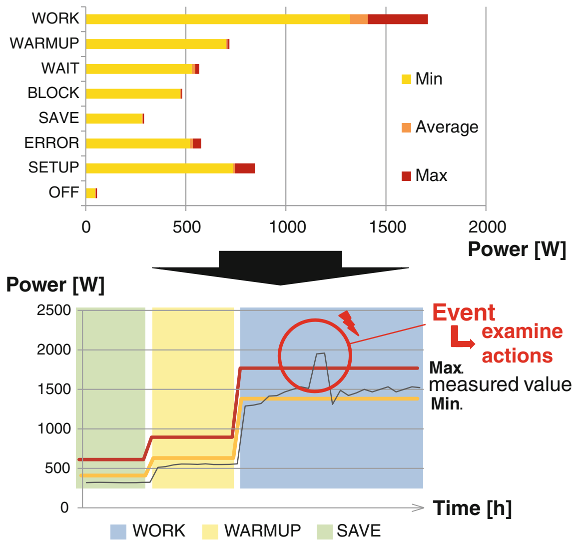

Fig. 12 Monitoring of energy consumption

5 Plant Based Control of Energy Consumption

5.1 Monitoring of Energy Consumption and Condition Monitoring

The monitoring functionality can visualize the current energy consumption graphically and give employees on the shop floor an idea of the current consumption. Due to the permanent log of minimal consumption, average energy consumption and maximum use, a tolerance channel can be specified in which the system ranges energetically. This tolerance channel is continuously adjusted based on new field data. The implementation can take place either on one machine or for the entire production line including the peripheral systems. Deviations of energy consumption from the tolerance channel can be detected at an early stage (see Fig. 12).

This functionality can be expanded into a comprehensive condition monitoring system, which is connected with the maintenance.

5.2 Messaging for the Energy-Optimal Control of Production

The bidirectional messaging system between the resources of the main processes and the management system and between the peripheral systems and the management system provides the core functionality of the developed method.

One exemplary application of the messaging system is the energy-optimal control of all resources that are involved in production.

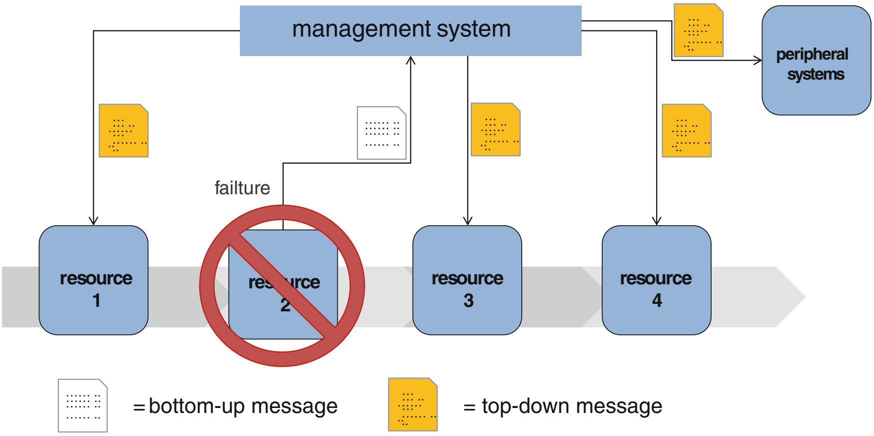

Fig. 13 Messaging system between resources and management system

In case of failure of one machine, the entire process chain including the periphery has to be set in an energy-optimal state. For this purpose, the failed resource reports a bottom-up message to the management system. This message includes the current time of the system, the station ID and the message ID of the failure. This message can be generated automatically. Alternatively, the maintenance engineer or the operator may select the message directly on the use terminal of the resource (see Fig. 13).

The failure ID allows the management system to determine the expected period of the failure via a connected database system. Based on this information, it can be decided whether any further systems involved will be put in a standby or sleep mode. It is not always appropriate that the same decision is made for all resources involved. Variable transient or long warm-up phases may be the reason for this. It is also possible that centralized peripheral systems provide several production lines and upstream and downstream resources of the main processes which have different buffer levels to be processed. These facts have to be considered when determining an energy-optimal global set of parameters for both resources of the main processes and peripheral systems. On this basis, the management system sends a top-down message to all systems involved to put them into an energy-optimal state.

6 Conclusions

In this chapter results of the research group ECOMATION have been described, for example, how different consumers in a working machine can be categorized into different groups depending on their ability to provide energy consumption values. Based on this categorization different approaches have been presented to determine attributes of different energy states required for energy consumption control. To support the automated use of the presented energy saving strategies, an energy information language containing all the necessary information for the use of simulation models and data available on the machine control has been introduced. Based on attributes of the different energy states, controls can switch to an energy-optimal state if information from the plant floor is available. To provide this information, mechanisms for the communication between machines and the plant floor have been illustrated. These different mechanisms can be used to create a production system-wide energy control loop to reduce the energy consumption considerably.

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Mobile Assistance for Energy-Efficient Production: Scenario Parameters and System Impact

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Abstract Increasing scarcity of resources and high energy costs have led to an increasing relevance of energy-efficiency over the last few years. While a lot of efforts are already being made to optimize energy-efficient production in large companies, there is still a lack of practicable support for small and medium enterprises (SME). While new equipment is mostly designed according to energy-efficiency requirements, feasible action is needed to decrease energy consumption of existing equipment on the shop-floor level. As actions on this small scale rely on dependable information and its use at the right time and place, involvement of ICT devices becomes evident. This chapter describes scenarios as well as a derived system design to integrate mobile and stationary devices for energy-efficient dimensioning and energy optimized operation within the framework of order-related manufacturing. Emphasis is placed on the consolidated consideration of various individual measures. The scenarios provide a basis for further requirements analysis and evaluation of the assistant system.

1 Introduction

Using resources responsibly is a paradigm drawing more and more attention. The consideration of aspects of sustainability in customer's buying decisions and federal legislation makes many enterprises reconsider their industrial practices. The provision of mechanical energy accounts for 64 % of the overall industrial

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energy consumption in Germany (Brischke 2010). Saving energy requires a responsible and demand-driven use which may save costs, prepare enterprises for future challenges and decrease the dependency on volatile energy prices (Ghoshray and Johnson 2010; Ratti et al. 2011). Various guidelines like energy management systems (DIN 16001:2009-08 (2009); ISO (International Organization for Standardization) 2011) or the use of key performance indicators (Bunse et al. 2011) have been developed to manage and control energy use within production. Furthermore, energy-efficiency is widely considered an important requirement within the planning process of new equipment. Integrated machines like machine tools or larger production equipment are more and more crafted to fulfil these requirements or possess particular energy saving modes. Still, many of these measures do not have the expected impact on small and medium enterprises (SME). In this environment, production equipment is not replaced every time the manufactured product changes. It is more likely to be modified in order to fit new product characteristics. Thus, the used equipment tends to have a longer life expectancy in SME and adjustments due to technical improvements do not occur as often as in larger enterprises. In addition, SME often do not possess the needed expertise within the field of energy efficiency. Finally, transparency regarding energy consumption on equipment level or even on component level is often not accessible. In a nutshell, SME often lack "initiation, market information, expertise and financial resources" (Bunse et al. 2011).

The research project AssiEff aims at the development of a mobile assistance system for energy-efficient production. Based on an in situ measurement of the individual components and the knowledge of the incoming orders, recommendations to improve the efficient use of the production equipment will be given. According to their individual information needs, decision makers, production engineers and machine operators are addressed differently. This approach aims at the involvement of the employees—from shop floor to decision level—to improve energy-efficiency within order-related production in SME.

The chapter is structured as follows. First we take a look at possible strategies at the shop floor level, these may include recommendations to exchange components or to operate the system more energy-efficiently. As these recommendations strongly rely on the actual conditions of system operation, the chapter then describes potential scenarios for order-related manufacturing. In the next section, the relevant stakeholders are introduced, who may influence energy-efficiency measures in a manufacturing context. The following sections focus on the design of the support system which fuses data from sensors reading e.g., energy meters, using metadata and formalized heuristics as well as planning information provided e.g., by an ERP system. Non-functional requirements with respect to the IT-system which are not addressed by the previous sections are then collected in order to derive a basic system architecture. As the system is specifically tailored towards the needs of SME, we show possible deployment scenarios such as temporary deployment and the provisioning of energy efficiency optimization as a service. We provide the reader with related work before we conclude the chapter.

2 Strategies to Support Energy Efficiency of Existing Production Facilities on the Shop Floor Level

Due to the growing interest in resource efficiency, energy aspects within the planning process of new production systems have moved into the centre of attention. Also considerable work and attention was spent to the development of new and energy efficient machine components like drives, pumps or fans.

Besides that, the optimization of existing production sites has by far not been exploited yet. The estimated saving potential in this field extends up to 50 % of today's energy costs (Schmid 2004; European Commission 2003).

To address these aspects, the ongoing research project AssiEff develops an assistance system for order-related, energy-efficient production. The achievement of the overall goal of a more efficient use of energy requires a stronger involvement of the employees. The projected assistance system aims to support decision makers, production engineers and machine operators in SME by a transparent display of the actual energy use and the recommendation of potential action. The approach is based on two basic strategies to save energy:

2.1 *Exchange of Components*

The life cycle of a production system commonly covers several product generations as well as various demand patterns and changes in production programs. Usually the active components of a production system, e.g., actuators, drives and pumps are designed to cover all possible demand patterns and to fulfil all possible workload conditions.

As a result, existing production sites frequently contain over-sized and therefore inefficient components. Recent surveys found that currently deployed electrical drives realistically reach energy conversion efficiencies of about 20 % (European Commission 2003) and also suggest quite similar figures for pneumatic components (Radgen and Blaustein 2001). Manufacturers estimate potential savings using state-of-the-art technology as high as 82 % of energy costs for compressors and above 50 % for components like pumps, hoisting drives or fans (Siemens 2011).

Despite this enormous potential, high-energy-consumption components are seldom replaced with newer, more energy-efficient ones tailored to the actual workload patterns (Schmid 2004).

Unlike during the planning of new production systems, energy-efficiency audits are not yet widely applied in the industry, specifically not in SME. Transparency of information about the actual energy consumption on component level is often missing and therefore, existing components are often reused over two or more product generations as replacing them seems more costly.

So, compared to current industrial practice in small and medium enterprises, the deployment of components dimensioned according to their predicted energy consumption may save energy and thus significantly save costs over their life span.

In the context of this strategy, we aim to estimate the ecological and economic benefits of an exchange of components in case of the reuse of an existing production system. Based on operating data and in situ measurement of the relevant components, their operating modes and the predicted utilization, energy savings and their economic impact in terms of return on investment are calculated. Furthermore, this data serves as a baseline to compare the actual utilization during operation to predict worthwhile component exchanges. The planning assistant aims to support decision-making based on a model of the component-level classification of energy-efficiency. Therefore, it needs realistic, timely input data, energy consumption of each component in different operating modes, operating hours, energy costs for kWh and information about alternative state-of-the-art components. The latter is necessary to provide a benchmark regarding the actual efficiency and cost improvements.

2.2 Energy-Efficient System Operation

Energy-efficient system operation as a second strategy addresses saving potentials that can be realized by dynamically controlling the use phases of production systems. By "Turn-Off-Engineering" and alterations of the order sequences, a more efficient use of resources is expected as it is shown in Fig. 1.

Within the field of order-related manufacturing, equipment is frequently left in idle states, consuming almost the same amount of energy as in full-load conditions.

As nowadays, a paradigm shift in the management of equipment from capacity utilization to flexible and adaptable production has already occurred, the utilization and thus energy consumption of machine equipment largely depends on its underlying demand patterns. Figure 2 shows the typical characteristics of energy use within order-related manufacturing. In the context of this research, tests were carried out at an automated production line for the customer-specific assembly of USB sticks. Short periods of production are followed by non-productive phases. Within these non-productive phases, energy of about 500 Watts is consumed by infrastructural parts of the equipment like data processing and energy supply for sensors and components. While producing, energy consumption is at about 2.000 Watts.

Energy-efficient system operation aims at reducing energy consumption by the use of short-time switch-offs—either of the entire equipment or some of its parts. Depending on the energy consumption and the length of non-productive operation, this may include the definition of additional machine states like stand-by or simmer modes. The following preconditions are therefore required:

- order-related manufacturing (significant non-productive phases);
- fast starting and stopping devices;
- real-time information about operating modes;
- real-time information about upcoming orders.

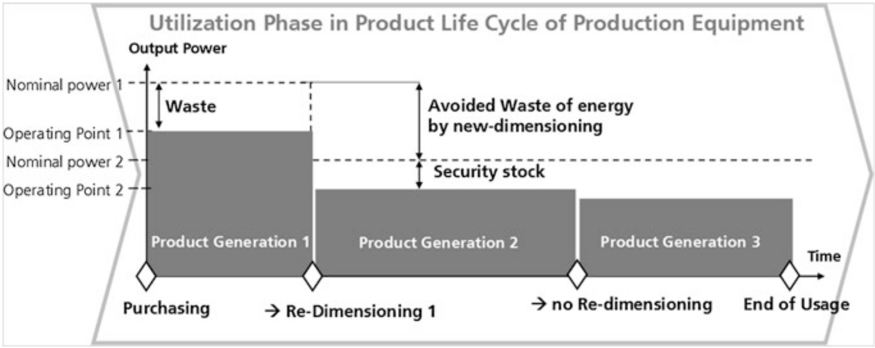

Fig. 1 Exchange of components, triggered by the consideration of operating points of different product generations. *Source* Schlund et al. (2011)

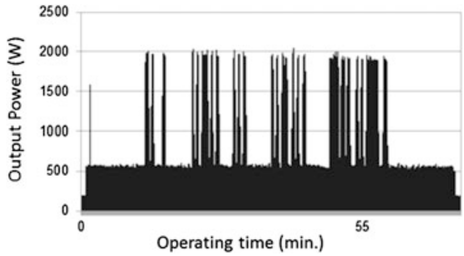

Fig. 2 Energy use at an automated production line for customer-specific assembly of USB sticks

Intelligent and IT-supported fast deactivation of components will be referred to as "Turn-Off-Engineering" (Schlund et al. 2011). Energy-efficient system operation, which is supported by real-time information about potential switch-off situations, closes inefficient gaps within the order status by the partial shutdown of the equipment. For the aforementioned production line, Fig. 3 displays the savings potential of the following aspects of "Turn-Off-Engineering":

1. Avoidance of idle states before start of production;
2. Avoidance of idle states between orders;
3. Use of separately switchable devices (drives);
4. Demand specific switching on/off of separate components during production process.
5. Optimization of switching on/off;
6. Parallel time-delayed manufacturing of multiple orders.

The measures 1–5 refer to different options of "Turn-Off-Engineering", which may be used combined. The parallel time-delayed manufacturing of multiple orders displays a change of the initial order sequence. Using the load curve, the arrows pinpoint the saving potential of each individual measure which is as high as 30 % for one single measure in the depicted example (measure 6).

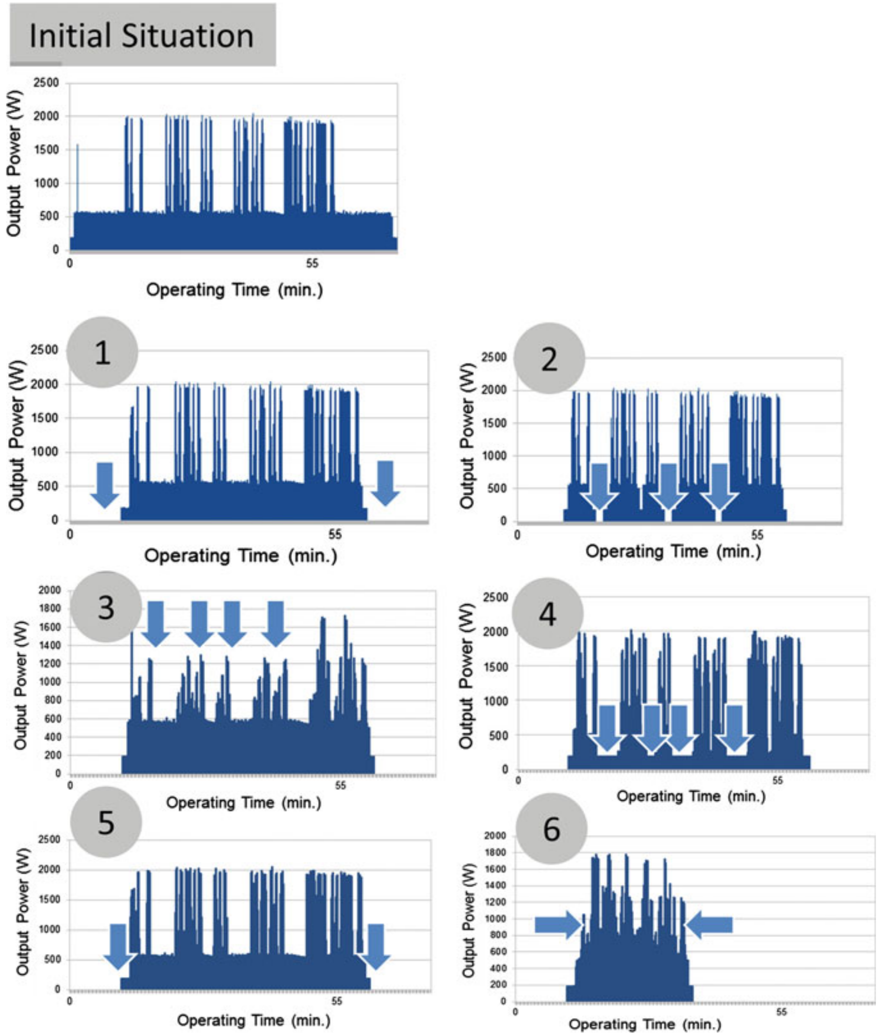

Fig. 3 Savings potential for energy-efficient system operation

3 Scenarios to Describe the Range of Use Cases

In order to estimate potential benefits of isolated or combined measures of the described strategies, scenarios are used. Scenarios are defined as a management tool for identifying a plausible future and a process for forward-looking analysis (Ahmed et al. 2010; Gelman 2010). For the design of mobile assistance for energy-efficient production, they are employed to provide a range of possible situations that may occur in order-related manufacturing of a (partially) automated production line.

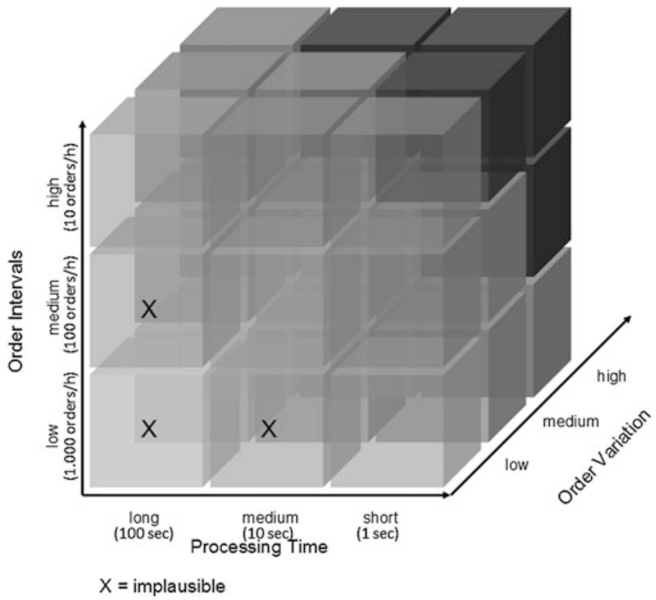

Fig. 4 Classification of scenarios according to their input data. *Source* Schlund et al. (2011)

To specify the possible situations for energy-saving measures, three main parameters are considered for each scenario:

- order intervals (orders/time);
- processing time (time/order);
- order variation (standard deviation of orders/time).

Combining these three dimensions and parameter values for each of the characteristics, 18 plausible scenarios could be identified. They describe the entire range from highly utilized equipment with constant load to low utilization with high variation. Figure 4 illustrates the results. Implausible scenarios caused by incompatible combinations of order interval and processing time (e.g., order Intervals: 1.000 orders/h and processing time: 100 s) are marked with an “X”.

Further parameters are either considered as largely constant like operating costs (energy costs) or may be derived from the main parameters above, like operating hours (in terms of the total hours of operation which is dependent on processing time and order intervals).

The scenarios form the basis for the decision models of the assistance system. For example, in the case of alteration of order sequences (e.g., bundling), they represent the full range of possible demand patterns. Based on the simulation of randomly created order distributions within those scenarios, decision support can be provided for a wide variety of SME. Currently an algorithm is created to bundle or withdraw orders based on energy saving constraints. Regarding the equipment,

Table 1 Relevant stakeholders and their typical questions within the decision process for energy-efficient measures

Stakeholder	
Production engineer	What component may be integrated to (re-)gain a reliable and stable process?
Machine operator	How does an exchange of components affect my daily tasks?
Plant maintenance	How expensive are the indirect effects of energy efficiency measures?
Purchaser	Does the energy efficiency measure pay?
Decision maker	Does the energy efficiency measure fit into the overall business objectives?
Component manufacturer	What is the best way to offer suitable and energy efficient components to my clients?

Source Schlund et al. (2011)

the needed time gaps between orders to change to an energy-efficient operating mode (or even to switch-off) provide the command variable.

4 Applications for the Most Relevant Stakeholders

Within the field of operation on the shop-floor-level there are basically two fundamental strategies to implement energy-efficiency measures. First of all, machine characteristics already consider "eco"-modes and adapt their behaviour to the actual needs. This approach is based on "intelligent" behaviour of the equipment to analyze and evaluate its operational parameters and provided data to react in an energy-efficient way. The other approach is based on intelligent behaviour of the relevant stakeholders. Actions within this field aim at the implementation of an "eco"-mode within their behaviour. Compared to the machine-oriented approaches, they rather focus on "soft" measures to provide transparency of energy use and influence a more careful use, e.g., in times of less utilization.

Obviously, these two approaches do not have to be employed separately. Depending on the use case and the possibilities of interference, fully automated equipment would be hard to adapt in the scope of the second approach. However, partially automated production lines with a lot of loosely connected energy-consuming devices may benefit significantly from including the work force and considering soft factors with the goal of saving energy. Furthermore, this approach needs possibilities to interfere into the individual machine controls to turn-off individual components, stable start-up processes and easy-to-change components, thus a flexible and versatile production system.

The AssiEff project follows this strategy. Based on a real-time display of energy use and the proposal of possible actions to be taken by the relevant stakeholders, it aims at a more considerate use of energy. Furthermore, by the recommendation of potential measures, the assistance system leaves it to the recipient to decide about what action is to be taken. To address the right person within the context of energy-efficiency, a stakeholder analysis has been carried out and basically six relevant groups of persons could be identified (Table 1).

Out of these six, the three stakeholders which most likely have an impact on influencing energy-efficiency were considered the following:

- The decision maker;
- The production engineer;
- The machine operator.

These roles are directly addressed by the assistance system through individual templates, which consider the specific requirements in terms of information provision and recommendations for possible action.

5 Adoption Barriers and Non-Functional System Requirements

Besides functional requirements, such as the use of scenarios and the consideration of the various stakeholders described in the previous sections, several non-functional requirements have to be met for the realization of the mobile assistance system.

For easy adoption in SME, it is necessary to lower barriers regarding the operation of the system. For example, it is desirable that the system can also be hosted by a third party vendor in order to reduce operation costs and efforts. For the same reason, it should also be possible to outsource operation and support of end user devices.

There are a number of barriers to the adoption of energy-efficiency projects. The barriers are quite heterogeneous, and vary from sector to sector (Kentor 2003; Schleich 2009). However, it is possible to generalize that in the commercial and services sectors, energy costs are usually below 3 % of the overall costs, and thus projects aiming at increasing energy efficiency within such organizations are often rejected simply because they are not seen as "strategic" (Kentor 2003). We address this problem by designing a system that enables outsourcing of large parts of the energy optimization process, reducing both the initial investment necessary to establish the process, and the necessary strategic commitment. Offering intermediate services through vertical service providers is a well-known strategy for supporting SME (Albino and Kühtz 2004).

Requirement I: The system should allow outsourcing of the metering and analysis processes to a specialized service provider.

As a result, it could improve the willingness of enterprises to adopt energy efficiency projects if the system was able to not only supply them with strategic information they can use when e.g., planning future purchases of manufacturing equipment, but also offers a way to identify immediate benefits (Lockett NJ and Brown 2005) that could be reaped by e.g., rescheduling tasks.

Requirement II: The system should allow for operational short-term analyses to enable immediate benefits for enterprises.

Alcántara et al. (2010) identify promising horizontal technologies for improving energy efficiency. The proposed technologies of metering energy and steam, and controlling these inputs, specifically by eliminating peak hours, seem promising approaches for IT assistance.

Requirement III: The system should integrate inputs from energy meters, and enable the machine operator to perform a fine-granular analysis of the current energy inputs and develop plans for improving energy efficiency, e.g., by eliminating peak hours. Additionally, planning information coming from e.g., an ERP system is required, meaning that the system has to provide a generic input interface.

Based on those requirements, we derived the system design presented in the next section.

6 System Design

The system is built upon the paradigm of service-oriented architectures (SOA) (Weerawarana et al. 2005). It uses a set of core services, utilizing open common Internet standards such as WSDL (W3C 2001) and BPEL (Business process execution language for web services 2003).

The system design is based on a layered architecture, separating frontend and backend services, enabling flexible adaptation of the SOA composition to the requirements of specific SME use cases, e.g., integration of specific enterprise protocols in the backend. The backend services, which are from a technical point of view the more complex part of the system, have already been implemented and tested on a wide range of test data, demonstrating the basic feasibility of our system design. The system's frontend services are still under design, as those require inputs from the actual people going to use them to reach their full potential. The preparation of pilot studies is ongoing.

6.1 Backend Services

The system's "intelligence" is realized on the server side by several backend services. In order to measure the real energy consumption of a production system and its components, an **Energy Consumption Monitoring Service** interfaces energy meters and stores the data in the backend. In order to use the stored data, further data processing is performed, such as data preparation (e.g., smoothing of measured data). For some parts of the offered decision support, forecast of future energy consumption and energy prices is needed to provide a base on which decisions, like component replacement, can take place. The service provides forecasting functionality based on past data by implementing a SARIMA model (Olsson and Soder 2008).

The **Data Management Service** is responsible for providing read/write access to the data and meta-data of the system. We use ontologies to describe the information from various platform-internal and external sources. This approach

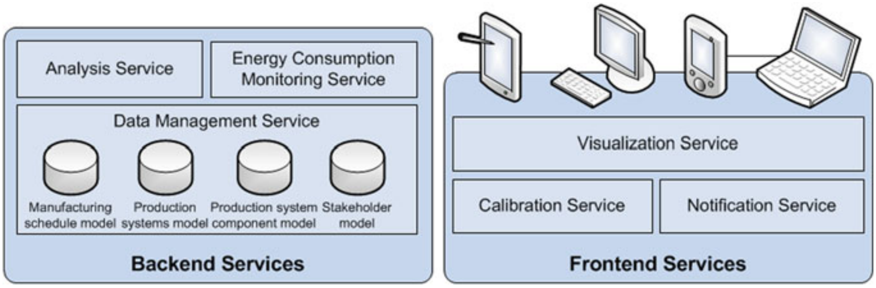

Fig. 5 System design overview

has already proven to be purposeful, especially in heterogeneous environments (Bullinger 2006; Bügel and Laufs 2008). The Information required by the system is structured in **specialized data models** (Fig. 5). For the realization of the backend models, we decided to use the web ontology language (OWL) (McGuinness et al. 2004) which is built upon the less expressive W3C standards RDF (Ankolekar et al. 2008) and RDFS (Celino et al. 2009).

6.2 Front End Services

When providing system functionality aimed at increasing energy efficiency to the stakeholders involved in the production process, an easy-to-use user interface is crucial. For a seamless integration into given processes, a mobile solution is desirable because it also allows to use the system directly in the production environment. Mobile systems also typically have less power consumption than stationary PCs. In order to provide an affordable solution that can amortize in SME, it is necessary to rely on products from the mass market in a low price range.

While smaller mobile devices like smartphones offer better mobility, the small dimension of the screen is of course an issue regarding the visualization of vast amounts of data e.g., for visualizations of the production system's configuration (Fig. 6).

In order to provide a mobile solution that can fulfil the requirements regarding the user interface but is also mobile, we decided to use tablet PCs for the implementation of the front end. Affordable tablets are available on platforms like Android and Windows. There are also versions available that have been designed for use in harsh industrial manufacturing environments.

Fig. 6 User interface

6.3 User Interface Concept

The user interface concept divides the provided functionality into four main sections. The sections are cross-linked wherever required. Parts of the sections are disabled based on the stakeholder's role defined in the role model.

Overview Section: This section of the user interface is designed for the support of users by providing a fast/clear overview which aggregates all relevant information on a high level. This way, detected inefficient states of the production system can be easily located and further, more detailed information or assistance can be accessed.

Assistance Tools Section: The user interface provides a specific assistance tool for each supported use case. For example, the assistance tool for exchanging components provides a specific recommendation for the exchange of a component, the system has recognized to be inefficient. While the assistance tool already provides the available information derived from measurements and forecasts, the user is able to modify all relevant parameters before performing a calculation of the time of amortisation.

Data Visualisation Section: For the more detailed information of some stakeholders, the user interface also provides additional data visualisations which include both aggregated visualisations as well as raw data visualisations e.g., diagrams containing the measured energy consumption or energy prices. For raising the awareness of energy consumed by the production system, also live data can be visualized.

Notification Section: In addition to the on-demand information provided in the other three sections, the notification section resembles a push-service that notifies the relevant stakeholders when new information or new recommendations are available. Notifications can be deactivated as needed based on the notification type. An example of a pushed notification is a "turn-off recommendation" for a specific component or system. In addition to the in-line notifications in the user interface, notifications can also be transported via e-mail or SMS to reduce the need of hardware e.g., for workers.

7 Related Work

There has been research in strategic, large-scale models, analyzing energy in- and outputs of whole value chains, and used in strategic planning of future development scenarios (Schleich 2009; Hu and Bidanda 2009) for assessing the sustainability of complex, large enterprises or entire industry sectors. The EU road mapping project IMS2020 provides a roadmap for future production research, identifying sustainable and energy-efficient production as key areas. Bunse and Vodicka (2010) offer a review of tools and performance criteria for Energy efficient production based on the project's results.

Information systems for supporting energy efficiency within enterprises also have been investigated. Roos and Hearn (2004) present a decision support system integrating enterprise planning systems with control systems and sensors to enable control of energy inputs in the ferroalloy industry. As they note themselves, such an integrated decision support system would need a high level of commitment from management, which is unlikely in most other industry sectors due to the less relevant role of energy costs (Kentor 2003) (Requirements I & II).

Similarly, Guo and Zhang (2009) propose an agent-based system for "intelligent manufacturing". This system would require a coordinated effort between the manufacturers, all its suppliers, and all suppliers of manufacturing equipment used. Therefore, it also does not meet our requirements. It is also notable in how it goes beyond energy efficiency, and aims at controlling entire value chains fully automatic. It seems unlikely such a system would be very attractive for the SME targeted by our approach.

Vijayaraghavan and Dornfeld (2010) present an approach for energy monitoring of machines in production, which supports and integrates analysis on various levels, from value chains to machine sub-components. Our approach is quite similar, but instead of presenting on the details of the energy monitoring model, we focus on the overall information system used to apply the model.

Bengtsson et al. (2011) propose a system based on a broad life cycle model of energy and material consumption as well as waste outputs, which are fed into a simulation component for forecasting of future. The system presented is applied to assess environmental impacts over the whole product life cycle, using Excel macros evaluated by domain experts. Our system is conceptually similar, but we present an integrated information system aimed at SME, which is less suitable for overall analysis, but offers an integrated user experience, requires less expertise, and focuses on realizing immediate benefits for SME.

8 Conclusions

The chapter describes scenario parameters as starting point to realize a value-based integration of mobile and stationary devices for energy-efficient dimensioning and energy-optimized operation within the framework of order-related manufacturing. Selected strategies for energy efficiency decisions on the shop-floor-level were taken into account. Role definitions were presented to address the key stakeholders within this context. Scenarios and role definitions set the stage for further analysis and evaluation of an assistance system to realize energy efficiency potential on shop-floor level.

A service-oriented architecture is used to allow portability of the system across different manufacturing environments. On the server side, a bundle of key services provides generic functionality like data management, sensor data fusion and state data analysis. In the system's frontend, stakeholder interaction such as notification and system calibration is realized using a front-end library that can support several platforms, many of which are especially energy-efficient.

Applying this approach, we expect to give viable support to assist decision makers facing the trade-off between potentially long life spans of existing equipment and energy-efficiency goals, as well as to realize energy efficiency potential on shop-floor level.

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Scheduling a Single Mobile Robot Incorporated into Production Environment

Quang-Vinh Dang, Izabela Ewa Nielsen and Kenn Steger-Jensen

Abstract Eco-production and logistics with environmental consciousness are playing a larger role in manufacturing firms. They involve scheduling, planning, developing and implementing manufacturing processes and technologies that are required not only to keep productivity high but also to respond to the challenges of issues such as energy conservation and pollution preventions. Facing the central tension between manufacturing and environmental drivers is difficult, but critical to develop new technologies, particularly mobile robots, that can be incorporated into production to achieve holistic solutions. This chapter deals with the problem of finding optimal operating sequence in a manufacturing cell of a mobile robot with manipulation arm that feeds materials to feeders. The "Bartender Concept" is discussed to show the cooperation between the mobile robot and industrial environment. The performance criterion is to minimize total traveling time of the robot with the smallest consumed amount of battery energy in a given planning horizon. A mixed-integer programming (MIP) model is developed to find the optimal solutions for the problem. Two case studies are implemented at an impeller production line to demonstrate the results of the proposed MIP model.

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1 Introduction

Environmental issue is rapidly emerging as one of the most important topics for manufacturing decisions (Azzone and Noci 1998). This is mainly driven by the escalating deterioration of the environment, for examples diminishing raw material resources, overflowing waste sites and increasing levels of pollution (Gungor and Gupta 1999). In the industry nowadays, managers take account of improvements in environmental performance one of the basic competitive edges, alongside lower costs and higher quality. Environmentally conscious manufacturing, or Eco-production, is the transformation of materials into useful products through a value-added process that simultaneously enhances economic well-being and sustains environmental quality (Darnall et al. 1994). It involves planning, developing, and implementing manufacturing processes and technologies that are required to not only keep productivity high but also respond to challenges a variety of issues, such as energy conservation, pollution preventions, and avoidance of ecological degradation (Sarkis 1995). Besides, today's production systems range from fully automated to strictly manual. While the former is very efficient in high volumes but less flexible, the latter is reversed. Hence, manufactures visualize the need for new production systems that combines the best of both worlds and considers environmental impacts by using eco-friendly production technologies such as new assistive automation and autonomous mobile robots.

Mobile robots have the capability to move around within their environment, and they are not fixed to one physical location. With embedded batteries and manipulation arms, mobile robots are more flexible to perform certain tasks such as transporting and feeding materials, machine tending, pre-assembly or quality inspection at different workstations in a manufacturing cell. Moreover, using mobile robots can lead to production efficiency gains (for example less energy usage than commonly industrial robots attached to a fixed surface), better housekeeping, safer and cleaner facilities. These superior advantages of these robots pave the way for meeting the need of the aforementioned new production systems. In this chapter, a given problem is particularly considered for mobile robots with manipulation arms, which will automate extended logistic tasks by not only transporting but also collecting containers of parts and emptying them into the place needed. Feeding operation studied here is a kind of extended logistic tasks. However, to operate mobile robots incorporated into production environment requires better inventory control with a central warehouse where supplies materials or parts for feeding tasks. Furthermore, to utilize mobile robots in an energy-efficient manner requires the ability to properly schedule this kind of tasks. Therefore, it is important to implement a specific concept for better working and environmental order as well as to plan in which sequence the robots process feeding operations so that they could effectively work while satisfying a number of technological constraints.

In the survey of the literature on production considering environmental impacts, Sarkis (1995) presented the environmental problems pertaining to manufacturing and operation management. The general framework on how to manage environmentally conscious issues in a manufacturing company is develop and discussed. Sarkis and Rasheed (1995) also identified and described the basic elements of an environmental conscious manufacturing strategy and techniques to enable businesses to pursue that strategy. Azzone and Noci (1998) introduced the contingency framework, which analyzed whether and how different "green" manufacturing must be deployed and accessed as well. Gungor and Gupta (2010) discussed the evolution of environmentally conscious manufacturing, which has taken place in the last decade, and new areas, which have come into focus during this time. Srinivasan and Sheng (1999a, b) presented a formalized approach towards integrating environmental factors in process planning which includes micro-planning and macro-planning. In micro-planning, process, parameter and common setups were selected for the individual features, while in macro-planning interactions between features are examined. Krishnan and Sheng (2000) developed an automatic process-planning agent for CNC machining for minimal environmental impact along major categories. The process planner is designed to interact with conventional generative planner as an advisory environmental agent. Jin and Balasubramaniam (2003) integrated the environmentally benign process planning with fuzzy set theories as fuzzy environmental processing planning can handle the vagueness and impreciseness associated with the data and can eliminate subjective decisions. Nielsen et al. (2010) suggested that a widely distributed and semi-structured network of waste producing and waste collecting/processing enterprises could improve their planning both by a proposed Decision Support System based on Constrained Logic Programming, and by implementing RFID technology to update and validate information. Besides, in the literature on production considering robot scheduling problem, which is NP-hard, this topic has attracted interest of researchers in recent decades. Dror and Stulman (1987) dealt with the problem of defining the best movement decision for a one-dimensional service robot. The simple simulation experiment was presented to illustrate an increase in production output with the help of sophisticated decision rules for robot's movement. Chen and Su (1995) addressed the problem of scheduling single-gripper gantry robots whose optimal schedule was developed by analyzing the cycle time formula for two and three-workstation production lines and then by extending the result for the problem of scheduling a production line with multiple workstations. Crama and van de Klundert (1997) considered the flow shop problem with one transporting robot and one type of product to find shortest cyclic schedule for the robot. The dynamic programming approach was developed to solve the problem in polynomial time. Afterwards, they demonstrated that the sequence of activities whose execution produces one part yields optimal production rates for three-machine robotic flow shops (Crama and van de Klundert 1999). Crama et al. (2000) also presented a survey of cyclic robotic scheduling problems, model for such problems, complexity of solving these problems, and the existing solution approaches. Kats and Levner (2010, 2011) considered an m-machine production line processing identical parts served by a mobile robot to find the minimum cycle time for 2-cyclic schedules. The strongly polynomial algorithm of time complexity and the improved algorithm with reduced complexity were proposed. Maimon et al. (2000) introduced a neural network method for the problem of sequencing tasks comprising loading and unloading of parts into and from the machines by material-handling robot. Suárez and Rosell (2005) analyzed the particular real case of feeding sequence selection in a manufacturing cell consisting of four parallel identical machines working alternately on two pallets, fed by one robot. Several feeding strategies and simulation model were built to select the best sequence. Most of the work and theory foundation considered scheduling robots, which are usually inflexible, move on prescribed path and repeatedly perform a limited sequence of activities. Another figure of a mobile robot that has been extensively studied and in common use today is automated/automatic guided vehicle, but it still follows markers, reflectors or guided wires on the floor. There is still lack of scheduling free-ranging mobile robots, which are able to move around within a manufacturing cell to process extended logistic tasks consisting of collecting, transporting and delivering parts or components right to places. The problem becomes interesting, as the robot has to be incorporated into manufacturing so that robot services maintain production in the lines. The complexity of the problem rapidly rises to be NP-hard when the robot has to serve more workstations (in one or several production lines) and/or work in a longer planning horizon. In addition, environmentally conscious issues, for examples energy conservation and warehouse management, have not intensively discussed in the production coordinated with mobile robots. Therefore, in this chapter we consider implementing the “Bartender Concept” for better working environment of the mobile robot and scheduling that kind of robot for feeding tasks, which could be pre-determined based on maximum and minimum levels of parts in feeders, so that all of tasks are completed with a smallest consumed amount of battery energy.

The remainder of this chapter is organized as follows: in the next section, the “Bartender Concept” is discussed to show the cooperation between the robot and industrial environment. This section also describes the problem statement. Section 3 presents the formulation of mathematical model, while case studies are investigated to demonstrate the result of the proposed model in Sect. 4. Finally, the chapter concludes and draws the future work in Sect. 5.

