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A Holistic Management Model for Manufacturing Companies and Related IT Support

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Abstract

Life cycle and management concepts are a necessity to compete in current turbulent markets. Small- and medium-sized enterprises (SME) struggle when realizing such concepts and accordant IT support. In this paper we review different concepts and their similarities and differences are discussed. We focus on Product Lifecycle Management (PLM), Supply Chain Management and Factory Lifecycle Management to integrate them into a holistic management model. Subsequently, we extend a service-based PLM architecture to support the holistic management model to continuously support processes. The usage of standardized technologies allows companies, and especially SMEs, to implement this architecture with low costs and effort.

Selection and peer-review under responsibility of Professor Pedro Filipe do Carmo Cunha

Keywords: Product Lifecycle Management; Supply Chain Management; Factory Lifecycle Management; Holistic Management Model; IT Integration; Service-oriented Architecture; Enterprise Service Bus

1. Introduction

Competitiveness of manufacturing companies gets increasingly harder in today's hard-fought worldwide market. Additionally, the complexity rises due to higher individualization of products and efforts because of sustainability requirements. The companies face these problems by introducing concepts like Product Lifecycle Management (PLM), Supply Chain Management (SCM) and Factory Lifecycle Management (FLM) to manage complexity of manufacturing systems and to get a better control over their processes. Furthermore, they implement and include software tools all along the product life cycle and supply chain to support managers, employees and customers in executing their tasks and thus speed-up the processes.

In many cases, the selected concepts and their IT realization is not synchronized, which reduces the impact of IT systems and the desired benefits are not reached. Especially small- and medium-sized enterprises (SME) do not have enough capacity to implement the concepts effectively and efficiently. Additionally, problems arise when implementing many applications which are badly integrated. This results in a lack of continuous processes and much effort is needed to exchange data and information between isolated applications.

The existing turbulent environment and new requirements concerning sustainability increases the problem of defining processes and require more process flexibility and a better organizational IT infrastructure [1]. The flexibility of the IT infrastructure directly influences the flexibility of processes, because processes are mapped in IT systems to execute them faster. Nowadays, the inflexible IT infrastructure prevents to quickly adapt processes to the current situation and therefore resources are not optimally used.

This paper reviews different life cycle and management concepts and the possibility to subsequently integrate them in a holistic management model for manufacturing companies. The main components of each concept as well as their dependencies are discussed to point out the importance of IT systems. An efficient and flexible service-oriented PLM architecture is presented and how it can be extended to support the holistic management model. Finally conclusions are drawn.

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2. Life Cycle and Management Concepts

To manage the growing complexity of manufacturing systems and keep control over all processes, resources and employees, different management concepts were developed in literature and partly applied in practice. Three main themes in those concepts will be highlighted:

- The product is at the center of the PLM.
- The factory is in the focus of the FLM.
- The logistics chains and their design are evaluated.

A review on these concepts is performed in the following sections before their similarities, differences and interactions are discussed.

2.1. Product Lifecycle Management (PLM)

The product is at the heart of all manufacturing companies. It is the source for their revenue and thus needs the most attention.

Emphasizing the variety of activities, the life cycle of the product is typically split into phases. In the literature the segmentations vary in the number and content of the single phases. E. g., Stark uses five phases: imagine, define, realize, use/support and retire/dispose [2], presented in Fig. 1. This process structure is simple, but clear, it has stages for the early pre-engineering activities, the engineering activities, the manufacturing of the product, the usage and finally the end of live.

Fig. 1. Phases of the Product Life Cycle (based on [2])

This clear structure of Stark is often mixed with other concepts like the product life cycle presented by Schuh, which has eight phases: product-planning, construction, work preparation, production-planning, manufacturing and assembly, distribution, service, and recycling [3]. Eigner uses a similar separation with seven phases: requirements, product-planning, development, process-planning, production, usage, recycling [4]. The last product life cycle presented here is from Vajna and is split into eleven phases: research and development, sales and marketing, styling, development, construction, process planning, production control, production, distribution, usage, and recycling and disposal [5].

