19

Production System's Life Cycle-Oriented Innovation of Industrial Information Systems

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1. Introduction

Global companies of various industries – for instance the automotive industry – increasingly compete for key market shares. This frequently leads to an innovation race between competitors which often centers around certain trends or changed basic conditions (see Kiefer et al., 2006). Examples for these conditions are (see also Figure 1):

1. Increase of complexity of production systems due to higher demands on flexibility and the need to minimize necessary resources
2. Increase of number of mechatronic components within the production system
3. Reduction of startup / ramp up times
4. Increase of production life cycle

For Siemens AG as supplier of automation solutions for production systems the postulated changed basic conditions as well as trends result in challenges, which need to be addressed in an adequate manner:

1. Increased complexity of production systems leads to an increased complexity of the engineering process of production systems. The complexity must be handled during the engineering phase by means of efficient engineering processes and methods.
2. The increased number of mechatronic components demands new engineering methods, which efficiently support the overall approach of mechatronic components.
3. Reduction of startup as well as ramp up times (time-to-operation) demands standardization of solutions including efficient concepts of reuse.
4. Increase of production life cycles demands a change from craft- and phase-specific approaches towards an integrated view on production systems over the whole life cycle (Preiss et al., 2001) in order to reduce total cost of ownership and increase total value. It also demands an increasing importance of offerings for technical services and modernization.

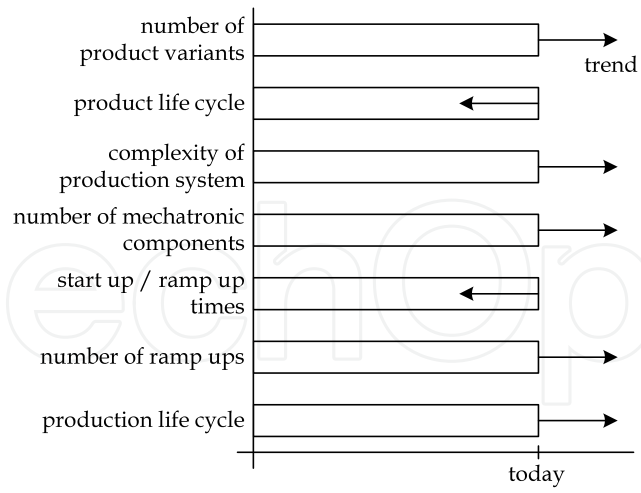

Fig. 1. Changed Basic Conditions (based on Kiefer et al., 2006)

Industrial Information Systems are becoming a more-and-more important instrument to increase the productivity of production systems by supporting engineers during all phases of the production system's life cycle adequately. But the Industrial Information Systems currently available on the market are often not designed adequately in order to cope with challenges posed by above mentioned trends and conditions. Instead they support craft-specific tasks and automation device specific functions, which are mostly craft- and device-centric. Furthermore Industrial Information Systems often lack integration along a production system life cycle and are therefore not capable to affect the overall life cycle cost effectively.

From the automation solution supplier's point of view new approaches are needed, which are capable of coping with the altered basic conditions. In order to reduce the total cost of ownership, i.e. demanded reduction of cost and time over the whole life cycle (Schott, 2007) on the one hand and to increase the total value of ownership on the other, the focus must be set to (Abel et al., 2003)

- integration of automation with other crafts
- integration along the complete production system life cycle,

while at the same time considering the implications for Industrial Information Systems.

The vision pursued by Siemens AG to address above mentioned challenges is the *Digital Factory* (Wucherer, 2006). Digital Factory is the generic term for a comprehensive network of digital models, methods and tools. Its aim is the holistic planning, evaluation and ongoing improvement of all the main structures, processes and resources of the real factory (VDI 4499, 2008). The term Digital Factory is well established in the field of factory automation and especially within the automotive industry. Behind this term stands the idea to digitize all information belonging to a production system and represent it by models - especially mechanical-, electrical-, as well as automation related information - and to provide it during all life cycle phases using suited tools, i.e. Industrial Information Systems (example see Figure 2).

For instance, engineering the production system based on mechatronic components in the Digital Factory takes place in a virtual manner using Industrial Information Systems.

According to (VDI 2206, 2008), mechatronics is an interdisciplinary field in which the following crafts - respectively corresponding systems - interact: Mechanical systems […], electronic systems, information technology. According to Siemens AG a mechatronic component can be understood as a collection of mechatronics aspects (especially mechanical, electrical and automation related) that represent a functional intent. So the mechatronic component is a digital representation in the production system life cycle and contains all information that is needed during production system life cycle means. The aim is to plan, check and control a production system entirely from the initial engineering to operation in order to make production as a result more flexible and cost effective. Only when all elements of the production system's life cycle are seamlessly linked to each other, flexible production can be achieved to the fullest degree. According to Siemens AG, integrated engineering for mechanics, electrics and automation will be available in 10 to 15 years not only but especially for automotive industry (Hiesinger, 2008). In subsequent life cycle phases of the production system the Digital Factory provides benefits by visualization and simulation of the processes taking place in the real production system.
In order to face the described changed basic conditions and trends as well as the resulting challenges for automation solution suppliers, powerful Industrial Information Systems are needed. But nowadays Industrial Information Systems do not provide the concepts necessary to realize the vision of the Digital Factory. Therefore an evolutionary and step-by-step method to innovate Industrial Information Systems towards the idea of the Digital Factory is needed. Such a method for life cycle-oriented innovation of Industrial Information Systems is introduced in the following chapters.

Fig. 2. Digital Factory (Source: Siemens AG)

2. Industrial Project Business

Aim of every production system is to implement a technical process in a cost and resource efficient manner so that a certain target corridor of quality is reached for the produced goods. The production system owner's intent is to maximize the Total Value of Ownership (TVO). Of course the cumulated cost across all life cycle phases has to be considered when calculating the TVO. The life cycle can be divided into six phases: Engineering, commissioning, operation, technical service, modernization and decommissioning.
Although engineering is one of the shorter phases of the production system's life cycle, a major part of the total cost that emerges in later phases - like for instance operation or service - is determined during engineering. As one can easily reason when looking at Figure 3, it is not sufficient to consider only one particular life cycle phase when trying to maximize the TVO.