2 Problem Description and the “Bartender Concept”

The automation technology in combination with advances in production management has dramatically changed the equipment used by manufacturing companies as well as the issues in planning and control. These changes have led to an enormous increase in efficiency and flexibility so that progress in term of automation has become a necessity to survive global competition (Crama and van de Klundert 1999). As a result, highly automated or unmanned production systems have become more popular in several industrial areas such as chemical and plastics, automotive, pump manufacturing, etc. A typical automatic production system includes intelligent and flexible machines programmed and grouped into cells in such a way that entire production of each part can be carried out within one of the cells. This machine pooling helps to reduce material handling activities. Within a manufacturing cell, material handling is usually performed by one (or several) robots/automatic guided vehicles or human operator. When the former is the case, the performance of the cell becomes highly dependent on the interaction between automatic material handling device(s) and the machine(s) (Crama and van de Klundert 1999).

The relatively small number of machines and material handling device(s) in flexible cells, along with their high degree of automation make them an ideal environment for automated production scheduling. In general, a flexible manufacturing system with multiple machines, multiple storages, and a single robot transporting parts in between machines, also between machines and storages or from storages to feed machines are taken into account. For instances, in an automated printed circuit board assembling environment, the robot has to transport the boards in-between insertion machines and also between insertion machines and buffers at the right time before the adhesive become dry (Maimon et al. 2000), or in car-parts manufacturing factory, the robot moves a fixed track to load parts into the pallets from the storage line. The set of move requests (tasks) is assumed to be known in advance, thus the robot can be considered to have a set of tasks to carry out at each planning point. The problem is to sequence the tasks, with the objective of minimizing some performance measure such as the total travel time of the robot. Apart from the total travel time of the robot, other local performance measures can be considered for this problem such as the amount of time a task waiting for to be completed by the robot. Alternatively, completion time of a task could also be modeled as a constraint to ensure that a task is completed before a certain time. An example of it is in water fabrication facilities in which time windows for the tasks to be carried out are a consideration (Maimon et al. 2000). Besides, industrial production technology has traditionally focused on improving the quality and quantity of production with little attention paid to environmental and social costs. For instance, fixed industrial robots along with safety fences, conveyors, and prescribed material flows are ideal for repetitive tasks, increase manufacturing throughput and quality. However, operating these kinds of robots have consumed a substantial amount of energy and required high costs of changeover and worker protections. The growth in environmental consciousness has led to a significant change in this attitude, and—willingly or otherwise—businesses and manufacturing are now forced to confront the consequences of their actions (Sarkis 1995). Modern technologies with automatic material handling devices (e.g. flexible mobile robots with embedded batteries, manipulation arms and various end-effectors) incorporated to production offer the promise of gaining benefits of environmental consciousness. These kinds of devices or robots might initially be more expensive than other solutions. However, through additional creations of values and by a faster adaptation to changes with new levels of robustness, availability, and completeness of jobs, the alternative solutions could yield an earlier return of investment, safer and cleaner facilities, lower future costs for disposal and worker protection, as well as improved product quality and higher productivity of entire production.

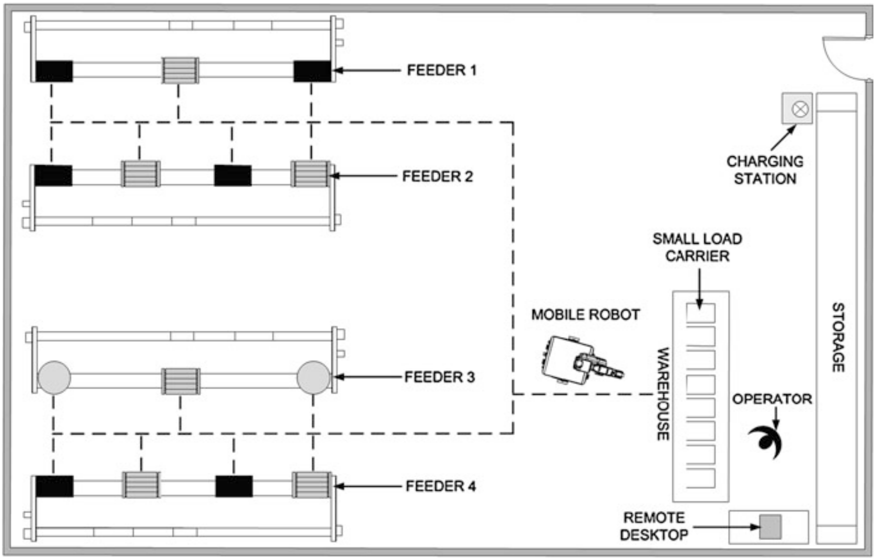

Fig. 1 Illustration of the "Bartender Concept" in the manufacturing cell

The automatic material handling devices such as mobile robots can be used in either fully automated or in-between fully automated and strictly manual production systems. Thus, they have been widely employed in not only small companies, which focus on exact application and a smaller range of products, but also large companies, which can diversify their applications in the longer term and larger range. However, the increasing market uncertainties and environmental issues require both small and large series productions to quickly respond to changing customer demands and implementing environmentally conscious manufacturing. Hence, the companies need to understand how these devices could be used to meet those requirements. Within the scope of this study, the interaction between one of the automatic material handling devices, a mobile robot, and machines in a cell, which focuses on a class of robotic scheduling, is considered under environmental consciousness. Figure 1 shows a typical layout of the manufacturing cell. In particular, the work is developed for a real cell that produced parts or components for the pump manufacturing industry at a factory in Denmark.

Before coordinating a mobile robot to industrial environment, the manufacturing cell has one or several production lines, which consists of multiple machines. Feeders are designed to automatically supply parts or components to these machines. Pallets or boxes, which contain the parts, are placed next to these feeders. Multiple-parts feeding that is the process of loading many parts at a time into feeders from the pallets or boxes is manually performed, non-value adding manufacturing task, and quite often disruptive (in-between and periodic) for production workers. In case that the workers forget to fill the feeders with parts, this may lead to a serious problem of stopping the production lines. A strategy that can reduce the dependence of the multiple-part feeding tasks on human intervention is having a mobile robot taking over parts of what humans used to do. However, to utilize the autonomous mobile robot in this scenario requires changing the working environment in the former stage and carefully planning in the latter stage.

The “Bartender Concept” is implemented to meet the requirement of the former stage as well as to make multiple-part feeding tasks performed by the mobile robot more flexible and complete. In this concept, instead of scattered pallets or boxes containing parts next to the feeders, a warehouse (the bar) is created to gather different parts into one area. An operator (the bartender) puts parts into small load carriers (SLCs) which are placed in the warehouse. The robot retrieves and carries these SLCs, moves to each feeder and feeds all parts inside a SLC to each feeder, then returns to the warehouse to unload all empty SLCs and take filled SLCs if needed. It can be seen that the benefits obtained by applying the “Bartender Concept” include safer, cleaner facilities and better opportunities for process control.

In the latter stage, with the restructured production environment, the feeders have to be served a number of times in order to keep producing all of products, so the robot has a set of multiple-parts feeding tasks to carry out during production time of products. The number of these feeding tasks is mainly influenced by the number of parts, or the total weight of parts, inside a SLC that the robot is able to carry. The more parts, or the heavier, the robot transports each time the fewer tasks it has to perform in a given planning horizon and vice versa. In order to accomplish all the movements with the smallest consumed amount of battery energy, the total traveling time of the robot is an important objective to be considered. Hence, it is crucial to determine in which way the robot should supply the feeders of machines with parts in order to minimize its total traveling time within the manufacturing cell while preventing the production lines from stopping working. A mathematical formulation is developed to achieve this objective in the next section.

3 Mathematical Formulation

In this study, a mix-integer programming (MIP) model is developed to determine optimal route of the mobile robot visiting a number of feeders to process multiple-parts feeding tasks. The model is inspired by well-known vehicle routing problem in which all the feeders (customers) corresponding to SLCs deliveries are known in advance. The (s, Q) inventory system (Silver et al. 1998) is applied to determined time-windows for part-feeding tasks. The upper bound of time window is set on the time when the number of parts inside a feeder drops to a certain level s, while the lower bound is defined on the time when there is no part in the feeder. The task for each feeder must start within an associated time window and the robot must remain at the feeder location during service. Soft time windows can be violated, while hard time windows do not allow the robot to arrive at a feeder after the latest time to begin service. In the latter case if it arrives before the feeder is ready to begin service, it waits (Toth and Vigo 2002). We will concentrate on hard time window scenarios in this model. The robot is based at a single warehouse and the capacity restriction of the robot is imposed. The certain number of parts Q is predefined to fill feeders where the robot visits each time.

MIP problem consists of some of decision variables that are constrained to have only integer values. Integer variables make an optimization problem non-convex, and therefore far more difficult to solve. Memory and solution time may exponentially rise as the size of the problem increases with more added integer variables. Therefore, in practice the MIP model can be applied to small-scale problems with a few numbers of feeders, products and short planning horizon. Under these scenarios, the MIP model is reasonably fast to give exact optimal solutions, which can be used as reference points to quantify the scale of benefits achieved by a meta-heuristic method further developed. Moreover, this MIP model attempt to minimize total traveling time of the robot; in other words, minimize battery energy consumption that is one of the important aspects of ecological production. Consequently, by saving battery energy for non-value added transportation of parts around shop floor, the mobile robot is able to take full advantage of flexible characteristics to perform other tasks at other workstations that leads to higher productivity of the entire production. Assumptions, notations and formulation for the MIP model are extensively described in the following subsections.

3.1 Assumptions

- A fully automatic mobile robot is taken into account in disturbance free environment.
- The robot can carry several SLCs at a time.
- All tasks are periodic.
- All tasks are assigned to the same robot.
- All tasks are independent which means that there are no precedence constraints.
- Working time and traveling time of the robot between any two locations, in which either one of the locations can be a feeder or warehouse place, are known.
- Consuming rate of parts in a feeder is known.
- All of feeders of machines have to be fed up to maximum level and the robot starts from the warehouse at the initial stage.

3.2 Notations

N: set of all task (0: index of task at the warehouse)
n_i: total number of times which task i has to be executed
R: maximum number of route $(R = \sum n_i, \forall i \in N \backslash \{0\})$
e_{ik}: k-th released time of task i
d_{ik}: k-th due time of task i

p_i: period time of task i
w_i: working time per SLC of task i
t_{ij}: traveling time of robot from task i location to task j location
c_i: consuming rate of parts in feeder at task i location
v_i: minimum level of parts in feeder at task i location
u_i: maximum level of parts in feeder at task i location
Q: maximum number of SLCs that can be carried by the robot

Decision variables :

$$x_{ik}^{jlr} = \begin{cases} 1 & \text{if robot travels from } k\text{-th task } i \text{ location to } l\text{-th task } j \text{ location in the route } r \\ 0 & \text{otherwise} \end{cases}$$

$y_{ik:}$ route number in which k-th task i belongs
$S_{ik:}$ k-th starting time of task i

3.3 Mixed-Integer Programming Model

$$\text{Objective function: min } \sum_{i \in N} \sum_{k=1}^{n_i} \sum_{j \in N} \sum_{l=1}^{n_j} \sum_{r \in R} t_{ij} x_{ik}^{jlr} \tag{1}$$

Subject to:

$$p_i = (u_i - v_i)c_i \qquad \forall i \in N \backslash \{0\} \tag{2}$$

$$e_{ik+1} = e_{ik} + p_i \qquad \forall i \in N \backslash \{0\}, k = 1 \div n_i \tag{3}$$

$$d_{ik} = e_{ik} + (v_i - 0)c_i \qquad \forall i \in N \backslash \{0\} \tag{4}$$

$$e_{ik} \le s_{ik} \le d_{ik} \qquad \forall i \in N \backslash \{0\}, k = 1 \div n_i \tag{5}$$

$$\sum_{j \in N \backslash \{0\}} \sum_{l=1}^{n_j} x_{01}^{jl1} = 1 \tag{6}$$

$$\sum_{j \in N \backslash \{0\}} \sum_{l=1}^{n_j} \sum_{r \in R} x_{01}^{jlr} \le 1 \tag{7}$$

$$\sum_{i \in N} \sum_{k=1}^{n_i} x_{ik}^{ikr} = 0 \qquad \forall r \in R \tag{8}$$

$$\sum_{r \in R} x_{ik}^{jlr} \leq |Z| - 1 \quad \forall i, j \in N, k = 1 \div n_i, l = 1 \div n_j, i \neq j, Z \subseteq Z_T, Z \neq \Phi \tag{9}$$

$$\sum_{j \in N} \sum_{l=1}^{n_j} \sum_{r \in R} x_{ik}^{jlr} = 1 \quad \forall i \in N \backslash \{0\}, k = 1 \div n_i \tag{10}$$

$$\sum_{i \in N} \sum_{k=1}^{n_i} \sum_{r \in R} x_{ik}^{jlr} = 1 \quad \forall j \in N \backslash \{0\}, l = 1 \div n_j \tag{11}$$

$$\sum_{i \in N} \sum_{k=1}^{n_i} \sum_{j \in N \backslash \{0\}} \sum_{l=1}^{n_j} x_{ik}^{jlr} \leq Q \quad \forall r \in R \tag{12}$$

$$s_{ik} + \left(w_i + t_{ij} \sum_{r \in R} x_{ik}^{jlr} \right) - L\left(1 - \sum_{r \in R} x_{ik}^{jlr} \right) + \left(y_{jl} - y_{ik} \right) \times \left(t_{i0} + w_0 + t_{0j} - t_{ij} \right) \leq s_{jl} \; \forall i, j \in N, k = 1 \div n_i, l = 1 \div n_j, \forall r \in R \tag{13}$$

$$y_{jl} = \sum_{i \in N} \sum_{k=1}^{n_i} \sum_{r \in R} r \times x_{ik}^{jlr} \quad \forall j \in N \backslash \{0\}, l = 1 \div n_j \tag{14}$$

$$y_{jl} \geq y_{ik} \sum_{r \in R} x_{ik}^{jlr} \quad \forall i, j \in N, k = 1 \div n_i, l = 1 \div n_j \tag{15}$$

$$x_{ik}^{jlr} \in \{0, 1\} \quad \forall r \in R, \forall i, j \in N, k = 1 \div n_i, l = 1 \div n_j \tag{16}$$

$$y_{ik} : \text{positive integer variable} \quad \forall i \in N, k = 1 \div n \tag{17}$$

The objective is to minimize the total traveling time of robot. Constraints (2), (3), and (4) set period time of each task, released time and due time of each execution of each task, respectively. Constraint (5) ensures that starting time of each execution of each task satisfies its time window. Constraints (6) and (7) indicate that the robot starts from the warehouse at the initial stage. Constraint (8) prevents the robot repeating an execution of one task. Constraint (9) eliminates the sub-tours among executions of tasks, where Z is a subset of Z_T, where Z_T is a set of all executions of tasks at feeders and the warehouse, and Φ denotes and empty set. Constraints (10) and (11) force each execution of each task in one route to be done exactly once. Constraint (12) forbids the robot to feed more SLCs than the maximum number of SLC Q it allows to carry. Constraint (13) handles the traveling time requirements between any pair of executions of tasks, where L is a given sufficiently large constant. In case two executions of the same task or different tasks are connected but they are not in the same route, the robot should visit the warehouse to unload empty SLCs and load filled ones. Constraint (14) assigns each execution of each task to a route and constraint (15) guarantees the ascending sequence of route numbers for executions of tasks. Constraints (16) and (17) imply the types of variables.

4 Case Studies

To examine performance of the MIP model, case studies are investigated at the CR factory at Grundfos A/S. The chosen area for the case studies is the CR 1-2-3 impeller production line that produces impellers for the CR products. The CR line consists of a warehouse and four feeders that have to be served by the mobile robot. The warehouse is indexed 0 and the feeders are indexed from 1 to 4 (N = {0, 1, 2, 3, 4}) and named Back Plate, Van Feeder 1, Van Feeder 2, and Front Plate respectively. Besides, different feeders are filled by different kinds of parts, namely back plates for feeder 1, vanes for feeder 2 and 3, front plates for feeder 4. To produce an impeller on the CR 1-2-3 line, three types of parts, which consist of six vanes (with three vans from feeder 2 and the other three vans from feeder 3), one front plate from feeder 4 and one back plate from feeder 1, are automatically assembled. The design weights of vane, front plate and back plate are 1 g, 50 g, and 50 g per part respectively. Figure 2 shows the different parts of an impeller, while Fig. 3 particularly illustrates the aforementioned production area where the presented model has been implemented. It can be seen that the safety fences and warning signs are used as described in Fig. 3 to ensure that no people enter the area as well as to prevent the mobile robot leaving that area while the implementation is taking place.

The average number of parts per SLC fed to feeder 1 or 4 is 125 (approximately 2 kg/SLC), while the average number of parts per SLC fed to feeder 2 or 3 is 1100 (approximately 1 kg/SLC). The maximum and minimum levels and consuming rate of parts in each feeder are given in Table 1, while Tables 2 and 3 show working time of robot at each task's location and traveling time of robot from one task's location to another (feeder 0 means the warehouse).

In the early design, the mobile robot has capability of carrying up to three SLCs at a time to perform multiple-part feeding tasks at the feeders. Therefore, two case studies were investigated corresponding to two maximum numbers of SLCs ($Q = 2$ and $Q = 3$) that can be carried once by the robot. These cases were executed during approximately 50 min because of robot's battery limitation. The parameters p_i, e_{ik}, and d_{ik} are respectively computed from (2), (3), and (4) in the section 3.3.

The MIP model has been coded and solved by the mathematical modeling language ILOG OPL 3.6 which is a sophisticated and computationally efficient solver that can handle linear programming problems with hundreds of thousands of variables and mixed-integer linear programming problems with tens of thousands of variables. Using this modeling language is particularly advantageous for development of new models and for documentation of models that are subjected to potential changes (Chang et al. 2001). Both case studies have 4040 decision variables including 4000 integer variables x_{ik}^{jlr}, 20 integer variables y_{ik} and 20 variables s_{ik}. The problem of the case studies have been run on a PC that has Intel Core 2 Duo CPU and 2.2 GHz processor (2 GB RAM).

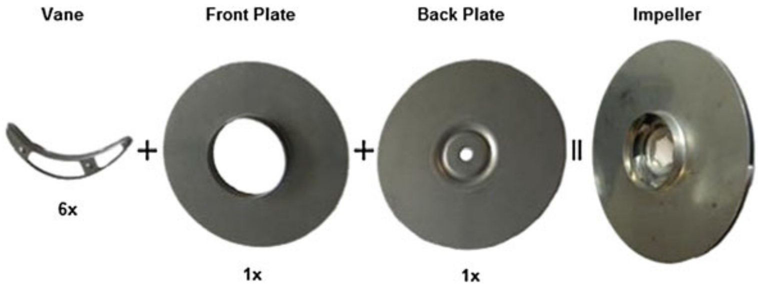

Fig. 2 Different parts of an impeller produced on the CR 1-2-3 line

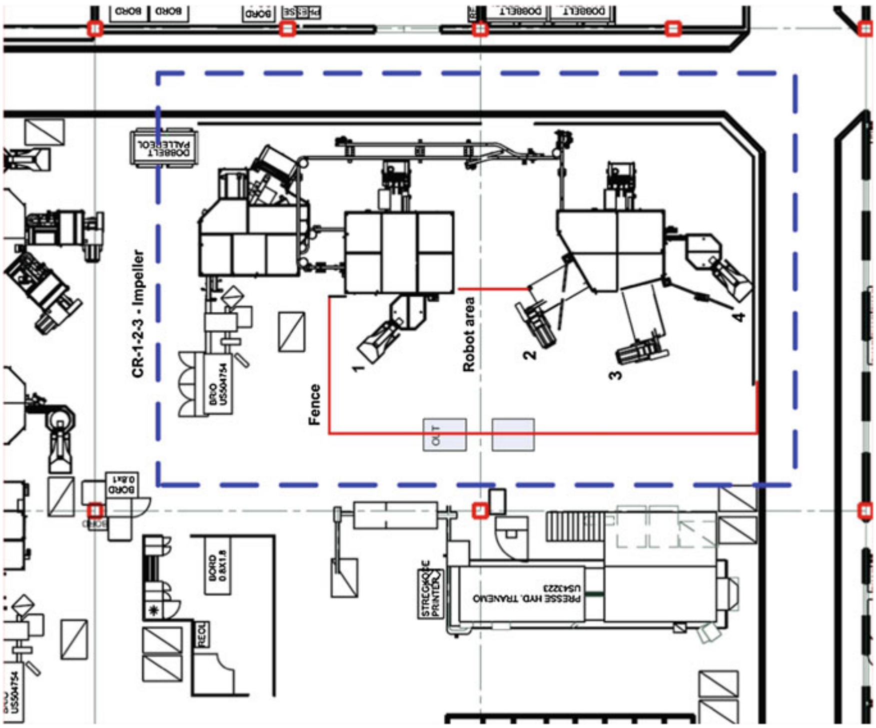

Fig. 3 CR 1-2-3 impeller production line

Table 1 Maximum and minimum levels and consuming rat of parts in feeders

Feeder	1	2	3	4
Maximum level u_i (part)	250	2000	2000	250
Minimum level v_i (part)	125	900	900	125
Consuming rate c_i (sec/part)	4.5	1.5	1.5	4.5

Table 2 Working time of robot at feeders

Feeder	0	1	2	3	4
Working time w_i (sec)	90	42	42	42	42

Table 3 Traveling time of robot from one feeder location to another

Traveling time t_{ij} (sec)	0	1	2	3	4
0	–	49	44	43	38
1	49	–	58	45	58
2	46	58	–	35	48
3	42	43	35	–	47
4	44	56	47	46	–

4.1 Case Study 1

The first case considered that the mobile robot could only carry up to two SLCs at a time during its performance. The optimal solution obtained from this case is given as $x_{01}^{411} = x_{41}^{022} = x_{02}^{112} = x_{11}^{122} = x_{12}^{033} = x_{03}^{423} = x_{42}^{433} = x_{43}^{044} = x_{04}^{134} = x_{13}^{055} = x_{05}^{445} = x_{44}^{145} = x_{14}^{066} = x_{06}^{216} = x_{21}^{316} = x_{31}^{077} = 1$, the others $x_{ik}^{jlr} = 0$ and $y_{01} = y_{41} = 1$, $y_{02} = y_{11} = y_{12} = 2$, $y_{03} = y_{42} = y_{43} = 3$, $y_{04} = y_{13} = 4$, $y_{05} = y_{44} = y_{14} = 5$, $y_{06} = y_{21} = y_{31} = 6$ which form the entire route 0 - 4 - 0 - 1 - 1 - 0 - 4 - 4 - 0 - 1 - 0 - 4 - 1 - 0 - 2 - 3 - 0, with the total traveling time being 624 s which makes up 20.8 % of the total time. The detailed solution is summarized in Table 4 and Fig. 4 below.

4.2 Case study 2

The second case considered that the mobile robot could carry up to three SLCs at a time during its performance. The optimal solution obtained from this case is given as $x_{01}^{411} = x_{41}^{111} = x_{11}^{121} = x_{12}^{022} = x_{02}^{422} = x_{42}^{432} = x_{43}^{132} = x_{13}^{033} = x_{03}^{443} = x_{44}^{044} = x_{04}^{144} = x_{14}^{314} = x_{31}^{214} = x_{21}^{055} = 1$, the others $x_{ik}^{jlr} = 0$ and $y_{01} = y_{41} = y_{11} = y_{12} = 1$, $y_{02} = y_{42} = y_{43} = y_{13} = 2$, $y_{03} = y_{44} = 3$, $y_{04} = y_{14} = y_{31} = y_{21} = 4$ which form the entire route 0 - 4 -1 - 1 - 0 - 4 - 4 - 1 - 0 - 4 - 0 - 1 - 3 - 2 - 0, with the total traveling time being 543 s which constitute of 18.1 % of the total time. The detailed solution of the case is summarized in Table 5 and Fig. 5 below.

These above optimal solutions of the case studies 1 and 2 are initial schedules for the mobile robot. The initial schedule serve as inputs to a program called Mission Planner and Control (MPC), which is implemented in VB.NET. The Mission Planner and Control program is accessed using XML-based TCP/IP communication to command and get feedbacks from the robot, and interact with ERP system of the company. By integrating the mobile robot into the general enterprise network, it is possible to plan and control globally, as the mobile robot become a resource on the same level as corresponding manufacturing device. During the practical

Table 4 Detailed optimal solution of the case study 1

Feeder/Task	Index of execution	Starting time (s_{ik})	Route
4	1	810.0	1
1	1	1125.0	2
1	2	1378.5	2
4	2	1687.5	3
4	3	1935.0	3
1	3	2250.0	4
4	4	2510.0	5
1	4	2608.0	5
2	1	2923.0	6
3	1	3000.0	6

multiple-parts feeding operations at CR 1-2-3 impeller production line, the mobile robot was able to continuously pick/place SLCs from/to the warehouse and empty them into the different feeders so that the initial schedules were executed in sequence and they prevented all of feeders running out of parts. Hence, the CR 1-2-3 production line can keep manufacturing impellers without shortage of parts that are fed from feeders.

From those case studies, it reveals that the higher maximum number of SLCs the robot can carry, the less traveling time it has; in other words, the less battery energy it consumes. It can be also observed that the robot only visits the central warehouse 3 times in the second case as opposed to 5 times in the first one. Because of fewer times on visiting the warehouse, the robot can also save its battery energy from the work consisting of unloading all empty SLCs and loading newly filled SLCs there. Consequently, when the mobile robot gains less energy usage, it can perform multiple-part feeding tasks in a longer planning horizon, or move to other workstations with its ability to automatically change various end-effectors in order to serve other types of tasks, for examples single part feeding, pre-assembly, machine tending, quality inspection, process execution during its idle time if required. These apparently lead to more sustainable production, higher productivity, and demonstrate the superior characteristics of mobile robots to industrial robots, which are attached to a fixed surface, or automatic guided vehicles, which follow markers, reflectors, guided wires on the floor in the context of environmentally conscious manufacturing.

5 Conclusions and Further Research

In this chapter, a new problem of scheduling a single mobile robot, which is incorporated into production lines considering environmental consciousness, to perform multiple-parts feeding tasks is studied. In order to reduce the human interventions and intensively utilize the mobile robot, the “Bartender Concept” was implemented to restructure the working environment. Benefits obtained from that implementation

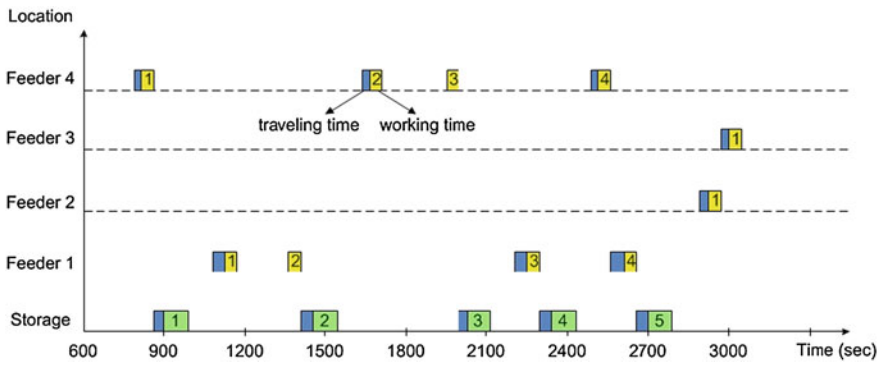

Fig. 4 Gantt chart for the optimal solution of the case study 1

Table 5 Detailed optimal solution of the case study 2

Feeder/Task	Index of execution	Starting time (s_{ik})	Route
4	1	1027.0	1
1	1	1125.0	1
1	2	1378.5	1
4	2	1687.5	2
4	3	2152.0	2
1	3	2250.0	2
4	4	2497.5	3
1	4	2812.5	4
3	1	2923.0	4
2	1	3000.0	4

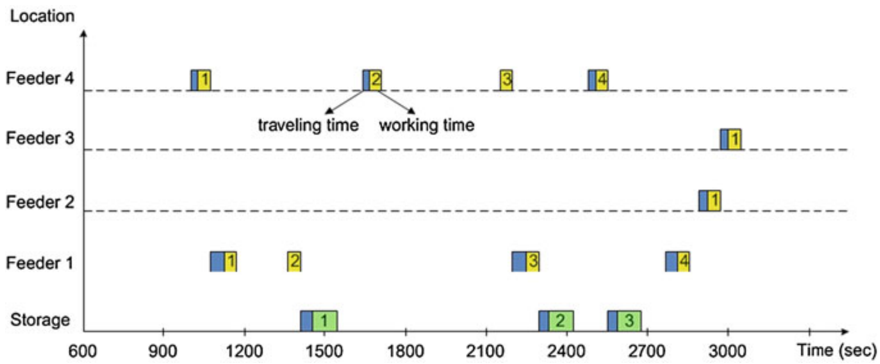

Fig. 5 Gantt chart of the optimal solution of the case study 2

consist of safer, cleaner facility layout, and better opportunities for process control. Besides, to accomplish all the tasks within allowable limit of battery capacity, it is important for mission planners to determine optimal feeding sequence to minimize total traveling time of the mobile robot while taking into account specific features of the robot and a number of technological constraints.

A new mix-integer programming model was developed to find optimal solution for the problem. This model could be coded and solved by using the mathematical modeling language ILOG OPL 3.6 which is advantageous for development of new scenarios due to potential changes of dynamic production environment. The proposed model can be applied in practice with small-scale problems with a few numbers of feeders, products and short planning horizon. The particular real cases of the impeller production line composing of four feeders were described to show result of the proposed model. The result was quite properly applied during practical feeding operations and it demonstrated that all feeders had no shortage of parts fed to the production line. Furthermore, it can be seen from the real cases that along with the flexible characteristic of the mobile robot, if it has higher ability to carry more number of SLCs at a time, it can save time on transporting parts around the shop floor and working at the central warehouse. Consequently, this can lead to eco-efficiency gains such as less energy usage, more sustainable production and higher productivity, as well as demonstrate the superior characteristics of mobile robots to fixed industrial robots or automatic guided vehicles.

For further research, the complexity of the problem categorized as being NP-hard will increase when considering a large number of feeders and/or long planning horizon. Hence, a meta-heuristic method will be taken into account for solving the large-scale problem of mobile robot scheduling. Besides, during the implementation of the real case studies at the shop floor, different interruptions occasionally happened because of various reasons such as losing communication between the robot and the MPC program, failure of the robot to picking/placing SLCs from/to the central warehouse or empty SLCs at the feeders, even stopping the production line due to scrap materials. These interruptions require the MPC program to have the robust ability to recover the system state before errors and then re-schedule the remaining tasks based on obtained schedules and feedback from the shop floor. Hence, a re-scheduling mechanism with an integrated real-time discrete event simulation model might be developed to deal with these aforementioned real-time disturbances. Moreover, multi-objectives function concerning environmental impacts to improve eco-production and logistics could be considered for future work.

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Declarative Approach to Cyclic Scheduling of Multimodal Processes

Grzegorz Bocewicz and Zbigniew A. Banaszak

Abstract In this chapter, we deal with the cyclic scheduling problem usually observed in the FMS producing multi-type parts where the AGVS plays a role of a material handling system. Finding the conditions guaranteeing the AGVs deadlock-free and collision-free movement policy is the aim of this work. The AGVs co-sharing the common parts of the transportation route while executing repetitive processes, can be modeled in terms of Cyclic Concurrent Process Systems (CCPSs). The chapter suggests a novel approach for schedulability analysis employing the declarative modeling. In turn, the schedulability analysis for a given CCPS answers the question whether a cyclic schedule exists or not. A reference model of constraint satisfaction cyclic scheduling problem shows that unschedulability can be caused by a relation among an initial state and dispatching rules selected. The sufficient conditions guaranteeing CCPS schedulability are discussed and the recursive approach to their designing is proposed. Possible implementations are illustrated on example of the flexible manufacturing system operation.

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1 Introduction

The Flexible Manufacturing System (FMS) (Lawley et al. 1998; Pinedo 2005) produces multi-type parts, in which the Automated Guided Vehicle System (AGVS) is used as a material handling system. The Automated Guided Vehicles (AGVs) scheduling problem is a special case of the cyclic blocking flow-shop one, where the jobs might block either the machine or the AGV at the processing time. A cyclic schedule (Liebchen and Möhring 2002; Von Kampmeyer 2006) is one in which the same sequence of states is repeated over and over again. A cycle in such a schedule begins at any state and ends when that state is encountered next. Finding the conditions guaranteeing the AGVs deadlock-free and collision-free movement policy is the aim of this work. In that context, the problem of the cyclic scheduling of multimodal processes can be stated as follows: Given a set of transportation routes, each one treated as a repeating sequence of workstations serviced by dedicated AGVs. Some routes may share the common workstations as well as sections of the transportation paths. The question considered is: What is a transportation route between two designated terminal load/unload stations in the AGVS providing the shortest travel time subject to above mentioned constraints? In other words, a best transportation route of the so called multimodal process, i.e. sharing different transportation routes, is sought.

In general case, however, besides of AGVS that can be treated as a kind of internal transport, other emerging trends concerning the logistics (e.g., supply chains management) and city traffic (e.g., infrastructure of the public transport) issues can be modeled. For instance, as the relevant multimodal processes that can be seen as the passengers traveling between assumed destination points in the environment of the local processes encompassing the subway lines network might be considered as well.

The AGVs co-sharing the parts of the transportation route and executing repetitive tasks assigned to the vehicles passing along machine tools in a cyclic way, can be modeled in terms of Cyclic Concurrent Process Systems (CCPSs) (Bocewicz et al. 2009, 2007, 2011; Polak et al. 2004). The existing constraints connected with the available traveling route width (not allowing for vehicle passing by), the topology of travelling routes and itineraries of individual vehicles, lack of simultaneous access to the stations, etc. imply the necessity to investigate conditions leading to possible vehicle collisions and deadlocks (Gaujal et al. 1995; Song and Lee 1998). This means that the cyclic scheduling problem, i.e. guaranteeing the AGVs, collision-free and deadlock-free schedules, belongs to the class of NP-hard problems (Levner et al. 2010).

The existing approach to solving the problem base usually upon the simulation models, e.g. the Petri nets (Alpan and Jafari 1997; (Song and Lee 1998), the algebraic models, e.g. upon the (max, +) algebra (Polak et al. 2004) or the artificial intelligent methods e.g. upon the genetic algorithms (Cai and Li 2000). In this context, this work constitutes some continuation of the investigations conducted in (Bocewicz et al. 2009, 2007, 2011; Polak et al. 2004).

Moreover, since the cyclic scheduling of CCPS can be seen as a kind of Diophantine problem (Bocewicz et al. 2009), hence its solvability, i.e. schedulability, plays a pivotal role (Guy 1994; Smart Nigiel 1998). Schedulability analysis for a given (CCPS) answers the question whether a cyclic schedule exists in the reachability space of this system or not. Therefore the problem considered in this chapter reduces itself to determination of the sufficient conditions ensuring the collision-free and deadlock-free execution of the concurrent cyclic processes. In that context, we suggest a novel approach for schedulability analysis employing the declarative modeling as well as the recursive approach to sufficient conditions designing.

The chapter is organized as follows. In the next section, the reference model of the AGVS scheduling problem is defined. In the third section, the schedulability of AGVs is discussed. Sufficient conditions for CCPS deadlock avoidance are proposed. Following that, the cyclic steady states space and a way of precedence digraphs designing are described. In the fourth section, an illustrative example of AGVS redeveloping is shown.

2 A Reference Model

2.1 AGVS Model

The AGVs can be modeled in terms of a CCPS, wherein the cyclic processes (vehicles) are interconnected one with another by use of the AGVS common resources. In Fig. 1 an illustration of the FMS with distinguished AGVS is presented while its CCPS model is shown in Fig. 2.

Three local processes are considered P_1, P_2, and P_3, that reflect operation of individual vehicles. The transportation route consists of six parts (sectors), treated as resources R_1–R_6 the vehicles have to pass by. For the systems of that type, it is assumed that the cooperation of the processes is determined by the following constraints (Polak et al. 2004):

- the processes share the common resources in the mutual exclusion mode,
- commencement of a successive process operation happens immediately after completing of the current operation provided that there is a possibility of making use of the successive resource requested by the given process,
- during waiting for a busy resource, the process does not release the resource allocated,
- the process is not pre-emptive, i.e. the resource may not be taken of the process while it is using it,
- the processes are executed cyclically,
- in one cycle, a process may pass via any resource only once.

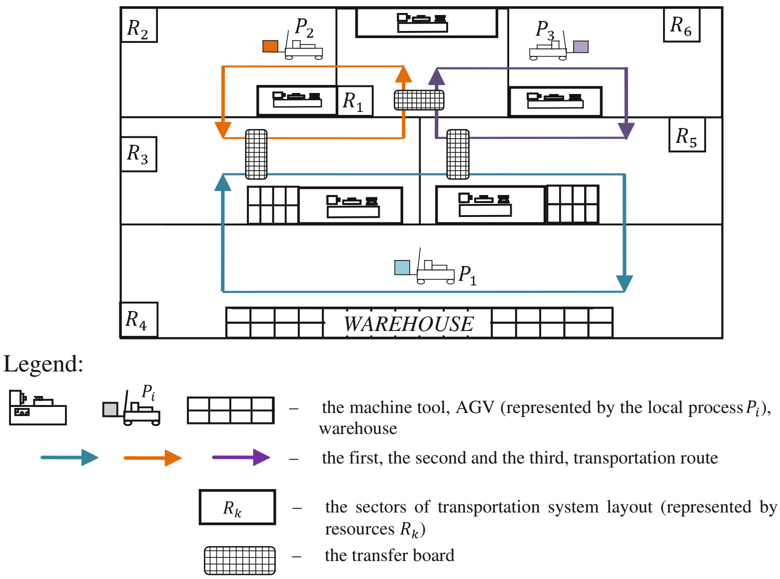

Fig. 1 An example of the FMS: AGVS layout

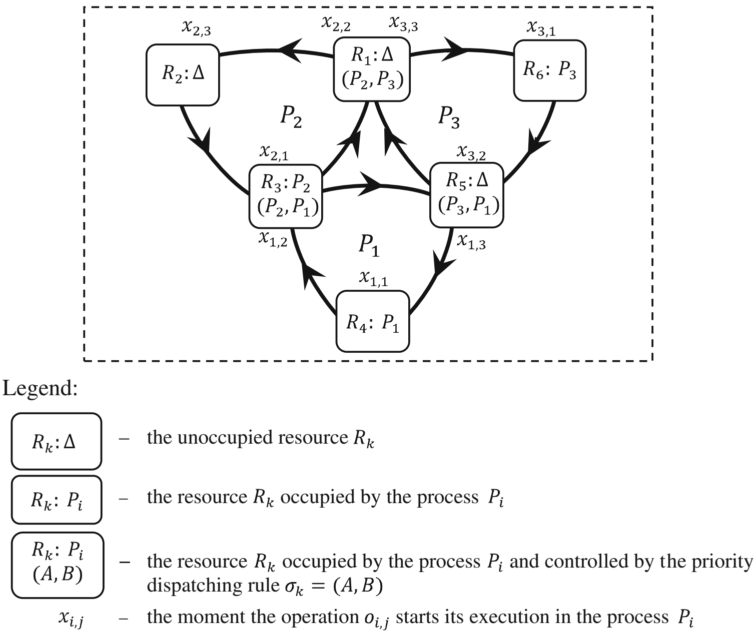

Fig. 2 An example of the FMS: CCPS model of AGVS

In the model of CCPS the following definitions are used (Bocewicz et al. 2011; Polak et al. 2004):

- A sequence $p_i = \left(p_{i,1}, p_{i,2}, \ldots, p_{i,lr(l)}\right)$specifies **the route of the local process** P_i, and its components define the resources used in course of process operations execution, where: $p_{i,j} \in R$ (the set of resources: $R = \{R_1, R_2, \ldots, R_m\}$)—denotes the resource used by the i-th process in the j-th operation; in the rest of the chapter **the** j**-th operation executed on resource** $\boldsymbol{p_{i,j}}$ **in the process** P_i will be denoted by $o_{i,j}$; $lr(i)$—denotes a length of cyclic process route.
- $T_i = \left(t_{i,1}, t_{i,2}, \ldots, t_{i,lr(i)}\right)$ specifies **the operations time in the** i**-th process**, where $t_{i,j}$ denotes the time of execution of the j-th operation by the i-the process. For the sake of simplicity let as assume the all operation times are the same and equal to the 1 unit of time.
- $\Theta = \{\sigma_1, \sigma_2, \ldots, \sigma_m\}$ is the set of **the priority dispatching rules**, where $\sigma_i = \left(s_{i,1}, \ldots, s_{i,ip(l)}\right)$ is the sequence, the components of which determine the order in which the processes can be executed on the resource R_i, $s_{i,j} \in P$ (the set of processes: $P = \{P_1, P_2, \ldots, P_n\}$, each process executes periodically in infinity).