Despite their differences, these concepts of Schuh, Eigner and Vajna commonly focus on production, while Stark focuses clearly on the product. Therefore Stark's concept will be used in our analysis.

2.2. Supply Chain Management (SCM)

"A supply chain consists of all parties involved […] fulfilling a customer request" [6]. Those parties not only include the customer, the manufacturer and the supplier, but also transporters, retailers and many others. All together they fulfill functions like product development, marketing operations, distribution etc., in order to satisfy customers. While the SCM has its focus on managing the players in the supply chain, the value chain concentrates on aspects of value creation processes [7]. The classical value chain concept includes primary and supporting activities. The first category consist of: inbound logistics, operations, outbound logistics, marketing & sales and service. These activities are supported by the firms' infrastructure, human resource management, technology development and procurement.

The supply chain concept has similarities with the 'production view of the firm', which distinguishes buying raw materials from suppliers, converting materials into products and selling products to customers [8].

All three concepts are somehow linked to logistics in production industries (sometimes the constructs 'logistic chain' and 'supply chain' are used synonymously [9]), but with different foci (on function, processes, material flow). As the product life cycle, all these different chain concepts have to be carefully designed and managed efficiently.

In Fig. 2, a basic concept of a supply chain life cycle is illustrated. It encompasses all kinds of suppliers and distributers as well as B2B and B2C relations. It emphasizes, that both are strongly dependent on production. This is similar to the PLM, which also centers on production. But priority on this SCM is on decisions designing the chain. These include supplier selection, control of material flows, forming logistic networks, etc. The life cycle of such a chain can be similar to the life cycle of products, but also to that of a factory, dependent on the kind of production. For example the life cycle for supplying and maintaining the machinery in the factory will be longer than the life cycle for supplying resources to a short-lived product that is produced within the factory.

Fig. 2. Supply Chain Lifecycle Management

2.3. Factory Lifecycle Management (FLM)

Compared to PLM and SCM the concept of FLM is less diffused.

Westkämper et al. define a factory life cycle which is separated in five phases: design and planning, construction, operation and maintenance, refurbishment or obsolete, and disposal or dismantling [10].

Constantinescu et al. present a more detailed life cycle for the 'Grid Engineering for Manufacturing

Laboratory' (GEMLab) containing eight phases: production development, investment and performance planning, site and network planning, buildings, infrastructure and media planning, internal logistics and layout planning, process, equipment and workplace planning, ramp-up and project management, factory operation and manufacturing execution, and finally maintenance and equipment management [11].

We merged these two life cycles (LC) concepts in a new one – as illustrated in Fig. 3 – which is comparable to the PLM of Stark.

Fig. 3. Phases of the Factory Life Cycle (based on [10])

2.4. Other Management Concepts

Production networks are discussed as an effective response to meet customer needs [12] in current turbulent and volatile markets [13] and as an option to gain more resilience at the same time [12]. Such networks extend the discussed LC-concepts. "Production network nowadays refers to cross-company cooperations. These networks go beyond customer-supplier relationships like logistic chains to the building up of stable network arrangements and to variable production networks." [14]. Thus, they follow a broader perspective, are more systemic, and are increasingly used as a strategic option [15].

The Stuttgart Enterprise Model (SUM) has much in common with networks. It defines the factory as an internal network of semi-autonomous adaptive production units and includes factory networks as well. The model, based on system theory, is scalable from the level of machines up to the level of factory networks. It fits the situation of dynamic complexity and interprets the production system as an adaptive system in the sense of complex adaptive systems [16]. So far SUM is still a vision, but there is evidence, for an increasing attractiveness in the world of industrial production.

The need for changeability postulated by SUM has to be applied to the presented management concepts and especially to their IT support.

2.5. Similarities and Differences of Concepts

The LC-concepts PLM, SCM and FLM have engineering, production and recycling phases in common, but differ in the early phases as well as in the usage phase. Some of these LC-concepts integrate elements from other LC-concepts, e.g., the process planning is sometimes part of the product life cycle.