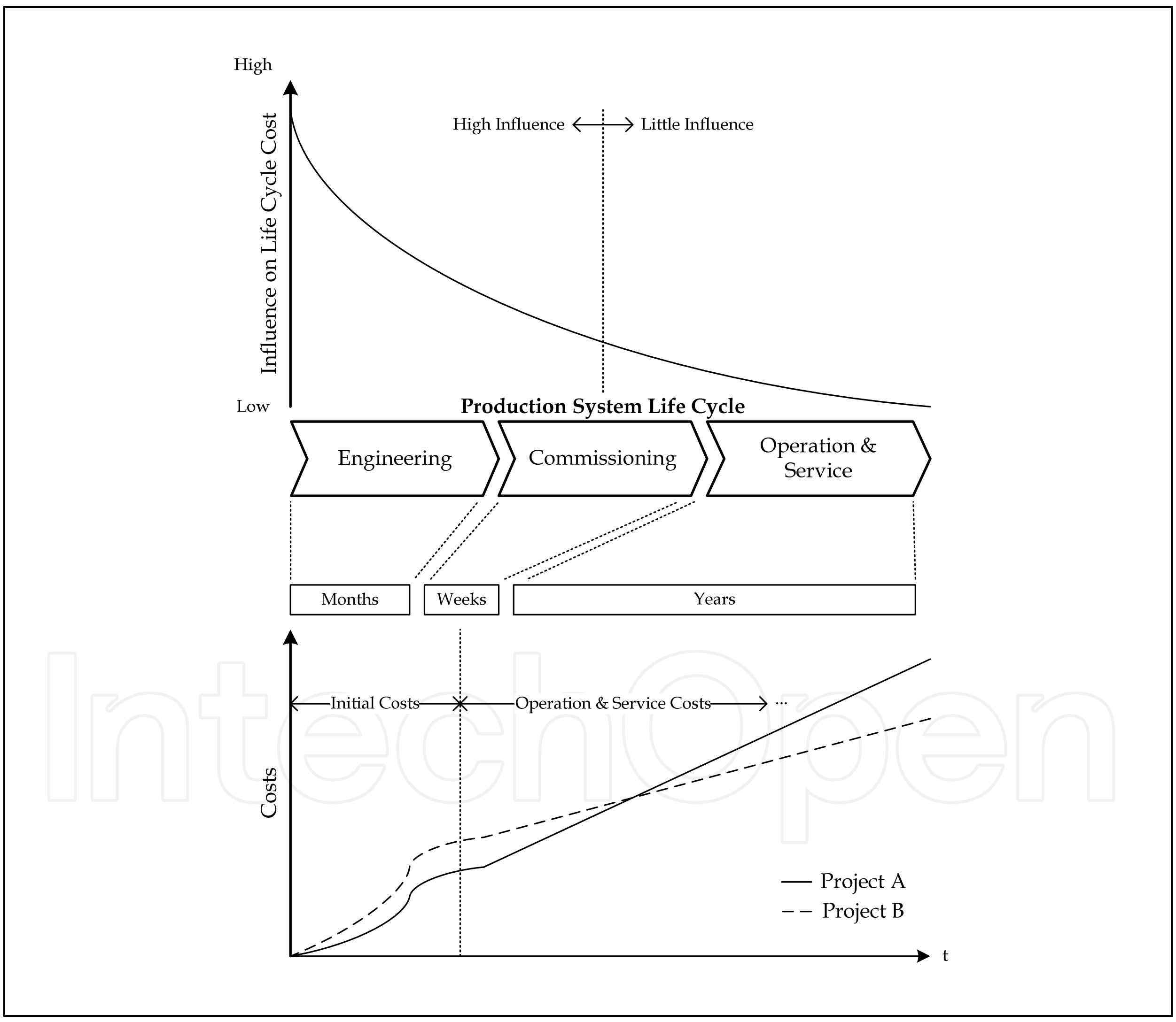

Fig. 3. Cost distribution across the production system life cycle (based on Preiss et al., 2001)

Therefore Siemens Corporate Technology, together with Friedrich-Alexander-University Erlangen-Nuremberg and Universität Stuttgart, have developed a method for targeted innovation of Industrial Information Systems (IIS) which is introduced below. This method explicitly considers interrelations between single life cycle phases and thereby supports the innovation of IIS so that their application can help enhancing the TVO. Those IIS are not only used by production system's owners but also by other stakeholders like those who provide engineering, procurement and construction - so-called EPC - or suppliers. Both generate a major part of the TVO during for instance operation or modernization (see Tayeh, 2009). The IIS have to support their users when executing tasks while at the same time they have to embed themselves into the user's workflows to maximize the TVO. In order to assess the latter property first of all the activities IIS have to support during the entire production system's life cycle have to be examined.

2.1 Activities during a Production System's Life Cycle

When analyzing the activities different stakeholders engage in during the life cycle of a production system it can be observed that two fundamentally different kinds of activities exist:

- *Order-dependent activities* describe tasks, that are executed by a particular stakeholder as part of a dedicated customer project for which the stakeholder accepted a specific order from a customer. Examples for these activities are the engineering of a particular production system as well as its commissioning, operation, service, and modernization.
- *Order-independent activities* are carried out independently from a customer's particular order to prepare order-specific activities in the future. Especially during engineering the costs of customer projects can be reduced significantly due to targeted order-independent development of reusable sub-solutions (Fay et al., 2009). A systematic execution of order-independent activities includes an analysis of the application domain, the business strategy, planning activities as well as the implementation and test of reusable work results (VDI 3695, 2009).

Examples for typically order-independent activities during engineering are the development of a technological production system structure as well as the preparation of mechatronic components that can be used repeatedly. But systematic preparation of reusable work results can increase efficiency during other life cycle phases, too. An example for a life cycle phase-spanning as well as order-independent activity is the provision of an integrated chain of IIS to support order-dependent activities in particular customer projects.

Interdependencies between order-independent and order-dependent activities of a production system's life cycle are visualized in Figure 4. The work results gathered during order-independent activities or during earlier projects can be put into libraries, standards or IIS in order to be reused in later projects. To ensure that these reusable work results comply to customer, market as well as project requirements, the experiences gathered in order-dependent activities have to be fed back.

These activities aren't executed by one single organization. Other stakeholders beside the production system's owner are EPC as well as a multitude of suppliers, which are either responsible for particular activities or might assign them to external suppliers. To maximize the TVO it is again not sufficient to optimize every single activity regarding its cost-value-ratio but to instead consider the interdependencies between particular activities in a global context.