In that context a CCPS can be defined as the following quadruple (Bocewicz et al. 2011):

$$SC = (R, \Pi, T, \Theta) \tag{1}$$

where:

$R = \{R_1, R_2, \ldots, R_m\}$—the set of resources,
$\Pi = \{p_1, p_2, \ldots, p_n\}$—the set of local process routes,
$T = \{T_1, \ldots, T_n\}$—the set of local process operations times,
$\Theta = \{\sigma_1, \sigma_2, \ldots, \sigma_m\}$—the set of dispatching priority rules.

For instance, the relevant model of CCPS shown in Fig. 2 can be specified as follows:

$$\begin{aligned}
&R = \{R_1, R_2, R_3, R_4, R_5, R_6\}\\
&\Pi = \{p_1, p_2, p_3\}, p_1 = (R_4, R_3, R_5), p_2 = (R_3, R_1, R_2), p_3 = (R_6, R_5, R_1),\\
&T = \{T_1, T_2, T_3\}, T_1 = T_2 = T_3 = (1, 1, 1), \text{(the unit operation times are assumed)},\\
&\Theta = \{\sigma_1, \sigma_3, \sigma_5\}, \sigma_1 = (P_2, P_3), \sigma_3 = (P_2, P_1), \sigma_5 = (P_3, P_1)
\end{aligned}$$

The model considered (1) describes the parameters characteristic for CCPS structure. In that context the main question concerns of CCPS cyclic behavior and a way this behavior depends on direction of local transportation (process) routes Π as well as on priority rules Θ and a set of initial states, i.e., an initial processes allocations to the system resources. Assuming the sought cyclic behavior of CCPS there exists the next question regarding its periodicity evaluation plays a pivotal role.

2.2 CSP-Driven Cyclic Scheduling

Since parameters describing the CCPS model (1) are usually discrete, and linking them relations can be seen as constraints, hence related to them cyclic scheduling problems can be presented in the form of the Constraint Satisfaction Problem (*CSP*) (Bocewicz et al. 2009; Schulte et al. 1998). More formally, *CSP* is a framework for solving combinatorial problems specified by pairs: (a set of variables and associated domains, a set of constraints restricting the possible combinations of the variable values). In this context, the *CSP* is defined as follows:

$$CS = ((V, D), C) \tag{2}$$

where:

$V = \{v_1, v_2, \ldots, v_{lv}\}$—a finite set of discrete decision variables,
$D = \{D_i | D_i = \{d_{i,1}, d_{i,2}, \ldots, d_{i,ld}\}, i = 1, \ldots, lv\}$—a family of finite domains,
$C = \{C_i | i = 1, \ldots, l\}$—a finite set of constraints limiting the domains of variables.

The solution to the CS is a vector $\left(d_{1,i}, d_{2,k}, \ldots, d_{n,j}\right)$coordinates of which satisfy constraints C. The inference engine consists of the following two components: constraints propagation and variable distribution (Bocewicz et al. 2011).

In the considered case the CSP relevant to the CCPS can be stated as follows (Schulte et al. 1998):

$$CS = ((\{R, \Pi, T, \Theta, X, Tc\}, \{D_R, D_\Pi, D_T, D_\Theta, D_x, D_{Tc}\}), C), \tag{3}$$

where:

- R, Π, T, Θ are the decision variables describing the structure of the CCPS, i.e., (1), and X, Tc are the decision variables describing the cyclic behavior of the CCPS. $X = \{X_1, X_2, \ldots X_n\}$, is the set of sequences $X_i = \left(x_{i,1}, x_{i,2}, x_{i,lr(i)}\right)$, where each variable $x_{i,j}$ determines **the moment of $o_{i,j}$ operation beginning** in any (the $k-$th) cycle: $x_{i,j}(k) = x_{i,j} + k \cdot Tc,\ k \in \mathbb{Z}$, (where $x_{i,j}(k) \in \mathbb{Z}$—means the moment the $o_{i,j}$ operation starts its execution in the k-th cycle) and Tc is the CCPS periodicity,
- the following domains of decision variables are considered:
  D_R—the family of the set of resources,
  D_Π—the family of sets of admissible routings,
  D_T—the family of sets of admissible operation times,
  D_Θ—the family of sets of admissible dispatching priority rules,
  D_X—the family of sets of admissible coordinate values X_i, $x_{i,j} \in \mathbb{Z}$,
  D_{Tc}—the sets of admissible values of variables Tc,
- the constraints determining the relationship between the structure (specified by the four-tuple (R, Π, T, Θ)) and the behavior following from this structure (specified by (X, Tc)) can be defined as follows:

$$x_{i,j} = max\Big\{\big(before\big(X_i, x_{i,j}\big) + before\big(T_i, t_{i,j}\big) + \gamma\big(x_{i,j}\big)\big), \big(\alpha\big(x_{i,j}\big) + 1 + \beta\big(x_{i,j}\big)\big)\Big\}, i = 1, \ldots, n; j = 1, \ldots, lr(i) \tag{4}$$

where:

$before(A, a_i)$—the function providing the element preceding the a_i in the sequence A, and in the case a_i is the first element in the sequence $A = (a_1, \ldots, a_{i-1}, a_i, \ldots, a_l)$ the function provides the last one, i.e. a_1.

$$before(A, a_i) = \begin{cases} a_{i-1} & if\ a_i \neq a_1 \\ a_l & if\ a_i = a_1 \end{cases}$$

$after(A, a_i)$—the function providing the element succeeding the a_i in the sequence A, and in the case a_i is the last element in the sequence $A = (a_1, \ldots, a_{i-1}, a_i, \ldots, a_l)$ the function provides the first one, i.e. a_1.

$$after(A, a_i) = \begin{cases} a_{i+1} & if\ a_i \neq a_1 \\ a_l & if\ a_i = a_1 \end{cases}$$

$$\alpha\big(x_{i,j}\big) = \begin{cases} before\big(X_i, x_{i,j}\big) & \text{if } o_{i,j} \text{ executes on unshared resource,} \\ after\big(X_a, x_{a,b}\big) & \text{if } o_{a,b} \text{ executes on shared resource } R_k \text{ previous} \\ & \text{to } o_{i,j}\text{; where } R_k = p_{a,b} = p_{i,j} \text{ and } p_a = before(\sigma_k, p_i) \end{cases}$$

$$\beta\big(x_{i,j}\big) = \begin{cases} 0 & \text{if } \alpha\big(x_{i,j}\big) \text{ is the moment of } o_{a,b} \text{ starts, where } o_{a,b} \text{ and } o_{i,j} \\ & \quad \text{are executed in the same cycle} \\ -Tc & \text{if } \alpha\big(x_{i,j}\big) \text{ is the moment of } o_{a,b} \text{ starts, where } o_{a,b} \text{ and } o_{i,j} \text{ are executed} \\ & \quad \text{in the same cycle preceding of } o_{i,j} \text{ execution,} \\ Tc & \text{if } \alpha\big(x_{i,j}\big) \text{ is the moment of } o_{a,b} \text{ starts,where } o_{a,b} \text{ and } o_{i,j} \text{ are executed} \\ & \quad \text{in the same cycle suceeding of } o_{i,j} \text{ execution} \end{cases}$$

$$\gamma\big(x_{i,j}\big) = \begin{cases} 0 & \text{if } before\big(X_i, x_{i,j}\big) \text{ is the moment of the operation } o_{i,b} \\ & \quad \text{starts, where } o_{i,b} \text{ and } o_{i,j} \text{ are executed in the same cycle} \\ -Tc & \text{if } before\big(X_i, x_{i,j}\big) \text{ is the moment of the operation } o_{i,b} \\ & \quad \text{starts, where } o_{i,b} \text{ is executed in the cycle preceding of} \\ & \quad o_{i,j} \text{ execution} \end{cases}$$

Execution of local processes in the CCPS has to follow the constraints (4), that means the operation $o_{i,j}$ from the process P_i may began its execution (at the moment $x_{i,j}$) on the resource R_k only if the preceding operation has been completed (at the moment $before(X_i, x_{i,j}) + before(T_i, t_{i,j}) + \gamma(x_{i,j})))$ and the next operation from the process P_l preceding P_i starts its execution (at the moment $a(x_{i,j}) + 1 + \beta(x_{i,j}))$ on the resource $R_q = after(p_1, R_k)$. The constraints allow concurrent execution of processes awaiting each other for releasing (Bocewicz et al. 2007). Moreover, similarly to the already considered case (Bocewicz et al. 2007) they guarantee the deadlock-free (i.e. cyclic) processes execution (see Sect. 3).

Due to our assumptions **the system's cyclic behavior** encompasses itself through values of decision variables X, guaranteeing its periodicity $Tc : x_{i,j}(k+1) - x_{i,j}(k) = Tc, i = 1, \ldots, n, j = 1, \ldots, lr(i); \forall k \in \mathbb{Z}$. So, the parameters determining the CCPS's cyclic behavior such as X and Tc can be found as solution to the problem (3), i.e. as values of decision variables following the set of constraints C (4), determining the CCPS's structure (1).

2.3 CSP: Reference Model

A CCPS can be seen as a composition of subsystems (also belonging to the class of CCPSs) in particularly as a composition of elementary (local) cyclic processes. For instance, the CCPS from Fig. 2 consists of three elementary cyclic processes, each one determined by the transportation route composed of operations executed on three resources. Of course, the CCPS considered can be seen as a part of the large one, see Fig. 3.

Moreover, the structural composition of the CCPS can be easily encompassed by the structure of constraint satisfaction problems (3), i.e. each particular CSP can be seen as a composition of a set of sub-problems each one modeling the corresponding CCPS component.

In general case, the problem CS (3) corresponding to the CCPS can be seen as the problem $CS^{(i)}$ obtained in the consequence of the i-th compositions of the elementary CCPS (see Figs. 3 and 4):

$$CS^{(i)} = \varphi\left(CS^{(i-1)}, CS^{(i)}_{join}\right), i > 1, \tag{5}$$

where: $CS^{(1)} = CS^{1}_{join}$,

$CS^{(i)}_{join}$—constraints satisfaction problem (3), representing a joined structure $SC^{(i)}_{join}$ (1), where each $CS^{(i)}_{join}$ belongs to the set $CS_{join} = \{CS^{(1)}_{join}, CS^{(2)}_{join}, \ldots, CS^{(n)}_{join}\}$
$CS^{(i)}$—constraints satisfaction problem (3), can be seen as corresponding to the structure $SC^{(i)}$(1) obtained by composition of the i structures kind of CS_{join},
φ—composition function of constraints satisfaction problems CS (3) (see Fig. 5),
IF: $CS^A = ((V^A, D^A), C^A), CS^B = ((V^B, D^B), C^B), CS^C = ((V^C, D^C), C^C)$,
AND: $CS^A = \varphi(CS^B, CS^C)$
THEN: $V^A = V^B \cup V^C, D^A = D^B \cup D^C, C^A = \left(C^B \backslash C^B_W\right) \cup \left(C^C \backslash C^C_W\right) \cup C^{(A)}$

where:

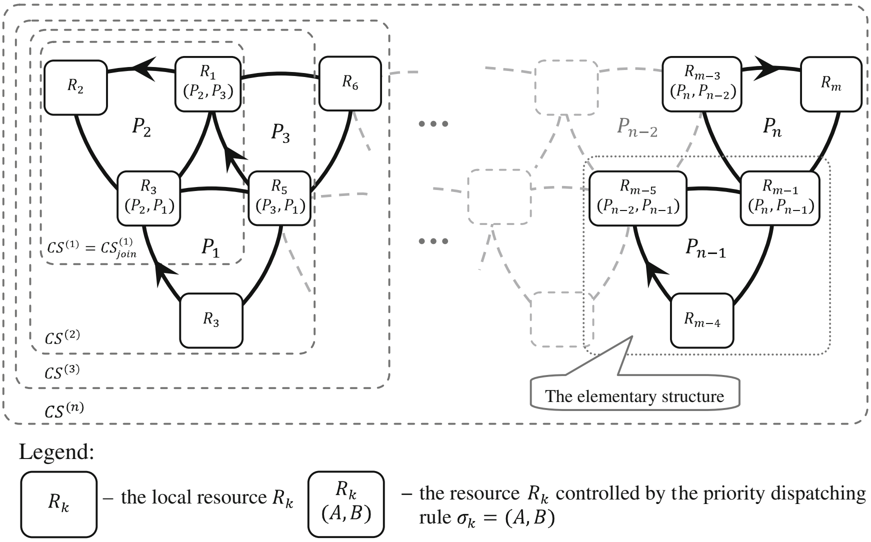

Fig. 3 Illustration of the recurrent structure composition of the CCPS from Fig. 2

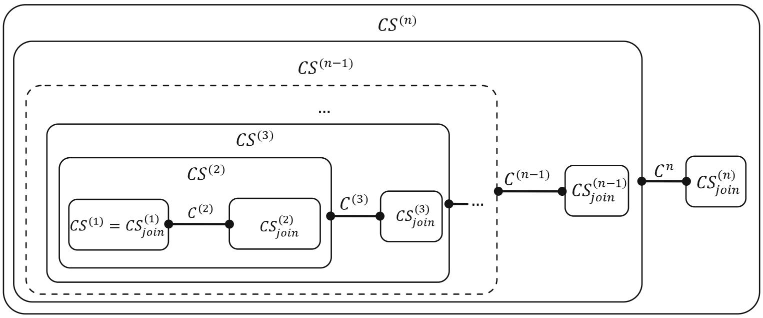

Fig. 4 The CSP reference model following CCPS from Fig. 3

C_W^B—subset of constraints C^B determining the moments of operations beginning on unified resources, i.e. resources joining component transportation routes (e.g. resource R_1 from Fig. 5),

C_W^C —subset of constraints C^C determining the moments of operation beginning on unified resources (e.g. resource R_1 from Fig. 5),

$C^{(A)}$—subset of constraints (4) determining the moments of operations ($x_{1,1}$, $x_{2,1}$ from Fig. 5) beginning on unified resources (e.g. resource R_1 from Fig. 5), **due to the assumed priority rule** (priority rule σ_1 from Fig. 5).

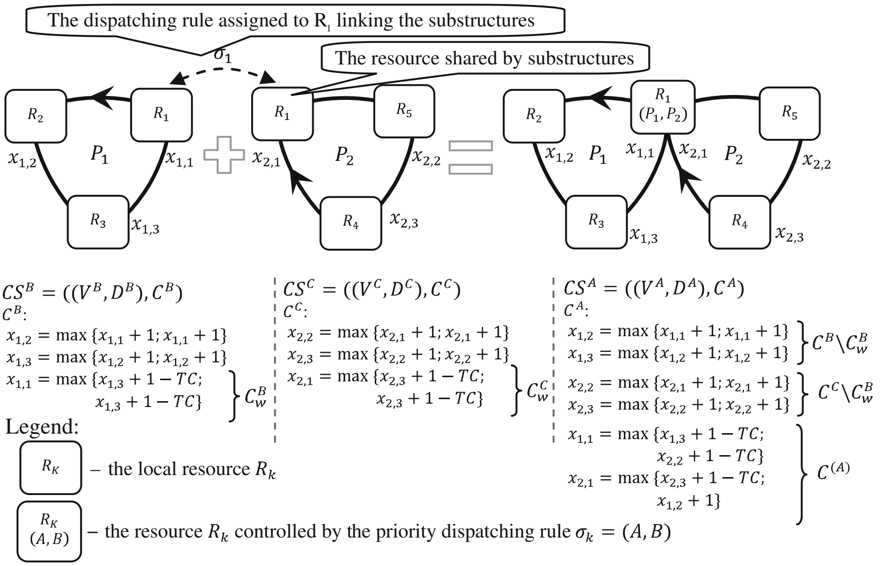

Fig. 5 Illustration of structures CS^B, CS^C joining

In general case the structures composed can be the same: $CS^*_{join} = CS^{(1)}_{join} = CS^{(2)}_{join} = \ldots = CS^{(n)}_{join}$. Such illustration provides Figs. 1 and 3 where systems' structures are composed of the same components—each one containing three operations executed on three resources.

Composition of CSP corresponding to component CCPS play a key role in evaluation of possible cyclic behavior of systems composed of a given set of CCPSs.

2.4 Problem Statement

Consider a CCPS specified by a given set of dispatching rules and initial processes allocation. The main question concerns of CCPS periodicity. In case it behaves periodically the next question regards of the CCPS's period. Other questions regard of admissible initial processes allocation (i.e. the possible AGV dockings), and the dispatching rules guaranteeing a given CCPS periodicity while preserving assumed frequency of local processes execution within a global period Tc. In the general case two kinds of problems can be considered.

- **Forward problem** statement where for a given CCPS structure the cyclic behavior is sought:

PS.1

Given is : SC (structure of CCPS) described by CS (3).
Question: Does there exist a cyclic behavior of SC?

Taking into account a structural character of the CCPS's reference model the problem considered can be extended to the following one:

PS.2

Given are : $SC^{(i-1)}$ described by $CS^{(i-1)}$ and $SC_{join}^{(i)}$ described by $CS_{join}^{(i)}$ (representing two different CCPSs), and the cyclic behaviors following these structures.

Question: Does there exist a cyclic behavior of $SC^{(i)}$ composed of $SC^{(i-1)}$ and $SC_{join}^{(i)}$?

- **Backward Problem** statement where for a given cyclic behavior the structural parameters of the CCPS guaranteeing such behavior are sought:

PR.1

Given is: a cyclic behavior determined by the variable X and/or Tc.
Question: Does there exist SC which guarantees a given behavior is achievable?

Particular instance of CCPS backward formulation (for the sake of further considerations treated as reference one) can be defined as follows:

PR.2

Given are: $SC^{(i-1)}$ described by $CS^{(i-1)}$ and $SC_{join}^{(i)}$ described by $CS_{join}^{(i)}$ (and representing two different CCPSs), and characterizing them cyclic behaviors.

Question: Does there exist the set of priority dispatching rules Θ linking $SC^{(i-1)}$ with $SC_{join}^{(i)}$which guarantees $SC^{(i)}$ periodicity?

Both kind of problems i.e., the forward and backward one can be formulated in terms of CSPs (3), (5) and then implemented in constraints programming languages. Depending on actually considered kind of problem the relevant set of decision variables are taken into account: X, Tc for forward problem formulation, and R, Π, T, Θ for backward problem formulation. The rest of decision variables are included in the set of constraints. So, the problems considered can be defined as follows:

- forward formulation of the CSP problem:

$$CS_{PS} = ((\{X, Tc\}, \{D_X, D_{TC}\}), C) \tag{6}$$

- backward formulation of the CSP problem:

$$CS_{PR} = ((\{R, \Pi, T, \Theta\}, \{D_R, D_\Pi, D_T, D_\Theta\}), C) \tag{7}$$

Above stated problems can be implemented and then resolved in constraint programming environment.

3 AGVS Schedulability

Besides of possible cyclic behaviors specified by variables X, Tc, where a number of operations executed in a cycle is determined by components of X, the transient and deadlock states can be observed in a CCPS. Because the CSP reference model introduced does not allow considering the transient as well as the deadlock behaviors the concept of CCPS's state space is introduced. Moreover, in general case for a given SC and the same priority dispatching rules the different cyclic behaviors (e.g., differing in a number of local processes execution per cycle) can be observed. That means, however, the solution to the relevant problem CS_{PS} (6) do not take it into account at all.

3.1 State Space

Consider **the *k*-th state** S^k (8) composed of the sequence of processes allocation A^k, the sequence of semaphores (encompassing the rights of process's guaranteeing their access to a resource) Z^k, and the sequence of semaphore indices Q^k:

$$S^k = \left(A^k, Z^k, Q^k\right) \tag{8}$$

where:

$A^k = \left(a_1^k, a_2^k, \ldots, a_m^k\right)$ **—the processes allocation** (m—a number of CCPS resources), $a_i^k \in P \cup \{\triangle\}$ (P—a set of processes: $P = \{P_1, P_2, \ldots, P_n\}$) means the process is allotted to the i-th resource R_1 in the k-th state, $a_i^k = P_g$ means, the i-th resource R_i is occupied by the process P_g, and $a_i^k = \triangle$—the i-th resource R_i is unoccupied. In the case considered (see Fig. 2) the processes allocation is specified by the sequence: $A^o = (\triangle, \triangle, P_2, P_1, \triangle, P_3)$.

$Z^k = \left(Z_1^k, Z_2^k, \ldots, Z_m^k\right)$ **—the sequence of semaphores** corresponding to the k-th state, where $z_i^k \in P$ means the name of the process (specified in the i-th dispatching rule σ_i allocated to the i-th resource) allowed to occupy the i-th resource R_i. For instance, $z_i^k = P_g$ means that at the moment the process P_g is allowed to occupy the i-th resource R_i. For the CCPS from Fig. 2 the sequence of semaphores has the following form: $Z^{\text{o}} = (P_2, P_2, P_2, P_1, P_3, P_3)$.

$Q^k = \left(q_1^k, q_2^k, \ldots, q_m^k\right)$—**the sequence of semaphore indices** corresponding to the k-th state, where q_i^k means the position of the semaphore z_i^k in the priority dispatching rule σ_i: $z_i^k = crd_{\left(q_i^k\right)}\sigma_i$, $q_i^k \in \mathbb{N}$ $(crd_i D = d_i$, for $D = (d_1, \ldots d_i, \ldots, d_w)$. For instance, $q_2^k = 2$means the value of the semaphore z_2^k is placed at the 2nd position in the priority dispatching rule σ_2. For the CCPS from Fig. 2 the sequence of semaphores Z has the following form: $Q^{\text{o}} = (1, 1, 1, 1, 1, 1)$.

The state $S^k = \left(A^k, Z^k, Q^k\right)$ is feasible only if for any of its a_i^k co-ordinate $A^k = \left(a_1^k, a_2^k, \ldots, a_m^k\right)$ the following conditions hold:

(i)
$$\forall_{i \in \{1,2,\ldots,n\}} \exists!_{j \in \{1,2,\ldots,m\}} \left(P_i = crd_j A^k\right) \tag{9}$$

(ii)
$$\forall_{i \in \{1,2,\ldots,m\}} \left(crd_i A^k \in P \cup \{\triangle\}\right) \tag{10}$$

(iii) if the values of the semaphore Z^k and **the sequence of semaphore indices** Q^k result from allocation (9), (10) (i.e., semaphores determining busy resources show the processes allotted to them, while indexes show semaphore values).

The set of all feasible states is called **a state space** $\mathbb{S}$. Consider two feasible states $S^k, S^l \in \mathbb{S}$:

$$S^K = \left(\left(a_1^k, a_2^k, \ldots, a_m^k\right), \left(z_1^k, z_2^k, \ldots, z_m^k\right), \left(q_1^k, q_2^k, \ldots, q_m^k\right)\right) \tag{11}$$

$$S^l = \left(\left(a_1^l, a_2^l, \ldots, a_m^l\right), \left(z_1^l, z_2^l, \ldots, z_m^l\right), \left(q_1^l, q_2^l, \ldots, q_m^l\right)\right) \tag{12}$$

The state $\boldsymbol{S^l}$ is directly reachable from the state $\boldsymbol{S^k}$ if the following conditions hold (Bocewicz et al. 2011):

$$\forall_{i \in \{1,2,\ldots,m\}} \forall_{j \in \{1,2,\ldots,n\}} [(a_i^k = \varDelta) \wedge (a_{\beta_i(P_j)}^k = z_i^k) \Rightarrow (a_i^l = z_i^k)] \tag{13}$$

$$\forall_{i \in \{1,2,\ldots,m\}} \forall_{j \in \{1,2,\ldots,n\}} [(a_i^k = \Delta) \wedge (a_{\beta_i(P_j)}^k \neq z_i^k) \Rightarrow (a_i^l \neq p_j)] \tag{14}$$

$$\forall_{i \in \{1,2,\ldots,m\}} [(a_i^k = \Delta) \Rightarrow [(z_i^l = z_i^k) \wedge (q_i^l = q_i^k)]] \tag{15}$$

$$\forall_{i \in \{1,2,\ldots,m\}} [(a_i^k \neq \Delta) \wedge (a_i^l \neq \triangle) \Rightarrow [(z_i^l = z_i^k) \wedge (a_i^l = a_i^k) \wedge (q_i^l = q_i^k)]] \tag{16}$$

$$\forall_{i \in \{1,2,\ldots,m\}} [(a_i^k \neq \Delta) \wedge (a_i^l = \triangle) \Rightarrow [(z_i^l = crd_{(q_i^l)}\sigma_i) \wedge (q_i^l = \gamma(q_i^k))]] \tag{17}$$

$$\forall_{i \in \{1,2,\ldots,m\}} [(a_i^k \neq \Delta) \wedge (z_{\alpha_i(a_i^k)}^k = a_i^k) \Rightarrow (a_{\alpha_i(a_i^k)}^l = a_i^k) \wedge (a_i^l = \triangle)] \tag{18}$$

$$\forall_{i \in \{1,2,\ldots,m\}} [(a_i^k \neq \Delta) \wedge (z_{\alpha_i(a_i^k)}^k \neq a_i^k) \Rightarrow [(a_i^l = a_i^k) \wedge (q_i^l = q_i^k)]] \tag{19}$$

where:
m —a number of resources, n—a number of processes,

$\beta_i(P_j)$—the index of resource directly proceeding the resource R_i in the j-th process route p_j, $\beta_i(P_j) \in \{1, 2, \ldots, m\}$,

$\alpha_i(P_j)$—the index of resource directly succeeding the resource R_i, in the j-th process route $p_j, \alpha_i(P_j) \in \{1, 2, \ldots, m\}$,

$\gamma_i(q_i^k)$—the function defined by (20):

$$\gamma_i(a) = \begin{cases} a+1 & for\ a < lp(i) \\ 1 & for\ a = lp(i) \end{cases} \tag{20}$$

where: $lp(i)$—the number of processes dispatched by the rule σ_i.

The conditions (13–19) determining the assumed CCPS functioning can be interpreted as follows:

- the i-th resource released in the successive state S^l can be occupied by awaiting him process only if in a current state S^k the priority dispatching rule associated to the resource indicates this process, else remains released (13, 14),
- if in the successive state S^l the i-th resource's allocation remains unchanged, then the semaphore values and relevant indices remains unchanged too (15, 16, 19),
- if in the state S^k the i-th resource has been released by the process, then in the state S^l the same process starts its next operation (due to the transportation route) and the i-th resource semaphore indicates succeeding (following dispatching priority rules) process (17, 18).

Feasibility of the state S^l means that there is the state S^k such that S^l is directly reachable from S^l, that is denoted by: $S^k \to S^l$. In general case, the states S^k and S^l can be linked by other states, e.g. S^r, S^w what leads to the following sequence of transitions: $S^k \to S^r \to S^w \to S^l$, $S^k \xrightarrow{i} S^l$ in short, where: i—means the number of states S^r, S^w linking S^k, S^l, e.g., in case consider $S^k \xrightarrow{2} S^l$, and $S^k \xrightarrow{0} S^r$.

In general case, however, some states $S^k \in \mathbb{S}$ have not their successors, so **the deadlock state** S^k (denoted in the rest of the chapter by S^*) is defined as the state such that does not exist any feasible state $S^l \in \mathbb{S}$, following the transition $S^k \to S^l$. In other words, the deadlock state means the all processes in the CCPS are suspended.

Consider the CCPS and its state space $\mathbb{S}$ composed of the set of all feasible states defined by (8). For a given an initial state $S^0 \in \mathbb{S}$ the following CCPS behaviors are considered:

- if there exists the set of states Su^*, $((Su^* \subset \mathbb{S}))$ such that there exists the chain of transitions $S^0 \xrightarrow{i} S^k$ (called **the transient state leading to the deadlock state**), then the state S^0 results in the CCPS deadlock state while following the transition (21):

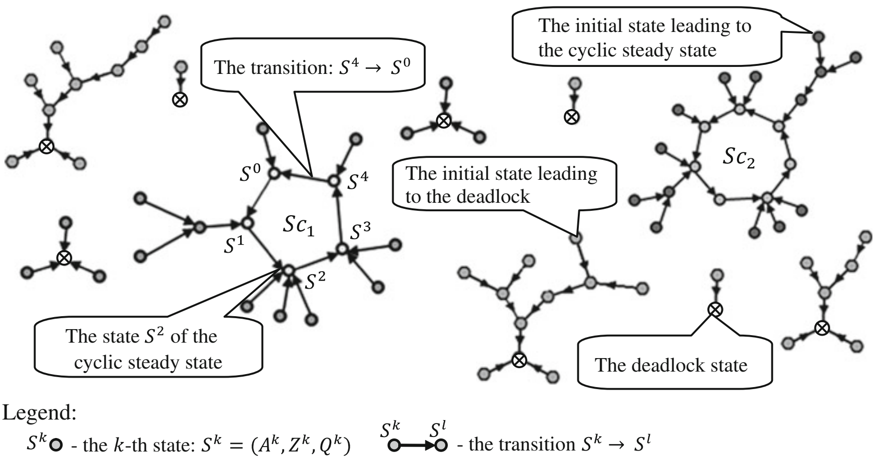

Fig. 6 The state space of the CCPS from Fig. 1 following dispatching rules: $\sigma_1 = (P_2, P_3), \sigma_3 = (P_2, P_1), \sigma_5 = (P_3, P_1)$ and assumption the all operation times are the same and equal to 1 unit of time

$$S^0 \xrightarrow{i} S^k \rightarrow S^*, i \geq 0, \tag{21}$$

- if there exists the set of states Su $((Su \subset \mathbb{S}))$ such that exists the chain of transitions $S^0 \xrightarrow{i} S^k$ (called **the transient state leading to the cyclic steady state**) then the state S^0 results in the CCPS cyclic state while following the transition (22):

$$S^o \xrightarrow{i} S^k \xrightarrow{Tc-1} S^k, i \geq 0, Tc \geq 2, \tag{22}$$

In other words a cyclic steady state Sc consists of the set of states starting from which it is possible to reach the rest of states and finally reach this distinguished states again. Each cyclic steady state is specified by so called period of the cyclic steady state Tc.

A cyclic steady state period $\boldsymbol{Tc}$ is defined as follows: $Tc = \|Sc\|$. Of course, for any $S^a \in Sc$ the following property holds: $S^a \xrightarrow{Tc-1} S^a$.

The graphical illustration of the state space (containing the cyclic steady states, and deadlock states as well as leading to them transient states) generated by the system from Fig. 1 is shown in Fig. 6. There are two cyclic steady states periodicity of which are equal to 5 (in case of Sc_1) and 7 (in case of Sc_2), respectively.

Note, that searching for the CCPS cyclic behavior, i.e. a searching for the problem PS.1 (see Sect. 2.4) solution, can be seen as the searching for a cyclic steady state Sc while assuming that the SC structure and a set of initial states are given. So, assuming the given set SS of admissible cyclic steady states Sc seen as potential solutions, the already introduced concept of Sc (1) structure can be extended as follows (23):

$$SSC = (R, \Pi, T, \Theta, SS, \delta) \tag{23}$$

So, the SSC specifies the CCPS through parameters characterizing its structure R, Π, T, Θ and behavior SS as well as the rules determining the processes execution δ (i.e. the next state function $S^l = \delta(S^k)$defining transitions $S^K \longrightarrow S^l$ following conditions (13–19)). Consequently, the six-tuple (23) can be seen as determining the structure and behavior of the CCPS.

3.2 Operations Precedence Digraph

Let us consider **the operations precedence digraph** G_1 associated with the cyclic steady state Sc_1 (see Fig. 6) shown in Fig. 7a. States from the cyclic steady state Fig. 7a, correspond to the prisms stages in operations precedence digraph (see Fig. 7b). Each the triangular basis build prism corresponds to the local cyclic processes P_i. The circles (seen as digraph vertices) in each prism distinguish the beginning of the particular operations in the considered local process. In turn the length of arcs linking subsequent (following the time axis) vertices determines the number of unit times the relevant resource (associated to the vertex of the triangle base prism) is occupied by the particular local process. Of course, the order of arcs in the digraph path follows the local transportation route determining the resources order.

Besides the arcs encompassing the local cyclic processes activities there are ones linking vertices belonging to different prisms. This kind of arcs describes the operations precedence order following the priority dispatching rules, i.e., the arc's arrow points the vertex associated to the beginning moment of the successive (due to the dispatching priority rule) operation. For instance, the variable $x_{1,2}(k)$= 2 (see the vertex $x_{1,2}(k)$ placed on the level 2, in Fig. 7b), is greater than $x_{1,1}(k) = 0$ because the operation $o_{1,2}$ follows $o_{1,1}$ in the route p_1; moreover $x_{2,2}(k) = 1 < x_{1,2}(k) = 2$ because due to the priority dispatching rule σ_3 the operation $o_{1,2}$ executed by the process P_1 can be realized after the resource occupied by the process P_2 can be release, i.e., after the operation $o_{2,2}$ beginning.

The considered acyclic digraph G_1 consists of infinite amount of vertices which allocation (taking into account prisms corresponding to local processes) encompass the execution of succeeding cyclic steady states.

In the case considered there are following states of the Sc_1 (Fig. 7a):

$$\ldots \rightarrow S^0 \rightarrow S^1 \rightarrow S^2 \rightarrow S^3 \rightarrow S^4 \rightarrow S^0 \rightarrow \ldots$$

corresponding to execution of operations:

$$\rightarrow (o_{1,3}, o_{3,1}) \rightarrow (o_{1,1}, o_{2,1}) \rightarrow (o_{2,2}, o_{3,2}) \rightarrow (o_{2,3}, o_{1,2}) \rightarrow (o_{3,3}) \rightarrow (o_{1,3}, o_{3,1}) \rightarrow$$

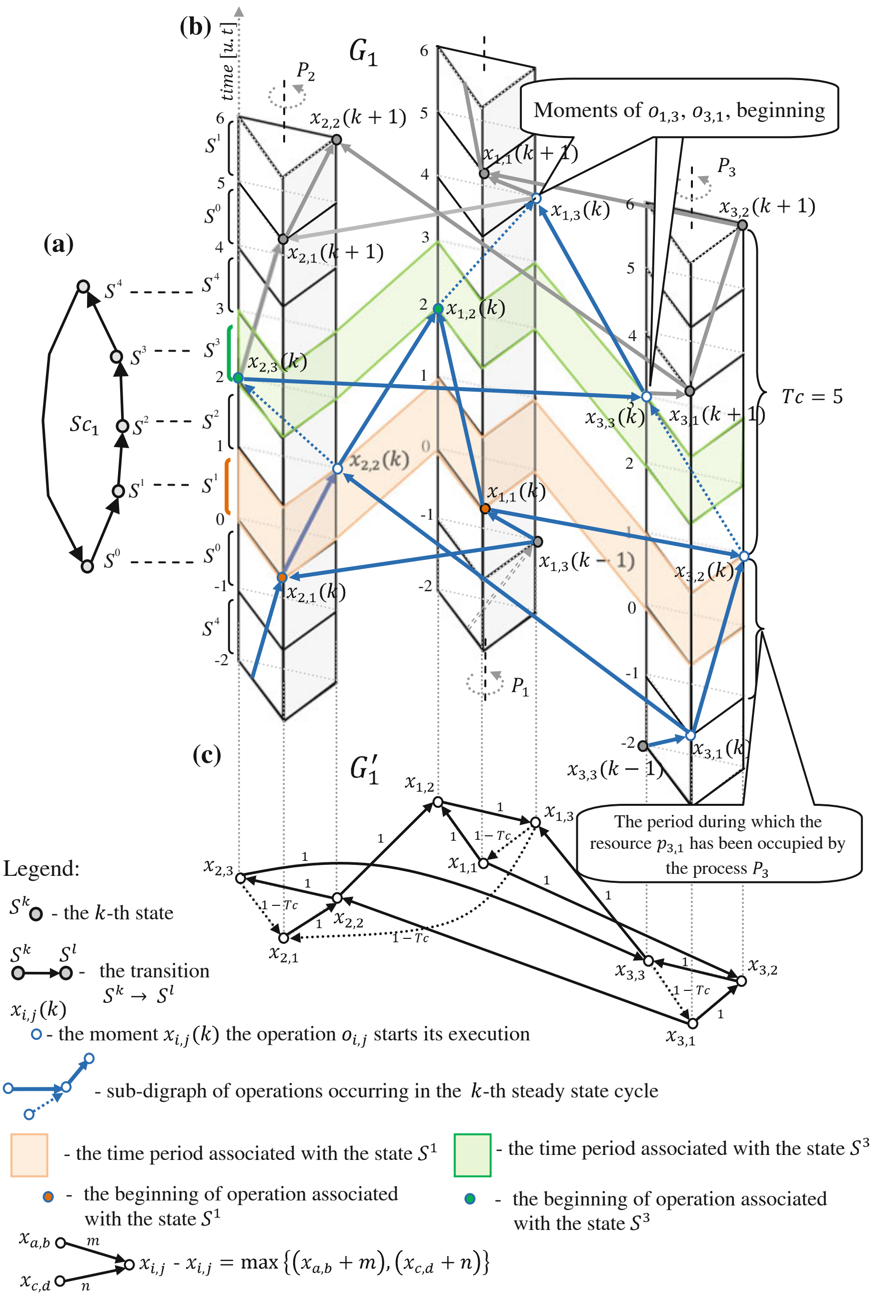

Fig. 7 The cyclic steady state of the CCPS following the dispatching rules: $\sigma_1 = (P_2, P_3), \sigma_3 = (P_2, P_1), \sigma_5 = (P_3, P_1)$ (**a**) the operations precedence digraph associated with Sc_1 (**b**), the digraph's projection on the plane (**c**)

Table 1 The moments of operations beginning corresponding to the states of cyclic steady state Sc_1

States	S^0	S^1	S^2	S^3	S^4
Operations	$(o_{1,3}, o_{3,1})$	$(o_{1,1}, o_{2,1})$	$(o_{2,2}, o_{3,2})$	$(o_{2,3}, o_{1,2})$	$(o_{3,3})$
Start moments	–1	0	1	2	3
	4	5	6	7	8
	9	10	11	12	13
	…				

Where, to each of the i-th state S^i corresponds the n-tuple $\left(o_{a,b,}, \ldots, o_{c,d}\right)$ describing the operations have been started in the period of time defining the state considered. For instance, by gray color (▨) the space associated to the state S^1 is distinguished; see Fig. 7b). In turn, within the following period of time $(0, 1)$ associated to that state operations $o_{1,1}$, $o_{2,1}$ can start (moments of operations beginning, distinguished by pink color, are: $x_{1,1} = x_{2,1} = 0$). By analogy, the following pair $\left(o_{2,3}, o_{1,2}\right)$ corresponds to the state S^3 (distinguished by $\circ$).

It means, every cyclic steady state Sc can be described by the set of operations sequences and corresponding set of moments of operation beginnings. Such moments are shown in the Table 1, where in each column, the relevant operations and associated to them possible moments of beginning following the state in successive cycles are shown.

The values corresponding to vertices in the digraph G_1, describe the moments of operations beginning, for instance $x_{2,2}(k)$ and $x_{3,2}(k)$ mean the moments of concurrent operations $o_{2,2}, o_{3,2}$ beginning are always equal in successive cycles: k, $k+1$, $k+2$, …, i.e., 1, 6, 11, … . That is because each operation is repeated within the same period equal to 5 units of time. So, the digraph vertices are ordered due to the moments $x_{i,j}(k)$ the operations $o_{i,j}$ start their execution, i.e., the moments determined by the relation *max* (24):

$$x_C(k) = max\{x_B(k) + 1; x_A(k) + 1\} \tag{24}$$

where: $x_A(k)$, $x_B(k)$, $x_C(k)$—the values labeling vertices of the operations precedence digraph, and $x_A(k)$, $x_B(k)$are predecessors of $x_C(k)$.

The Table 2 (see the first column) presents the illustration of the constraints (24) following the case of the digraph G_1, see Fig. 7b. The constraints enable to determine the moments of beginning of any operation $o_{i,j}$ in any cycle k. Due to the assumption from the Sect. 2.2 $x_{i,j}(k) = x_{i,j} + k \cdot Tc$, $k \in \mathbb{Z}$, the constraints can be simplified to the formulas linking only the values $x_{i,j}$, i.e. releasing from recurrent dependence on k. The new constraints are shown in the second column of the Table 2.