The time lines in these concepts can be very different, depending on the industry. Supply chains usually support the product life cycle, but are also connected to production within a factory. Relations with suppliers and customers can last very long and encompass several product life cycles. Usually the factory life cycle is the longest one, lasting up to decades.

2.6. Combination of Management Concepts

Successful manufacturing companies more or less apply all these concepts as already recognized by Hummel and Westkämper. They integrate PLM and FLM to improve coordination between these LCs [17].

We extend this approach and combine respective management concepts in a model depicted in Fig. 4. The production phase in all cases has proceeding and succeeding phases which are mostly interdependent, illustrated as clouds in Fig. 4. Their dependencies result in high coordination effort. Isolation of organization units, different IT systems and inconsistent processes make the task of coordination even more complicated.

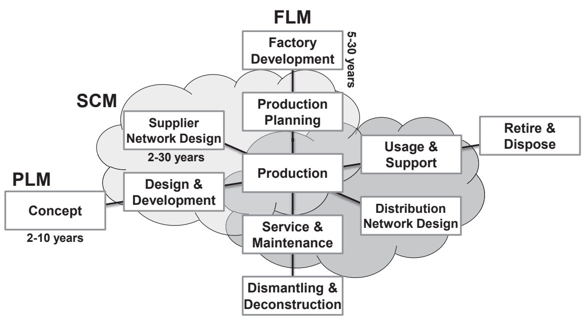

Fig. 4. Holistic Management Model combining PLM, SCM and FLM

Defining and executing cross-domain business processes can create severe problems because different disciplines with different dominant mind sets are involved. For example, Concurrent Engineering describes coordination between design & development and production planning, but without considering the design of the supplier network

The main components on this model including its dependencies are described in the following Section 3. The role of IT systems and how they can better support the business processes is discussed in Section 4.

3. Components and their Dependencies

Parallel to the management concepts are different components, which have to be addressed when managing a company. Stark defines the PLM grid with nine important components which have to be considered and efficiently managed for a successful PLM implementation: metrics, people, organization structure, methods, equipment, applications, data and documents, processes, products [2].

These components are not only valid for PLM, but also for SCM and FLM. They have to be successfully managed in the whole enterprise to be competitive.

In the following we focus on the four most important components and describe their dependencies:

- Processes: The efficient design and execution of processes is a key aspect for companies. Nowadays, the flexibility of processes is an important issue to permanently adapt them to new requirements in a turbulent environment [1]. A fast execution of processes is another issue, why they are more and more implemented in IT systems to automatically and faster execute them.
- Methods: To improve quality, methods are developed to allow a structured and efficient execution of tasks in a repeatable manner
- IT-Systems: Applications support employees performing methods and tasks more efficiently or executing them semi-automatically or automatically.
- Employees: They process tasks to execute processes supported by IT systems and methods

The components organizational structure and data are each an issue covered by employees and IT systems respectively. The employees have to be organized somehow and the IT systems have to manage their data.

Fig. 5 shows the dependencies of the four main components. The quintessence of this figure is that all processes are executed by employees. Executing them more efficiently, the employees are supported by IT systems and methods. Moreover, the methods can be implemented in IT systems to execute them faster.

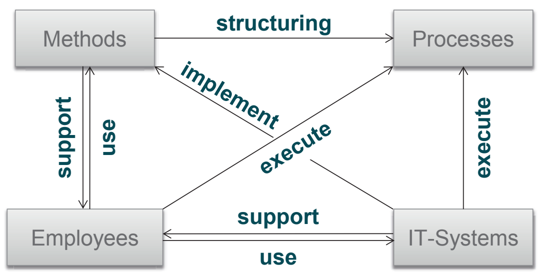

Fig. 5. Dependencies of Components

In the following we want to focus on the IT systems with their intermediate role and impact on employees and processes. As already mentioned, companies need to improve their flexibility to be able to react faster on turbulences. The problem is that parts of the processes are implemented in IT systems and cannot be changed as fast as required.