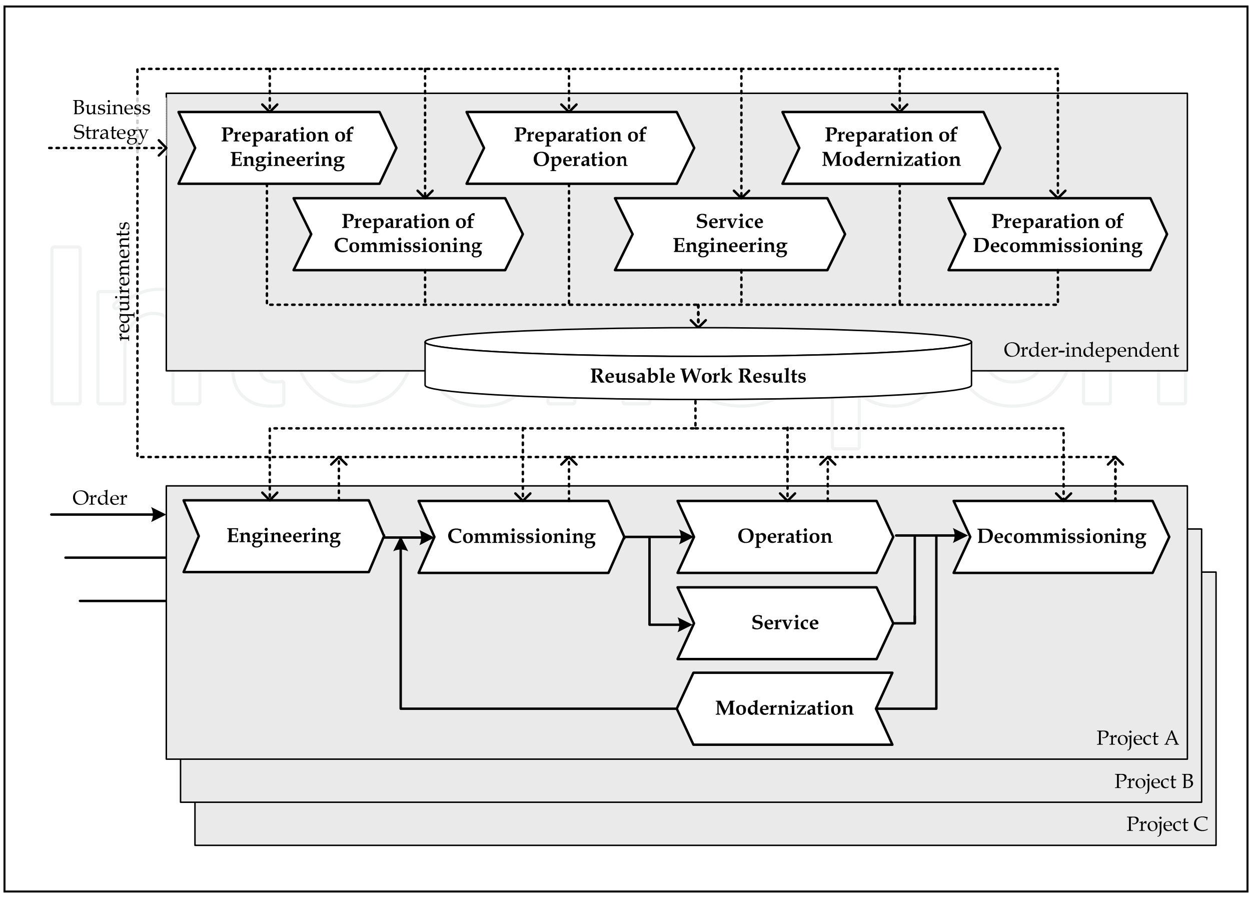

Fig. 4. Order-independent and order-dependent activities in industrial project business

2.2 Challenges of Enhancing Efficiency and Quality

Primary tasks of the activities described in the previous section are of technical nature; after all their intent is to engineer, operate, maintain, modernize, and (de)commission a production system. Challenges of trying to efficiently provide tasks arise primarily from technical activities and belong to one of the following two types:

- Life cycle phase-dependent – Since during every life cycle phase-specific technical tasks have to be accomplished, different challenges arise from particular phases of the production system's life cycle.
- Life cycle phase-spanning – Due to above mentioned properties of the industrial project business common challenges arise, which have to be addressed in all life cycle phases.

During engineering, commissioning, operation, service and modernization of a production system experts of different crafts, for instance mechanical construction, fluid technology, electrical engineering, automation, as well as software engineering, have to work together. Especially technical information has to be shared and interdependencies between individual crafts have to be taken into account. Since every craft uses specific methods, abstractions and modeling languages, integrating the participating crafts is a special challenge.

During the life cycle of a production system a huge amount of technical information emerges. Sometimes this information is needed in only one life cycle phase. Other information is relevant for several life cycle phases and evolves during this process.

Pursuing the idea of the Digital Factory, the relevant digital information has to be accessible in all life cycle phases and needs furthermore to be expandable as well as changeable.
Beside the aspect of life cycle phase integration, integration among different abstraction layers - for instance those of the automation pyramid - is crucial. Although the tasks involved with the particular layers of automation differ in nature, they all access the same technical information of a production system. But this information varies intensely in granularity.
The third aspect of integration is the challenge to integrate information among different crafts. The three aspects of integration are visualized in Figure 5.