Note that newly obtained constraints describe the precedence relation in the digraph G_1' **being the projection of the digraph** G_1 **on the plane** (see Fig. 7c). That means the values $x_{i,j}$ allow one to determine $x_{i,j}(k)$ and then the relevant operations precedence digraph G_1. Constraints from the Table 2 follow conditions

Table 2 The sets of constraints following digraphs G_1, G'_1

Constraints determining the moments $x_{i,j}(k)$ of operations beginning for the operations precedence digraph G_1 (Fig. 7b)	Constraints determining the moments $x_{i,j}$ of operations beginning for the digraph G'_1 (Fig. 7c)
$x_{1,1}(k) = \max\{x_{1,3}(k-1)+1; x_{1,3}(k-1)+1\}$	$x_{1,1} = \max\{x_{1,3}+1-Tc; x_{1,3}+1-Tc\}$
$x_{1,2}(k) = \max\{x_{1,1}(k)+1; x_{2,2}(k)+1\}$	$x_{1,2} = \max\{x_{1,1}+1; x_{2,2}+1\}$
$x_{1,3}(k) = \max\{x_{1,2}(k)+1; x_{3,3}(k)+1\}$	$x_{1,3} = \max\{x_{1,2}+1; x_{3,3}+1\}$
$x_{2,1}(k) = \max\{x_{2,3}(k-1)+1; x_{1,3}(k-1)+1\}$	$x_{2,1} = \max\{x_{2,3}+1-Tc; x_{1,3}+1-Tc\}$
$x_{2,2}(k) = \max\{x_{2,1}(k)+1; x_{3,1}(k)+1\}$	$x_{2,2} = \max\{x_{2,1}+1; x_{3,1}+1\}$
$x_{2,3}(k) = \max\{x_{2,2}(k)+1; x_{2,2}(k)+1\}$	$x_{2,3} = \max\{x_{2,2}+1; x_{2,2}+1\}$
$x_{3,1}(k) = \max\{x_{3,3}(k-1)+1; x_{3,3}(k-1)+1\}$	$x_{3,1} = \max\{x_{3,3}+1-Tc; x_{3,3}+1-Tc\}$
$x_{3,2}(k) = \max\{x_{3,1}(k)+1; x_{1,1}(k)+1\}$	$x_{3,2} = \max\{x_{3,1}+1; x_{1,1}+1\}$
$x_{3,3}(k) = \max\{x_{2,3}(k-1)+1; x_{3,2}(k)+1\}$	$x_{3,3} = \max\{x_{2,3}+1-Tc; x_{3,2}+1\}$

(4) determining the constraint satisfaction problem CS (3), and particularly CS_{PS} (6).

Property 1 *If digraph G' is the projection of the operations precedence digraph G where vertices $x_{i,j}(k)$ follow the constraints* (24), *then the vertices $x_{i,j}$ of the digraph G' also follow the constraints* (24) *while assuming $x_{i,j}(k) = x_{i,j} + k \cdot Tc$ holds.* □

The above considerations can be summarized as follows:

- to any cyclic steady state Sc in the space $\mathbb{S}$ corresponds the operations precedence digraph G,
- vertices of the operations precedence digraph G, determine the moments $x_{i,j}(k)$ of operations $o_{i,j}$ beginning in the CCPS
- to any precedence digraph G, corresponds the digraph G' determining the values $x_{i,j}$,
- the digraph G' can be considered as a graphical representation of the CS_{PS} (6).

In other words it means that to each cyclic steady state Sc corresponds CS_{PS} solution to which determines the digraph G' and consequently the digraph G. That can be show finally, that analysis of the digraph G can be useful for deadlock evaluation of the CCPS behavior.

3.3 Deadlock Avoidance Constraints

Consider the CCPS as shown in Fig. 8a. The system differs from the one shown in Fig. 1 by assuming changed orientation of the local process P_3 and reversed formulation of dispatching priority rules σ_1 and σ_5. An initial processes allocation

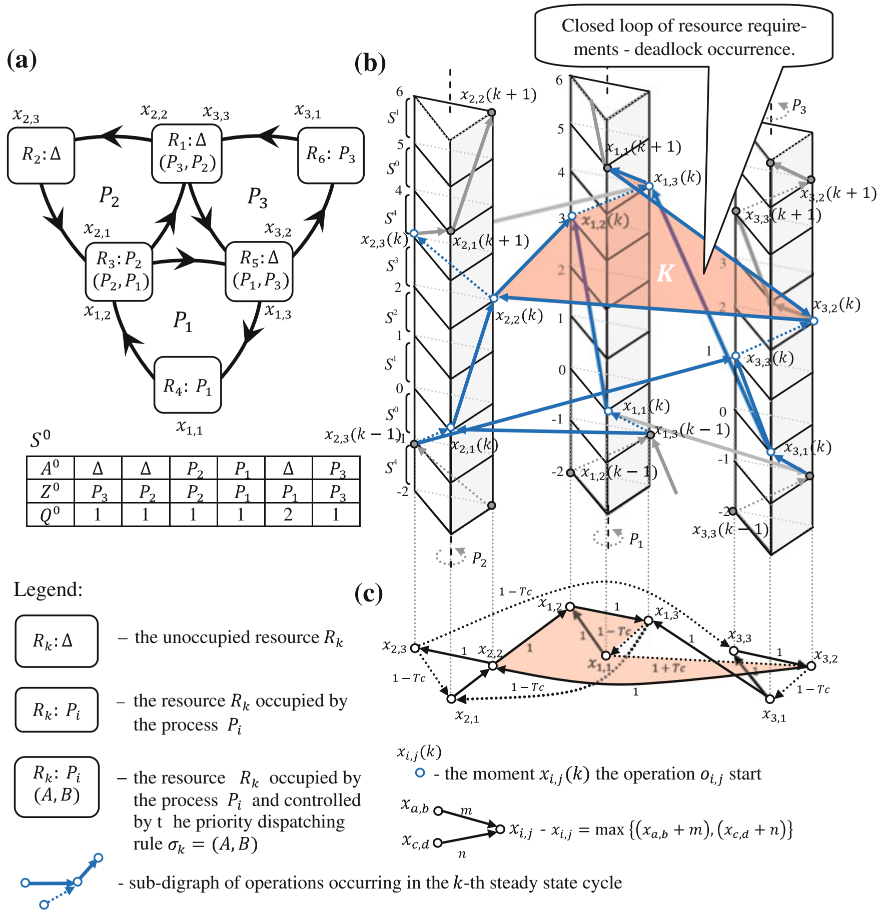

Fig. 8 The CCPS following dispatching rules: $\sigma_1 = (P_3, P_2)$, $\sigma_3 = (P_2, P_1)$, $\sigma_5 = (P_1, P_3)$ and the initial state S^0(**a**), the operations precedence digraph corresponding to a deadlock state occurrence (**b**), the projection of the operations precedence digraph on the plane (**c**)

A^o is the same as in the case show in Fig. 1, and values of semaphores Z^o indicate the first elements specified in assumed dispatching rules. Note that system is not deadlock-free (Bocewicz et al. 2007).

Let us note the arcs within the zone K (distinguished by gray), and distinguished by blue line arcs create contours in the operations precedence digraph G encompassing the CCPS behavior, see Fig. 8b.

In case the one of the contours become a cycle, e.g., $x_{2,2}(k)$, $x_{1,2}(k)$, $x_{1,3}(k)$, $x_{1,1}(k+1)$, $x_{3,2}(k)$, $x_{3,2}(k)$, (see Fig. 8b) it can be proved that relevant initial state, e.g., S^o, leads to a deadlock. It means the operations precedence digraph G consists of cycles encompassing the deadlock occurrence in the CCPS behavior.

Property 2 *If the operations precedence digraph G is acyclic, then the cyclic steady state Sc there exists, i.e., the CCPS behavior is deadlock-free.* □

Property 3 *The operations precedence digraph G is acyclic only if the digraph G' does not contain any cycle including at least one vertex labeled by value does not following the condition* $x_C(k) = max\{x_B(k) + 1;\ x_A(k) + 1\}$ *(24) (where*: $x_{i,j}(k) = x_{i,j} + k \cdot Tc$). □

That means the cycle's occurrence in the digraph G imply the cycle's occurrence in the digraph G' (see Fig. 8c). In turn, the vertices included in the cycles (observed in the digraph G') and leading to the deadlocks occurrence are labeled by values $x_{(i,j)}$ do not following the constraints (24).

Property 4 *The digraph G' does not contain any cycle (i.e., vertices of which do not follow constraints (24)), only if there exist a solution to the CS_{PS} (6) following the SC.* □

That means in case a solution to the problem CS_{PS} (6) does not exist (i.e. the constraints C are contradictory ones) the CCPS modeled by the SC is free of any cyclic behavior. In other words, in case the solution to the CS_{PS} (6) there exists, then the CCPS behavior is deadlock-free.

In case of the CCPS from the Fig. 8a the following set of contradictory constraints is considered:

$$\begin{aligned}
&x_{1,1} = \max\{x_{1,3} + 1 - Tc; x_{1,3} + 1 - Tc\}, x_{1,2} = \max\{x_{1,1} + 1; x_{2,2} + 1\},\\
&x_{1,3} = \max\{x_{1,2} + 1; x_{3,1} + 1\}, x_{2,1} = \max\{x_{2,3} + 1 - Tc; x_{1,3} + 1 - Tc\},\\
&x_{2,2} = \max\{x_{2,1} + 1; x_{3,2} + 1\}, x_{2,3} = \max\{x_{2,2} + 1; x_{2,2} + 1\};\\
&x_{3,1} = \max\{x_{3,2} + 1 - Tc; x_{3,2} + 1 - Tc\}, x_{3,2} = \max\{x_{3,3} + 1; x_{1,1} + 1 + Tc\},\\
&x_{3,3} = \max\{x_{2,3} + 1 - Tc; x_{3,1} + 1\}.
\end{aligned}$$

4 Illustrative Example

4.1 AGVS Redeveloping

Given an FMS of the structure depicted in the Fig. 1. Consider the processes P_2, corresponding to an AGV. The relevant $AGVS_1$ is modeled by the CCPS shown in Fig. 9a. This kind of the CCPS can be seen as an elementary structure $SC_{join}^{(1)}$, which could be then extended to the CCPS from Fig. 2 by adding the same succeeding elementary structure. The relevant $CS_{join}^{(1)}$ (3) corresponding to this structure can be stated as (25):

$$CS_{join}^{(1)} = ((\{R, \Pi, T, \Theta, X_1, Tc\}, \{D_R, D_\Pi, D_T, D_\Theta, D_X, D_{Tc}\}), C_1) \tag{25}$$

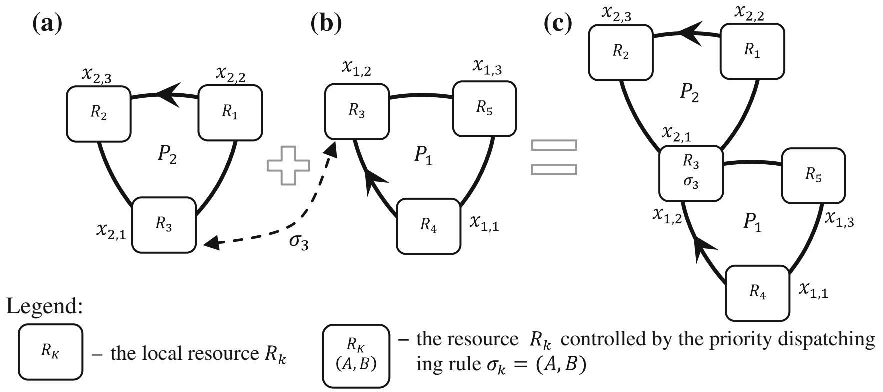

Fig. 9 An illustration of CCPS redeveloping: components (**a**), (**b**), the final structure (**c**)

where decision variables X_1 are following ones:

$$X_1 = \left(x_{1,1}, x_{1,2}, x_{1,3}\right)$$

and the set of constraints C_1 consists:

$$x_{1,1} = \max\{x_{1,3} + 1 - Tc; x_{1,3} + 1 - Tc\}, x_{1,2} = \max\{x_{1,1} + 1; x_{1,1} + 1\}, x_{1,3} = \max\{x_{1,2} + 1; x_{1,2} + 1\}.$$

Assume the AGVS_1 considered has to be modernized by adding extra AGV, i.e. AGVS_2 (see Fig. 9b). The added structure $SC^{(2)}_{join}$ corresponds to the problem $CS^{(2)}_{join}$ specified as below (26):

$$CS^{(2)}_{join} = ((\{R, \Pi, T, \Theta, X_2, Tc\}, \{D_R, D_\Pi, D_T, D_\Theta, D_X, D_{Tc}\}), C_2) \tag{26}$$

where decision variables X_2 are as follows:

$$X_2 = \left(x_{2,1}, x_{2,2}, x_{2,3}\right)$$

and the set of constraints C_2:

$$x_{2,1} = \max\{x_{2,3} + 1 - Tc; x_{2,3} + 1 - Tc\}, x_{2,2} = \max\{x_{2,1} + 1; x_{2,1} + 1\}, x_{2,3} = \max\{x_{2,2} + 1; x_{2,2} + 1\}.$$

The AGVS_1 and AGVS_2 have to be connected by common shared resource R_3. The desirable structure $SC^{(2)}$ is shown in the Fig. 9c. So, in the context of the given structures $SC^{(1)}_{join}$, $SC^{(2)}_{join}$ the following question can be stated: Does there exist the priority dispatching rule σ_3 associated to the resource R_3 linking $SC^{(1)}_{join}$ with $SC^{(2)}_{join}$ which guarantee a cyclic behavior of $SC^{(2)}$? This question determines a

Table 3 The moments of operations beginning for $SC^{(2)}$

Start moments	$x_{1,1}, x_{2,1}$	$x_{2,2}$	$x_{1,2}, x_{2,3}$	$x_{1,3}$
Values	0	1	2	3

kind of the backward problem (*PR.2*—see Sect. 2.4), in which parameters guaranteeing the CCPS cyclic behavior are sought.

Due to the formulae (5) the structure $SC^{(2)}$ can be specified as follows:

$$CS^{(2)} = \phi\left(CS^{(1)}_{join}, CS^{(2)}_{join}\right)$$

The consequences of $CS^{(2)}$ constraints (especially $C^{(A)}$) depends on assumed dispatching priority rule σ_3. Searching for that rule the following principle was assumed: The given priority dispatching rule σ_3 guarantees the deadlock-free behavior of the CCPS only if considered constraints set C of the problem $CS^{(2)}$ constraints is not contradictory. An observation that the system is deadlock-free only if the operations precedence digraph G' does not contain any cycle, i.e. there exists solution to the relevant problem CS (in this case to the problem $CS^{(2)}$) stands behind of that principle.

Therefore, the sought dispatching priority rule σ_3 can be seen as solution to the following problem CS

$$CS_\sigma = \left(\left(\{\sigma_3, CS^{(2)}\}, \{D_{\sigma_3}, D_{CS}\}\right), \left\{CS^{(2)} = \varphi\left(CS^{(1)}_{join}, CS^{(2)}_{join}\right)\right\}\right)$$

Let us arbitrary assume the values of the dispatching priority rule σ_3 can be sought in the set D_{σ_3}, composed of pairs of elements P_1, P_2. Solution to the CS_σ implemented in OzMozart is $\sigma_3 = (P_2, P_1)$ leading to the $CS^{(2)}$ with non-contradicting each other constraints:

$$\begin{aligned}
x_{1,1} &= \max\{x_{1,3} + 1 - Tc; x_{1,3} + 1 - Tc\}, x_{1,2} = \max\{x_{1,1} + 1; x_{2,2} + 1\};\\
x_{1,3} &= \max\{x_{1,2} + 1; x_{1,2} + 1\}, x_{2,1} = \max\{x_{2,3} + 1 - Tc; x_{1,3} + 1 - Tc\},\\
x_{2,2} &= \max\{x_{2,1} + 1; x_{2,1} + 1\}, x_{2,3} = \max\{x_{2,2} + 1; x_{2,2} + 1\}.
\end{aligned}$$

The constraints hold for decision variables values of which are show in the Table 3.

That means, in the structure $SC^{(2)}$ obtained by joining $SC^{(1)}_{join}$ and $SC^{(2)}_{join}$ while synchronized by dispatching priority rule $\sigma_3 = (P_2, P_1)$, there exists the reachable cyclic behavior—observe the operations precedence digraph (vertices allocation follows the obtained values $x_{1,1}, x_{1,2}, x_{1,3}, x_{2,1}, x_{2,2}, x_{2,3}$) shown in Fig. 10c. This digraph does not contain any cycle. The Gantt's chart of the CCPS processes realized in the structure $SC^{(2)}$ is show in Fig. 11. The cycle of the cyclic steady state is equal to the $Tc = 4$.

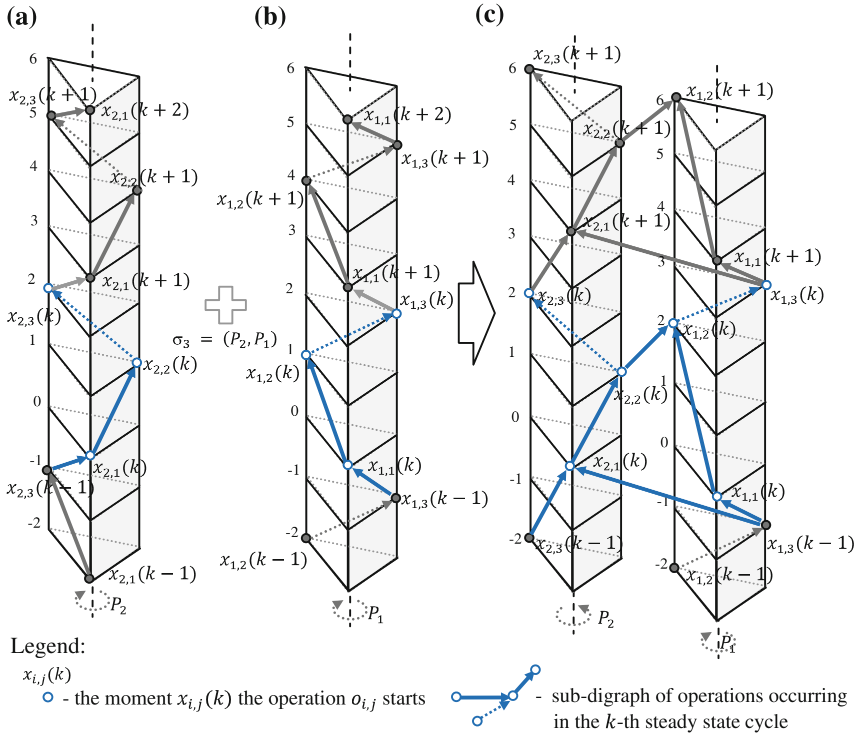

Fig. 10 An illustration of CCPS (Fig. 9) redeveloping: component operations precedence digraphs (**a**) and (**b**), the final structure of the operations precedence digraph (**c**)

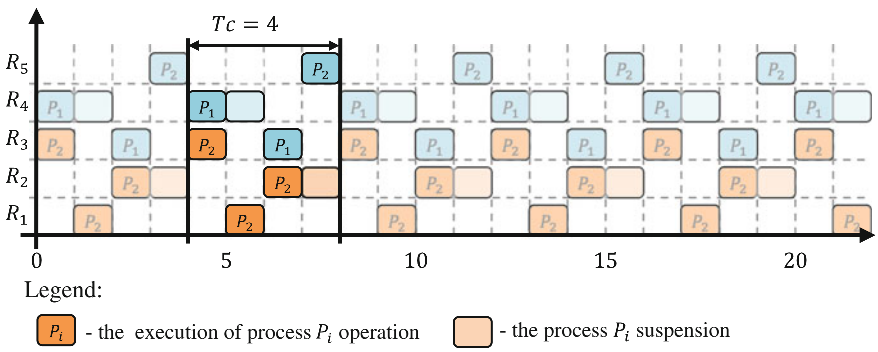

Fig. 11 Gantt's chart of the CCPS from Fig. 9c following Fig.10c

Consider the AGVS_{12} specified by the structure $SC^{(2)}$ (Fig. 12a). Assume its extension (modernization) to the AGVS_3 represented by $SC^{(3)}_{join}$ (see Fig. 12b).

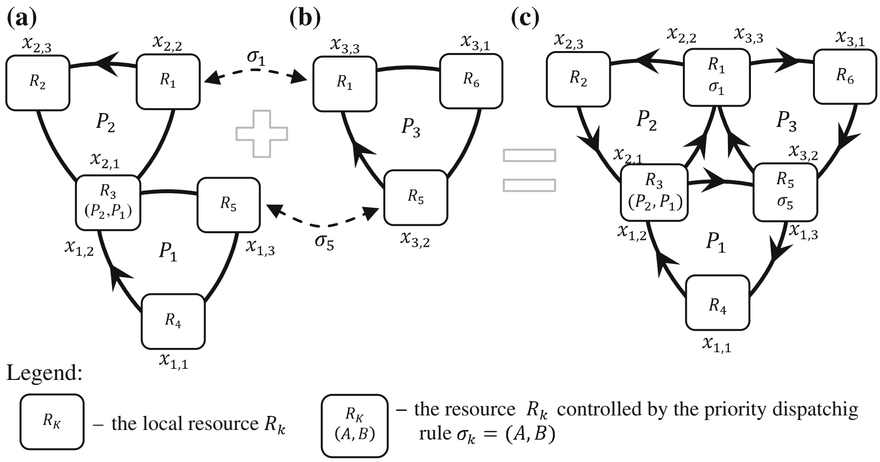

Fig. 12 An illustration of CCPS redeveloping: components (**a**), (**b**) the final structure (**c**)

Note that to the structure $SC_{join}^{(3)}$ the following $CS_{join}^{(2)}$ corresponds:

$$CS_3 = ((\{R, \Pi, T, \Theta, X_3, Tc\}, \{D_R, D_\Pi, D_T, D_\Theta, D_X\}), C_3)$$

where decision variables X_3 are following:

$$X_3 = \left(x_{3,1}, x_{3,2}, x_{3,3}\right)$$

and the set of constraints C_3:

$$x_{3,1} = \max\{x_{3,3} + 1 - Tc; x_{3,3} + 1 - Tc\}, x_{3,2} = \max\{x_{3,1} + 1; x_{3,1} + 1\}, x_{3,3} = \max\{x_{3,2} + 1; x_{3,2} + 1\}.$$

Just like in the previous case the AGVS_{12} and AGVS_3 have to be connected by common shared resources R_1 and R_5. Sought are the rules associated to those resources guaranteeing cyclic behavior of the $SC^{(3)}$ (Fig. 12c). In other words the response to the following question is sought: Does there exist the priority dispatching rules σ_1 and σ_5 linking $SC^{(2)}$ with $SC_{join}^{(3)}$ which guarantee a cyclic behavior of the resultant $SC^{(3)}$?

Response to this question requires the following problem solution:

$$CS_\sigma = \left(\left(\{\sigma_1, \sigma_5, CS^{(3)}\}, \{D_{\sigma_1}, D_{\sigma_5}, D_{CS}\}\right), \left\{CS^{(3)} = \varphi\left(CS^{(2)}, CS_{join}^{(2)}\right)\right\}\right)$$

The resultant two rules $\sigma_1 = (P_2, P_3), \sigma_5 = (P_1, P_3)$ determine the following set of constraints of the $CS^{(3)}$

Table 4 The moments of operations beginning for $SC^{(3)}$

Start moments	$x_{1,1}, x_{2,1}$	$x_{3,1}$	$x_{2,2}$	$x_{2,3}, x_{1,2}$	$x_{1,3}$	$x_{3,2}$	$x_{3,3}$
Values	0	3	4	5	6	8	9

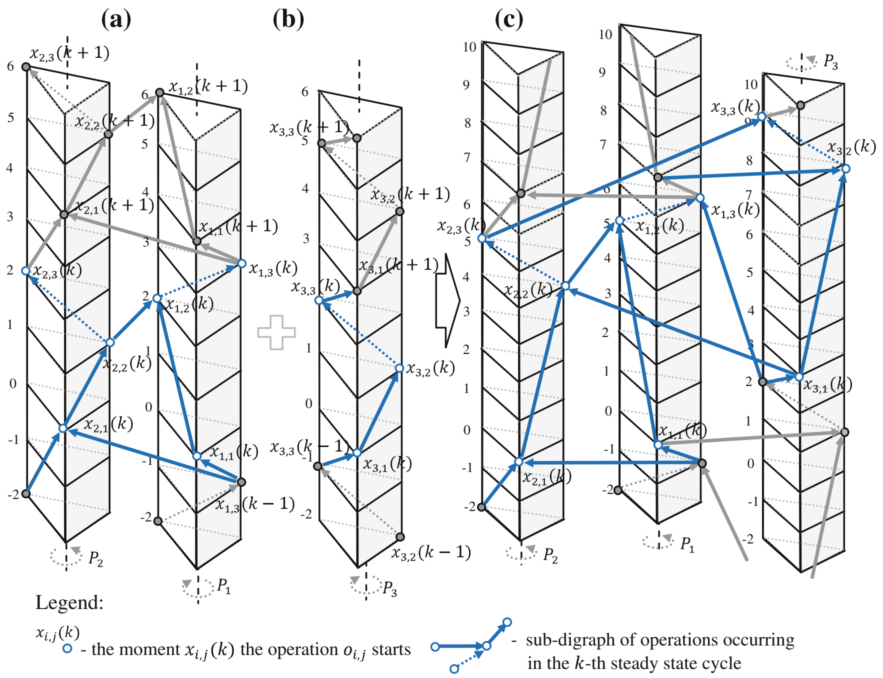

Fig. 13 An illustration of CCPS redeveloping: component operations precedence digraphs (**a**) and (**b**), the final structure of the operations precedence digraph (**c**)

$$x_{1,1} = \max\{x_{1,3} + 1 - Tc; x_{1,3} + 1 - Tc\}, x_{1,2} = \max\{x_{1,1} + 1; x_{2,2} + 1\},$$
$$x_{1,3} = \max\{x_{1,2} + 1; x_{3,3} + 1 - Tc\} x_{2,1} = \max\{x_{2,3} + 1 - Tc; x_{1,3} + 1 - Tc\},$$
$$x_{2,2} = \max\{x_{2,1} + 1; x_{3,1} + 1\}, x_{2,3} = \max\{x_{2,2} + 1; x_{2,2} + 1\},$$
$$x_{3,1} = \max\{x_{3,3} + 1 - Tc; x_{3,3} + 1 - Tc\}, x_{3,2} = \max\{x_{3,1} + 1; x_{1,1} + 1 + Tc\},$$
$$x_{3,3} = \max\{x_{2,3} + 1; x_{3,2} + 1\}.$$

In turn, the constraints are satisfied by the following variables $x_{i,j}$ see Table 4

The obtained values $x_{i,j}$ specify the digraph G' being a projection of the operations precedence digraph G (Fig. 13c) determining the cyclic behavior in the $SC^{(3)}$ structure. The resultant digraph is also acyclic one. So, the modernized AGVS is deadlock-free and its periodicity is equal to 7 (see Fig. 14).

The introduced operations precedence digraph based approach enables to determine the cyclic steady state behaviors following from the CCPS structure. That can be seen from the states space $\mathbb{S}$ perspective (see Sect. 3.1) as well as

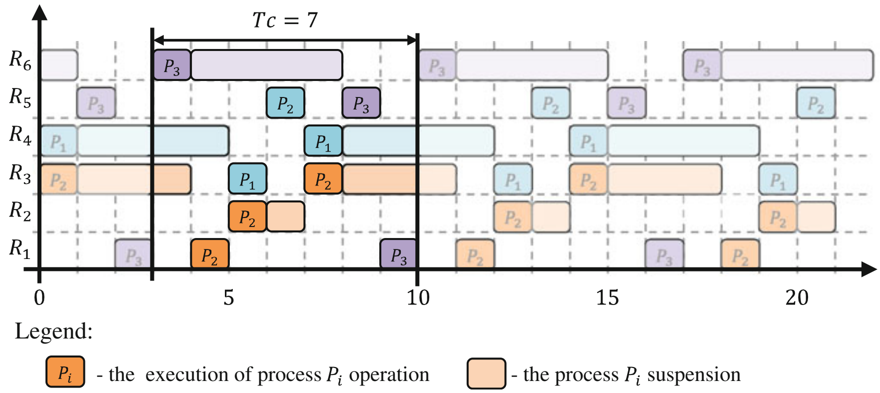

Fig. 14 Gantt's chart of the CCPS from Fig. 12c following Fig. 13c

Table 5 The initial states of $SC^{(3)}$ (see Fig. 13c)

S^0: $\quad R_1, R_2, \boxed{R_3}, \boxed{R_4}, R_5, \boxed{R_6}$ $A^0 = (\Delta, \Delta, \boxed{P_2}, \boxed{P_1}, \Delta, \boxed{P_3})$ $Z^0 = (P_3, P_2, P_2, P_1, P_3, P_3)$ $Q^0 = (2, 1, 1, 1, 2, 1)$	The resource R_6 can be seen as an AGV's potential docking place	S^1: $A^1 = (\Delta, \Delta, P_2, P_1, P_3, \Delta)$ $Z^1 = (P_3, P_2, P_2, P_1, P_3, P_3)$ $Q^1 = (2, 1, 1, 1, 2, 1)$
S^2: $A^2 = (P_3, \Delta, P_2, P_1, \Delta, \Delta)$ $Z^2 = (P_3, P_2, P_2, P_1, P_1, P_3)$ $Q^2 = (2, 1, 1, 1, 1, 1)$	S^3: $A^3 = (\Delta, \Delta, P_2, P_1, \Delta, P_3)$ $Z^3 = (P_2, P_2, P_2, P_1, P_1, P_3)$ $Q^3 = (1, 1, 1, 1, 1, 1)$	S^4: $A^4 = (P_2, \Delta, \Delta, P_1, \Delta, P_3)$ $Z^4 = (P_2, P_2, P_1, P_1, P_1, P_3)$ $Q^4 = (1, 1, 2, 1, 1, 1)$
S^5: $A^5 = (\Delta, P_2, P_1, \Delta, \Delta, P_3)$ $Z^5 = (P_3, P_2, P_1, P_1, P_1, P_3)$ $Q^5 = (2, 1, 2, 1, 1, 1)$	S^6: $A^6 = (\Delta, P_2, \Delta, \Delta, P_1, P_3)$ $Z^6 = (P_3, P_2, P_2, P_1, P_1, P_3)$ $Q^6 = (2, 1, 1, 1, 1, 1)$	

noticed from the Gantt's charts (e.g., see Fig. 14 corresponding to the cyclic steady state denoted by SC_2 and shown in Fig. 6).

Note, however, that the cyclic steady states can be recognized as rings of states creating cycles, e.g., SC_2, seen in the operations precedence digraph (assuming the trajectories leading to the cyclic steady states are skipped out, i.e. the paths composed of states leading to the circles). In that context, the set of states leading to the cyclic steady state, e.g., SC_2, is treated as the set of initial states. So, in the case considered, the initial states corresponding to the digraph shown in Fig. 13c are summarized in the Table 5.

4.2 The Mesh-Like Structure AGVS

Consider the FMS composed of 16 industrial robots, 6 machine tools, and 6 input/output buffers shown in Fig. 15a. Robots transporting work pieces from input

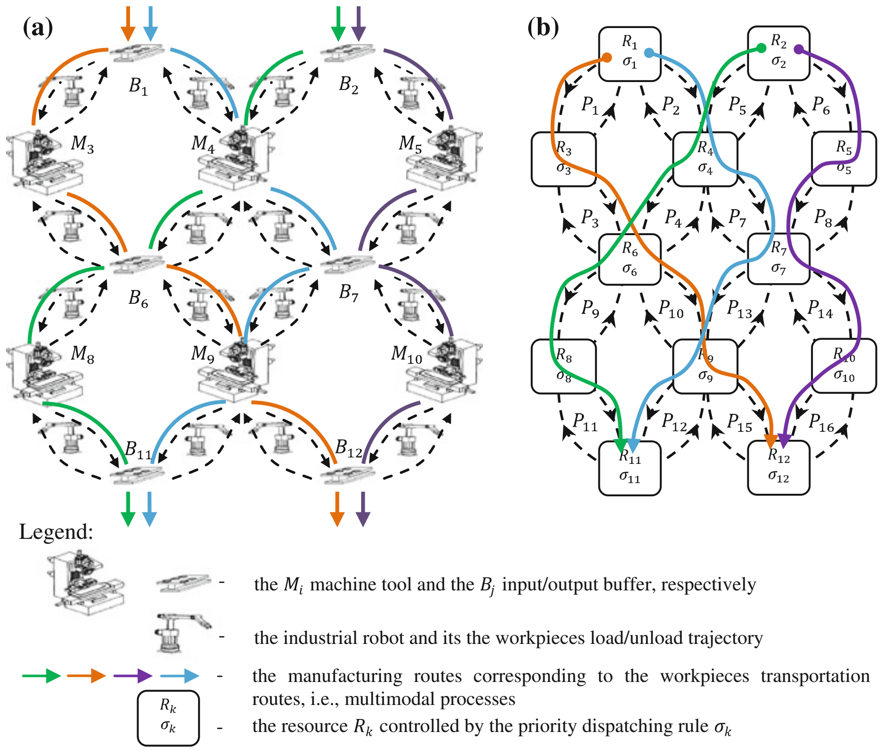

Fig. 15 The illustration of mesh-like layout (**a**) the CCPS of the robotized FMS (**b**)

buffer or machine tool to another machine tool or output buffer serve for work pieces handling—in the case considered four kinds of work pieces are processed along four different production routs. Production routes can be seen as cyclic repetitively executed processes supporting the work pieces flow along different production routs (Bocewicz et al. 2011)—Fig. 15b. In such structures different cyclic scheduling problems can be considered. The typical problem concerns of work pieces routing, in which a single robot has to make multiple tours with different frequencies. The objective is to find a minimal make span schedule in which the robots repeat their handlings with given frequencies while completing assumed amount of work pieces machined along each production route. In other words, in the mesh-like (or fractal-like) structure of the robotized FMS the problem of multimodal cyclic processes is considered.

Returning to our case from Fig. 1 the similar mesh-like structure can be considered see Fig. 16. Moreover note, that suggested in the last section iterative approach to the CCPS (see Fig. 2) synthesis, assuming the $CS^{(1)}_{join}$ joining with successive $CS^{(2)}_{join}$ and $CS^{(3)}_{join}$ can be concluded in the following procedure:

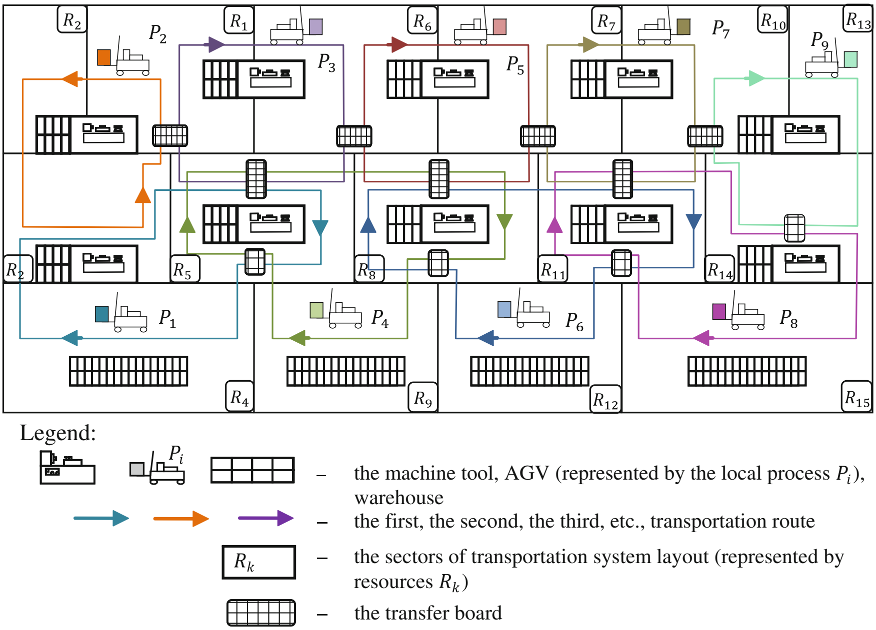

Fig. 16 The extension of the AGVS from Fig. 1

where:

function RedevelopingCCPS(CS_{join})

$CS^{(1)} \leftarrow CS^{(1)}_{join}$

$j \leftarrow 2$

$DS \leftarrow \emptyset$

while $j \leq$ Cardinality(CS_{join}) **do**

$CS_\sigma \leftarrow$ CreateCsSigma$(CS^{(j-1)}, CS^{(j)}_{join})$

$DS^j \leftarrow$ Solve(CS_σ)

If $DS^j = \emptyset$ **then**

return $DS \leftarrow \emptyset$

else

$DS \leftarrow DS \cup DS^j$

$CS^{(i)} \leftarrow$ CreateCs$\left(DS^j, CS^{(j-1)}, CS^{(j)}_{join}\right)$

end

$j \leftarrow j + 1$

end

return DS

end

CS_{join}—is the set of constraints satisfaction problems, represented by a joined structure [see (5)], CS^i—is the constraints satisfaction problem obtained by

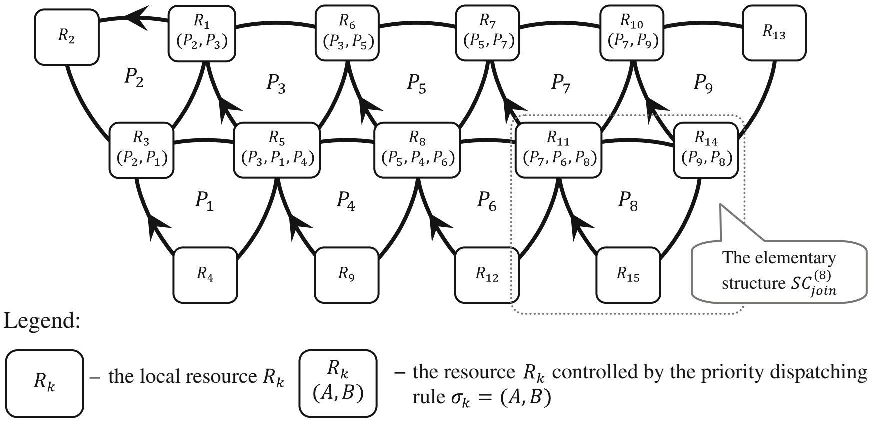

Fig.17 Illustration of extension of the CCPS from Fig. 12c

composition of the i-th elementary CCPSs CS_{join} (5), DS—the algorithm's output, the set of priority dispatching rules of the CCPS sought, DS^j—the set of priority dispatching rules included in the CCPS composed of the j elementary CCPS,
Cardinality$\left(CS_{join}\right)$—the function providing the CS_{join} cardinality.
CreateCsSigma$\left(CS^{(i-1)}, CS_{join}^{(i)}\right)$—the function providing the CS_σ as $CS^{(i-1)}$ and $CS_{join}^{(1)}$ joining,
Solve(CS_σ)—the function providing the set of CS_σ solutions, i.e., the set of dispatching priority rules assigned to the resources on the base of which the joined structures are composed,
Create $CS\left(S^j, CS^{(i-1)}, CS_{join}^{(i)}\right)$the function providing the CS^i as result of $CS^{(i-1)}$ and $CS_{join}^{(1)}$ joining employing the S^j rule.

An algorithm RedevelopingCCPS allows one to calculate the set of dispatching priority rules DS guaranteeing cyclic behavior of the CCPSs, which implemented in Oz Mozart environment, allows determining priority dispatching rules in case of CCPS from Fig. 17, i.e. extension of the CCPS from Fig. 12c by 6 elementary structures. Considered CCPS represents the FMS from Fig. 16.

In the case considered the set of problems CS_{join} describing the behaviors of the joined structures $SC_{join}^{(i)}$ is the algorithm's input data. Each elementary structure from the CCPS in Fig. 17 consists of three resources occurring uniquely in the local transportation route. Therefore, the CCPS consists of nine elementary structures. In each the i-th algorithm's iterations the set of dispatching priority rules DS^j corresponding to the newly added structure $SC_{join}^{(i)}$ is provided. The delivered rules are solutions of the CS_σ implemented in the algorithm, i.e., Solve(CS_σ).