The next Section 4 presents common software solutions for the presented management concepts before we extend our service-based PLM architecture to support the whole management model.

4. Support by IT – Review

IT systems play a significant role in today's digitalized world. They support the employees by simplifying tasks, improve communication and optimize quality. This should lead to a faster processing of the tasks and thus speed up the processes.

Supporting the previously presented concepts, different solutions were implemented and are established nowadays. A very common solution to support SCM and Customer Relationship Management (CRM) is the Enterprise Resource Planning (ERP) system. PLM software was developed to efficiently manage and execute PLM processes. Only FLM is not supported by a standard software solution from end-to-end. These software systems are presented in the following.

4.1. Available Solutions for Management Concepts

Using ERP systems is very common, as they support a wide breadth of disciplines in their work. Beside SCM and CRM, they also implement financial and accounting, human resource, operations and logistics, resource planning, sales and marketing, and more functionality, which is seamlessly integrated by the solution [18].

The most important software vendors for ERP solutions are SAP, Microsoft and Oracle, but there are a lot more companies, which focus on industry specific or customized ERP solutions. The standard solutions R/3 from SAP, Dynamics AX and Dynamics NAV from Microsoft and the Oracle E-Business Suite are in general customized by service providers for each industry sector.

While ERP systems include more and more disciplines and functionality over the time, PLM software went through a more evolutional process. To support product designers and developers, Computer-aided Design (CAD) tools were provided to digitalize this process. With growing number of CAD drawings, Product Data Management (PDM) was established to manage these data in all variants and versions together with a controlled development process. The limitations to the product development prevented the management and engineers to get a holistic view on the product. Thus PLM software was developed to overcome the limitations of PDM and get an end-to-end management of the organization, applications and data, and processes.

The IT landscape along the product life cycle is often characterized by a bunch of heterogeneous applications, which are sporadically integrated. Siemens PLM Software, Dassault Systèmes and PTC are three software vendors, which offer a holistic software solution to manage the whole product life cycle [19].

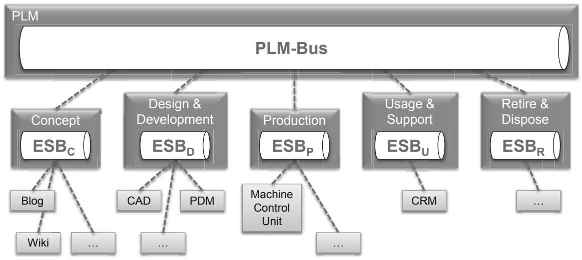

Fig. 6. Service-oriented PLM Architecture, cf. [23]

The support for FLM is not yet realized in an independent software tool. However, some PLM software solutions contain components like production process planning or simulation, but they do not realize the whole factory life cycle. These applications are in generally summarized with the term digital factory tools.

4.2. Service-oriented Architecture

The challenge to establish and maintain an efficient IT is unsolved. The problem is that grown infrastructures with many applications, which were installed to support one or more tasks, are often badly integrated and do not support continuous processes. When applications are integrated, often point-to-point interfaces were used. This quickly leads to unmanageable and unmaintainable infrastructures. On the other hand, the powerful ERP and PLM software solutions seamlessly integrate their domains, but lack in process flexibility and open interfaces to communicate with other applications.

To overcome the problem of point-to-point integration and the lack of process flexibility, the paradigm of the Service-oriented Architecture (SOA) was developed [20]. SOA provides a flexible integration of applications by loose coupling and reusing services, which are self-contained, platform-independent and discoverable. Thus, heterogeneous applications can be easily integrated by exposing service interfaces described in a standardized technology such as web services. The composition and loose coupling of services within workflows, which are specified in a standardized description language such as Business Process Execution Language (BPEL), enable the mapping of business processes as continuous and flexible IT processes.