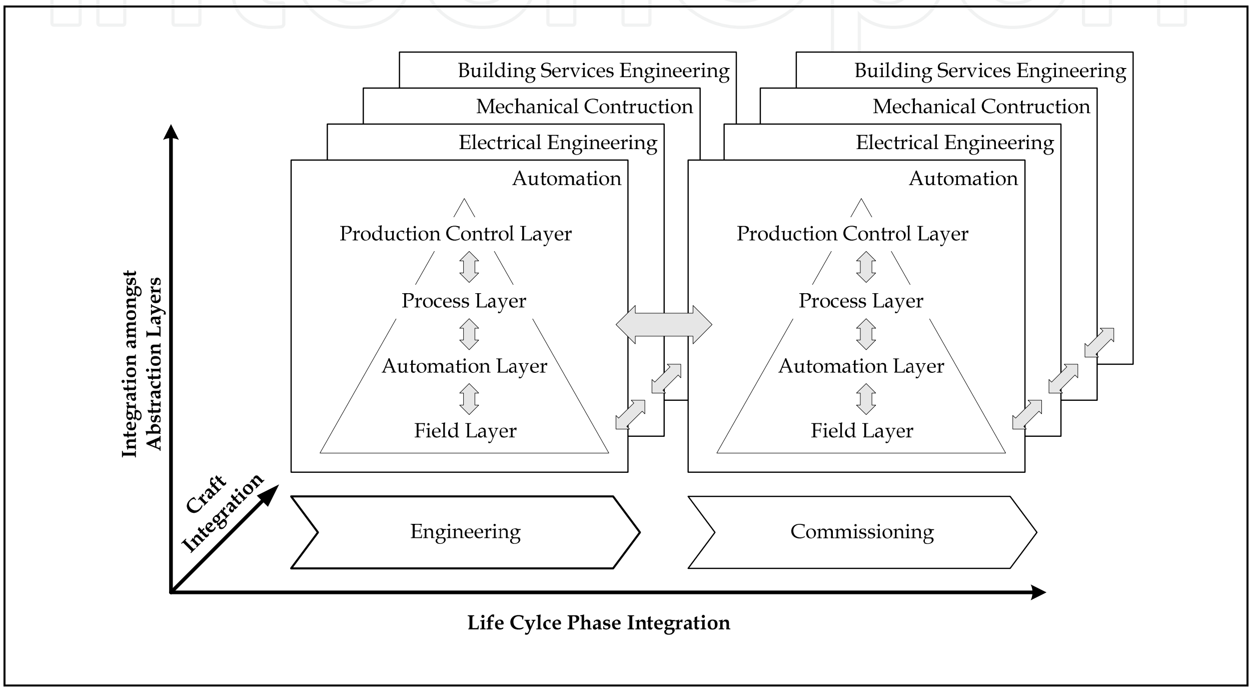

Fig. 5. Dimensions of Integration in Industrial Project Business

Production systems are complex systems which consist of large amounts of often similar components like for instance sensors and actuators. Consequently a generic challenge arises from the efficient handling of large amounts of data sets. These data sets have to be generated, saved, analyzed as well as changed in an efficient manner.
Due to the multitude of stakeholders and the complexity of a production system, it is sometimes necessary to change the planned or even already built production system during particular life cycle phases. These changes must not lead to inconsistencies within the digital information or even worse safety-critical malfunctions during operations. This challenge becomes more meaningful when changes influence multiple crafts or even multiple abstraction layers.
When considering the different aspects of integration it is always important for digital information to represent the real plant correctly. Hence the quality of this digital information, and thus the benefit of a Digital Factory, can be determined by measuring the fraction of digital information, which can be processed by a computer and represents the production system correctly, to the overall information available on the production system. This quality is visualized by the distance between the two curves shown in Figure 6. Due to

undocumented tasks and modifications during for instance commissioning or service the real plant diverges from it’s digital shadow. This leads to a reduction in quality of the digital information which consequently necessitates in additional efforts to maintain the digital information.

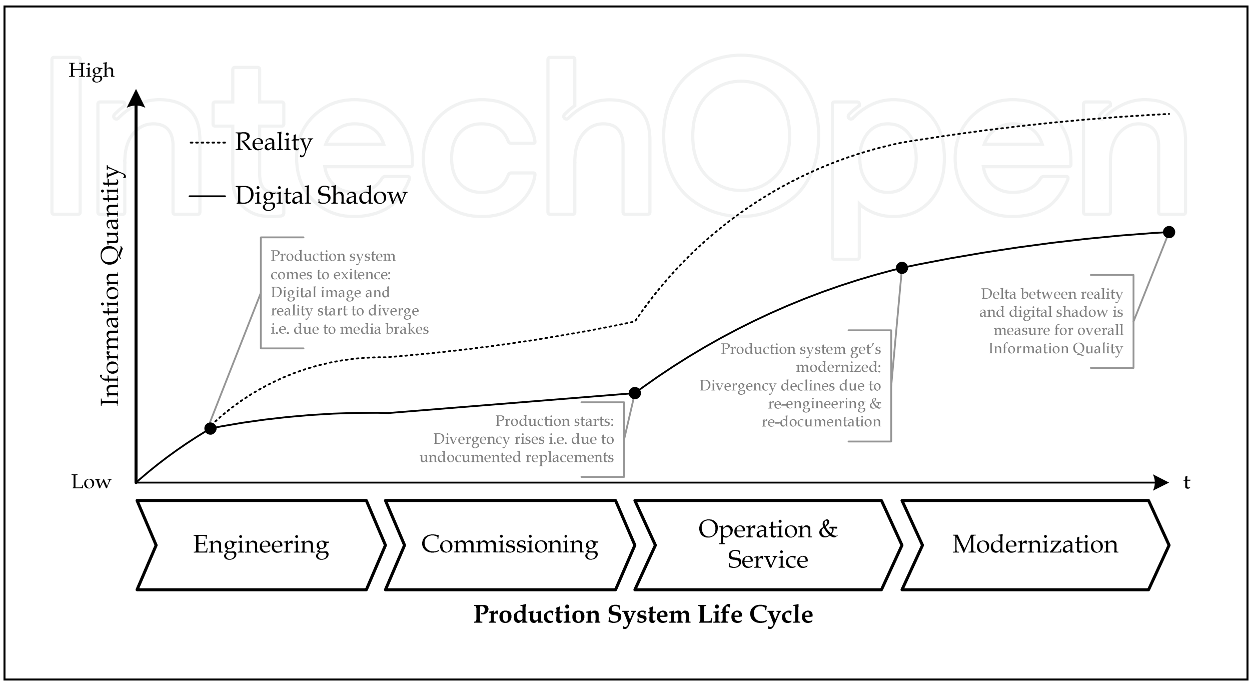

Fig. 6. Digital and computer-processable Information alongside the Production System’s Life Cycle

2.3 Concepts to handle Challenges

In order to handle the above mentioned order-independent challenges, as well as challenges associated with individual life cycle phases, it is necessary to systematize the industrial project business (Löwen et al., 2005). This systematization is enabled by means of targeted application of concepts. A concept is a systematic approach to solve a specific problem. By systematically using concepts, which address above mentioned challenges, it is possible to actively cope with the challenges of industrial project business.

Table 1 shows an example of selected concepts as well as the appropriate challenges. Additionally the life cycle phase is given, in which the concept can be applied.

The concept of mechatronic components for example can be used to face the challenges crafts integration and life cycle integration during all life cycle phases. The encapsulation and integration of all information belonging to one mechatronic component facilitates the synergistic cooperation of all involved crafts and the provision of consistent information on the mechatronic component during the whole life cycle of the production system.

Every stakeholder uses a specific set of concepts to address the challenges when executing his tasks. Depending on the task the usable concepts can vary heavily. Often several concepts exist, which all support coping with a particular challenge – of course often having different degrees of performance.

The concept's potential to cope with challenges in industrial project business can be utilized if these concepts are supported adequately by Industrial Information Systems. This aspect is covered within the next chapter.