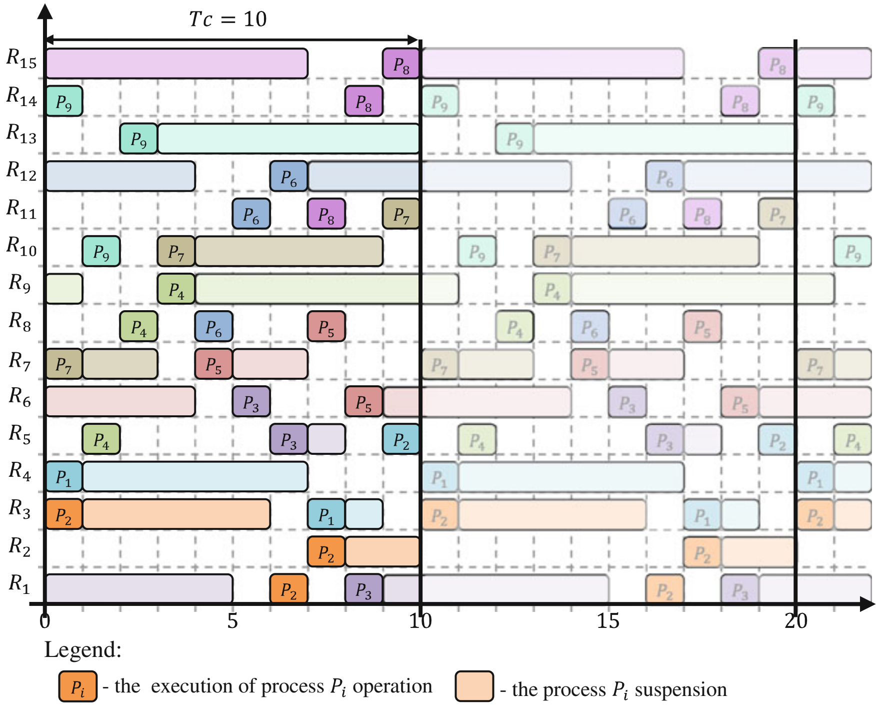

Fig. 18 Gantt's chart of the CCPS from Fig. 17

In case considered the solution was obtained in 8 iterations. In each iteration 24 steps (one step includes both constraints propagation and variables distribution (Schulte et al. 1998) were executed in order to reach the CS_σ sought.

The obtained set DS consists of the following dispatching priority rules:

$$\sigma_1 = (P_2, P_3), \sigma_3 = (P_2, P_1), \sigma_5 = (P_3, P_1, P_4), \sigma_6 = (P_3, P_5), \sigma_7 = (P_5, P_7),$$
$$\sigma_8 = (P_5, P_4, P_6), \sigma_{10} = (P_7, P_9), \sigma_{11} = (P_7, P_6, P_8), \sigma_{14} = (P_9, P_8).$$

The rules obtained guarantee the cyclic behavior of the CCPS considered, i.e., $Tc = 10$ (see Fig. 18).

The benefits standing behind of the computational efficiency follow from applied iterative procedure, where in the one step (corresponding to the actually added elementary structure) the priority dispatching rules are determined. Because the rule once determined remains unchanged the searching process is backtracking free. Of course, an idea standing behind of the algorithm considered employs the greedy strategy concept. That means, the algorithm considered does not guarantee any solution there exist.

5 Concluding Remarks

In contradiction to the traditionally offered solutions the approach presented allows one to take into account such behavioral features as transient periods and deadlock occurrence. So the novelty of the modeling framework offered lies in evaluation of Diophantine problems solvability (in domain of integers cyclic scheduling problems belong to a class of Diophantine ones), declarative approach to reachability problems (the questions regarding cyclic steady states determination as well as conditions guaranteeing transitions between them can be considered), and evaluation of multimodal cyclic process executed within cyclic processes environments.

CCSP that can be seen as a model of AGVS leads to two fundamental questions: Does there exist a control procedure (i.e. a set of dispatching rules and an initial state) enabling to guarantee an assumed steady cyclic state (e.g. following requirements caused by AGVS at hand) subject to AGVS's structure constraints? Does there exist the AGVS's structure such that an assumed steady cyclic state (e.g. following requirements caused by AGVS at hand) can be achieved? Response to these questions determines our further works.

We believe that this approach leads to solutions based on sufficient conditions that allow the designer to compose elementary systems in such a way as to obtain the final AGVS scheduling system with required quantitative and qualitative behavior features. So, we are looking for a method allowing one to replace the exhaustive search for the admissible control by a step-by-step structural design guaranteeing the required system behavior.

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Part III
Information Systems and Information Management Supporting Sustainability

Simulation Software and Technologies for "Green" Eco-Production

Paweł Pawlewski and F. Javier Otamendi

Abstract The chapter presents the results of the research related to the applicability of software technologies for simulation in green production and logistics. Green requirements for these technologies are defined. In the first phase, simulation techniques like spreadsheets, programming languages, programming libraries, specialist simulation software and agent technologies are evaluated and compared. In the second phase, five specialist simulation packages were chosen and evaluated in detail. From this list, one package was selected with built-in "green" functions. Finally, an example of using the selected software package to investigate carbon dioxide emissions in factory which produce bottled milk and cheese was described.

1 Introduction

Nowadays, more companies are starting the initiative to go green and reduce their impact on the environment. Going green has become the newest item in the mission statement of several manufacturers and third party logistics companies. The main subject which dominates conversations between manufacturers and environmentalists is the controversy concerning global warming and manufacturing. In order to reduce waste, several manufacturers and third part logistics

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companies have begun going green. Organizations are under huge pressure to reduce their carbon emissions and save money by eliminating waste from their processes. The two sets of initiatives go hand-in-hand:

- the less energy you use and waste,
- the less energy you pay for.

The challenge lies in the ability to model processes to understand what energy is being used where, and for what, instead of in the recognition of the need to reduce energy use for the sake of the planet and the balance sheet. The questions are: how can we cut energy costs without having an impact on customer service, profitability and competitiveness? It is difficult to find full answers for those questions. But manufacturers and third party logistics companies are increasingly recognizing that they can use simulation and optimization techniques to model their use of, and investment in, energy supplies.

The pressure to reduce energy use in business stems from three main sources:

- one regulatory,
- one fiscal,
- one environmental by simply doing the right thing for the environment.

In many ways, understanding energy use in industry is the same as in households or offices. Attitudes of the companies and consumers have changed over time. Now they recognize the need to reduce energy use in order to slow climate change and save money. But achieving these goals is very difficult because organizations neither have nor use the proper tools that enable them to add energy analysis on top of other process rules and calculations. Organizations must invest in technology to easily understand the effects on energy use of manufacturing and supply chain changes. But these problems are traditionally classified as 'too difficult' or 'too expensive'. Simulation techniques, especially visual interactive simulation (VIS) (Hurrion 1978), help to work with these highly complex scenarios and calculations. Simulation software supports choices and decisions between different options.

Understanding the true cost of energy is not typically an intuitive process. The questions are: What happens to our energy costs if we make or deliver a particular product once a day or every half an hour? What impact will sourcing subproducts locally have on our fuel bill? Simulation technology can help to find answers using graphical representation of the impact of different choices on energy use. The following green requirements for simulation might be defined: the ability to model and track a process may shed new light on how to optimize the use of the resources and the materials consumed along the supply chain. This is in addition to the normal improvement of efficiency, service and production levels.

This chapter is organized as follow: in Sect. 2 the available simulation techniques, like spreadsheets, programming languages, programming libraries, specialist simulation software or multi-agent technologies, are described. Section 3 presents the selected simulation software packages, Anylogic, ExtendSim, Arena, FlexSim, Witness and Quest, in terms of their "green" features. Example of using one selected simulator in green implementation is included in Sect. 4.

2 Simulation Software Techniques

Researchers work on expanding the use of simulation upon new problem categories (Farr et al. 2007). The question is why it is so. As a matter of fact, simulation is based on modeling the reality. In his classic work, Forester (1965) presented the classification of models used in the management and economical sciences. Forester noticed that most of the models used in the discussed area, were stable-steady state models. The models of stable-steady state category can be successfully used for describing certain management problems, i.e. mainly layout planning and modeling problems and, to a wider extent, problems of changes in an organization (Ciszak 2007).

This section discusses the possible uses of process simulation software techniques and their applicability to "green" environmental engineering and management. The main questions are:

- What types of software can be used for developing simulation models?
- What specific packages are available?
- How can an appropriate package be selected?
- Which "Green possibilities" are available?

Full overview of the features of all types of simulation are to be found in the work of Ingalls (2008). Looking for the clarification of the explanation, the following simulation groups of software techniques are to be introduced and explained in the following paragraphs:

- Spreadsheet,
- Programming languages,
- Programming libraries,
- Specialist simulation software,
- Multi-agent technologies.

2.1 Spreadsheets

First, a spreadsheet is a computer application that displays multiple cells that together make up a grid consisting of rows and columns, each cell containing either alphanumeric text or numeric values. Spreadsheets are frequently used for financial information because of their ability to re-calculate the entire sheet automatically after a change to a single cell is made. Visicalc is usually considered to have been the first electronic spreadsheet. This application was enabled on Apple II computers. When DOS was the dominant operating system on PC, Lotus 1-2-3 was the leading spreadsheet. Today, spreadsheets are available for all of the major desktop operating systems: Windows, Unix/Linux and Mac OS. Since Mac OS X is a derivative of BSD Unix, all of the Unix spreadsheets (as well as other software) will eventually be available for this platform. The most prevalent spreadsheet today is Microsoft Excel, which is part of Microsoft Office. Most other spreadsheets operate similarly and have features like those of Excel (Pichitlamken et al. 2008). "Spreadsheet simulation" refers to the use of a spreadsheet as a computer platform for representing simulation models and performing simulation experiments. Spreadsheet simulation simply involves the use of a spreadsheet to represent the model, do the sampling, perform the model computations and report the results.

Spreadsheet packages, such as Excel, provide some rudimentary capabilities for simulation modeling. It is relatively straightforward to develop a simple time-slice model using the basic capabilities of a spreadsheet. In Excel, random numbers can be generated using the "RAND" function (Seila 2004). Samples can be taken from empirical distributions using the "IF" function or more succinctly with a lookup function ("VLOOKUP" or "HLOOKUP"). Some functions for sampling from statistical distributions are provided by Excel, for instance, normal and gamma distributions.

Beyond a very rudimentary level, however, it becomes necessary to use some programming capabilities within the spreadsheet, for instance, macros or Visual Basic for Applications in Excel. It is also difficult to develop a model animation using a spreadsheet, although a basic display can be provided.

2.2 Programming Languages

Secondly, many programming languages are offered on the market, but the beginnings are in the 50s. The 1950s saw the first computer simulation. In the decade that followed, the advent of programming languages such as Fortran greatly benefited the simulation community. The General Simulation Program of K. D. Tocher and D. G. Owen is considered the first "language effort" (Banks et al. 2005).

GPSS (General Purpose Simulation System—originally Gordon's Programmable Simulation System) developed by Geoffrey Gordon at IBM—appeared in the 1960s as the first specialist simulation languages. This language was developed for quick simulation of communications and computer systems, but its ease of use quickly spread its popularity to other application areas. GPSS is based on a block diagram representation (similar to a process-flow diagram) and is suited for queuing models of all kinds. A system is modeled as transactions enter the system and are passed from one service (represented by blocs) to another. This is particularly well suited for problems within a factory. It was popular in the late 1960s and early 1970s but seldom used today due to its lack of flexibility compared to other tools.

Simula was also developed in the 1960s at the Norwegian Computing Center in Oslo, by Ole-Johan Dahl and Kristen Nygaard. Simula is a name for two programming languages, Simula I and Simula 67. Simula is considered the first object-oriented programming language. Simula 67 introduced objects, classes, subclasses, virtual methods, co-routines, discrete event simulation, and features garbage collection. Simula was designed for doing simulations, and the needs of that domain provided the framework for many of the features of object-oriented languages today.

This early developments pioneered the development of other discrete event simulation packages: AutoMod, eM-Plant, Arena, GASP, GPSS, Plant Simulation, SimPLE++, SimPy—an open-source package based on Python, SIMSCRIPT II.5—a well established commercial compiler, Simula, Poses++—a discrete-event simulation system with Petri net based modeling.

Hybrid solutions, which combines continuous and discrete events capability, were then developed: AMESim—simulation platform to model and analyze multi-domain systems and predict their performances; AnyLogic—multi-method simulation tool, which supports System dynamics, Discrete event simulation as well as Agent-based modeling; Modelica, open-standard object-oriented language for modeling of complex physical systems; EcosimPro Language (EL)—continuous modeling with discrete events; Saber-Simulator—continuous and discrete event capability, with applications in different engineering domains (hydraulic, electronic, mechanical, thermal, etc.); Simulink—continuous and discrete event capability; XMLlab—simulations with XML; Flexsim 4.0 powerful interactive software for discrete event and continuous flow simulation; Simio software for discrete event, continuous, and agent-based simulation. Standard programming languages like Visual Basic, C++ and JAVA are also liable to be used in simulation works.

2.3 Programming Libraries

Thirdly, programming libraries in JAVA form a new class of simulation software. Operating system independence, opening for network and internet cause JAVA to stand out as one of the most popular and the most important computer language. Based on JAVA, three libraries might be listed as freely available for use (free access): DESMO-J, JiST and SIMKIT.

DESMO-J is a simulation framework that has been under active development at the University of Hamburg for many years (Page and Kreutzer 2005, 2003). The acronym "DESMO-J" stands for "Discrete-Event Simulation and MOdelling in JAVA". DESMO-J is public domain software which is licensed under the APACHE public license. The internet platform for DESMO-J is www.desmoj.de. A main advantage of DESMO-J is that it supports both event-based and process-

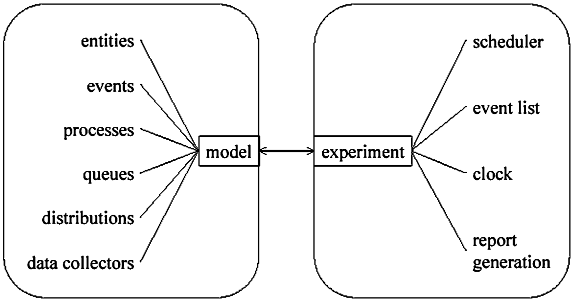

Fig. 1 Separation of model and experiment in DESMO-J. *Source* (www.desmoj.de)

based model descriptions and allows experimentation with these alternative world views within the same software. DESMO-J supports the separation of model and experiment, a widely acknowledged requirement of good simulation software as it allows for performing the same experiment with different models which may represent competing system designs or alternative strategies as well as performing different experiments with the same model. In DESMO-J the model class handles all the model components whereas the experiment class provides the simulation infrastructure. Both are explicitly connected during a simulation run. This situation is presented in Fig. 1.

The framework provides the user with the standard functionality for discrete event models and provides some predefined abstract classes where the user can add his model-specific behavior to the framework (so-called Hot-Spots). In summary the simulation functionality of DESMO-J includes:

- the simulation scheduler encapsulating the event list and simulation clock;
- process-oriented as well as event-oriented simulation objects, including their combination;
- queues with priorities and automatic statistics;
- replaceable random number generators and various statistical distributions (Uniform-, Exponential-, Normal-, Erlang-, Poisson-, Triangle, user-defined or empirical distribution, etc.);
- higher modelling components for process synchronization, i.e. more compact simulation modeling on a higher abstraction level such as resource competition, conditional waiting, direct process cooperation (master/slave relations), storage bins as inventories, or process interrupts;
- automatic reporting for queues, distributions and higher model components;
- reporting, trace, debug and error output in HTML and XML format (i.e. platform independent representation of output data).

JiST is a high-performance discrete event simulation engine that runs over a standard JAVA virtual machine. This software has been developed and maintained by Cornell Research Foundation, by its authors: Rimon Barr, Prof. Zygmunt J. Haas, Dr. Robbert van Renesse (Barr et al. 2005). This work has been supported in part by the DoD Multidisciplinary University Research Initiative (MURI) program administered by the Office of Naval Research and by the Air Force Office of

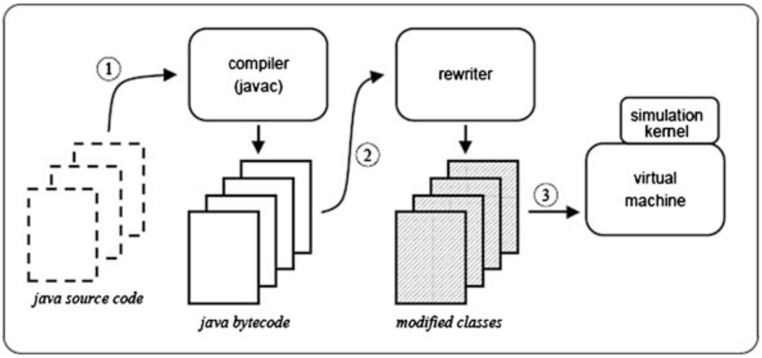

Fig. 2 The JiST system architecture. *Source* Barr et al. (2005)

Scientific Research. The acronym Jist stands for "JAVA In Simulation Time. The internet platform for JiST is http://jist.ece.cornell.edu.

Figure 2 presents the JiST architecture, in which the application architecture works as follow:

- a simulation is first compiled,
- then dynamically rewritten as it is loaded,
- finally executed by the virtual machine with support from the language-based simulation time kernel.

The execution of simulations using only a standard language and runtime is a primary goal of JiST (Barr, 2004). Consequently, the compiler and runtime components of the JiST system can be any standard JAVA compiler and virtual machine, respectively. Simulation time execution semantics are introduced by the two remaining system components: the rewriter and simulation time kernel. The rewriter component of JiST is a dynamic class loader. It intercepts all class load requests and subsequently verifies and modifies the requested classes. These modified, rewritten classes now incorporate the embedded simulation time operations, but they otherwise completely preserve the existing program logic. The program transformations occur once, at load time, and do not incur rewriting overhead during execution. Scalable wireless network simulator SWANS was built based on JiST architecture.

SIMKIT is copyrighted under the GNU Public License and it is an Open Source Package which may be downloaded from the internet at <http://diana.gl.nps.navy.mil/Simkit/>. Simkit is a programming toolkit that supports this kind of component-based modeling. In its current form, the simulation modeler interacts with Simkit at the Application Programmer Interface (API) level, in contrast to commercial Graphical User Interface (GUI) environments. A GUI for more intuitive model building in SimKit is currently under development. SimKit creates simulation using a component framework, which is based on a listener design pattern especially useful for simulation models. The objects created are called Listener Event Graph Objects, so the component framework is called LEGO (Buss 2002). The LEGO component framework is powerful, flexible, and promotes designing generic, reusable simulation models (Buss and Sanchez 2002). This type of component simulation modeling is distinct from the commercial process-oriented modeling environments because of the loose-coupling between components brought by the two listener patterns in the methodology. In addition to bringing much more flexibility to creating models, the loosely-coupled component approach supports substantially more reuse of developed modules (components) than traditional approaches. A particularly useful feature of the approach is the ability to decouple the model dynamics from all uses of the simulation data. Simkit is based on an Event Graph world view (Pichitlamken et al. 2008). Event Graphs are the simplest and most natural way to represent Discrete Event Simulation (DES) models (Buss and Sanchez 2005).

The defining feature of DES models is that they have state variables whose trajectories in simulated time are piecewise constant. State transitions only occur at discrete time epochs, which are designated as events. The Event List is responsible for determining which events occur and that the appropriate state transitions are executed. The occurrence of an event may trigger the occurrence of other events at later times. These future occurrences of events are implemented in a DES model by placing the appropriate scheduled events on the Event List. The Event List algorithm sorts the events in ascending temporal order and executed the simulation by always Specification of a DES model therefore consists of:

- Defining the state variables;
- Defining the state transitions corresponding to events;
- Defining the scheduling relationships between events.

2.4 Specialist Simulation Software

Fourth, many specialist simulation software packages are available on the market. Two broad types of specialist simulation package are identified (Law and Kelton 2000):

- General purpose simulation packages are intended for use on a wide range of applications, albeit they might have special features for some applications.
- Application oriented simulation packages are focused on specific applications, for instance, medical, production scheduling or call centers. A more focused package tends to be easier to use, possibly only requiring the entry of relevant data, but it obviously has a much narrower range of application.

The majority of specialist packages enable a simulation to be built as well as run in a visual and interactive manner. The software provides a predefined set of objects and the user selects required objects from the menu. The logic of the model

Table 1 List of specialist simulation software

Software	Supplier
ExtendSim AT	Imagine That Inc. (USA) www.extendsim.com
The Decision Tools Suite	Palisade Corporation (USA) www.palisade.com
Anylogic	XJ Technologies (Russia) www.xjtek.com
Witness	Lanner Group Limited (England) www.lanner.com
ShowFlow2	Incontrol Simulation Product Software BV (England) www.showflow.com
AutoMod	Applied Materials (USA)) http://www.appliedmaterials.com/products/automod_2.html
Bluesss Simulation Software	Raczynski Consulting (Poland/Mexico) www.raczynski.com
Enterprise Dynamics	Incontrol Enterprise Dynamics Inc. (Holand) www.enterprisedynamics.com
Micro Saint Sharp	Alion MA&D Operation (USA) www.alionscience.com
Portfolio Simulator	ProModel Corporation (USA) www.promodel.com
eM-Plant	Tecnomatix (Germany) www.ugs.com
Vanguard System	Vanguard Software Corporation (USA) www.vanguardsw.com
AutoShed AP	Brooks Automation (USA) http://www.automod.de/autosched-ap.html
Flexsim Software	Canyon Technology Center Park (USA) www.flexsim.com
Simcad Pro	Createasoft (USA) www.createasoft.com
Crystal Ball Professional	Oracle Crystal Ball Global Business Unit (USA) www.decisioneering.com
Expert Fit	Averill M. Law & Associates (USA) www.averill-law.com
L-Sim	Lanner Group Limited (England) www.lanner.com
Lean Modeller	Manufacturing Resources Group of Companies (Canada) www.mrgc.org
SAIL	CMS Research Inc. (USA) www.cmsres.com
Promodel	ProModel Corporation (USA) www.promodel.com
Analytica	Lumina Decisions System (USA) www.lumina.com
MAST	CMSResearch (USA) www.cmsres.com
Arena	Rockwell Automation (USA) www.arenasimulation.com
Simul8	Simul8 Corporation (USA) www.simul8.com

is built as process flow between simulation objects. For more complex logic, the packages enable their own internal language, so the modeler requires little in the way of programming skills.

As a result of the execution of different projects within the Department of Management Engineering at the Poznan University of Technology, a list of specialist simulation software with their characteristics has been formed, including data about suppliers, documentation and demonstration version availability. Table 1 summarizes this list of specialist simulation software with their suppliers and their actual internet addresses as of December 2010.

2.5 Multi-Agent Technologies

The use of multi-agent technologies is the latest trend in simulation to account for collaborative decision support systems and decision making. As examples, two modeling environments are included in this section: NetLogo and JADE.

NetLogo was designed and authored by Wilensky (1999), director of the Northwestern University's Center for Connected Learning and Computer-Based Modeling. The development was funded by the National Science Foundation and other foundations. NetLogo was designed in the spirit of the Logo programming language to be "low threshold and no ceiling" to enable easy entry by novices and yet meet the needs of high powered users. The NetLogo environment enables exploration of emergent phenomena. It comes with an extensive models library including models in a variety of domains such as economics, biology, physics, chemistry, psychology and many other natural and social sciences. Beyond exploration, NetLogo enables the quick and easy authoring of models. It is particularly well suited for modeling complex systems developing over time (Kawa 2008). Modelers can give instructions to hundreds or thousands of independent "agents" all operating concurrently. This makes it possible to explore the connection between the micro-level behavior of individuals and the macro-level patterns that emerge from the interaction of many individuals. NetLogo has many thousands of active users. It is freely available from the NetLogo website—http://ccl.northwestern.edu/netlogo/. NetLogo is in use in a wide variety of educational contexts from elementary school to graduate school. Many teachers make use of NetLogo in their curricula. NetLogo comes bundled with a large library of sample models covering many domains in natural and social sciences (Gilbert and Troitzsch 2005).

JADE (JAVA Agent DEvelopment Framework) is another agent software framework and it is fully implemented in JAVA language (Vrba 2003). JADE is also a free software which is distributed by Telecom Italia, the copyright holder, in open source software under the terms of the LGPL (Lesser General Public License Version 2). Since May 2003, a JADE Board has been created to supervise the management of the JADE Project. Currently the JADE Board lists five members: Telecom Italia, Motorola, Whitestein Technologies AG, Profactor GmbH, and France Telecom R&D. The internet platform for JADE is http://jade.tilab.com. JADE simplifies the implementation of multi-agent systems through a middleware that complies with the FIPA specifications and through a set of graphical tools that supports the debugging and deployment phases (Bellifemine et al. 2007). The acronym FIPA stands for "The Foundation for Intelligent Physical Agents". The internet platform for FIPA is www.fipa.org. The FIPA mission is the promotion of technologies and interoperability specifications that facilitate the end-to-end interworking of intelligent agent systems in modern commercial and industrial settings. The main goal of JADE is to simplify the development while ensuring standard compliance through a comprehensive set of system services and agents. JADE can then be considered as an agent middleware that implements an Agent

Table 2 A comparison of process simulation modeling tools

Feat.	Spread sheet	Program. language	Program. library	Specialist simulation software	Multi-agent technologies
A	Low	High	Medium	Medium	Low
B	Low	High	Medium	Medium	Medium
C	Medium	Long	Short	Short	Medium
D	Medium	Low	Medium	High	Medium
E	Medium	Low	Medium	High	Medium
F	Low	High	High	Medium	Medium
G	Short (medium for macro use)	Long	Medium	Medium	Medium
H	Low	Low	Low	High	Low
I	Low	Low	Medium	High	Medium
J	Low	Low	Low	Medium/High	Low

Platform and a development framework. It deals with all those aspects that are not peculiar of the agent internals and that are independent of the applications, such as message transport, encoding and parsing, or agent life-cycle. The latest version of JADE is JADE 4.0.1 released on 7 July 2010.

2.6 Comparison

The comparison among the five classes of simulation software is presented in Table 2. It is based on the following traditional extended features (Robinson 2004):

A. Range of application;
B. Modeling flexibility;
C. Duration of model building;
D. Ease of use;
E. Ease of model validation;
F. Run speed;
G. Time to obtain software skills;
H. Price;
I. Support;
J. Built-in "green" functions.

As built-in "green functions", the main object of this research, we understand those functions which can factor in the cost of electricity, oil gas or other energy sources into scenarios and adjust calculations for the optimum outcome.

It is striking to see that nowadays only some specialist simulation packages offer possibilities to use built-in "green" functions. If manufacturers and third party logistics companies want to use other software techniques, they must invest in programming works to disguise, develop and include these functions according to their requirements. Therefore, the call is for the use of specialist simulation software, which is further analyzed in the upcoming section.

3 Specialist Simulation Software

3.1 Selected Software

Based on the list of simulation software presented in Table 1 and on the authors' impressions and experiences from the premier international forum for disseminating recent advances in the field of system simulation—Winter Simulation Conference 2010— six simulators were selected for "green" evaluation:

- AnyLogic,
- ExtendSim,
- Arena,
- Witness,
- Quest,
- FlexSim.

AnyLogic is a simulator that has its roots in Agent Based Simulation. It is a product from XJ Technologies (www.xjtek.com). In the past few years they have tried to widen its appeal by including in the same structure Discrete Event and Continuous Simulation. A key point about AnyLogic is that the platform for the simulation is JAVA. This makes it possible to take any model and export it as a JAVA applet which will run on a web page. However, the interlinking of the different model types and some of the interface look a lot like programming—not easy for non coders. The model needs compiling before it will run which for large models can take a significant time. The new 3D module shown at WinterSim—looks limited being in JAVA—is loaded as a control on the simulation view with very simple graphics—but again is portable to JAVA as an applet.

ExtendSim is a low cost, low level, very visual product from Imagine That Inc. based in the US (Diamond et al. 2010). The basic modeling approach is block diagram—i.e. like process modeling in Visio or suchlike. More logic is visible on screen than in other systems as you need a block to add logic, distributions, etc. This makes it friendly at first. The sheer quantity of blocks on the screen is a major weakness with larger models due to the cluttered displays. When areas of blocks are collapsed into modules then the user has to navigate several levels to see the logic—again this is cumbersome. Models are fairly easy to construct with lots of mouse input. The 3D view has some nice touches—such as footprint trails but is essentially very cartoony. The blocks on the screen however makes simple models look complicated.

Arena is a simulator from Rockwell Automation. It has a strong and well respected link to the 1970s simulation programming language Siman. Its continued link to that code makes it somewhat unwieldy as it still generates Siman code as an intermediate step before running a model, although this is largely hidden from the user now. This does make the package less interactive than other simulators. As main disadvantages, Arena model may only be based on push logic—difficult to model pull strategies—and it lacks name change cascading—change a name and you will need to change all the references. Arena is now owned by Rockwell—this is visible in their recent developments which have entirely focused on factory planning and integration with the Rockwell database and the support of other planning tools in the Rockwell family (Kuhl and Zhou 2009). The basic Block diagramming approach is a bit like process modeling (say in Visio). This is fine but then all layout has to be done in addition—time consuming. A great strength of Arena is university teaching and its use—especially in the US—is very widespread.

Witness is the product from Lanner Group. The range and capability of elements in Witness is unparalleled. Using the correct construct for the correct model leads to quick effective modeling. The richness of functionality within the basic element types gives the modeler professional flexibility through direct specification of complex constructs such as multi-cycle activities (machines), specialised 'power-and-free' elements, supplied process modules, tracks and vehicles, fluids or complex arrival profiles. Witness rules offer the most powerful options in simulation systems today—in addition to the traditional Push, also Pull, Least, Most, Percent and Sequence are another built-in rules. Witness has more powerful options such as nested If rules and Match options. Witness is one of the few simulation products to offer truly powerful hierarchical modeling. Through unlimited levels of module structure the modeler has the speed and power of being able to clone and reuse whole sections of previous models. Witness is very easy to use. The method of modeling is straightforward and easy to learn—select and place elements/modules from the wide range supplied. Witness also offers the widest range of data linkage—Direct links to Excel and any OLE DB database (ORACLE, SQL Server, Access, etc.), CAD systems, Process Mapping systems or XML save formats. It also facilitates a wide range of picture and video display formats and is one of the few products to offer integrated recording of the model to video. Witness offers both 2 and 3D modeling, although 2D modeling is less appealing than JAVA-based software interfaces and 3D models are somewhat difficult to build and very time-consuming. Witness incorporates unique optimization technology. The Witness optimizer offers an easy to use interface to specify experiments and algorithms developed by world leaders in optimization technology.

And more importantly, it allows for green modeling by using built-in functions that track and calculate energy usage. The modeler may define which measures to focus on. From carbon to water, from electricity to oil, all measures may be defined using the Costing and Sustainability definition tab located in the Model/Options menu dialog—Fig. 3.

The modeler may also select the units for each measure. These can be the full words or typical abbreviations such as kWh for kilowatt-hours. The unit definitions

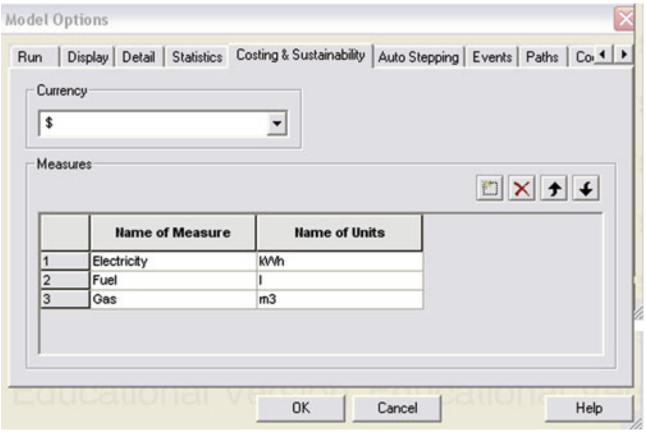

Fig. 3 Model/Options menu dialog for selection measures in witness

are the measuring units that should be used throughout the model and also form the display for the standard sustainability reports.

Delmia/Quest is a product almost entirely focuses on manufacturing from Dassault (Bzymek et al. 2008). Users create 3D worlds directly from libraries of specific manufacturing components. The physical nature of their direct modelling in 3D lends their models greater accuracy and in some ways smoother and easier virtual reality (VR) than is possible with other simulators. However the physical detail also makes the modelling task take too long and the code to introduce logic into a model is much more complicated than for example in Witness. Delmia offers a suite of other modelling tools that embrace areas such as Ergonomic modelling and Robotics—this offers manufacturers a unified marketing suite of modelling products. Quest is disappearing inside the whole Delmia suite with little emphasis or development momentum. Their main strength is the integration within the suite and will usually be sold as part of a much larger deal.

FlexSim is an object oriented; 3D discrete event simulation software developed by FlexSim Software Products Inc. FlexSim uses object oriented design as its software structure. Special objects used by FlexSim (Garrido 2009) are defined and programmed in the following classes:

- fixed resource class—this is the one that includes the main objects of the simulation which determine the flow of the simulation model, including source, queue, processor, sink, conveyor, etc.;
- task executer class—the objects inherited from this class obtain tasks from the objects inherited from the fixed resource class and assign the tasks to other objects, including operator, transporter, etc.;
- node class—the objects inherited from this class are used to design the working route of objected inherited from the task executer class, including network node and traffic control;

- visual object class—the objects inherited from the class are used to display and collect the input/output message, icon, diagram and tables. The model is built by dragging and dropping the abstracted predefined 3D objects from different classes to the layout. The entire dragging and dropping procedures can be realized and the object parameters and behaviors can be modified using both FlexScript and C++ programming languages. Flexsim uses OpenGL, the same graphics library used in today's hottest 3D games. Realistic spatial relationships, dynamic lighting or environmental effects help make models appealing to the user.

3.2 Comparison

In Tables 3, 4, 5 and 6 comparisons based on different sets of criteria are presented.

Witness appears to be useful for a wider range of applications since its programming is less focus on particular areas or industries. Its model development capabilities are unique and based on a powerful hierarchical object-oriented structure. The time to develop and analyze models is ever shorter in the last versions. Its main disadvantage is its graphical displays that require certain time to be appealing.

Focusing therefore on ease and scalability of development, it has incorporated many built-in functions. One of these functions covers the necessity of this research since it allows for the modeling of energy usage and cost calculations. In fact, nowadays Witness is the only simulation package to offer built-in "green" functions, whereas modelers using the rest of the simulation software packages will have to invest in programming works to develop and use ad-hoc green functions.

Therefore, the assessment of the capabilities of simulation software as they relate to green modeling call for the primary use of Witness. It looks to be the package that best and quickest develops models to address green thinking along the supply chain, fulfilling the objective of this research. For testing purposes, what follows is a real case of a food factory.

4 "Green Simulation" Example

A small factory which produces bottled milk and cheese (Borucki et al. 2011) is seeking to define its manufacturing and logistic policy based on "green" environmental concerns while maintaining its service level to the clients. Knowing about the adequacy of simulation modeling in general to address delivery problems and Witness in particular to compute and track energy usage, a study was performed to optimally set the parameters that defined the characteristics of the deliveries: batch sizes and frequency of deliveries (Lanner 2010).

Table 3 A comparison of specialist simulation software—general criteria

Software		Any logic	Extend sim	Arena	Witness	Quest	FlexSim
1.	Costs calculations	*	*	*	*	*	*
2.	OS Windows	*	*	*	*	*	*
3.	OS Unix/Linux	*				*	
4.	OS Apple	*	*				

Table 4 A comparison of specialist simulation software—analysis/simulation criteria

Software		Any logic	Extend sim	Arena	Witness	Quest	Flex sim
1.	Experiment planning	*	*	*	*	*	*
2.	Animation (2/3D)	*	*	*	*	*	*
3.	All-purpose	*			*		*
4.	Manufact.	*	*	*	*	*	*
5.	Procurement	*	*	*	*	*	*
6.	Material management	*	*	*	*	*	*
7.	Warehousing	*	*	*	*	*	*
8.	Distribution	*	*	*	*	*	*

Table 5 A comparison of specialist simulation software—modeling criteria

Software		Any logic	Extend sim	Arena	Witness	Quest	Flex sim
1.	Graphics model build.	*	*	*	*	*	*
2.	Program. model build.	*		*			*
3.	Nonlimited model size	*	*	*	*	*	*
4.	Program. possibilities	*	*	*	*	*	*
5.	CAD files import	*	*	*	*	*	*
6.	Optimizer	*	*	*	*	*	*
7.	Wizzards	*	*	*	*	*	*
8.	Interactive debugging	*	*	*	*	*	*

Table 6 A comparison of specialist simulation software—analysis/simulation criteria

Software		Any logic	Extend sim	Arena	Witness	Quest	FlexSim
1.	Programming	*	*	*	*	*	*
2.	Built-in “green” functions	–	–	–	*	–	–

4.1 Description of the System

Figure 4 shows the workflow at this small company. The raw milk is stored in a cooled tank, then is pasteurized and kept in a refrigerator. From there it is poured into the production lines of cheese and bottled milk. Finished products are packaged and delivered to two magazines. At the end of the process a recipient is used to collect the finished products at regular intervals. The milk is then delivered by a

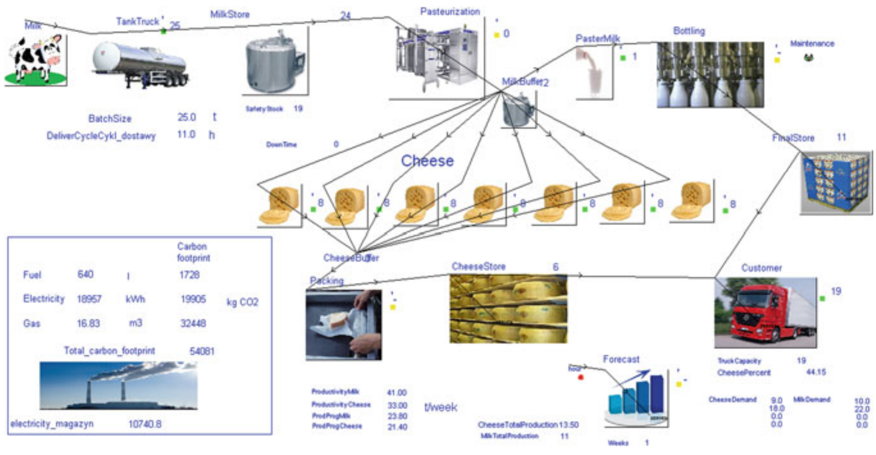

Fig. 4 Full process of milk and cheese production

tanker with a capacity of 24 tons from several farmers. In one cycle of delivery the lorry covers a distance of about 100 km.

During the supply chain, energy resources are worn: fuel, electricity and natural gas. In Table 7 consumption of these resources is presented.

The consumption of these resources generates carbon dioxide emissions (carbon footprint). Table 8 presents the carbon footprint (CO_2 units in kg) in terms of the type of consumed resource. This table was prepared based on data from USA Env. Protection Agency www.epa.gov/climatechange/emissions and http://www.carbonify.com/carbon-calculator.htm.

The objective of this company is therefore to set the delivery policy so that, on the one hand, the emission of CO_2 is minimized, while, on the other hand, the level of service is guaranteed in terms of the delivery times. The available options or alternatives are many and depend on two logistics factors: frequencies of deliveries and size of the batches. If the deliveries are organized with a high frequency and in small batches, the truck burns more fuel, but system requires less energy to store milk. On the other hand, large supplies involve burning less fuel, but the milk must spend more time in the refrigerator, and electricity consumption increases. A model in Witness must therefore be set to virtually experiment with the system and decide on the best logistic settings.