The communication backbone is typically realized by an Enterprise Service Bus (ESB) concept [21]. It provides binding components for all prevalent communication standards such as HTTP, SOAP or FTP to enable the integration of heterogeneous IT landscapes. A content-based router [22] allows the loose coupling of applications, because the destination is not determined until the messages arrive at the ESB. Most of the ESB products possess a BPEL engine to execute the deployed workflows directly within the ESB environment. Additional services, e.g., for transformation and monitoring, may expand the functionality of the ESB.

4.3. Service-oriented PLM Architecture

To apply the SOA paradigm in the manufacturing environment, we developed and prototypically implemented a modular architecture for PLM [23], which is shown in Fig. 6.

Each phase of the product life cycle is integrated by a domain-specific ESB. Thus, the ESB can be adapted to the requirements of each phase like availability, response time and amount of data transmitted through the ESB. Another benefit of phase-specific ESBs is that the local IT department can develop and maintain their own ESB. Integrating the whole IT infrastructure with a single ESB would cause major changes of the IT organization.

The PLM-Bus is the mediator between the local ESBs. It avoids the unfavorable point-to-point connections between domain-specific ESBs by integrating them centrally. This advantage is increased when having more phase-specific ESBs to integrate.

4.4. Extension and Application of Service-oriented PLM Architecture

The presented service-oriented PLM architecture integrates an arbitrary number of phase-specific ESBs over the PLM-Bus. Thus, the architecture can be easily extended to integrate other domains beyond the product life cycle. Applying this on the holistic management model we obtain the architecture shown in Fig. 7.

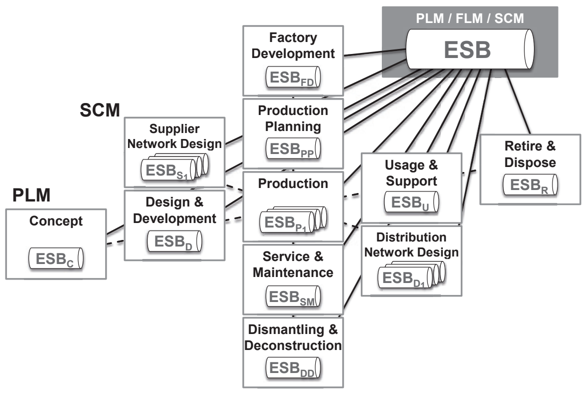

Fig. 7. Service-oriented Enterprise Architecture

The PLM-Bus is replaced in this figure by an Enterprise wide Service Bus, which integrates all ESBs of the enterprise. Compared to the phases of the product life cycle and factory life cycle, the supplier and distribution network phases use multiple ESBs, one for each supplier or distributor. To improve the performance and availability in the production phase, the corresponding ESB can be replicated in each site.

Assuming that all resources are available through web service interfaces, processes can be defined in a very flexible manner throughout the whole architecture across multiple domains.

If resources are outsourced to a partner or contractor, they can be integrated in the same manner into the processes as internal resources. Of course, additional security and privacy features have to be implemented.

This architecture offers a huge advantage especially for SMEs. They are more dependent on external resources [24]. Innovation is generated through cooperation with other players [25], and a flexible, extendable IT could support them.

5. Conclusion

The complexity in manufacturing companies is continually rising. To manage the complexity, on the one hand management concepts are applied and on the other hand IT systems are implemented.

This paper made a literature review on different management concepts, namely the Product Lifecycle Management, Supply Chain Management and Factory Lifecycle Management, to derive a holistic management model for manufacturing companies. This model concentrates on the most evident domains and shows their dependencies in proceeding and succeeding phases of the production.

Furthermore, the dependencies between employees, methods, IT systems, and processes as key components in each company are described. The intermediate role of IT systems and their lack in flexibility prevents manufacturing companies to adapt changes faster.

A service-oriented PLM architecture is presented, which has the ability to provide this flexibility. Hence, the architecture is extended to support the already mentioned holistic management model and thus allows the required flexible and continuous process definition.

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