Concept	Life Cycle Phase	Challenge
Use of Mechatronic Components	All	Crafts integration Life cycle integration
Filing of all information in standardized file formats	All	Data integration Crafts integration
Library of reusable templates	Engineering	Efficient execution of engineering Quality of engineering results
Standard for configuration of technical devices	Commissioning	Integration of devices from different suppliers
Views with different abstractions on diagnostic data	Service	Integration of abstraction layers (i.e. layers of automation pyramid)

Table 1. Concepts associated with Challenges (Examples)

3. Industrial Information Systems

3.1 Definition

Industrial Information Systems are combined hard- and software systems, which support users when executing tasks with primarily technical focus within the industrial project business. These systems consist of at least a software tool executed on a computer. Examples are software tools used for the parameterization of field and safety devices (e.g. Siemens SIMATIC Step 7) as well as motion control units like for instance Siemens' Simotion Scout. Other IIS support their users within several life cycle phases and provide means to be customized to specific application cases. An example for this class of IIS is Siemens' COMOS®. IIS might also bring dedicated hardware components with them, specialized to be coupled to the production process while simultaneously complying to special pro-tection /safety requirements. Examples for this type of IIS are Manufacturing Execution Systems (e.g. Siemens' SIMATIC IT) or Process Control Systems (e.g. Siemens SIMATIC PCS 7) including process-oriented components as well as service and diagnostic tools with corresponding hardware units for the logging of process data (e.g. Siemens' SIPLUS CMS).

3.2 Supporting the Industrial Project Business with Industrial Information Systems

In order to support the user when executing tasks as part of the industrial project business, IIS must implement the user's concepts, in order to cope with above mentioned challenges.
Users of IIS are therefore heavily interested in using those IIS, which support the concepts they are employing as accurately as possible. Especially when choosing an IIS but also during its customization, the user needs knowledge regarding the concepts the particular IIS supports. The set of concepts supported by an IIS determines the *philosophy* of the IIS. The

user's aim is to choose not only the one IIS, which offers all functions necessary for the tasks but which also fits well into his workflows and business strategy. Consequently the IIS-supplier needs detailed knowledge regarding the concepts which might be used within a certain craft and also life cycle phase. On the other hand the IIS-supplier needs to know the life cycle phase-spanning concepts which are needed to support the challenges in industrial project business. If the supplier's IIS does not address both the life cycle phase-specific and the life cycle phase-spanning concepts, it does not support the users adequately.
Especially if the IIS-supplier wants to enhance and innovate IIS, a choice must be made which concepts are going to be integrated in which upcoming version of the IIS. To support the IIS-supplier within these decisions, the next chapter introduces a concept catalog, that allows targeted innovation of IIS and can be easily integrated into common information systems development processes.

4. Targeted Innovation of Industrial Information Systems

Knowing the concepts used in industrial project business is necessary but not sufficient for targeted innovation of IIS. The concepts need to be operationalized in order to be integrated into IIS. The aim is to align further development strategically – especially in comparison to competing IIS-suppliers - to increase productivity. Therefore it is necessary to analyze as a first step the underlying philosophy of an IIS in detail. In a second step, measures for a targeted innovation of the IIS can be planned. It is self-explanatory that the development phase is the place to insert this step.

4.1 Information System Development Process

The first process model formally describing the development of not only IIS but information systems in general was introduced by (Royce, 1970) and is called Linear Sequential Model. It describes the information system's life cycle as well as its realization - with a focus on development. It is considered to be the origin that almost all other models - for instance the spiral model or the V-Model - are derived from (Green & DiCaterino, 1993).
Multiple points of criticism exist when it comes to the Linear Sequential Model, for instance:

- it doesn't reflect the possibility to incorporate late changes
- resulting documents are not specified sufficiently regarding their granularity
- the process is – at a whole – unidirectional.

All these points have been addressed in the past and where enhanced piece-by-piece within later models. But almost all of them are based on the Linear Sequential Model, which is why it can be seen as the lowest common denominator. This is why it will be used as an example to demonstrate the insertion of the concept catalog into the development process of IIS.
In the simplest case developing an IIS consists of five phases (see Figure 7). In the requirements analysis phase, the problems addressed by the IIS are specified along with the desired service objectives (goals) and underlying constraints are identified. During the specification phase the IIS' specification is produced from the detailed definitions of the first step. The resulting documents should clearly define the information system's function. In the IIS' design phase, the system specifications are translated into a real life system. The system developer at this stage is concerned with aspects like data structure, architecture, algorithmic detail and interface representations. By the end of this stage the system engineer should be able to identify the relationship between hardware, software and associated

interfaces. Any faults in the specification should ideally not be passed down stream. During the implementation and testing phase the designs are translated into a working system. At this stage detailed documentation from the design phase can significantly reduce the implementation effort. Testing at this stage focuses on making sure that any errors are identified and that the IIS meets its required specification. In the integration and system testing phase all the parts are integrated and tested to ensure that the complete IIS meets the requirements. After this stage the IIS is delivered to the customer. Feed back loops allow for corrections to be incorporated into the model. For example a problem / update in the design phase requires a revisit to the specifications phase. When changes are made at any phase, the relevant documentation should be updated to reflect that change.