4.2 The Modeling Approach to Optimization

A robust decision on the settings of the logistic policy must be taken for this food company. The modeling approach is a framework of experimentation and analysis that adds credibility to the optimization study. First, it helps with the definition of the criteria that are going to be used to decide on the best policy. It also helps with

Table 7 Elements consumption of energetic resources

Element	Resource	Consumption	Calculation
Cheese buffer	El.energy	2(kWH)	hour/ton
Cheese store	El.energy	2(kWH)	hour/ton
Packing	El.energy	0.4(kWH)	operation
Milk buffer	El.energy	2(kWH)	hour/ton
Final store	El.energy	2(kWH)	hour/ton
Paster milk	El.energy	2(kWH)	operation
Milk store	El.energy	2(kWH)	hour/ton
Bottling	El.energy	0.4(kWH)	operation
Pasteurization	El.energy	0.01(kWH)	operation
Cheese	El.energy	3(kWH)	operation
Tank truck	Diesel oil	35(l)	delivery cycle
Pasteurisation	Natural gas	0.03(m^3)	operation

Table 8 Carbon footprint depends on type of consumed resource

Resource	Unit	CO_2 units in kg
Electric energy	kW H	1.05
Diesel oil	l	2.7
Natural gas	m^3	1928

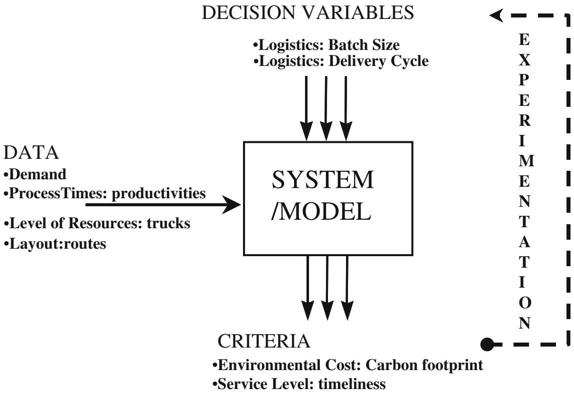

Fig. 5 The modeling approach for the food firm

the characterization of the decision variables whose values affect on the criteria, and with the listing of the data that is necessary for the running of the model. Second, it includes a model that relates the criteria, the decision variables and the data, and helps with the evaluation of each alternative. And third, it helps with the experimentation phase leading towards the optimization of the system by generating alternatives through the proper combination of the feasible values of the decision variables. The available alternatives are then evaluated using the data and the model; the selection of the best alternative according to the criteria follows.

Table 9 Ranges of parameters used in simulation experiment

Parameter	Range	Step
Batch size	1–25 tons	1
Delivery cycle	1–24 h	1

Table 10 20 best results sorted in ascending order

Evaluation	Delivery cycle	Batch size	Total carbon footprint
31	**2**	**7**	**352,858,333**
6	1	7	354,935
5	1	6	356,550,5
7	1	8	359,539
8	1	9	360,664,833
35	2	11	365,706,167
9	1	10	365,913,833
138	6	14	367,943
10	1	11	367,910,5
113	5	14	371,189,667
36	2	12	372,825,167
88	4	14	373,508,333
37	2	13	373,533,667
11	1	12	375,082,833
12	1	13	375,626,5
64	3	15	378,530,833
38	2	14	378,550,833
13	1	14	380,353,667
39	2	15	381,142
14	1	15	383,208,833

Figure 5 includes a graphical representation of the modeling approach particularized for the case in hand. The two criteria are the carbon footprint, which is to be minimized, and the service level, which is to be optimized via timely deliveries. The available data includes the demand, the milk and cheese productivities as well as the location of the customers and the transportation routes. The variables that define the delivery patterns are: the size of the batches and the frequency of deliveries. The search for optimization of the values of the decision variables is controlled by the experimentation phase in which different alternatives are successively evaluated and compared.

4.3 Experimentation and Analysis

The model was built in Witness and the objective functions defined with its built-in functions for energy usage (carbon footprints) and timely delivery (downtime of the client). To calculate their average values for each alternative, 6 runs of the model were performed. Each run lasted 12 weeks after a warm-up period of 1 week.

The available alternatives were defined by combining feasible values for each decision variable. Table 9 includes the feasible ranges. The total number of alternatives is therefore 600 (25×24).

Table 10 includes the best 20 results.

They are sorted in ascending order according to carbon footprint, after selecting those alternatives that completely fulfilled the delivery requirements. The decision variables of the best alternative are a batch size of 7 and a delivery cycle of 2.

The best settings correspond to small lot sizes (7 in a range between 1 and 25) with frequent deliveries (2 h in a range with a maximum of 24). This result is driven by the necessity to comply with timely deliveries which are favored by small batches, following the lean production philosophy. The study has helped to optimize then the green features within robust manufacturing philosophies.

5 Conclusions

In the chapter, the authors present the survey concerning software techniques for "green" simulation. Based on research, the software package Witness was selected for experiments. The main reason for this choice was the fact that it was the only software package with some built-in "green" functions. The test-case experiment was performed using data from a milk and cheese factory. Building the process and using "green" possibilities were very easy to do. Therefore, managers of plants or supply chains may easily use Witness to model green processes and improve their performance in terms of energy usage.

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Assessing Environmental Impact in Environmental Information Systems: Measurements and Monitoring

Marina Erechtchoukova and Peter Khaiter

Abstract An evaluation of an organization's environmental performance has to be done using two general categories of indicators: (1) indicators describing management and operation performance; and (2) environmental condition indicators that reveal the organization's impact on the environment. The latter cannot be done without systematic standardized observations and measurements conducted directly on the impacted environment. Integration of an organization's environmental performance evaluation into the organization's governance requires automated procedures for data collection and analysis. This chapter considers an organization's environmental impact assessment with respect to water resources. It investigates formal approaches to temporal monitoring design producing sufficient data for the assessment and demonstrates how these approaches can be incorporated into organizational environmental information system.

1 Introduction

Recognition that sustainable development is a necessity for human society calls for thorough auditing of human activities in terms of their influence on relevant natural systems and further re-engineering of business activities with the ultimate aim of reducing adverse anthropogenic impacts on the environment. The attempts to transform production processes into environmentally friendly technologies and to enforce environmental standards have been undertaken in the past. To support

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such efforts, the International Standards Organization (ISO) has formulated a set of protocols underlying environmental management systems. The environmental management systems verify and reduce the impact of an organization's activities on the environment. These systems also help organizations to formulate their environmental policies and to evaluate how they have been implemented in the organization through sustainable management.

The ISO 14001 standard can be viewed as a framework for environmental management system development (ISO 2004). The ISO 14004 standard provides guidelines on general principles of such systems, their compatibility with other management systems in an organization and on technologies that can be used for their implementation, operation and maintenance. The ISO 14005 standard describes activities for the implementation phase of such systems and how to use environmental performance indicators. The most recent standard ISO 14006 can be used in organizations which have already implemented environmental management systems in order to incorporate ecodesign into existing environmental management systems.

The implementation of an environmental management system in an organization requires an evaluation of environmental performance as one of the main components of such systems. An evaluation of an organization's environmental performance can be done, for example, by measuring 'the interactions between the business activity and the environment' (Bennete and James 1999). According to the ISO 14031 standard, the evaluation of an organization's environmental performance has to be done by using two general categories of indicators which describe the management and operation performance and the environmental condition indicators that reveal the organization's impact on the environment. The latter cannot be done without systematic standardized observations and measurements conducted directly on the impacted environment.

This chapter considers an organization's environmental impact assessment with respect to a water resource. It investigates formal approaches to temporal monitoring design producing sufficient data for the assessment and how these approaches can be incorporated into an organization's environmental information system. The algorithm for developing efficient temporal monitoring designs common for several water quality parameters was introduced in (Erechtchoukova and Khaiter 2011). This chapter presents its applicability to the extended list of environmental indicators and within the context of evaluation of an organization's environmental performance.

2 Environmental Performance Evaluation

The ISO 14000 family of standards provides generic recommendations suitable for organizations of various types and sizes on environmental management, including the issues of integration of an environmental management system into organizational governance. It gives organizations a necessary flexibility to meet their internal objectives and external environmental requirements. There are case studies investigating the details of various implementations of environmental systems (e.g., Lopez-Fernandes and Serrano-Bedia 2007; Christini et al. 2007). The analysis of these results led to a recommendation to modify existing information systems or to introduce new systems, such that information technology support for environmental management be included into enterprise-wide management information systems (Oktem et al. 2007; Erechtchoukova et al. 2010).

There are several critical aspects in the evaluation of an organization's environmental performance. The complexity of data collection, data compatibility, and difficulties in integrating environmental, financial, and economic data with qualitative characteristics are among them (Cagno et al. 2007). An effective evaluation of an organization's environmental performance must be based on a set of indicators reflecting operational activities, including consumption of an environmental resource and the resulting waste. The latter is required for an evaluation of the organization's impact on the environment. For this purpose, environmental performance indicators must be complemented by the environmental condition indicators in order to assess current and future impacts and to identify improvements or deterioration. The environmental condition indicators reflect a cumulative effect on the environment resulting from all of an organization's activities (Azzone et al. 1996). These indicators can be used for regulatory purposes demonstrating that the organization conforms with existing regulations or to determine cause-and-effect relationships between operational indicators and the environmental impact.

In order to assess an organization's environmental performance (that is, to identify problems, their causes, and the required mitigating actions), the systematic collection of data on selected indicators is necessary. These data are usually supplied by a monitoring system which operates under a specified program. Monitoring and measurements require clear understanding and development of procedures for observations on key characteristics of an environmental resource and organizational activities which generate significant environmental impact on this resource, for tracking performance, and for data collection and processing. Traditionally, values of environmental indicators are compared against existing standards to demonstrate whether or not the organization meets the requirements. Since monitoring is always subject to technical and budgetary constraints, it is important to select indicators which help to quantify and track significant impacts of the organization on the environmental resources.

3 Monitoring Organization's Impact on an Aquatic Environment

The ISO environmental standards do not specify any particular environmental performance indicators, or levels of environmental performance which can be used as benchmarks. They provide a framework for a holistic approach to ensure continual improvements. The indicators and corresponding levels may vary significantly for different business activities. Verfallie and Bidwell (2000) recommend measuring an organization's environmental performance via the concept of eco-efficiency. This measurement framework is based on an estimation of the influence imposed on the environment while a product is being created. Five indicators of this influence are specified as: (1) energy consumption; (2) material consumption; (3) water consumption; (4) greenhouse gas emissions; and (5) ozone depleting substance emission. With respect to an aquatic environment, the interaction of a business activity and the habitat results not only in the water uptakes, but also in using the natural waterbody as a place to deposit wastewaters. Thus, the list of indicators must be extended to include indicators reflecting both quality and quantity of pollution being discharged into aquatic systems. The ISO 14031 standard also suggests considering contaminant concentrations in surface waters for environmental performance evaluation.

Water quality in an aquatic environment is described by a set of physical, chemical, and biological properties reflected in the values of concentrations of water chemical constituents and other parameters. These parameters characterize the resulting state of an aquatic environment under anthropogenic impact. Traditionally, water quality objectives are formulated as the maximum allowable concentrations of water constituents. Thus, an assessment of water quality is based on a comparison of the observed concentrations of pollutants in a water column with these objectives.

The US EPA Clean Water Act introduced another approach to tracking an organization's impact on an aquatic environment, namely the Total Maximum Daily Load (TMDL) process. This process determines the amount of a pollutant that can be tolerated by an investigated waterbody without violating water quality standards. The process of TMDL is based on monitoring pollution loads from industrial and municipal water treatment facilities. Therefore, chemical loads become representative indicators of environmental performance. They are usually calculated using the values of water discharges and the corresponding values of concentrations of investigated parameters in the discharged water. Evaluation of both indicators, the average concentrations and the chemical load of pollutants, requires systematic measurements at a given site where wastewaters are released into a waterbody.

A list of water constituents which must be monitored depends on the composition of wastewaters. Although automated samplers which can generate detailed series of water quality parameters are preferable, not all parameters can be measured in this way. For such water constituents, their concentrations are derived from water samples collected manually with subsequent analytical processing in a laboratory. When observations and measurements are implemented manually, a monitoring design prescribing frequencies of sample collection in time and space is required.

3.1 Monitoring Designs

The development of an efficient monitoring design unavoidably implies the cost-effectiveness analysis as one of the important stages of the process. Since monitoring subsystems operate under financial constraints, cost estimates of a monitoring system are important. They allow for straightforward comparison with the allocated budget and between different monitoring programs. Although Groot and Schilperoort (1983) considered the process of deriving the financial estimates simply as a technical exercise, the absolute values of the estimates or their components are not always available. At the same time, the cost of a monitoring program definitely depends on the number of collected samples.

If the effectiveness of a monitoring program can be expressed in monetary terms, the cost-effectiveness analysis can be done as a direct comparison. However, such estimates are usually not available. In this case, the comparison can be replaced by constrained optimization techniques which do not require the goal function and constraints to be expressed in the same units of measurements, although both the goal function and the constraints must have common variables.

3.2 Role of Models in Monitoring Designs

The effectiveness of a monitoring design should quantitatively express the extent to which monitoring results meet the objectives. Although monitoring systems generate series of data, the main outcome of a monitoring program is the information needed for decision making in accordance with the monitoring objectives. This information is usually obtained through the processing of monitoring data using simple or complex models. Therefore, the evaluation of the effectiveness of a monitoring design should include mathematical models transforming observation data into information.

Observation data supplied by monitoring systems are a mandatory component of any environmental decision making process, but this component becomes useful only if the data are synthesized into information. Ideally, information has to be comprehensive and complete to meet multiple relevant needs. Environmental indicators convert extensive monitoring data into scientifically valid information which represents the state of the environment in a concise form (Environment Canada 2005). The conversion is implemented by means of selected statistical or mathematical formulae generating aggregate values. Models can be used to restore missing values of required environmental quality parameters. In this case and in many other cases of environmental decision making, understanding interactions of key environmental processes is vital. It cannot be achieved by observations along or even via simple summaries of observation data and requires more sophisticated models.

Environmental models form a diversified set of techniques based on different mathematical and computational methods. In order to be applied, models impose additional constraints on the way the data are acquired. A data set available for the analysis must satisfy the assumptions that underlie mathematical techniques employed for data analysis, namely, for obtaining values of environmental indicators and their further transformation into information for decision making.

Therefore, data collection must fit the entire modelling process (Richardson and Berish 2003). Formal representation of these assumptions can be used to determine frequencies of observations sufficient for deriving statistically meaningful results.

4 Optimization of a Monitoring Design

Automated optimization procedures require an objective function to be formulated in mathematical terms. The function reflects the goal of optimization and, at the same time, allows for a quantitative comparison of different monitoring designs. Mathematical properties of the objective function restrict or even determine computational algorithms to be applied to derive monitoring designs which are at least satisfying. The cost-effectiveness analysis implies two possible articulations of the problem of an efficient monitoring system: (1) to maximize the effectiveness of the design under the limited budget and; (2) to minimize the cost of the design within an acceptable level of effectiveness. In each case, it is necessary to provide quantitative estimates of the cost and the effectiveness of a monitoring design.

Although the cost of a monitoring network comprises various components which may not be independent, it is reasonable to assume that this cost increases monotonically with the number of samples collected at the monitoring sites and the number of sites. This assumption validates the replacement of a cost estimate by the total number of samples in an operation research model for the development of a monitoring design. This assumption also leads to the articulation of the problem of an efficient water quality monitoring design in the form (2), since the articulation in the form (1) requires explicit estimates of the cost of a monitoring design.

Monitoring objectives impose additional requirements on data sets used for data analysis. These requirements can be formulated using models describing environmental indicators selected for the preprocessing of raw observation data, e.g. the mean or the stratified mean of a selected indicator.

The effectiveness of a monitoring program should be a quantitative measure evaluating the extent to which monitoring objectives are satisfied. At the same time, this measure should demonstrate to what extent one monitoring design outperforms another. Meeting the monitoring objectives means to provide data sufficient to derive reliable estimates. In general, the estimates derived from monitoring data are considered reliable when their uncertainty does not exceed an established level. The articulations of the effectiveness in terms of uncertainty has been discussed earlier (Erechtchoukova and Khaiter 2010).

4.1 Uncertainty in Water Quality Monitoring Data

There are various classifications of uncertainty in observation data (Harmel et al. 2006; Cuadros-Rodriguez et al. 2002). In the chapter, uncertainty of observation data is classified into two types: observational artifact and the uncertainty introduced by temporal and spatial resolution of a monitoring system, particularly by selecting sampling sites and frequencies of observations. Model utilization for evaluating environmental indicators and generating conclusions makes model uncertainty an important factor in the overall assessment of water quality monitoring uncertainty.

Observational artifact is produced by measurement tools and analytical methods used in laboratories in order to obtain values of environmental indicators of interest. The type of uncertainty was defined in ISO Guide (1993), which suggests the ways for the evaluation of standard and expanded types of uncertainty. Although the proposed methods have given rise to some concerns regarding their statistical validity among statisticians (e.g., Gleser 1998), the methods provide formulae for approximation of measurement uncertainty in a consistent way. The current study does not deal with this type of uncertainty, admitting, however, that although some improvements of the results are attainable, this type of errors in monitoring data is unavoidable.

The very idea of the monitoring to describe continuous fields of concentrations of chemical constituents or physical parameters by discrete samples collected from time to time implies the uncertainty since it is based on an assumption that values of observed water quality parameters remain steady in a neighbourhood of a sampling site for some period of time which is not always true. This type of uncertainty can be reduced by optimizing spatial and temporal monitoring design and, most likely, by introducing additional sampling sites with higher frequencies of observations, but can hardly be eliminated entirely. Usually, monitoring guidelines recommend keeping both types of uncertainty below a 10% level.

Model uncertainty plays an important role not only in evaluating of environmental indicators, analysis and interpretation of monitoring data, but also in identifying an appropriate temporal and spatial resolution of a monitoring system. Frequencies of observation are derived from model properties and seem to contain an error. Being a simplified representation of reality, no model can fully duplicate real system behaviour and, thus, introduces an error which is also referred to as model uncertainty. Model uncertainty, in its turn, transforms into the errors in recommended frequencies of observations. These errors can be minimized by selecting a model which, under given assumptions, describes an investigated system better than others. Models receive the uncertainty from previous monitoring phases and convert it into uncertainty of information required for decision making. The resulting uncertainty must be understood, quantified, and limited to a reasonable extent with respect to the cost of possible consequences of decision errors.

A commonly accepted definition of model uncertainty interprets it as deviations of simulated system variables from their known or observed values (Campolongo et al. 2000). It allows to evaluate the uncertainty as the variance of an estimate which has been obtained on data collected in accordance with a monitoring design and a model used for the estimate. Model uncertainty undoubtedly influences the process of conversion of monitoring data into information.

4.2 Temporal Monitoring Design

A formal definition of the effectiveness of a monitoring design requires selection of an indicator of interest. Since the presence and amount of various constituents in a water column are determined based on their concentrations, the current study used the average concentration ($\bar{C}$) of a substance over an investigated period of time as one of the primary indicators of water quality. The severity of the organization's impact on a waterbody depends on the amount of pollution released into the waterbody. Therefore, the chemical load ($\bar{L}$) over an investigated period of time is considered as another representative indicator of an organization's environmental performance. The chemical load is calculated as the total amount of a substance contained in a given volume of water. The variance of this estimator can be directly obtained from the variance of concentrations of selected constituents. The effectiveness of a monitoring design monotonically decreases with the increasing uncertainty of the estimate. Assuming that the maximum effectiveness is achieved when the accurate estimate is available, the problem of optimization of a temporal monitoring design can be formulated as the following operation research model:

$$\min\ n\ \text{subject to} \tag{1}$$

$$\left|\frac{D(I(n))}{I(n)}\right| \times 100\,\% \leq V \tag{2}$$

where n is the total number of observations in the design, I is the selected estimator, $I(n)$ is its estimate on a set of n observations, $D^2(I)$ is the variance of the estimator I, and V is the acceptable level of the uncertainty in I.

The investigation of monitoring designs developed using various criteria of effectiveness and indicators for a single water quality parameter has been done earlier (Erechtchoukova and Khaiter 2009). It has been shown that the total number of observations required to achieve a desired level of uncertainty in the estimate significantly varies for different parameters. Since modern analytical methods determine concentrations of several water quality parameters from the same water sample, it is necessary to compromise monitoring designs for individual constituents so, that estimates of all these water constituents meet monitoring objectives. For this purpose, the constraint function (2) must be replaced by a set of constraints individual for each investigated parameter:

$$\left|\frac{D(I_k(n))}{I_k(n)}\right| \times 100\,\% \leq V_k, k = 1, \ldots, K \tag{3}$$

where I_k is the estimator of the kth constituent, V_k is the acceptable level of uncertainty in this estimate, and K is the total number of constituents of interest.

An obvious advantage of the models in the form of either (1) and (2) or (1) and (3) is that they do not require site specific parameterization. The constraint functions (3) are evaluated based on the time series of concentrations of the selected water quality parameters collected at the investigated sites. The solutions of the models (1) and (2) and (1) and (3) have been obtained using non-gradient constrained optimization method implemented in MATLAB 7.1 (Conn et al. 1997).

Since the objective function (1) is linear, the optimal solutions are expected to be found on the border of the area formed by the constraint functions. Hence, the solution of the model (1) and (3) recommends the number of observations which is the maximum of the numbers for all K water constituents. It may result in over-sampling for many water constituents. Given that concentrations of these parameters form under common hydrological and climatic conditions, it is reasonable to assume that series of concentrations are somehow related. If such relationships are registered, they can be used to restore the values of more variable water quality parameters based on the values of the parameter with the lesser variability and to reduce the number of water samples required to achieve the established level of uncertainty in the estimates. If the concentration of a water constituent can be expressed as

$$C = f(C_{CMV}) \tag{4}$$

where C_{CMV} is the concentration of the water constituent with the minimal variance, and f is a regression function, the following substitution

$$D(I_C) = D(I(f(C_{CMV}))) \tag{5}$$

can be used in (3) to develop efficient monitoring designs.

5 Case Study

The proposed approach to the development of efficient monitoring designs has been applied to the data sets collected at the cross-section Vyatskiye Polyany of the Vyatka River. The Vyatka River is a large Eastern-European river with a length of 1,370 km and a watershed area of 129,000 km^2. The selected cross-section is located in the industrial area and the section of the river experiences an anthropogenic impact. The level of pollutants in the waters of the investigated section depends on their concentrations in the wastewaters, the amount of wastewaters released into the river, and hydrological characteristics of the water flow. The selected cross section is characterized by the average annual water discharge of about 22.6 km^3.

Two years with different hydrological characteristics have been chosen. Year 1 has a unimodal type of hydrograph and sharp rising and falling limbs for spring-summer high flow events. The hydrograph in Year 2 is bimodal: high flow events took place in spring-summer and late fall. Both hydrographs exhibit distinct hydrological seasons with sharp rising and falling limbs for spring-summer high flow events.

The approach has been applied to a series of concentrations of major ions. Chloride ions (Cl), hydrocarbonate ions (HCO_3) and total dissolved solids (TDS) were selected as water quality parameters of the interest mainly due to the availability of daily water discharges and detailed series of concentrations. Their chemographs are presented in Fig. 1. The series of instantaneous loads have been derived by multiplying the corresponding water discharge and concentration values. The statistical summary of the investigated time series is presented in Table 1.

The total number of required observations has been determined for individual water constituents using models (1) and (2) for different levels of uncertainty in the estimates of the average concentrations over a year period and the total annual chemical loads of the chosen water quality parameters (see Fig. 2).

On the next step, the total number of observations required to achieve the established level of uncertainty has been recalculated using models (1) and (3). The results for the Year 1 and Year 2 are presented in Table 2.

5.1 *Adding the Model to Improve the Monitoring Designs*

Simultaneous satisfaction of the constraints in the form of (3) produces the annual number of observations in the designs sufficient to estimate the most variable of the investigated constituents, chloride ions. Following this recommendation, the two other water quality parameters would be observed with the frequency exceeding the required one for the evaluation of the average concentration by 60 %. This can be explained by the fact that the fitness function is linear. Even by adding the weighting coefficients to the constraints this outcome cannot be avoided.

Similar effect has been observed for the chemical load estimates. This indicator is evaluated based on instantaneous loads exhibiting higher variability compared to the series of concentrations of the water constituents. That is why the recommended total number of observations for the load estimates exceeds the numbers sufficient for the evaluation of the average concentrations.

The regression analysis of the series of concentrations of the investigated water constituents revealed the high level of correlations among them. Thus, the correlation coefficient between TDS and HCO_3 ions was 0.98 and the same coefficient between TDS and chloride ions was about 0.76. Such correlation among a set of water quality parameters observed at the same sampling site is expected. The presence and level of concentrations of different water constituents are affected by waterbody processes as well as anthropogenic and natural factors, typical for a sampling site and common for all or some of the water constituents observed at this site. At the very minimum, common hydrological conditions contribute to the dynamics of all observed parameters. At the same time, due to

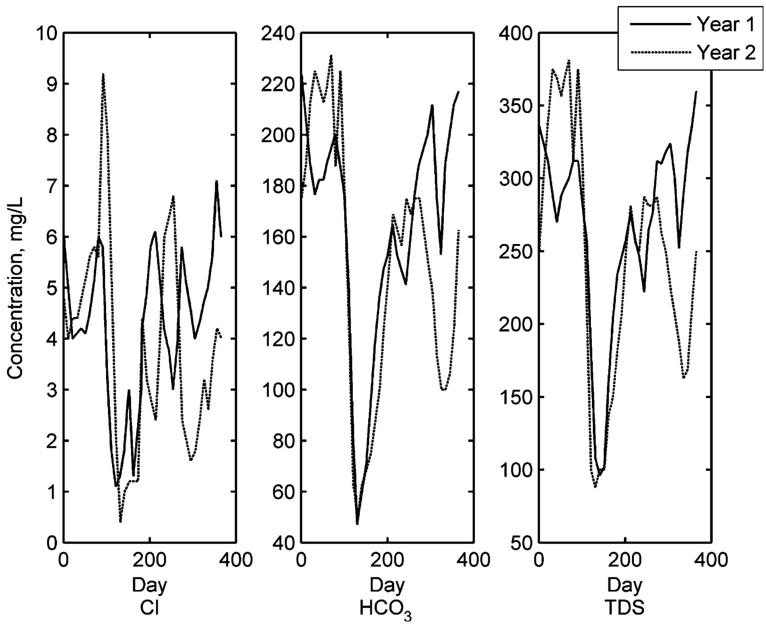

Fig. 1 Chemographs of water quality parameters

Table 1 Basic characteristics of the selected water constituents and water quality indicators

Years	Indicator	Water constituent		
		TDS	HCO_3	Cl
Year 1	$\bar{C}$ (mg/L)	263.2	161.6	4.2
	Variation coefficient of $\bar{C}$	0.240	0.269	0.341
	$\bar{L}$ (g/s)	135,669.2	80,428.1	2.077.8
	Variation coefficient of $\bar{L}$	0.730	0.694	0.848
Year 2	$\bar{C}$ (mg/L)	245.8	148.1	3.8
	Variation coefficient of $\bar{C}$	0.337	0.342	0.514
	$\bar{L}$ (g/s)	121,446.6	72,925.3	1,784.3
	Variation coefficient of $\bar{L}$	0.672	0.671	0.847

specific biochemical properties and external factors, the investigated water constituents exhibit different variability which explains the distinctions in monitoring designs when each of them was considered separately.

The correlations among the series of instantaneous loads were even stronger than those among the series of concentrations in Year 2 and almost the same in Year 1. The polynomial regression analysis showed that the relationships between series of concentrations of the investigated water constituents are described by linear functions very well. The increase in the polynomial degree does not yield the improvement of the least square fitting. The same result has been obtained for

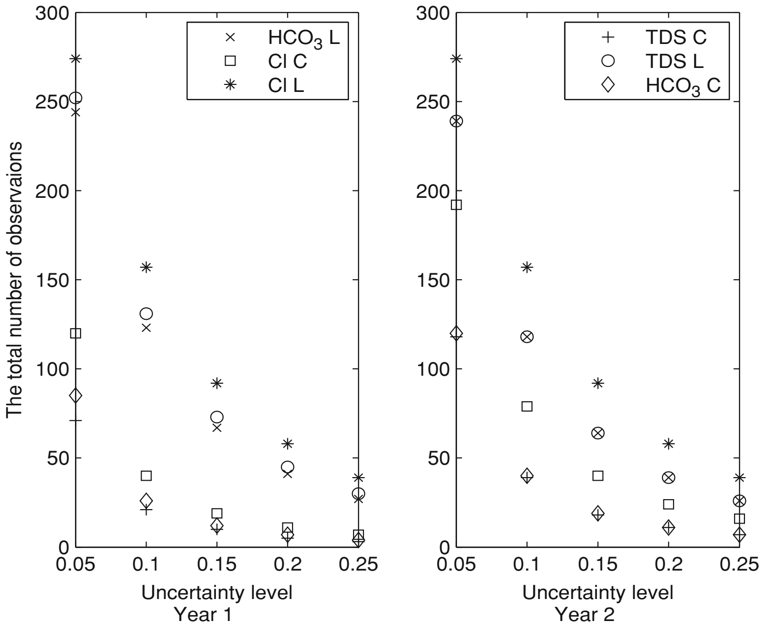

Fig. 2 The total number of observation versus uncertainty in the estimates

Table 2 The total number of required observations to estimate all investigated water quality parameters versus uncertainty level

Years	Indicator	Uncertainty level (%)				
		5	10	15	20	25
Year 1	$\bar{C}$	120	40	19	11	7
	$\bar{L}$	274	157	92	58	39
Year 2	$\bar{C}$	192	79	40	24	16
	$\bar{L}$	274	157	92	58	39

the series of instantaneous loads. The polynomial coefficient of the highest degree decreased significantly diminishing contribution of non-linear terms (see Fig. 3). Assume that the concentration C of a water quality parameter is estimated as:

$$C = a \times C_{CMV} + b \quad (6)$$

where C_{CMV} is the concentration of the constituent with the minimal variability, a and b are regression coefficients identified based on the least squares fitting. Then, the variance of the estimator I_C can be evaluated using the series of the constituent with the minimal variability in the following way:

$$D(I_C) = a^2 \times D(I_{CMV}) \quad (7)$$

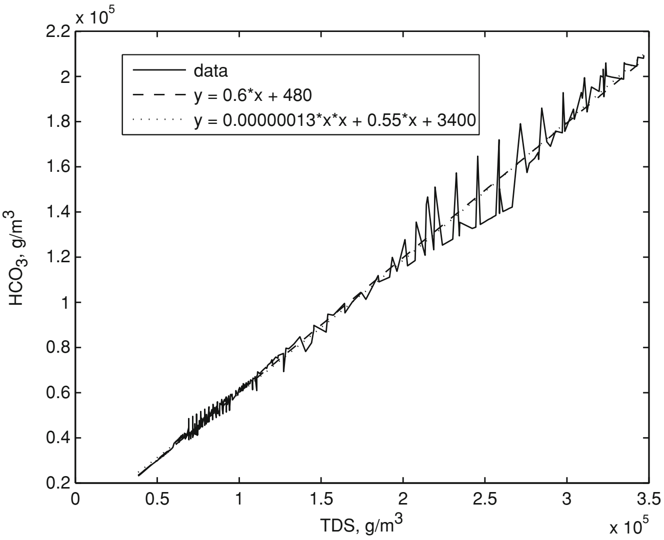

Fig. 3 The results of the regression analysis of the series of the total dissolved solids and hydrocarbonate ions, Year 2

Formulae (6) and (7) have been used in the constraint expression (3) to obtain monitoring designs sufficient to estimate the average concentrations and the total annual chemical loads of all three water constituents for a given level of uncertainty. The suggested designs for Year 1 and Year 2 are presented in Table 3.

6 Discussion and Conclusions

The linear regression models applied in this study to describe concentrations of water quality parameters with the higher variability help to reduce the total number of water samples for the evaluation of the average concentrations over a year period of all three water quality parameters by 37% in Year 1 and by 45% in Year 2. Although these numbers exceed the numbers of required observations for total dissolved solids, the absolute values of the increment are relatively small. Introducing model (6) for the estimation of the total annual loads of the investigated water constituents also reduced the total number of required observations by up to 30% in Year 1 and up to 50% in Year 2. Overall, the results support the application of the regression models for the estimation of the missing concentrations of the water constituents with higher variability. The study showed that the better the model describes the relationships between water quality parameters, the closer is the common total number of observations to the number recommended for the least variable water constituent.

Table 3 The total number of observations required for the evaluation of all investigated water quality parameters with different levels of uncertainty

Years	Indicator	Uncertainty level (%)				
		5	10	15	20	25
Year 1	$\bar{C}$	83	40	12	7	4
	$\bar{L}$	252	131	73	45	30
Year 2	$\bar{C}$	127	43	21	12	8
	$\bar{L}$	240	118	64	39	26

Formula (7) suggests that, in general, a model application by itself does not guarantee improvements in monitoring designs. It is important that the variance of a simulated series of data is less than the variance of observed data. In the case of a linear model, the regression coefficient a must be less than 1.0. If this condition is not satisfied, the model amplifies the variability and, hence, the total number of required observations increases.

In the current case study, the least variable water quality parameter (the concentration of TDS) had the largest mean value. That is why the coefficient a in (6) is less than 1.0 and the variance of the estimate based on the regression function is less than the variance of the mean for either hydrocarbonate ions or chloride ions. The aggregate nature of TDS allows for an assumption that the same pattern will be observed on many other monitoring sites and waterbodies. If the constituent with the highest variability would also have the largest mean value of concentrations, the approach may not necessarily reduce the number of required observations. The choice of an appropriate water constituent as a base parameter will be investigated in the future. Since the total dissolved solids reflects the cumulative contents of several water quality parameters, the mean value of this water quality parameter will always be higher than the mean values of other parameters determined from the same water sample. That is why TDS can be considered as a parameter which determines the sampling design.

Suggested monitoring designs are obviously model-dependent. The choice of linear regression functions in this study is justified by the statistical properties of the investigated series of data, namely, their high correlations. These relationships can vary from one site to another and over time. In general, it is necessary to determine the appropriate form of the regression function, which will be waterbody and site specific. It is worth noting that monitoring designs are developed for future use based on observations conducted in the past. The relationships between constituents in a water column are conditioned by the factors typical for a site. These factors may vary slowly and can be considered as static. Nevertheless, it is necessary to check periodically the validity of the parameters of the selected models.

The numbers of required samples obtained from the models (1), (3), (6) and (7) for Year 1 and Year 2 are different due to the natural variability of the selected water constituents. The designs common for both years and all indicators and ensuring the estimates with the desired levels of uncertainty are those corresponding to Year 1 for the total annual load of chloride ions evaluation (see Table 3).

The developed monitoring designs depend on the selected estimators of environmental indicators. On the same data set, values of estimator's variance may vary significantly for different mathematical expressions. The estimators should be built on the same mathematical assumptions as those that determine an appropriate monitoring design. However, numerous examples demonstrate that objectives may change between the time a monitoring design was developed and the time it is applied for data collection. Moreover, data collected for one set of objectives can be used for the purposes which were not even considered at the planning stage. Following Overton and Stehman (1995), utilization of monitoring data for various types of data analysis requires simple sampling designs. The latter explains the choice of the non-stratified estimators and the variance of the estimator as a measure of uncertainty which implies simple random designs.

The total numbers of observations in the designs common for all investigated water quality parameters are sufficiently higher than numbers prescribed by existing monitoring recommendations for archiving the declared 10% uncertainty in information. If uncertainty level of 15% or higher is acceptable for some water constituents due to a site specific or project specific needs, different levels of uncertainty can be recommended for water quality parameters according to their importance for a task at hand. The proposed approach can generate simple random designs with reduced numbers of required observations.

The proposed approach to the development of efficient monitoring designs is based on statistical methods and the operation research model which are implemented in the form of computer programs. These programs allow for automatic development of the monitoring designs and can be easily integrated into organization's management systems.

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Conception of Interactive Information and Decision Support System for Urban and Industrial Air Quality Management: Extension

Cezary Orłowski, Łukasz Szczygielski and Krzysztof Bartosiewicz

Abstract This chapter presents conception of interactive information and decision support system for urban and industrial air quality management and describes in detail possible solution based on *AirWare* system developed within *Eureka WEBAIR* project. The emphasis of the project is on real-time analysis and multimedia information, and the support of distributed and mobile clients through the Internet. The approach integrates meteorological data and forecasts, air quality and emission monitoring including mobile sources such as traffic, dynamic 3D simulation modeling and forecasting, GIS, expert systems, optimization, decision support and reporting tools in a unified, modular client/server framework implemented as a range of web accessible application services.

1 Introduction

The aim of this chapter is to present a model of a decision support system and its application to air quality management. The project is within the framework of the global undertaking *Eureka WEBAIR*.

The first part presents the general characteristics and assumptions of *Eureka WEBAIR*. Then the merits of the project for the Tri-City area are discussed and the

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main objectives of the decision support system created for the project are characterized. The next section discusses the construction of the model and the stages of its implementation. The presented work is concluded with a summary and an assessment of the system's practicality.

2 Background of the Model: *Eureka WEBAIR* Project

2.1 Eureka Project

The emphasis of the project is on real-time analysis and multi-media information, and the support of distributed and mobile clients through the Internet. The approach integrates meteorological data and forecasts, air quality and emission monitoring including mobile sources such as traffic, dynamic 3D simulation modeling and forecasting, GIS, expert systems, optimization, decision support and reporting tools in a unified, modular client/server framework implemented as a range of web accessible application services.

WEBAIR will develop, test, and implement a web based information- and decision support system for urban and industrial air quality assessment and management in support of relevant EU Directives such as the Air Quality framework Directive for urban conglomerates (96/62/EEC) and major industrial emission sources such as thermal power plants (88/609/EEC) or incinerators (89/429/EEC, 89/369/EEC), and 90/313/EEC on freedom of access to environmental information.

The basic idea is to offer an integrated set of tools to support regulatory compliance and reporting requirements for and on behalf of cities and industries subject to the above environmental directives. The basic business concept is complete or partial outsourcing of a range of web-accessible application services for distributed and mobile clients. Regulatory reporting as well as public information is the information product derived as an added value service from basic meteorological and environmental data. Value added in public–private partnership, and open access to environmental information as foreseen under (90/313/EEC), packaged as attractive, informative, and educational multi-media content for a range of user communities, are key concepts.

Technically, the emphasis is on real-time analysis, combining on-line monitoring and model-based assessment into multi-media information and report for a broad range of consumers, including the general public interested in environmental quality. The support of distributed and mobile clients through the Internet adds an additional business perspective for network and mobile phone operators.

The approach integrates a range of real-time and on-line data sources and tools: meteorological data and forecasts, air quality and emission monitoring including mobile sources such as traffic from on-line observations and counts, dynamic 3D simulation modeling and forecasting, GIS, expert systems, optimization, decision support and reporting tools in a unified but modular client/server architecture implemented as a range of web accessible application services. In addition to real-time monitoring and assessment with on-line publication of the information in real time as well as forecasts, and regular compliance reporting to meet regulatory requirements, the tools will also support strategic analysis of emission control using complex optimization technologies.

The technological developments in *WEBAIR* will focus on a number of specific closely related areas:

- acquisition and real-time processing of monitoring and observation data; the emphasis is on capture of potentially large volumes of diverse data, efficient storage, quality assurance (plausibility, completeness, consistency) and retrieval in support of real-time processing, integration of diverse data sources including meteorological data and forecasts, air quality monitoring, satellite imagery, emission monitoring, and traffic observations;
- integration of real-time modeling tools to augment the monitoring data from a few locations into a complete yet detailed spatial coverage of air quality information; in addition to the real-time now casting and data assimilation, short and medium term forecasts based on meteorological forecasts and dynamic emission models will be run on a regular basis, synchronized with the observation frequencies. Specific topics will include complex terrain, coastal locations and sea breeze, urban heat islands, behavior of fine particles and the explicit treatment of urban structures in dynamic 3D models;
- automatic translation of this information into attractive multi-media formats for web access including low-resolution mobile clients, as well as the automatic generation of summary reports over various periods according to the regulatory requirements;
- testing these components under real operational conditions in a number of applications and developing the necessary exception handling and error correcting methods for an automatic but highly reliable assessment and high availability mission critical performance.

The system offers a variety of opportunities for industry. Since it supports air quality monitoring and all industries are subject to regulatory requirements it can be used by the companies for monitoring purposes. It is possible that industries could gain a commercial access to the system to confirm on a daily basis that they fulfill regulatory requirements. Moreover since the system is available on-line it is possible to be used by industrial companies and cities as an important part of early-warning system for people and services responsible for pollution-related danger control. Finally the system can be also used by cities to support decisions in the process of urban development planning, especially by using its prediction models to find areas particularly suitable for inhabitancy (norm fulfillment forecasts).

The above-mentioned arguments show that the system can be very useful for industry and cities. That is why it is essential to involve partners from those areas in the project. The project invites industries subject to the Major Source Directive or cities subject to the Air Quality Framework Directive as test users of the system.

Technology partners sought include manufacturers of monitoring equipment and systems for meteorological data, ambient air quality, emissions, and traffic data. *WEBAIR* currently includes partners from Austria, Switzerland, Russia, Finland, Portugal, Cyprus, Morocco, Italy, Lithuania and Poland.