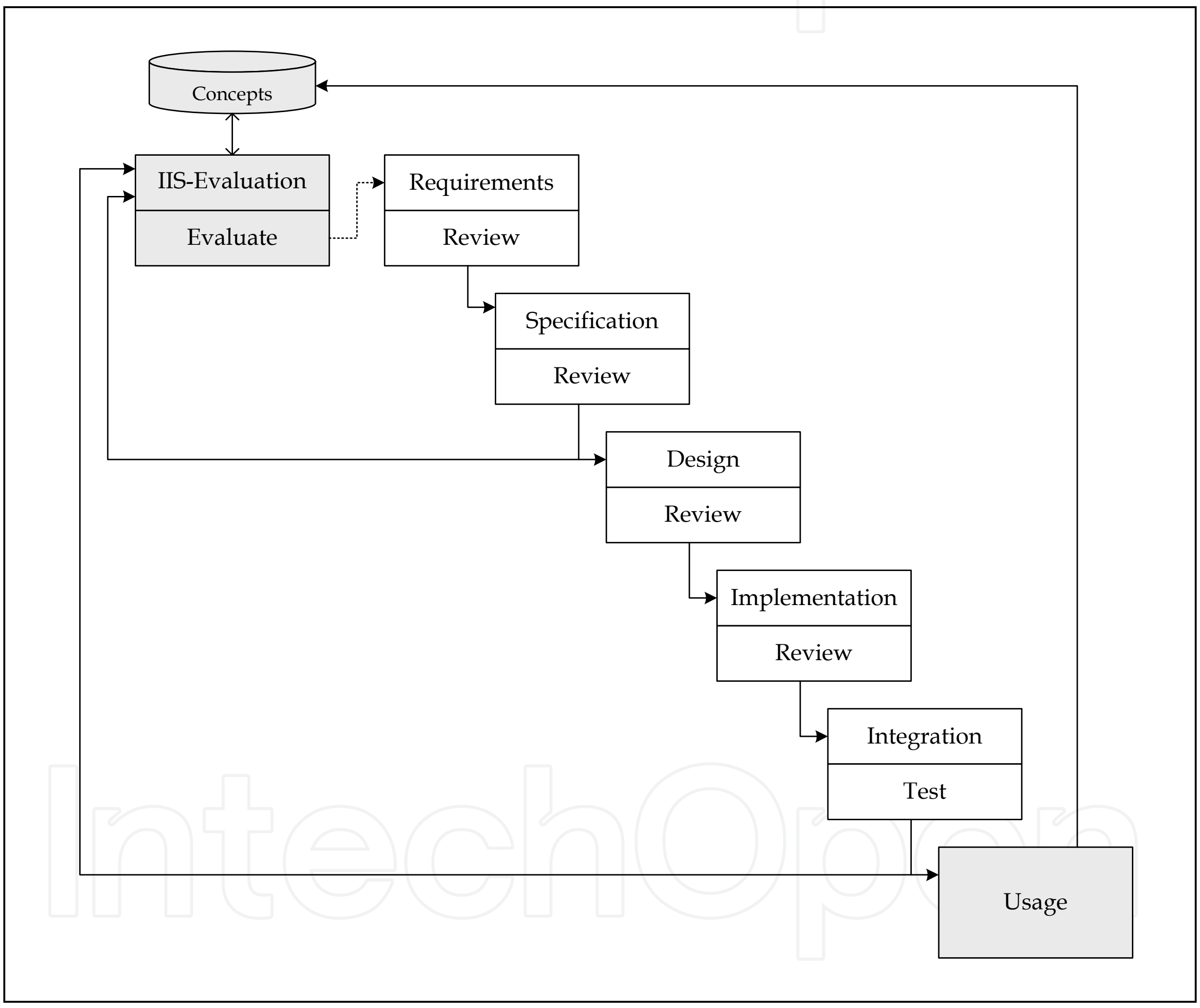

Fig. 7. Integration of concept catalog into an exemplary IIS development process

In Figure 7 the application of our concept catalog (IIS-Evaluation) is put just before the requirements phase, which is necessary for the purpose of targeted innovation. Since the insertion of the concept knowledge gathered should be carried out systematically, the method needs to incorporate a step to evaluate the IIS. During this step the IIS is assessed on the basis of results of chronologically prior process steps (i.e. documentations, specifications) in order to determine its status regarding the concepts and to disclose

potential for innovation - for instance gaps within the specification. Input of the IIS-Evaluation might be specifications – for instance a feature specification as shown in Figure 7 - as well as the released IIS. Depending on the development state the resulting output of the IIS-Evaluation can be incorporated into upcoming versions.
The external interfaces to the IIS-Evaluation, which makes use of the concept catalog, are now defined. It still bares the question how this process step looks like in the inside and especially how the concept catalog is designed in order to efficiently operationalize the concepts.

4.2 Operationalization of Concept Knowledge

In order to operationalize concept knowledge, concepts are aggregated and structured by a reference model. It features success factors of the industrial project business at the top. They are considered to be external quality characteristics IIS are measured with. "*External quality characteristics are those parts of a [system]. that face its users, where internal quality characteristics are those that do not*" (see McConnell, 1993). Some authors use the term *quality in use* and define it as "*the user's view of the quality of the software product when it is used in a specific environment and a specific context of use*" opposed to internal quality, which is measured during implementation phase and external quality measured during testing phase (see for instance ISO 9126-4, 2001). Much like in these definitions, it is the IIS-Evaluation's intention to measure the extent to which users can achieve their goals – but with a focus on a business scenario, rather than measuring generic properties of the plain IIS.
In order to measure quality in use, a multitude of approaches exists that all share the lack of consideration of business domain specificity and instead concentrate on common quality criteria - for instance reliability and usability. They do however bring with them evaluation workflows, structures for characteristics and metrics that can easily be adapted in order to operationalize concept knowledge instead of common quality characteristics. The most recent approach for measuring quality in use is described in ISO 9126, 2001 as well as the associated standard ISO 14598, 1999, which covers the development of an evaluation by means of a four step process:

- Establish evaluation requirements
- Specify the evaluation
- Design the evaluation
- Execute the evaluation

Step one mainly covers the external interfaces to integrate the IIS-Evaluation into a development process as described in chapter 4.1. Specifying structure and metrics of the quality characteristics to be used is part of step two. Fundamental aim of this structure is the applicability of quality characteristics (see also Balzert, 1998 as well as Abran & Buglione, 2000). In case of the IIS-Evaluation generic success factors as well as those of production system life cycle phases – namely engineering, commissioning, operation, service, and modernization – are used to structure the catalog of associated concepts, which are known to be realizable in IIS and simultaneously support the user in an adequate manner. When used on competing IIS as input, the IIS-Evaluation can reveal the used concepts and thereby derive the underlying philosophy of the IIS. This enables IIS-suppliers to innovate in a systematic manner for instance by implementing cutting-edge or unique concepts first and thereby to convince potentially undecided customers in favor of their IIS.

4.3 Structuring Concepts

The structure chosen to break down the universe of concepts follows the models introduced by McCall et al., 1977 and Boehm et al., 1976 which were later adopted by many models - ISO 9126 being one of them. They structure characteristics – which translate to what we identified as *Challenges* - and sub-characteristics hierarchically, having a metric on the lowest level. Every Challenge describes a success factor of either a specific life cycle phase or all life cycle phases and is subdivided further by a number of so-called Sub-Challenges. Every Sub-Challenge describes a single determinant on the efficiency of IIS regarding their addressed business – in our case the industrial project business. For every determinant described by a Sub-Challenge five different concepts are gathered, which cover the corresponding determinant within the IIS and act as a metric (Kitchenham, 1990). Attached to every Best Practice is one central question, which functions as a barrier that has to be overcome in order to reach a certain concept class. Examples are used to substantiate concepts by means of precise applications and case studies. Of course examples can be added as the concept catalog matures (i.e. after a special evaluation), refining it even further. The interrelation between Challenges, Sub-Challenges, Best Practices, Central Questions and Examples is described by a corresponding meta-model (see Figure 8).
The term Challenge in this context translates to characteristic in McCall's approach. It was chosen to reflect filling the structure with characteristics specific for the industrial project business. To discover these characteristics methods of social research like guideline based expert interviews and workshops of experts carrying business knowledge were used (see Yin, 1994). The results of our findings, which make use of the introduced structure, are described within the next section (see also Amberg et al., 2008).