2.2 The Argument for the Necessity of the Eureka Project in the Tri-City Area

The Tri-City (Gdańsk, Sopot, Gdynia), together with all its urban area is the largest industrial and cultural center in Central Pomerania. Its specific geographical location, the presence of all the everyday means of transport (road, rail and air) and the fact that it is home for some large and environmentally burdensome industries (such as shipyards, power plants, a refinery), are all sources of air pollution, and pose a threat of a major industrial incident. The communication system, and in particular the main thoroughfare that passes the centers of all the three cities, with dense housing either side, is also unfavorable from the viewpoint of environmental risk. From the main thoroughfare, there are connections to such areas as the ports, shipyards and other industrial plants.

It seems appropriate to create a distributed IT system to manage air quality, which takes into account this specific communication system and the influence of large companies (Lotos, CHP plant, the Port of Gdansk) on the formation of the air pollution map in the Tri-City. The developed solution will be an easily adaptable system for any urban area dealing with environmental problems and industrial hazards and the consequences for residents which arise from these risks.

The system developed under the *Eureka WEBAIR* project will create conditions for the construction of multi-annual investment plans and development strategies. It will be possible through the use of fuzzy urban development scenarios (Polish partner's contribution) and their verification in an integrated IT urban-ecological environment. This approach will allow for the verification of the effectiveness of company environmental management systems, based on ISO 14000 and EMAS, but will also allow for the rapid identification of possible risks arising from road transport.

3 The Decision Support System Model for Air Quality Management

The aim of the Polish part of the project is to develop a decision support system by building a distributed system to manage air quality in urban areas. It is aimed at the needs of large urban decision-makers to assist their planning decisions. Its design is based on the construction and use of fuzzy decision-making scenarios and their subsequent processing.

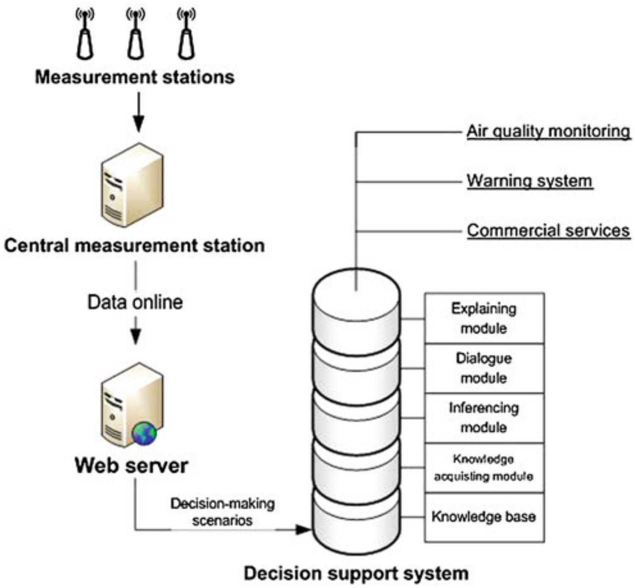

Fig. 1 Decision support system

The system developed within the *Eureka* project will help build and verify the long-term investment plans and development strategies for Gdansk up to the year 2025, while taking into account the specific communication system and the influence of large companies (Lotos, CHP plant and the Port of Gdańsk) on the formation of the pollution map in the urban area of the Tri-City. There is also a plan to use an alarm-warning system, in the event of threats resulting from transport, or industrial incidents.

The developed solution will be a system easily adaptable to any urban area dealing with environmental problems and industrial hazards and the consequences for the inhabitants resulting from the aforementioned threats. Therefore, an open solution will be implemented (in view of the other project partners) which will enable the system to cooperate with other systems to provide and publish data by these systems. It is also assumed that it will cooperate with the central national air pollution base JPOAT, and the system developed under the SUTRA project. In both cases, the system will automatically deliver online to the other systems the revised time series describing air pollution and the meteorological situation.

A general decision support system model for air quality management is shown in Fig. 1 (Niederlinski 2006):

Data from scattered measurement stations are transmitted to the central station. Then, the collected data are sent to the server in real time mode, which allows the measurements to be published online. These data are collected, processed and verified for the construction of decision-making scenarios. The revised scenarios for decision-making feed into the knowledge base of the expert system. The stages of the implementation of the model are shown below.

Stage 1. Extending the activity of measurement stations with devices and functions for checking air quality.

The provision of data for decision-making scenarios will be implemented by the Technical University of Gdańsk in cooperation with the *ARMAAG* Foundation and the Marshal's Office. The *ARMAAG* Foundation has 10 stations and central station software (CAS) assisted by applications for the verification, validation and visualization of information. The standard network activity of automated stations is carried out on the basis of the QA/QC plan (Quality Control/Quality Assurance).

Due to the needs of the decision-making scenarios, it will be necessary to ensure the quality of the automated measurements, which will require the application of appropriate quality control procedures throughout the measuring process. The data from all the automated stations will be transmitted to the central station in real time. The results and statuses of the measurements will be archived in local stations and stored in a raw data database without the possibility of changes being made by the operator. In addition, to ensure the quality of data, a plan for calibration is to be developed, according to which operations will be made to be included in the full calibration of an instrument.

It is also planned to expand networks in certain zones which, after consultation with the *ARMAAG* Foundation, were considered insufficient in terms of providing measurements (e.g. along the main thoroughfare of the Tri-City, as well as in areas of increased industrial hazard). To achieve this aim, modern monitoring stations, designed at the Multimedia Systems Department, are to be used. Apart from providing noise measurement and image analysis, they will cooperate with a highly integrated autonomous weather station. Moreover, thanks to its modular design, the system can be extended with pollutant sensors: SO^2, NO^2, CO, C^6H^6, O^3, WWA, PM10, PM2.5 as required. Such a plan will provide sufficient accuracy and quality of calibration, and thus will ensure the high quality (accuracy, completeness and consistency) of data collected with the use of analyzers prepared in such a way.

The concept of using online data in the construction of decision-making scenarios assumes that the data will be provided by a coherent measurement program and a model showing how the emitted substances spread, which will be well-suited to the local (regional) conditions. In the construction of decision-making scenarios, the policy makers—planners will need to take into account the specific meteorological and functional conditions of the Gdansk urban area (Sopot has the status of a spa), for which the objectified measurement system will become an indispensable and irreplaceable tool. Therefore, the quality of the measurements will be critical for the overall decision support system.

Stage 2. The development of a solution to provide pollution and meteorological data online to the needs of a web server.

It is suggested to develop a platform for a web application based on OpenACS (Open Architecture Community System—http://openacs.org). This offers a range of services necessary for creating web-based applications:

- a system of access rights defining precisely which functions can be implemented by individual users of the system;
- a secure user authentication using encrypted transmission SSL and user sessions based on a mechanism of digitally signed cookies;
- standard components of the user interface, a template system which allows:
  - separation of the logic of the application and of the presentation layer in accordance with the MVC design pattern (Model—Viewer—Controller);
  - mechanisms for putting application data into packets to allow software modularity;
  - mechanisms to monitor the process of running the application, watchdog, security logs and backup;
  - mechanisms for load-balancing, clustering and database replication, allowing an application to be built within a system which ensures high reliability and scalability;
  - the handling of database connection pools and a mechanism for SQL dialect abstraction of a specific product, the so-called Query Dispatcher.

On the basis of the above-mentioned services, it will be possible to efficiently create web-based applications with high performance and reliability.

Stage 3. Data acquisition and verification.

For the selection of decision-making scenarios, it is planned to provide historical data from monitoring the stations of the *ARMAAG* network and eleven upgraded stations belonging to the Provincial Sanitary—Epidemiological Station, where automated equipment will be implemented. The responsibility for this task will lie with: the Technical University of Gdansk and the *ARMAAG* Foundation. Data obtained from monitoring stations, and IT solutions for transferring and storing the data will be subject to verification processes. Therefore, it is assumed that the prepared solution should have the following features:

- automation of the measurement data publishing process and the simplicity and convenience of publishing supplementary information, giving the opportunity to operate an updated Internet service;
- a mechanism to automatically create back-up copies to protect against physical damage to the measurement system and its central station;
- professional security;
- the possibility to adapt the model for the collection of environmental measurements to any system for measuring and collecting results from multiple measurement systems simultaneously;
- the function of automated standardization of measurements, allowing the independence of changes in the configuration of the measuring system;

- the possibility of full control over published volumes of measurements thanks to modular validation of standardized measurement data;
- the possibility to export the measurement data, giving the option of processing them using external specialized tools;
- the publishing of up-to-date messages about environmental quality and detailed measurement data, with access to historical information;
- a simple and convenient user interface, accessible from anywhere on the Internet with a standard web browser, which does not require the installation of client applications;
- a modular construction, which allows the implementation of the system in stages, and helps to respond to a client's needs;
- the possibility to adapt the function of the modules to particular implementation requirements;
- a remote maintenance system which eradicates the need for employing highly qualified personnel to work on site.

Stage 4. The requirements of decision-making scenarios.

It is suggested to develop decision-making scenarios in collaboration with the Municipal and Marshall's Offices. These scenarios will be built based on the requirements of specialist decision makers from the Departments of Spatial Planning and on the basis of zoning plans prepared for the Tri-City. An analysis of zoning plans, selecting a group of experts and the construction of zoning plans with the help of specialists in scenario implementation are also planned.

Stage 5. The construction of decision-making scenarios.

Detailed linguistic scenarios are suggested on the basis of the developed groups of scenarios. On the basis of these developed linguistic scenarios, their fuzzy implementation is planned (Gorski and Orlowski 2010; Stefanowicz 2003). First, the number of input and output variables should be determined. It is assumed that this number should not exceed six in the first case, and three in the second. The choice of variables should be consulted with experts in the field of planning and pollution.

Then the construction of membership functions for input and output variables will be carried out. Multiple verification of parameters and shape is assumed. Then the process of fuzzy modeling (Ionescu and Cornell 2007), including inference and sharpening processes, will be conducted. Experts will suggest the values of output variables for the inference processes. The staff from the Technical University of Gdansk will perform the fuzzy modeling processes, as well as coordinating the cooperation with experts from the planning department.

Stage 6. Implementation and verification of decision-making scenarios.

The implementation of decision-making scenarios and the fuzzy model will be carried out in two stages. First, using such a design tool as a spreadsheet for the easy modification of scenarios and membership functions. In the second stage, the implementation of the model through a scripting language and its evaluation by the project partners are planned.

It then, in addition, becomes necessary to build a graphical user interface in English, as well as to construct an additional base for storing customer records and their feedback. This solution will shorten the verification time of the system by project partners. After the development of the model, decision-making scenarios will be subject to assessment. As was the case in the previous point, the use of the graphical user interface and the new database to record customer feedback is also suggested here.

Stage 7. Constructing the model of the decision support system.

The system will be built based on the architecture of open expert systems (Niederlinski 2006; Zielinski 2000), consisting of the following modules:

- a knowledge base containing a compartmentalized object description of decision-making scenarios;
- a module of knowledge acquisition—enabling, in dialogical form, the acquisition of linguistic knowledge from experts in the field of spatial planning;
- inference module—which creates conditions for the processes of prognostic and diagnostic reasoning, based on the decision-making scenarios in the knowledge base;
- dialogue module—containing commands that allow the user to communicate with the system;
- explaining module (Marakas 1999)—software for the interpretation of the decision.

Stage 8. The implementation and verification of the decision support system.

The result of the implementation process will be a web content management system (CMS), the functions of which will be implemented using the following modules:

- the management of the published information structure, enabling the addition and deletion of pages as well as their organizing into hierarchical structures to be used as a basis for clear navigation, a selection of published content on individual web pages and templates determining the appearance of the pages;
- a content repository for storing and organizing content for publication;
- a system of presentation templates for different types of information stored in the content repository.

The CMS system typically supports content in an unstructured form. The solution also offers the definition of additional attributes of objects which enables the process of storing structured information in the form of records. Structured information related to objects will also be published with the use of presentation templates.

Furthermore, adding support for structured information can simplify the management of large data sets. The CMS system and the content repository will also enable the management and publishing of information in the form of illustrations, files, multimedia, electronic maps, numerical data in graphs, tables, summaries and reports. Its capabilities will also encompass the process of allowing access to objects managed by additional modules, which possess some logic, such as polls, surveys, forms, interactive reports and statistics. The verification of the system will be implemented via expert sessions. Such sessions with the system will be carried out by different partners of the *Eureka* project. It is planned that the results of the sessions will be collected by use of, as was previously mentioned, graphical user interfaces and databases to keep records of the session results. They will form a basis for making changes to the system in accordance with the observations of potential users.

4 Proposed System Solution

4.1 Introduction to AirWare

System implementation can be based on *AirWare* solution. Developed within the *EUREKA* project E! 3266 *WEBAIR* with partners from now 19 countries, the *AirWare* system is a modular, cascading multiple model, nested grid, fully interactive, real-time, and web based Air Quality Assessment and Management Information System for national, regional and local, urban and industrial air quality management, aimed at major industries and public institutions in support of 2008/50/EC, daughter directives, IPPC (2008/1/EC) and similar national regulations. *AirWare* is implemented as a client–server system under Linux Open Source operating system, using any standard web browser on any PC as client. *AirWare* has an open architecture and can be configured for a wide range of applications including numerous fully integrated components such as:

- monitoring data management and analysis including real-time data;
- emission inventories and dynamic emission models;
- prognostic 3D, nested grid meteorological models;
- simulation and optimization models (including 3D photochemical) for scenario analysis, impact assessment, and real-time modeling with regular, automatic nowcast and forecast runs;
- public information system (web based) components and reporting on regulatory compliance.

AirWare is the “next generation” model-based real-time and web-based information and decision support system for urban and industrial air quality assessment and management. The system supports the implementation of European and national environmental legislation such as the European Air Quality Framework Directive 2008/50/EC (replacing 96/62/EC) and Daughter Directives, 88/609/EEC on major point sources, 89/429/EEC and 89/369/EEC on incinerators or 90/

313/EEC on public access to environmental information. *AirWare* supports integrated data management and modeling tools for:

- compliance monitoring, alerts and alarms, reporting;
- nowcasts, forecasts and public information, 3G mobile client support;
- scenario analysis and source apportionment, EIA and SEA studies;
- multi-criteria emission control optimization, policy design.

A tightly integrated system in distributed client–server implementation, open, modular architecture and a fully web-based user interface exploits the latest dynamic 3D models and network computing technologies, including high-performance distributed GRID and cluster implementations. The *AirWare* models can run within a real-time expert system framework, that coordinates data acquisition from a range of information resources, hourly now-cast model runs with data assimilation, regular e.g., daily forecast runs, using observed or simulated dynamic emissions and 3D dynamic meteorological models as pre-processors.

Designed primarily for urban agglomerations and industrial areas, the modular software system integrates monitoring data acquisition and analysis in real-time, emission databases and an embedded GIS, simulation and optimization models with coverage from local and near-field to regional scales with a nested grid approach and several, nested models with different resolution and scope.

A rule-based expert system for environmental impact assessment and a range of decision support tools, including the multi-criteria optimization of cost-effective emission control strategies complement the basic simulation models and associated databases.

4.2 Description of System Components and Models

AirWare combines emission databases, monitoring data management, and several simulation models for interactive analysis which are listed below (main models are described more thoroughly in the next section of this paragraph).

- *MM5*—the fifth generation Penn State/*NCAR* mesoscale model. A nonhydrostatic, 3D dynamic nested grid meteorological forecasting model;
- *CAMx*—the Comprehensive Air quality Model with extensions;
- Other models: *AERMET*, a diagnostic wind model, *TRAFFIC*, a high-resolution model, and *PUFF*, a 3D dynamic Gaussian/Lagrangian multi-puff for transient emission or mobile sources.

Dynamic 3D meteorological data are calculated using *PSU/NCAR* mesoscale model (known as *MM5*). *MM5* is a limited-area, nonhydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale atmospheric circulation. The model is supported by several pre- and post-processing programs, which are referred to collectively as the *MM5* modeling system. The *MM5* modeling system software is mostly written in Fortran, and has been developed at

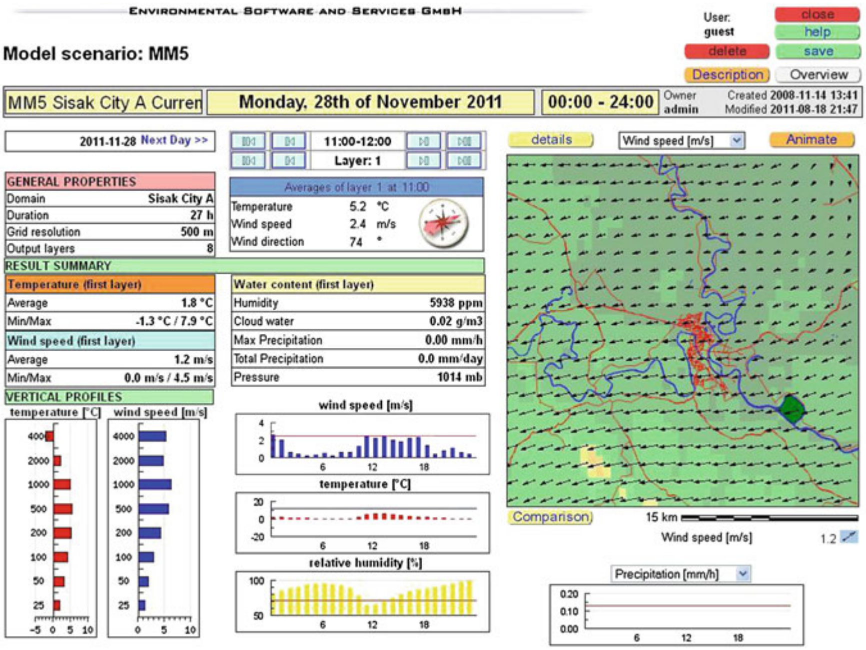

Fig. 2 Model scenario based on *MM5*

Penn State and *NCAR* as a community mesoscale model with contributions from users worldwide. (Reference: http://www.mmm.ucar.edu/mm5/mm5-home.html) *MM5* is implemented for a pre-defined domain covering an area large enough to account for the air flow during the 48 h simulation period. The model uses two-way nesting between mother domain at a coarse resolution ($\sim$27 km) and nested domains at finer resolutions (up to $\sim$3 km). The nesting ratio is always 3:1 for two-way interaction, meaning that the nest's input from the coarse mesh comes via its boundaries, while the feedback to the coarser mesh occurs over the nest interior (Fig. 2).

CAMx The Comprehensive Air quality Model with extensions (*CAMx*) is an Eulerian photochemical dispersion model that allows for an integrated atmosphere assessment of gaseous and particulate air pollution (ozone, PM-2.5, PM-10, air toxics, mercury) over many scales ranging from sub-urban to continental. *CAMx* is designed to unify all of the technical features required of state-of-the science air quality models into a single system that is computationally efficient, easy to use, and publicly available. The model code has a highly modular and well documented structure which eases the insertion of new or alternate algorithms and features. *CAMx* simulates the emission, dispersion, chemical reaction, and removal of pollutants in the troposphere by solving the pollutant continuity equation for each chemical species on a system of nested three-dimensional grids. The Eulerian continuity equation describes the time dependency of the average species

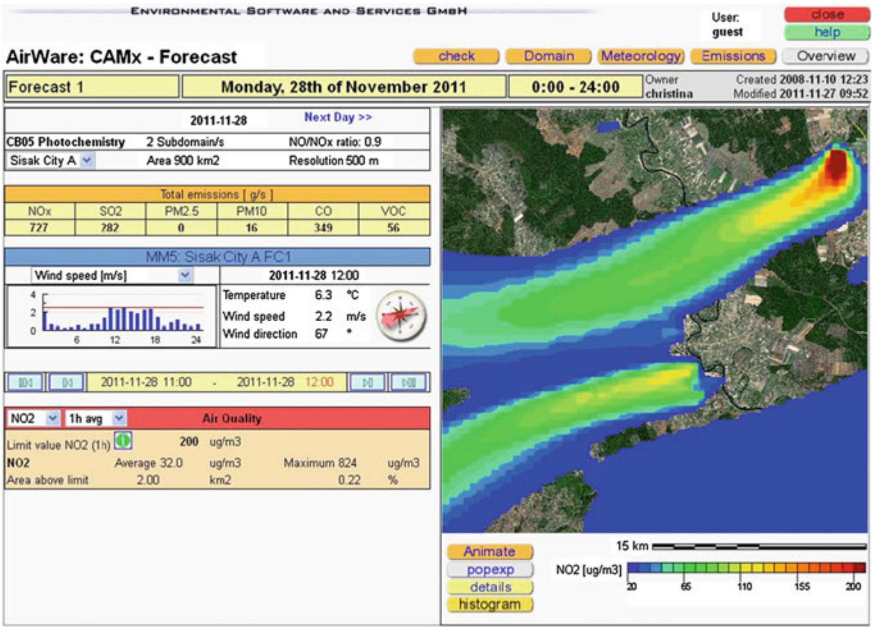

Fig. 3 Model scenario based on *CAMx*

concentration within each grid cell volume as a sum of all of the physical and chemical processes operating on that volume. The governing equations are expressed mathematically in terrain-following height coordinates. It considers a horizontal wind vector, net vertical entrainment rate, multiple vertical layers, atmospheric density, and turbulent exchange (or diffusion). The terms on the right-hand side represents horizontal advection, net resolved vertical transport across an arbitrary space- and time-varying height grid, and sub-grid scale turbulent diffusion. Chemistry is treated by simultaneously solving a set of reaction equations defined from specific chemical mechanisms. Pollutant removal includes both dry surface uptake (deposition) and wet scavenging by liquid precipitation (rain) (Fig. 3).

AERMOD is a steady-state Gaussian plume model(a regulatory EPA model), but uses concepts of boundary layer physics for the estimation of its (continuous) dispersion parameters. The model is always run for a day in 24 hourly time steps, or for an entire year with hourly results. In *AirWare*, *AERMOD* is used for:

- Scheduled runs: hourly nowcasts for the urban sub-domain and optional 24 h forecast runs;
- Interactive scenario analysis for all sources in a domain, 24 hourly runs;
- Computational kernel for the traffic convolution model, 24 hourly results; the computational kernel can be used both for individual road segments, or entire

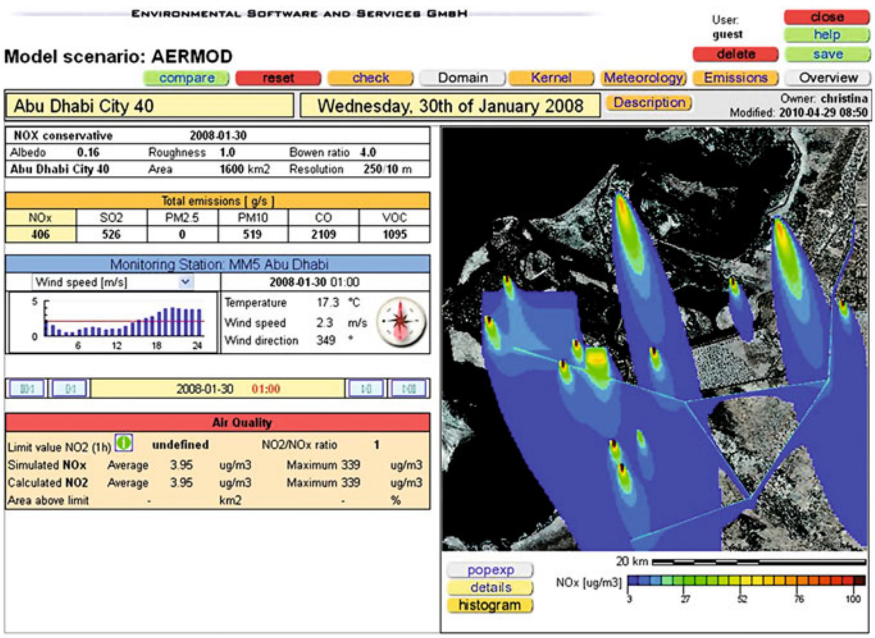

Fig. 4 Model based on *AERMOD*

domains, transparently integrated with the point and area source modeling (Fig. 4).

All the models used for the schedule hourly and daily runs are also available for interactive scenario analysis. All model scenarios are organized by object selectors that support their sorting, filtering, selection, and the creation of new scenarios. For scenarios, the user can select:

- The model domain (selecting from the set of model domains defined, or possibly creating a new domain if required);
- The data and period (hour) depending on the temporal resolution of the model;
- The meteorological conditions by selecting a representative meteorological monitoring station for the Diagnostic Wind field Model DWM (alternatively, historical data for an *MM5* run can be downloaded and used; however, to generate a meteorological scenario by *MM5* may take several hours.
- The pollutant and corresponding emission values: while these are (as readily available default values) provided automatically from the emission database, for a scenario run of any model the emission data are organized into an emission scenario, that makes it possible to modify the basic values by switching on or scaling individual sources for the scenario, or introduce new sources.
- Temporal emission patterns—monthly, daily, hourly.

Model output is shown as a transparent color coded overlay over the default map for the model domain. The user can specify the parameters for the color coding (minimum and maximum concentrations), and up to five levels of color coded isolines. Arbitrary multi-level zooming is supported.

5 Conclusions

This chapter presents the possibility of using an expert system for decision support related to the management of air quality. The suggested approach allows the use of an IT system by industry to monitor their compliance with regulatory requirements. It can also support cities in monitoring air quality in urban areas. Finally it can be used as an element of early-warning system and in decision making processes such as urban development planning. The use of fuzzy decision-making scenarios (easy to implement by experts and users of the system) as well as their subsequent processing, will provide users with accurate information about air pollution prognosis.

The system will comply with any spatial infrastructure arrangement, including the specific communication system of the Tri-City and the influence of large companies in shaping the map of air pollution in the Tri-City. The suggested solution is an indispensable tool for the implementation and monitoring of regulations under the Environment Protection Act. The open approach, which assumes the easily adaptable nature of the system, allows the use of the system in any urban area dealing with problems of environmental protection.

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Organizational Learning and Environmental Engineering with Special Focus on Health Care

Lars Rölker-Denker

Abstract The increase of information and knowledge is a general phenomenon and thus also applies to health care. Dynamic political and economic environments strengthen these effects. Multiple concepts addressing this challenge can be identified and "learning organizations" are one key concept in economics to handle knowledge increase and dynamic environment. Environmental engineering in general and Environmental Management Systems based on ISO 14001 or Eco Management and Audit Scheme (EMAS) in particular are possible ways of extending the organization's environmental awareness. The goal of this contribution is to analyze whether or not both concepts have these effects on (German) hospitals. Therefore, this contribution combines the concepts of environmental engineering, environmental management systems and learning organizations in context of hospital organizations.

1 Introduction

Health care organizations (HCOs) are typically acting in dynamic environments. Beyond their primary function of patient treatment, the HCO needs to manage an increase of knowledge and quality in health systems by providing, for example, suitable regular training, advanced training and continuous education for medical and nursing staff on the one hand and by research activities in the medical and nursing disciplines on the other hand. Furthermore there are political, economic, technical, social and increasingly ecological constraints to consider. And finally

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hybrid organizational forms (Stummbaum 2011), inter-organizational information systems (Haux et al. 2008) and uncertain organizational boundaries (Schreyögg 1999) are other aspects of their economic activity. Legal regulation concerning environmental issues is an increasing part of this challenge. But at the same time with the publication of the IS0 14001 and Eco Management and Audit Scheme (EMAS) standardized management systems are available to face this challenge (Junker et al. 2010). Furthermore the idea of learning organization is a more general concept to solve these problems. However, Environmental Management Systems (EMS) and learning organizations are rarely combined in this context. The intention of this contribution is to bring these concepts together and give some stimulation for further research. After a brief introduction on the basic concepts of environmental engineering, learning organizations (in the three dimensions of learning levels, learning types and learning determinants) and organizational memories, the concepts are integrated and analyzed using the Organizational Learning Cube. The main part of this contribution is the analysis of organizational learning processes initiated by environmental engineering. It is shown that these processes can be found in all three learning dimensions in a hospital. So the implementation of environmental engineering could be a possibility to extend organization's environmental awareness. At least empirical surveys are recommended to approve these mainly theoretical outcomes..

2 Basic Concepts

2.1 Environmental Engineering

Environmental engineering contains a wide field of research topics. In this contribution only the topics appropriate to organizational learning are included and broadly outlined.

Information systems like Corporate Environmental Information Management Systems (CEMIS) support an organization in corporate environment protection and offer adequate methods of informatics (Junker and Lang 2011). Like other information systems, and in this context especially hospital information systems (Haux et al. 1998), CEMIS are socio-technical information systems (Junker et al. 2010).

CEMIS cover a wide range of business objectives and application areas. Business objectives are, for example, legal compliance and the support of management systems (Arndt et al. 2011) like EMAS and ISO 14000. EMAS and ISO 14000 are standardized EMS similar to quality management systems (Junker et al. 2010).

An EMS has the purpose of developing, implementing, managing, coordinating and monitoring organizations' environmental activities to achieve two goals: compliance and waste reduction (Melnyk et al. 2003). The international standard is ISO 14001 (Niemeyer 2004), the European standard is EMAS (European Commission 2009). There are 43 health care organizations certified on EMAS in Germany (EMAS-Register 2010), reliable figures for ISO 14001 are not available.

Also introduced are “green buildings” (Bauer et al. 2007) having a strong impact on the organizational culture. Green buildings focus on reducing environmental impact, structure design efficiency and efficiency on water, energy and materials.

2.2 Learning Organizations

Organizational learning has been in scientific discussion since the late 1970s with a peak in the 1990s (Lipshitz and Popper 2000). In this context learning is equated with daily work. The goal is to establish periodic reflection, systematic identification of problems and errors in daily workflow. Therefore, organization members have to be enabled to individual learning and to share knowledge (Spieß and von Rosentiel 2010). Furthermore it has to be considered that organizational learning is more than just the accumulation of the organization members’ individual learning (Hedberg 1981).

Learning organizations can be described from different viewpoints. In this contribution Wengelowski’s approach is used. He provides three main areas: learning levels, learning types and learning determinants which all can be practically mapped over an organization for analyzing its accordance with the learning organization concept (Wengelowski 2000).

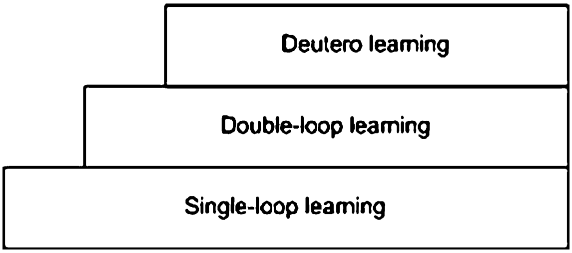
Four learning levels can be distinguished: individual learning, group (team) learning, organizational learning and inter-organizational learning. Individual learning means the changes in behaviour, theories and concepts by an individual whereas group learning means the same in a group context. “Learning in groups” as a pedagogical concept is part of the individual learning dimension. Multiple team membership connects the individual and group dimension (O’Leary et al. 2011). Organizational learning focuses on the changes in organizational behaviour or theory. If more than one organization is involved in the learning process, then inter-organizational learning can be identified.

Learning types can be differentiated into single-loop learning, double-loop learning and deutero learning (Hislop 2009). Single-loop learning focuses on incremental changes inside a constant framework while double-loop learning focuses on the framework itself. Finally, deutero learning focuses on the complete learning process and related advancements.

The learning types are based on each other (see Fig. 1). Single-loop learning is always possible without double-loop learning and deutero learning, but double-loop learning is not possible without single-loop learning and neither is deutero learning possible without single-loop and double-loop learning.

These abstract theories of learning levels and types are brought together into the organization by the learning determinants. Three determinants are discussed in

Fig. 1 Learning types



literature: organizational membership, organizational structure and organizational culture (Wengelowski 2000).

The organizational member with its unique competence setting is the first determinant. The specific utilization and advancement of competencies and qualifications among the organization members are fundamental tasks in learning organizations. Each organization member has their unique setting of competencies and qualifications, e.g. professional or social competence. Important levers are human resource development (further and advanced education) as well as staffing. The organizational structure gives the framework for all intra-organizational and partly inter-organizational processes and sets the scope of action for the organization members. Following the organizational view a differentiation can be made between organizational structure, operational structure/process organization, communicational/knowledge organization and informational organization. In detail the four types of organizational dimensions are:

- Organizational structure: The formal organizational structure describes the business entities of an organization (departments, roles, relations), the organization and deployment of resources, the definition of job activities, responsibilities and accountabilities. Several basic types of formal organizational structures can be distinguished: entrepreneurial structure, functional structure, product structure, divisional structure, matrix structure and federal structure (Carnall 1990).
- Operational structure/process organization: The coordination of business entities is the focus in this dimension. Operational structure is more common in standardized working settings like automotive industry or insurance industry whereas process organization is used if a flexible organization is required (research and development, consulting). There is a steady shift from operational structure to process organization in many industries (Bea and Göbel 2002). Business process modelling is a newer form of describing the process organization (Kurz 2010).
- Knowledge/communicational organization: The organizational infrastructure for learning processes and knowledge management is described in this dimension. Seminars, learning and quality circles (Wengelowski 2000) and also the possibility for informal meetings "next to water coolers and coffee machines" (Waring and Bishop 2010) represent areas of communication for the employees to share knowledge (Earl 2001).

- Informational organization: Subject of the informational organization is the structuring and distribution of internal/external information. Information can be distributed in written, spoken and digital form. Written media are comprised of records, documents, and company magazines whereas spoken information are mainly understood as the direct instruction respectively face-to-face communication between employees and direct supervisors (Wengelowski 2000). IT-based information systems include all kind of technical information systems. Together the informational organization is a socio-technical information system (Junker et al. 2010).

The organizational culture is the third dimension to be analyzed. Organizational culture can be interpreted as the informal organizational structure. This contribution uses the approach of Schein: subjects of study are artefacts, values and tacit assumptions.[1] Artefacts are the visible components of organizational culture like facilities, offices, visible awards as well as company slogans and the way of interacting with other organization members and outsiders. Shared values on the second level comprise the understanding of how the organization should act. On the third and deepest level the tacit assumptions can be found. These are unspoken rules followed by the organization's members (Schein 2004).

2.3 Organizational Memory

The concept of organizational memory describes the idea of storing data, information and knowledge in organizational structures and procedures (Hackbarth and Grover 1999).

An organizational memory can be divided into seven "bins" (Walsh and Ungson 1991):

- Individual bin: Individual information in the context of organizational experiences and observation is stored in the individual bin. This information should be stored in human-usable way to be used as a memory aid. Examples are emails, project reports or meeting minutes. The organization member's individual competence setting can also be part of the organizational memory when subject-competence (Delamare-Le Deist and Winterton 2005) is referred.
- Informational bin: The formal informational organisation is part of the organizational memory. As defined above, the information systems of an organization form the information bin.
- Cultural bin: All information stored in the organizational culture (Schein 2004) is part of the culture bin. Past experiences are embodied in this bin and are kept to deal with future developments. Due to its nature it is difficult to change. The

[1] For a more detailed analysis three different types of culture can be distinguished in the context of the learning organization: learning culture, communication culture and culture of trust.

culture bin manifests for example in language (May and Mumby 2005), symbols (Dandridge et al. 1980), storytelling (Swap et al. 2001; Boje 1991) and grapevine (Devine and Filos 2001).

- Transformational bin: In this bin all information regarding the processes inside organizations is stored. This knowledge is called procedural knowledge (Vera and Crossan 2003). Procedural knowledge consists of knowledge about how tasks should be performed inside a unique organization and it is also known as "know-how" (Cross and Prusak 2003). Transformation can be described with modelling languages, e.g. BPM (Business Process Modelling) (Kurz 2010).
- Structural bin: The organizational structure with departments, roles and the relations between them is the so-called formal organizational structure and can be described with organizational charts. A similar concept in business informatics is Enterprise Architecture (Aier et al. 2008) and connects the structural, transformational and informational bin.
- Ecological bin: Ecology in this context describes the physical structure of an organization (Hackbarth and Grover 1999) like buildings and office layouts. The ecology bin stores information about the organization and it also represents how members of the organization feel about the organization and how people outside the organization view a particular organization.
- External bin: External information about an organization is stored in this bin. The external bin can be formed from former employees, connected organizations in networks, external workers (like consultants, auditors, temporary workers) and government agencies. Modern information technology offers several possibilities like the World Wide Web, Wikipedia (Katz et al. 2005) and emerging social media technologies (Brzozowski 2009).

Environmental engineering covers a broad range of concepts, starting with standardized management systems and information systems right through sustainable constructing. Learning organizations include the dimensions of learning levels, learning types and learning determinants. Organizational memories as a concept are also part of the learning organizations and can be distinguished in seven bins as outlined before. In the next chapter, these concepts are generally brought together.

3 Organizational Learning and Environmental Engineering in General

Environmental engineering is a manifestation of deutero learning (Rölker-Denker 2011). It provides an alternative way of extending the organizational awareness of the organization's ecology.

EMS (Melnyk et al. 2003) as management systems are instances of the process organization, and Corporate Environment Information Management Systems (CEMIS) (Junker and Lang 2011) are instances of information systems. Both systems belong into the learning determinants in the dimension of the organizational structure.

Similar to sensor-enhanced health information systems in the context of ambient assisted living (Marschollek 2009) there are approaches to enhance environmental information services with sensor data (Karatzas 2011). External sensor data expand the organization's visibility range and thus is part of organizational learning. If external sensor data is available through external databases, these are also part of the organizational memory (Walsh and Ungson, 1991).

Several aspects of environmental engineering can be identified in an organizational memory:

- Individual bin: Individuals keep information and knowledge regarding environmental issues in their assumptions, beliefs and values (Walsh and Ungson, 1991). This could be internalized behaviour by following the waste management/separation guidelines or using ecological transportation on business trips.
- Informational bin: Information systems like CEMIS form the information bin. Organizational handbooks on environmental issues are also part of the information bin.
- Cultural bin: Internalized behaviour and assumption collected in the individual bin are also part of the cultural bin. Furthermore managers, who set the employees an example on responsible behaviour, for example in green fleet management, strengthen the culture and store good environmental behaviour in deeper levels of the organizational culture.
- Transformational bin: Management systems like EMS are either part of the transformational and the structural bin. In the transformational bin procedures and guidelines on environmental issues are stored.
- Structural bin: Roles like the environmental representative form the structural bin (Junker and Lang 2011). EMS describe the role of the environmental representative and the relations with departments regarding environmental issues.
- Ecological bin: Green buildings (Bauer et al. 2007) confirm the organization's sustainable intentions and visualize them to the public sphere. Green buildings can contain lighting modelling, solar energy, intelligent waste/water management and parking solutions.
- External bin: External databases, for example described in the STORM architecture (Solsbach et al. 2011), are part of the external bin. External sensor data can also be part of the external bin.

Despite the dissemination of the organizational learning and memory concepts a method for a systematic gathering of learning and knowledge-based processes is still missing. Due to the three dimensions proposed by Wengelowski and the inclusion of the organizational memory in the communicational/knowledge structure, a multidimensional and scalable method is required to address this issue. Hereafter, a method for the systematic gathering is introduced.

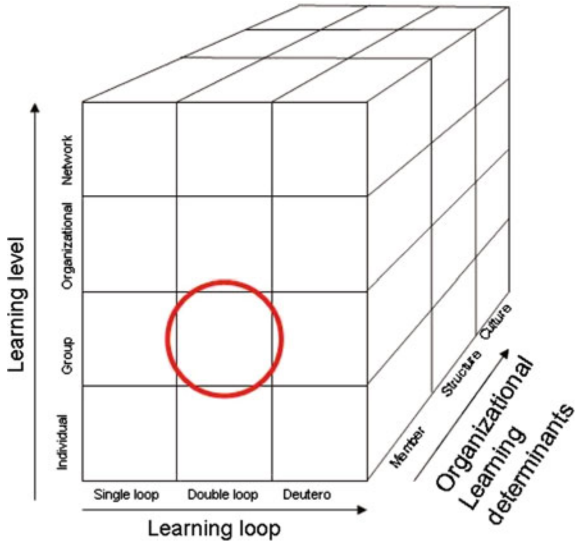


Fig. 2 Organizational learning cube (OLC)

4 Organizational Learning Cube

Two-dimensional cross-tabulation is already used for reducing the complexity of economic issues, e.g. the SWOT analysis by Albert S. Humphrey (Stanford Research Institute 2005) or the Product Portfolio Matrix by the Boston Consulting Group (The Boston Consulting Group 1970). These tools are well-suited if there are only two dimensions to be analyzed. It is possible to widen the focus of these tools (e.g. in an entrepreneurial SWOT on several departments) but they will still be limited to two dimensions.

The concept of a "data cube" can be defined as a relational aggregation operator for databases (Gray et al. 1997). Operations like rolling up/drilling down, slicing and dicing can be executed. The result is an imaginary multidimensional cube that can be processed to analyze, e. g. a care dealer's sales figures grouped by car model, colour, region etc. The data cube is not limited to three dimensions, so it is highly valuable for analyzing complex data sets.

For understanding organizational learning with the approach of Wengelowski, a three-dimensional tool is needed. For this purpose Rölker-Denker et al. (2011) propose the organizational learning cube. The concept is based on the idea of data cubes. Learning levels, learning types and learning determinants each represent a dimension and form the organizational learning cube. The cube consists of several smaller cells (similar to a geometric octant) focussing on details, e.g. the marked cell concretises group learning, double-loop learning and organizational members (see Fig. 2).

The basic idea of drilling up/down and slicing developed for databases can be also used in this context (see Fig. 3). Drilling up and down allows for an analysis

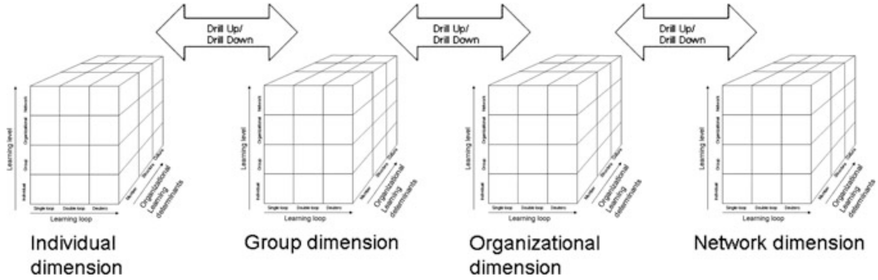


Fig. 3 OLC—Drill Up/Drill Down

on all organizational levels (individual, group, department, health care organization and network). Analyzing on the individual organizational level focuses on how the individual influences individual, group, organizational and network learning, analyzing on the group organizational level focuses on how the group influences individual, group, organizational and network etc. Finally slicing allows one to focus on one of the three dimensions of learning organizations.

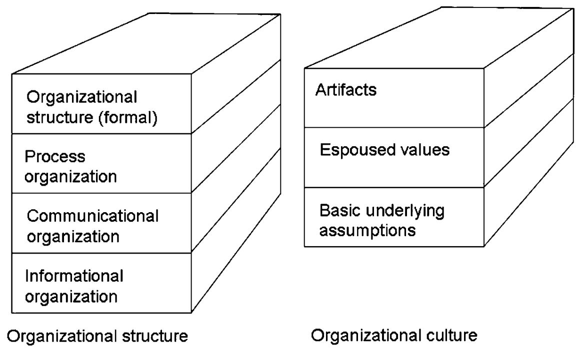
It is also possible to "zoom" into details (see Fig. 4). For example, the organization member's dimension offers some details about competencies (subject competence, personal competence, social competence, self-competence, method and learning competence, entrepreneurial competence (Delamare-Le Deist and Winterton 2005) and the culture dimension can be filled with organizational culture concepts by choice (e.g. Schein (2004)). Schein's concept of organizational culture offers the dimensions of visible organizational attributes (artefacts), values and basic underlying assumptions (tacit/unspoken rules). And at least, the organizational structure can be analyzed in the dimensions of formal organizational structure, process organization, communicational organization and informational organization (Rölker-Denker 2010). It is even possible zoom into greater details. The organizational memory can be found beneath the communicational (and knowledge) organization (Rölker-Denker 2010). Here the different bins of the organizational memory can be analyzed.

Afterwards the identification of general overlaps between environmental engineering, learning organizations and organizational memories and the introduction of a method for the systematic gathering of organizational learning processes the second part of this contribution is on the applicability in the health care sector. Previously the object of study, the German health care system is broadly outlined.

5 Organizational View on German HCOs

The German health care and health insurance system consists of two main parts: the health insurance providers and the service providers. There are other actors like related industries and federal institutions, for example the public health service

Fig. 4 OLC—Zoom In



with health departments and federal agencies (Kamke 1998). Three types of service providers can be distinguished: the in-patient sector with hospitals (public, private non-profit/semi-public and private-profit), the out-patient sector with ambulatory medical care, physicians (family doctors, specialists) and the rehabilitation sector. The focus of this work is on hospitals and, therefore, the organizational view is broadly outlined next.

Most organizational structures in German hospitals follow the matrix organization with a strong diversification by profession and function. Hierarchical structures are built among the professions and segmented into medical services, nursing services and administration with a steering board on top including the head of each profession. With the launch of the German DRG- (diagnosis related group) reimbursement system and case-based lump sums, process organization continues to replace the former classical process organization. In-patient treatment is shifting from "medical art" into a treatment process which can be completely managed. Clinical pathways are one key concept in this discussion (Vanhaecht 2007).

A clear definition of clinical pathways has not been found yet. In general a core definition of clinical pathways includes statements about patient-care management of a well-defined group, the goals and key elements of patient treatment, sequences of multidisciplinary activities and recommendations about communication, documentation and monitoring (De Bleser et al. 2006).

Several aspects need to be included in the communicational and knowledge organization: all kinds of training and education, knowledge management as well as internal and external quality management. Further and advanced education are important factors facing the continuous development of technical, medical and nursing advances. Further education implies continuing medical education and increasingly continuing nursing education whereas advanced training implies residency for medical staff and similar offerings for nursing staff (Rölker 2007). The informational organization can be divided into three parts of verbal, written and IT-based organization. Combined, these parts are forming the socio-technical information system of an organization with all functions on information processing and storage. In hospital environments these systems are socio-technical hospital information systems (Haux et al. 2004) including electronic patient records, subsystems such as radiology information systems or laboratory information systems, all kind of archives such as picture archiving and communication systems, learning management systems, employee magazines etc. At least, communicational/knowledge and informational organization form the organizational memory (Virani 2009).

6 Organizational Learning and Environmental Engineering in Health Care

The key concepts in learning health organizations are clinical pathways, nursing guidelines and standards (for details see (Rölker-Denker 2010)) as well as management systems. The basic idea behind the first three concepts is a structured patient treatment assisted by continuous improvement process. The basic concepts of structured and continuous improvement processes are similar to EMS. It can be supposed that both concepts (clinical pathways and EMS) will occur in similar ways but with different contexts and appearances. Beside EMS other aspects of environmental engineering are also part of the learning health care organization and will be contextualised.

6.1 EMS and Organization Members

The organization member supports the learning organization in different ways (see Fig. 5). At first, there are individual learning experiences. They appear in several forms. Regular, further and advanced education are the most visible ones and are completed by individual learning experiences in quality circles, environmental management systems and project groups on clinical pathways. EMSs provide individual experiences and suggestions for sustainably behaviour to the organizational member (Rölker 2007).

Adjustments on EMSs can be associated with single-loop learning. Examples are modifications during the continuous improvement process in existing environmental guidelines. The same applies to nursing standards and guidelines as well as adjustments in context of clinical pathways (Vanhaecht 2007).

Organization members support the learning hospital with their different qualifications and skills such as subject-competence, social competence, method competence, personal competence and entrepreneurial competence (Delamare-Le Deist and Winterton 2005). EMS aims on method competence, personal competence and entrepreneurial competence. Multiple team membership is a concept supported by the organization members and covers all four learning levels. If the implementation group on the broad theme complex of environmental engineering consists of organization members with manifold backgrounds (nursing teams, op teams and administration teams) the individuals have to role of knowledge multipliers

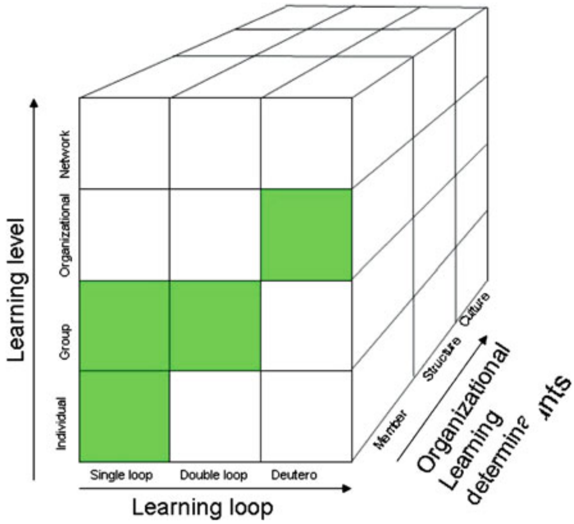


Fig. 5 OLC—EMS and Organization Member

(Cotterman and Kumar 1989). They distribute the knowledge into other groups, influence the organizational performance and even distribute into connected organizations if inter-organizational teams are implemented (O'Leary et al. 2011).

6.2 EMS and Organizational Structure

In context with the organizational structure, several instances are involved in EMS (see Fig. 6). At first, there is the environmental management representative similar to the quality management representative. He is the coordinator for all tasks regarding the EMS. Also typical is an environmental committee which is directly subordinated to the management board (e.g. (Klinikum Oldenburg gGmbH 2010)). Finally, the handbooks on EMS documenting the relevant processes are part of the organizational memory.

Double-loop learning is associated with the integration of completely new departments like energy or waste management (Rölker 2007). The implementation of an EMS or the introduction of the clinical pathway concept itself can be seen as deutero learning. These concepts (as well as nursing standards and guidelines) improve the organizational ability on environmental awareness (Picot et al. 2008).

The project groups on EMS, clinical pathways and quality circles themselves are part of the second category. Especially research and rule modifying circles meet the requirements of organizational learning. Research quality circles work on new guidelines, whereas rule modifying quality circles improve these guidelines. Group learning was proven to be an important factor for organizational effectiveness in hospitals (Jeong et al. 2007).

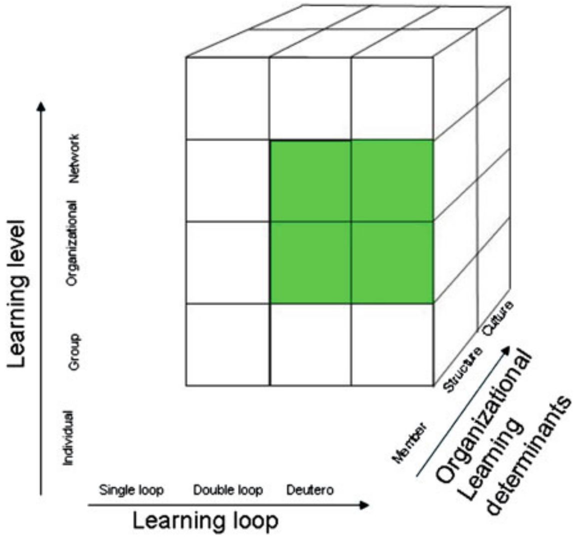


Fig. 6 OLC—EMS and Organizational Structure

Finally, an EMS occurs on the organizational learning level by improving the organizational environmental awareness in general. Similar to the concept of clinical pathways, EMSs appear in individual, group and organizational learning levels. The fourth learning level, inter-organizational learning, could be represented by highly integrated health care groups, but these are not realized yet.

6.3 EMS and Organizational Culture

Several aspects of environmental engineering represent cultural artefacts (see Fig. 7). An EMS can be interpreted as an artefact in organizational culture. The EMS represents the organizations' intention on environmental issues and is visible to all organization members and non-members. This can also be represented by an environmentally friendly constructed hospital building (Vittori and for Healthcare Engineering 2002).

6.4 Environmental Engineering and Organizational Memories

Several aspects of environmental engineering can be identified in an organizational memory:

- Individual bin: As outlined before, individuals keep information and knowledge regarding environmental issues in their individual bins. There are yet no specific bins in a health care setting.

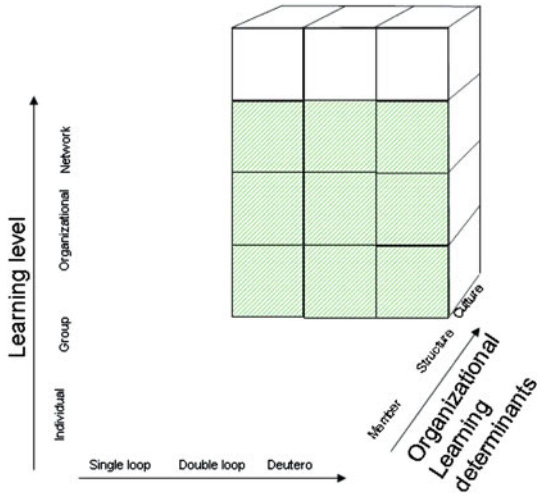


Fig. 7 OLC—EMS and Organizational Culture

- Informational bin: Hospitals use organizational handbooks to store environmental procedures and guidelines. Information systems are also in use (Rölker-Denker 2011). Information can also be stored in the environmental declaration.
- Cultural bin: Environmental Management Systems are artefacts in the organizational culture. They represent the organizations' intention on environmental issues and are visible to all organization members and non-members (Rölker-Denker 2011).
- Transformational bin: Management information systems like environmental management systems are also used in the health care industry. They store procedures and guidelines, for example guidelines on waste management and the sustainable use of resources (Townend and Cheeseman 2005).
- Structural bin: Health care organizations using EMSs store the information about, for example the environmental representative, in their structural bin.
- Ecological bin: A green-built hospital represents the organizations' intention in environment-friendly production of health care output. A green-built hospital also supports the healing process and can be described as a "green and healthy building" (Vittori and for Healthcare Engineering 2002). Ecological bin content is visible to all organization members and non-members an can also be interpreted as part of the organizational culture and bin.
- External bin: Hospitals can use several external bins. The German Federal Environment Agency and the German Federal Authority for Radiation Protection responsible for X-ray (both subordinated to the Federal Ministry for Environment, Nature Conservation and Nuclear Safety) have information available for health care organizations regarding environmental issues. The European Commission provides information about environmental management systems in general and EMAS in specific (European Commission 2009). This can also be interpreted as an external bin.

7 Conclusion

The theory-driven approach laid out in this chapter offers a basic overview of the field on environmental engineering in the context of learning health care organizations. Indicators for environmental engineering as a factor for organizational learning in hospitals were shown in all areas (learning levels, learning types, learning determinants). Therefore, environmental engineering seems to be a possibility for extending the capability of a health care organization for environmental awareness and for improving their own learning processes. Environmental engineering also affects organizational memories and supports an organization to store, retain and recall information and knowledge about its environmental behaviour.

Organizational learning processes initiated and stimulated by environmental engineering accumulate in the dimension of organizational membership and structure. However, it can be supposed that the influence especially on the organizational culture due to the origin of sustaining environmental behaviour is much more distinctive than worked out in this contribution. Therefore, further research should use standardized organizational diagnosis, especially on organizational culture and social capital.

The next step should be a detailed empiric survey involving an analysis of implemented Environmental Management Systems in health care organizations, mainly hospitals. Hospitals in learning health care networks can be supposed to comprise another research field. Emerging regional and nationwide health care groups will strengthen the inter-organizational cooperation and thus the inter-organizational learning processes, probably based on EMS.

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Complementary Information Systems on Research in Europe on ICT for Environmental Sustainability

Werner Geiger, Richard Lutz and Christian Schmitt

Abstract Within the scope of the FP7 project ICT-ENSURE, two complementary web-based information systems on research in Europe in the field of ICT for environmental sustainability have been developed: The ICT-ENSURE Research Programmes Information System that serves as an information source on national research programmes and projects in the European Union in the field of ICT for environmental sustainability, and the ICT-ENSURE Literature Information System which provides scientific literature on this field to the scientific community and other interested people. In this chapter, the goal, contents, functionality, and mutual interaction of the information systems are described. Furthermore, the tools for contents acquisition, the maintenance and quality assurance of the contents, as well as data privacy aspects are addressed.

1 Introduction

Research activities, programmes, and policies across Europe are rather fragmented in many research fields. In order to overcome this fragmentation and increase the efficiency and impact of public funding, European Research Area (ERA) activities have been initiated and are funded by the European Commission (ERA 2007). One such ERA activity is the ICT-ENSURE project (ICT Environmental Sustainability

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Research), which has been a Support Action within the Seventh Framework Programme of the European Commission (EC) and which was funded from May 2008 to April 2010 (Tochtermann et al. 2008).

ICT-ENSURE (http://www.ict-ensure.eu) was aimed at building a European Research Area in the field of information and communication technologies (ICT) for environmental sustainability. The ICT-ENSURE project consortium consisted of three partners: Graz University of Technology (TUG) that also acted as project coordinator, the International Society for Environmental Protection (ISEP), Vienna, that also represented the scientific coordinator, and the Karlsruhe Institute of Technology (formerly: Karlsruhe Research Centre) that was responsible for the development of the research information systems. In addition, several subcontractors for specific tasks were involved in the project.

A main problem with respect to a single European Research Area in the field of ICT for environmental sustainability is that information on current research activities and research results often are not generally available or can be obtained with considerable effort only. This especially applies to research funded on the regional level and on the level of the Member States of the EU. In order to overcome this problem, two complementary web-based information systems with free online access have been developed within the ICT-ENSURE project (Geiger et al. 2009):

- The ICT-ENSURE Research Programmes Information System which supplies information about national research programmes and projects in the field of ICT for Environmental Sustainability in Europe (http://is.ict-ensure.eu).
- The ICT-ENSURE Literature Information System which offers meta information and full-text papers of various scientific conferences and workshops and hence information on research results in the respective field (http://lit.ict-ensure.eu).

This chapter provides an overview on the objectives of the two ICT-ENSURE information systems. The common software architecture of the Research Programmes and the Literature Information System as well as interfaces with external information systems for indexing the literature will be described. The procedures chosen for the acquisition of metadata on national research programmes and projects and for collection of the literature metadata will be dealt with. A summary of the current contents of both information systems will be given. Then, the functionality of the two systems, including the user interface and the various access paths to the information, and the interaction between the two systems will be explained. Finally, the Authoring Component for the information acquisition, the maintenance and quality assurance of the contents, and data privacy aspects of personal data will be addressed.

2 Objectives and Basic Concept of the Information Systems

For researchers as well as research programme managers, it is time-consuming and costly to obtain an overview of research activities and research results in the field of ICT for environmental sustainability in Europe.

Some information on research programmes and projects is being provided e.g. by the CORDIS information system, the ERAWATCH website, and the UFORDAT information system. The CORDIS information system of the European Commission (CORDIS 2010) offers information on research programmes funded by the EC. However, it does not supply information on national research programmes. The ERAWATCH website (ERAWATCH 2010) focuses on national research policies, but offers information on few (very large) national research programmes only. The UFORDAT information system of the German Federal Environmental Agency (UFORDAT 2010) includes some research projects in the field. However, UFORDAT is geographically restricted to Germany, Austria, and Switzerland and is focused on the environment. In addition, the CISTRANA IST Research Portal (CISTRANA 2010) supported information on national programmes, but only on ICT programmes, not on ICT application programmes, and the CISTRANA portal is not available on the Internet any more.

For publication of the results of research in the field of ICT for sustainability there are only a few scientific journals. Scientific literature in the field largely consists of papers in conference proceedings (Pillmann et al. 2006). However, these proceedings were available almost exclusively to the conference participants (with little spread beyond). No or little support was provided when searching literature in these proceedings on a given topic and the full texts generally were available for downloading neither on the website of the publisher of the proceedings nor on the website of the conference organiser. Some literature has been included in the ULIDAT environmental literature database of the German Federal Environmental Agency (ULIDAT 2010). This literature database, however, comprises only a small part of the literature on ICT for environmental sustainability, since it is a literature database focusing on environmental topics. In addition, it is restricted to German-language publications and has not been updated systematically since 2004.

The Research Programmes Information System and the Literature Information System developed within ICT-ENSURE are tools to overcome these gaps.

The Research Programmes Information System serves as a central information source on national and regional research programmes and projects in the field of ICT for environmental sustainability in the European Union. The system helps programme managers, scientists, and experts to easily obtain information on research programmes and projects in the various EU Member States thus supporting the exchange of expertise and cooperation in this research field and contributing to the development of a pan-European research strategy.

For the characterisation of the research topics of the programmes and projects, a classification scheme for the field was developed. European national experts (subcontractors) compiled predefined metadata on national research programmes and projects, classified them using the classification scheme, and entered this information into the system by means of its Authoring Component (Schneider et al. 2010) (Sect. 6).

The Literature Information System provides scientific literature on the field of ICT for environmental sustainability in general and on environmental informatics in particular to the scientific community and other interested people. It offers metadata and—as far as possible—links to the full texts of conference and workshop contributions. So far, mainly conferences and workshops of the Technical Committee "Environmental Informatics" of the German Society for Informatics (Gesellschaft für Informatik, GI) have been included (Sect. 4).

To achieve a high benefit, it is important that a literature information system does not only contain metadata of the literature but also includes the full texts of the papers (preferably free of charge) or offers a link to the full texts. To ensure this, the problems regarding the rights for supplying full texts of the publications on the Internet have to be settled. In the case of conference and workshop proceedings issued by a publishing house, the rights for publication are typically settled in a contract between the publishing house and the organiser. The publishing house generally does not make the publications available on the Internet with free access. However, in many cases in the field of ICT for environmental sustainability, the organisers of conferences or workshops have the right to publish the proceedings on their websites some time after the conference with free access. This particularly applies to the EnviroInfo conferences held since 2004.

Because of this, organisers of conferences have been supported (or encouraged) to publish proceedings on their websites, and the Literature Information System has been conceived in such a way that also full texts of publications on external sites can be included. The full texts on external websites may be stored in the form of separate PDF files per publication or as complete proceedings volumes (see Sect. 4).

3 Architecture and Data Model

To implement both information systems, several alternative architectures were studied in terms of navigation facilities, maintainability, security, and integration of search engines (web application with database, wiki, content management system, Java portlets, etc.). Both information systems offer access to different information. However, by abstraction of the requirements and functionalities, both systems could be implemented on a joint basis.

The common system is based on the Model-View-Controller architectural pattern that separates presentation from business logic (Fig. 1). Accordingly, the system is divided into three layers. The model layer is responsible for handling of the underlying data stock. The view layer focuses on the presentation of the user interface. The control layer administrates data processing and is used as an interface between the model layer and the view layer (Lutz et al. 2009).

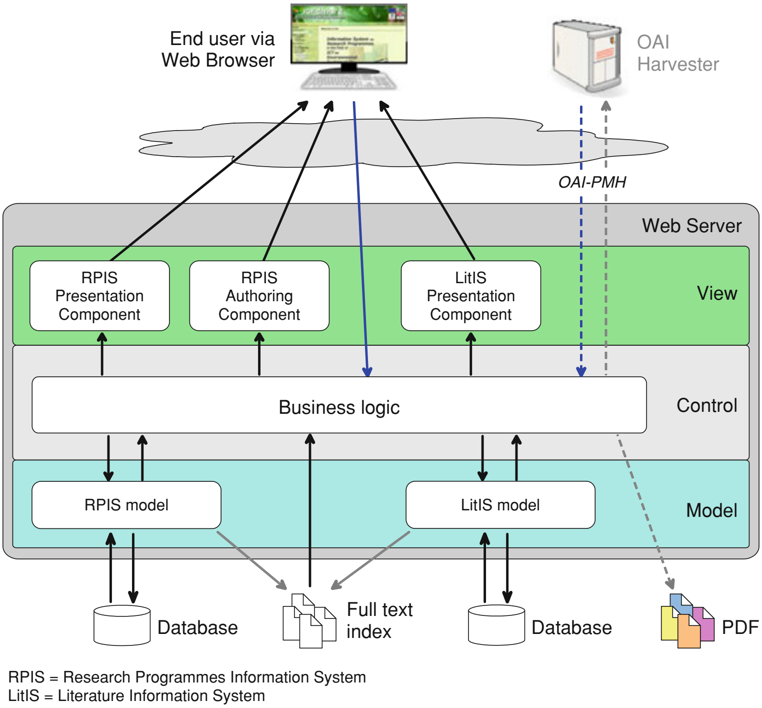

Fig. 1 Overall architecture of the two information systems

The base library for both systems was implemented on the basis of the Java EE servlet technology and can be used in a platform-independent manner.

On top of this common library, the specific user interfaces for both systems were implemented on base of the Apache Velocity template engine.

Mapping of the object-oriented Java model of both systems to the relational structures of the underlying MySQL databases is performed with the help of Hibernate, a Java Persistence API (JPA) implementation.

Full-text search capabilities are integrated by means of the Hibernate Search plugin, which is a facility to manage a full-text search index for the entire data stock based on the Apache Lucene full-text search engine (see also Lutz et al. 2010).

The library also supports various presentation layers for the same system which is used to implement an interface to OAI harvesters via the protocol OAI-PMH (Open Archives Initiative—Protocol for Metadata Harvesting) (OAI 2010). In this way, the literature information can be used by a large number of literature search engines supporting this protocol. This enhances the awareness of the system and its contents.

A popular OAI harvester and OAI search engine is ScientificCommons (http://www.scientificcommons.org/). To integrate literature information into the German Environmental Portal PortalU, an additional interface is planned based on a DSC iPlug and the iBus of PortalU (Klenke et al. 2010).

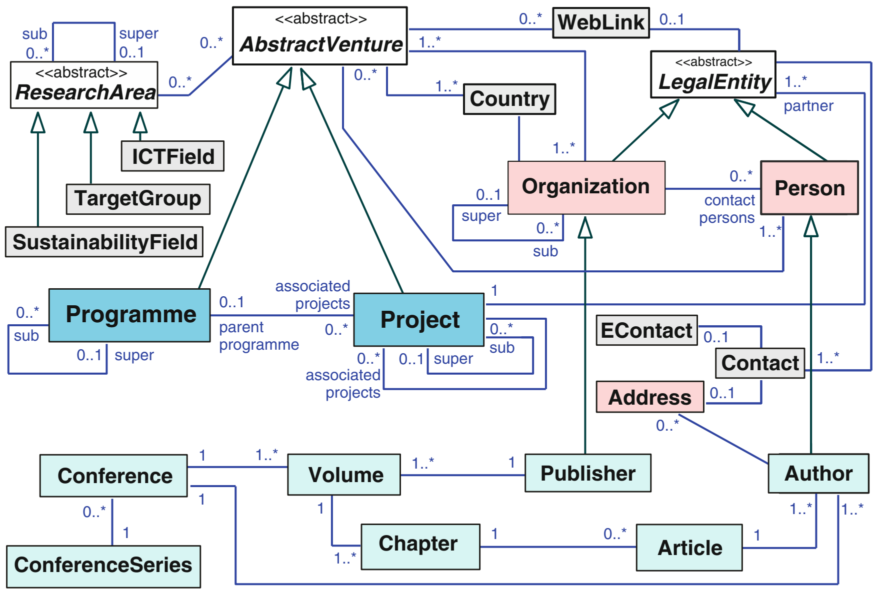

Fig. 2 Simplified conceptual data model of the two information systems

If available on the Internet, links to the full-text documents are provided (Sect. 2). In order to support various data sources, the control layer can be complemented with various generators for URL references to external document servers via a common generator interface.

Due to the customizing capabilities of the common library, the OAI-PMH interface and the document URL generator could be realized as specific extensions to the business logic for the Literature Information System.

The simplified data model of the information systems is shown in Fig. 2. Major object classes on the Research Programmes Information System side are (research) Programme, Project, and Research Area. The research area of a programme or project is characterized by its ICT Fields, Sustainability Fields and Target Groups. With respect to funding and management, data on the Organisations and Persons involved are recorded. Major information of the Literature Information System is contained in the classes Article and Author. Further classes like Conference, Volume and Publisher cover additional bibliographic information.

4 Contents Acquisition and Current Contents of the Systems

The Research Programmes Information System is aimed at compiling and presenting information on relevant national research programmes and projects on ICT for environmental sustainability in Europe. However, the information on national research programmes and projects provided on the Internet often is available in the national language only and is frequently insufficient and/or outdated. Collection of information for such a system—at least, initial collection—may be accomplished with good quality only with the support of national experts in this research field speaking the respective country's local language.

All in all, 20 national experts have investigated research programmes and projects in Europe and entered the collected data in the information system by means of the system's Authoring Component (Carrara 2010; Ribeiro and Fonseca 2010; Stehlíková 2010).

In September 2011, the Research Programmes Information System contained more than 130 programmes and 120 projects with information from all EU Member States. More than 250 programme managers and other contact persons are involved in the acquired research programmes and projects. These contact persons are an important target group for updating the information and for investigating new programmes and projects.

The collection and preparation of metadata for the Literature Information System started right at the beginning of the ICT-ENSURE project, in parallel to the software development of the final information system (Sect. 3), using a rapid prototype system (Schreiber 2010). The data of this prototype system were imported into the final system by means of a dedicated import interface which also performs a number of quality checks.

In September 2011, the Literature Information System comprised the metadata of more than 1,700 and the full texts of more than 1,000 publications. It included the publications of all EnviroInfo conferences from 1997 to 2010 and the publications of the Towards eEnvironment conference that took place in Prague in March 2009. Furthermore, the system included the papers of the workshops "Environmental Information Systems" 2005–2010, which were held by the corresponding Working Group of the German Society for Informatics. For the majority of these conferences and workshops, the full-text papers are available as separate PDF files for downloading at the websites of the conference organisers or promoters.

5 Functionality and User Interface

Both research information systems offer similar search and navigation facilities to the end users and largely have the same layout.

The search facilities provide information retrieval capabilities from the stored metadata via full-text search and attribute search. The navigation facilities allow browsing the database via different access paths as well as navigation via cross-references between related entities.

Figure 3 shows a screenshot example of the Research Programmes Information System. The different search and navigation aids can be found on the left. They include full-text search, search in major object classes (programmes, projects, organisations, and persons) according to given criteria for their attribute values, and navigation through classification of the research area. In addition, access is offered via the list of countries (interactive selection via a map of Europe) or the

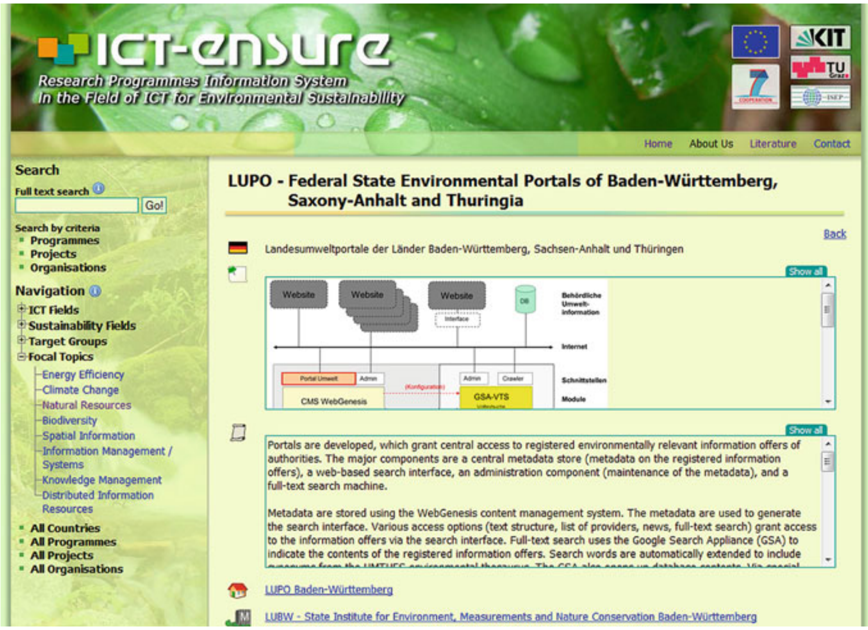

Fig. 3 Screenshot of the Research Programmes Information System

list of programmes, projects, and organisations. The menu bar with a link to the Literature Information System can be found at the top right.

The metadata of a research project or programme are represented on the right. These metadata include the acronym of the project or programme, its name in English and the national language, an abstract, a short description, responsible and participating countries and organisations, a contact partner, and other entries. By selecting the links, it is possible to navigate interactively through the data inventory.

Figure 4 shows a screenshot example of the Literature Information System. In this system, apart from the metadata of the papers in the database, the full texts of the papers (PDF files)—stored on the same website or on external websites—are integrated into full-text search.

As mentioned in Sect. 2, the publications may be stored in the form of separate PDF files per paper or as complete proceedings volumes. Also in the latter case, the full-text indexing of the papers is performed separately for each paper within the proceedings, and the links from the information system to the papers refer to the first page of each paper within the proceedings volumes. The "search by criteria" offers a search in the attributes of the object classes of articles, chapters, and volumes, e.g. a search for all publications of a specific author or all publications with a given term or combination of terms in the title.

In addition, the Literature Information System offers access to the literature via a list of all conferences and workshops contained in the system. The user can select hierarchically the conference or workshop, the volume of the conference/workshop

Fig. 4 Screenshot of the Literature Information System

proceedings, the chapter in the volume, and the article in the chapter and is given the metadata of the corresponding conference contribution (see Fig. 4).

The metadata of a contribution comprise various attributes: The list of authors and their associated institutions, the related conference, the publishing year, the abstract of the article (as far as available), and start/end page in the volume. The reference to the chapter and to the conference volume containing the article can be used for browsing through the database of the information system. If it is possible to download the full text of the article, a link to the download location is provided along with a text with information about the hosting server. Furthermore, the system offers a possibility to download literature references. Three popular citing formats are provided: RIS, EndNote, and BibTeX.

The information in both systems is interrelated. For supporting the user in overarching information gathering, interactions between the two information systems have been implemented. E.g., a number of persons are involved in both, the management of a programme or project and the publication of results, and so is present in both information systems. Therefore, if a person has been selected in the Research Programmes Information System, a direct link to the Literature Information System is offered which helps the user in searching for articles of this person. In a similar manner, when an article is

Fig. 5 Interaction between both information systems (for data privacy reasons, the entries displayed refer to one of the authors of this contribution)

shown in the Literature Information System, there is a direct link for each author to search for a corresponding match in the Research Programmes Information System (Fig. 5).

6 Authoring Component

In order to manage the considerable amount of metadata, which additionally is cross-linked to a big data network (programmes and sub-programmes, involved organisations, etc.), a simple but yet powerful management facility was required.

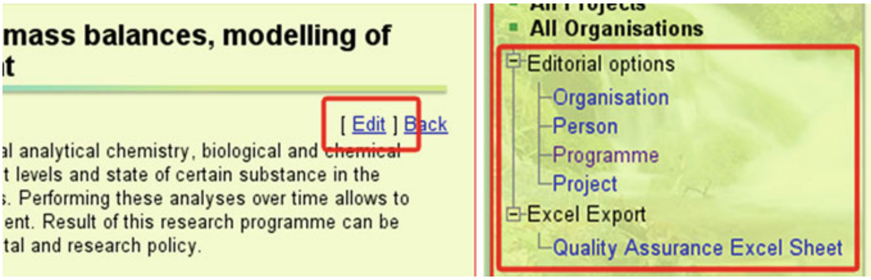

Fig. 6 Controls shown in the Authoring Component

The Authoring Component of the Research Programmes Information System realizes this sophisticated goal in a pragmatic manner.

The Authoring Component is fully integrated with the publicly available frontend of the information system and adds additional controls to the displayed entities as well as management facilities to the menu (Fig. 6). Depending on the access rights of the user, who is being authenticated by username and password, different controls and facilities are provided.

The input of basic textual attributes of the system entities like programmes, projects, and organizations is being realized by normal text fields for short, unformatted attributes like names. For more complex, formatted fields like abstracts and descriptions, powerful word processing tools are used. This is very common for web applications and well-known to end users.

Establishment of the references between the different system entities is more complex. It was accomplished by realizing a generic approach that can be applied to all kinds of system entities and references (1:1, 1:N, N:M; uni- and bidirectional).

Since creation of the data network has been a central task from the beginning, this feature had to be implemented at an early state of the project. Since the data model was still under discussion within the project, it was important to have an easy-to-adopt system for handling varying base entities without basic code revision.

In addition to the cross-linking capabilities, plausibility and data completeness checks have been integrated into the Authoring Component in order to prevent flawed or incomplete data.

In principle, the developed library could easily be used for the Literature Information System as well. However, since these data once entered do not change and usually complete conference proceedings are added, an interface importing entire volumes (and their structures) was developed for being more appropriate (Sect. 7).

7 Maintenance Tools and Quality Assurance

Both information systems were made available on the web in April 2010 and since then have been extended. Maintenance and quality assurance of the operational systems is a challenge, since a number of parties from all over Europe are involved in contributing to the contents of the systems. In order to support maintenance and quality of the databases, various tools have been developed, manuals have been prepared, and measures taken.

To ensure the quality, validity, and up-to-dateness of the information in the Research Programmes Information System, the contact partners of programmes and projects and the national experts involved in the initial data investigation are contacted regularly. The contact partners are informed about their programmes and projects in the information system and the data stored. The respective persons are asked to confirm or correct the information given. By contacting the persons directly involved and responsible for the research programmes and projects, the accuracy of the information is validated first hand through the best knowledge on the subject.

Furthermore, the programmes and projects managers as well as the national experts are asked for new programmes and projects relevant to the information system for extending the contents of the information system and improving the coverage of the research field.

For updating of the metadata by the national experts, the Authoring Component of the Research Programmes Information System (already applied for acquisition of the initial data) can be used. Alternatively, the data can be gathered offline by means of a Microsoft Excel™ sheet (template) provided and then entered into the system by the institution maintaining it.

The Authoring Component automatically performs various data quality checks and offers various quality support functions to the authors. These quality checks are also applied when importing the data from the MS Excel™ sheet. In a separate system administrator account, further data analysis and presentation facilities are provided for controlling the quality of the entered data.

Various tools have been developed for extension and quality assurance of the Literature Information System. To import the metadata of additional conferences, an import filter has been implemented. This import filter can be customised to various data sources. A special version of the import facility can import metadata from MS Excel™ sheets in a dedicated format for which a template is provided. In addition, some routines have been implemented for plausibility checks of the contents of the Literature Information System. These routines check the syntax of attributes (e.g. syntax of ISBN numbers) and the cross-references between various object classes (e.g. whether each article is linked with at least one author).

8 Data Privacy Aspects

Each published web-based information system containing personal data is required to accomplish several statutory provisions concerning data privacy according to the applicable data privacy regulations. This is relevant to data about programme and project managers which is stored in the Research Programmes Information System.

In case these data have already been published on the Internet, the German Data Privacy Act (which is relevant to the publication of the contents of the information system since the server is hosted at Karlsruhe Institute of Technology, Germany) allows the publication of name, office address, phone and fax numbers, and further minor information provided that the owner is informed about the data being published. No explicit written consent is required.

With this in view, the persons responsible for a programme or project have to be informed via e-mail about the data to be published. If an addressee disagrees, all data about the person have to be removed from the information system contents.

The fact that, up to now, none of the addressees has disagreed reveals the interest of the programme and project managers in contributing to the Research Programmes Information System.

For the Literature Information System, the data privacy situation regarding the presented information is different. The data shown is metadata on scientific literature in the field of ICT for environmental sustainability. According to copyright regulations, the authors of literary contents must be mentioned in such information systems. As a consequence, all personal data that is stated as author information in the literature item may be shown in the information system. Unlike the programme and project managers, whose personal data are shown in the Research Programmes Information System, the authors do not have to be notified.

9 Concluding Remarks

Both information systems—the Research Programmes Information System as well as the Literature Information System—are appreciated well by researchers and persons responsible for research programmes or projects. Interviews with national experts have confirmed that these systems close a gap in the needs of the European research landscape and facilitate an alignment of own research projects, plans, and results with similar or related programmes or projects in other European countries (Maurer et al. 2010).

Karlsruhe Institute of Technology (KIT) guarantees to provide both information systems on the web for at least 2 years after the end of project funding, i.e. at least until March 2012. The Technical Committee "Environmental Informatics" of the German Informatics Society is interested in taking over the Literature Information System within this time period. Alternatives to the future operation and update of the Research Programmes Information System have been examined (Geiger et al. 2010) and efforts are being taken to ensure the sustainability of the service.

End of 2010, a first systematic update of the contents was made employing the tools for maintaining them (Sect. 7).

The responsible persons registered in the Research Programmes Information System were addressed and asked to check the quality of their data stored in the system and to name other relevant research programmes and projects. The fact that most of the contact partners answered confirmed their interest in the system and the importance they attach to being represented in it.

The content of the Literature Information System was extended in autumn 2010 by the full-texts of the 2009 EnviroInfo conference and the metadata of EnviroInfo 2010. In doing so, the tools for importing literature data via the Excel sheet and the corresponding import interface were applied for the first time. These tools will also be used in the future for integration of literature metadata and full texts of further conferences and workshops.

The Literature Information System can be the basis for a joint provision of literature information of different scientific communities in Europe in the field of ICT for environmental sustainability. Such an extension could make it to an even more valuable contribution to establishing a single pan-European research area in this field.

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