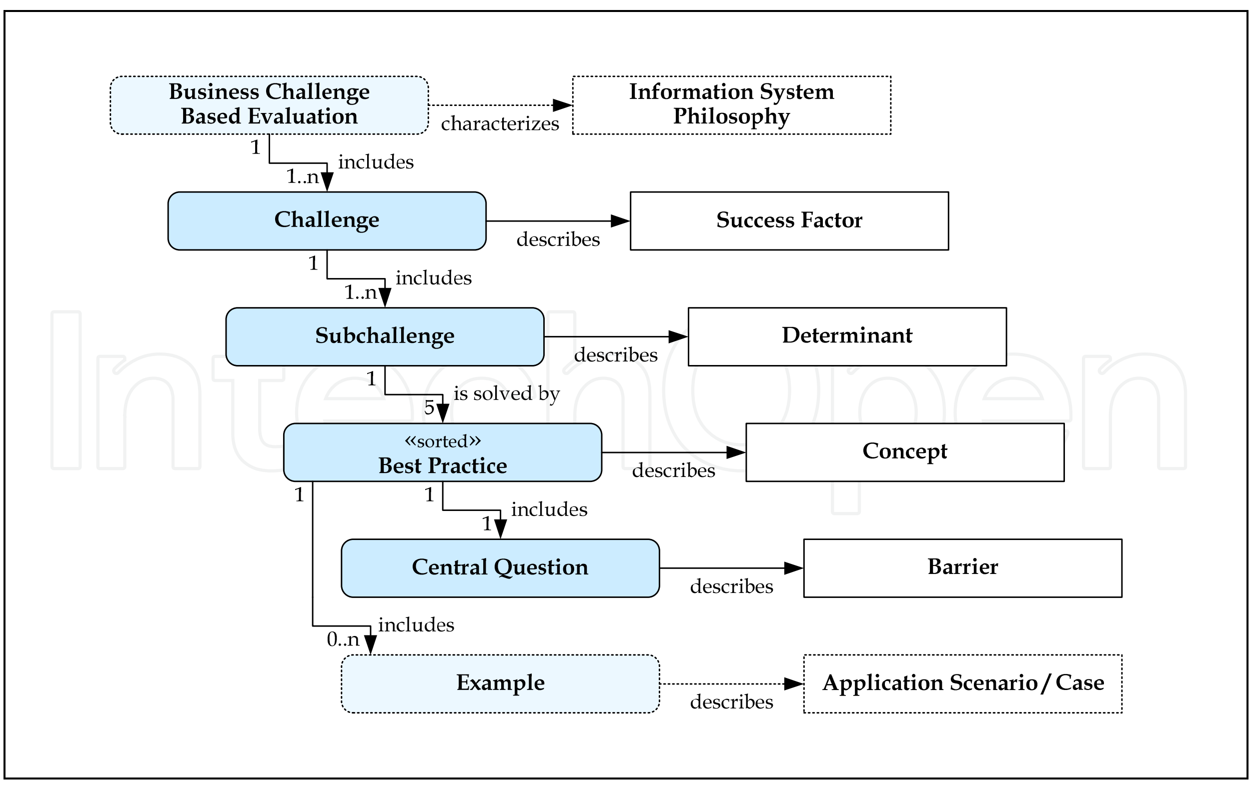

Fig. 8. Meta-Model used to structure the concept catalog used in IIS-Evaluation

4.4 Concept Catalog for the Industrial Project Business

Siemens Corporate Technology in cooperation with Universität Stuttgart and Friedrich-Alexander-University Erlangen-Nuremberg gathered a vast amount of concepts, life cycle phase-dependent as well as spanning, and aligned them based on the structure described within the previous section. The resulting pattern is called Siemens Challenge Reference Model and is depicted in Figure 9 for one particular IIS used in technical services as example.

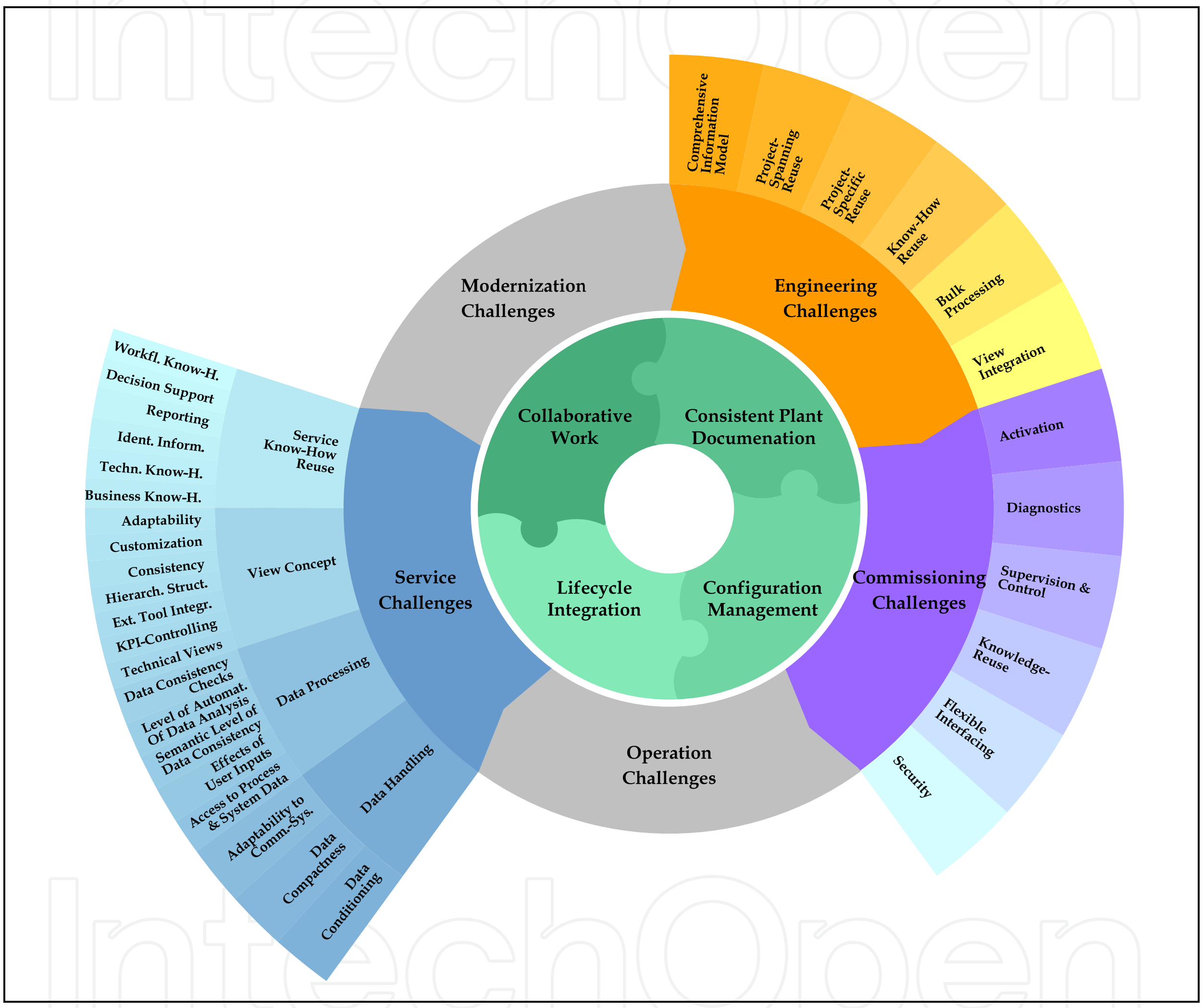

Fig. 9. Siemens Challenge Reference Model – Example: IIS used during technical service

The first type of Challenges is called Project Challenges and effects all life cycle phases of industrial project business (life cycle phase-spanning). Project Challenges are depicted within the center of the Siemens Challenge Reference Model shown in Figure 9. Yesterday's as well as today's IIS are mostly specialized in dealing with delimited tasks and therefore often support only sub-processes, for instance the execution of on-site but not remote maintenance. They often don't integrate with other IIS or information already gathered in preceding life cycle phases - for instance engineering data describing the production system's structure - which clearly offers room for improvement. Life cycle integration, collaboration, and configuration as well as continuous documentation are key success

factors aggregated in these Project Challenges that are valid for all IIS used in all production system life cycle phases.
The structure described within the previous section is reflected by making use of selected Challenges which in contrast to Project Challenges are life cycle phase-dependent. Figure 9 shows the applicable Challenges for an exemplary IIS which is setup during engineering as integral part of the production system. Naturally it is also element to the commissioning phase and is finally used continuously as part of technical services. The Challenges for the three corresponding phases engineering, commissioning, and service are expanded in Figure 9 and accordingly described below.
During engineering a lot of technical dependencies and risks have to be managed and experts from a great variety of crafts have to be coordinated, including for example electrical- and mechanical engineering. They are united by a superior task – namely the built of the production system – which was above referred to as project. Selected success factors during engineering are an comprehensive information model, intra- as well as inter-project reuse, and the reuse of engineering know-how, and bulk processing.
Commissioning the production system built during engineering usually is an strenuous task consisting of a step-by-step start-up of the production system and marking off long checklists of customer requirements. Selected and self-explanatory success factors are for instance an agile diagnostic of unexpected production system states, security as well as safety, and the re-use of commissioning knowledge.

	General Meaning of Class	**Example: Sub-Challenge External Tool Integration of Service Challenge View Concept**
Class 4	Concept for Generic Support of User	Plug-in-concept - access data on logic level (e.g. API, SOA)
Class 3	Concept for Explicit Support of User on a High Level	Standard file format - with automated im- / export
Class 2	Concept for Explicit Support of User on a Low Level	Standard file format
Class 1	Concept for Implicit Support of User	Access on DB-level
Class 0	No Concept Regarding Challenge	No support

Table 2. Concepts associated to Sub-Challenge Ext. Tool Integration of Challenge View Concept

Important activities of service execution are those summarized by the term maintenance. They cover inspection, monitoring, compliance test, function check-out, routine, overhaul, rebuilding, repair, fault diagnosis and localization, improvement, as well as modifications (see EN 13306, 2001). Maintenance for production systems is defined by (Ehrlenspiel et al, 2007) as „*all technical measures [necessary] to obtain or restore the functional state*" of an production system. Minimizing the cost accumulating during service, which may easily exceed a multiple of the initial costs of purchase, "*should be the primary goal of a cost-conscious developer*" (Ehrlenspiel et al,.2007). Challenges in service execution result mainly from the existence of an actual production system, for instance the need to respond to urgent malfunctions and the production system itself as data source of the IIS. Figure 9 shows the four Challenges of service and additionally the subsidiary Sub-Challenges. For each of the 21 Sub-Challenges five concepts have been gathered which break down each success factor's determinants even further (example see Table 2).

5. Application of the Concept Catalog

The Siemens Challenge Reference Model serves as a basis for instruments of evaluation and improvement of Industrial Information Systems that can be used from the perspectives of both the IIS-supplier as well as the user of IIS. Therefore two complementary methods (see Figure 10) were developed by Siemens Corporate Technology (Dencovski et al., 2008) together with Friedrich-Alexander-University Erlangen-Nuremberg and Universität Stuttgart:

- IIS-Profile - General assessment and evaluation of the concepts (philosophy) of an Industrial Information System
- IIS-Usage-Profile - Analysis of the user workflow in relation to the Industrial Information Systems used, and findings derived from this (e.g. strengths and weaknesses of IIS, requirements).

The first method, which is the IIS-Profile-Analysis, serves as a general evaluation of the concepts of IIS, and enables the positioning of released Industrial Information Systems. It works also on their requirements specification, feature specification, prototypes as well as user's manuals relative to the Challenges described above. The evaluation is based on a generic usage context as a reference of evaluation, and shows principal possibilities and concepts of IIS – hence *IIS-Profile.*

The second method, which is the IIS-Usage-Profile Analysis, supports the concrete development of an IIS-Usage-Profile. It is the goal to evaluate the effectiveness of IIS in their concrete usage context, that is, the user's processes, by means of a strengths / weaknesses analysis, and to derive from this evaluation well-founded, structured requirements for the IIS used or to be used. The basis for the method is, on the one hand, a standardized list of questions, and on the other hand, a workflow model that is created interactively with the users. In this process, the roles and concrete tasks (including expenditures), the Industrial Information Systems used in the process, the processed / generated technical information, and its logical dependencies in the workflow of a production system project are considered. This also enables the method to place the focus on processes and dependencies that overlap IIS. The workflow model has multiple tasks to accomplish (see Figure 11):

- Visualization and documentation of interrelationships between tasks, information and Industrial Information Systems for users and the generation of questions in the interview
- Demonstrations object: Problems with the use of the Industrial Information Systems become evident in the workflow model, especially with regards to existing interrelationships
- Basis for the processing of concrete, common visions of Industrial Information Systems and systems landscapes; concepts can be clearly positioned, organized, demonstrated, and evaluated using the workflow model.

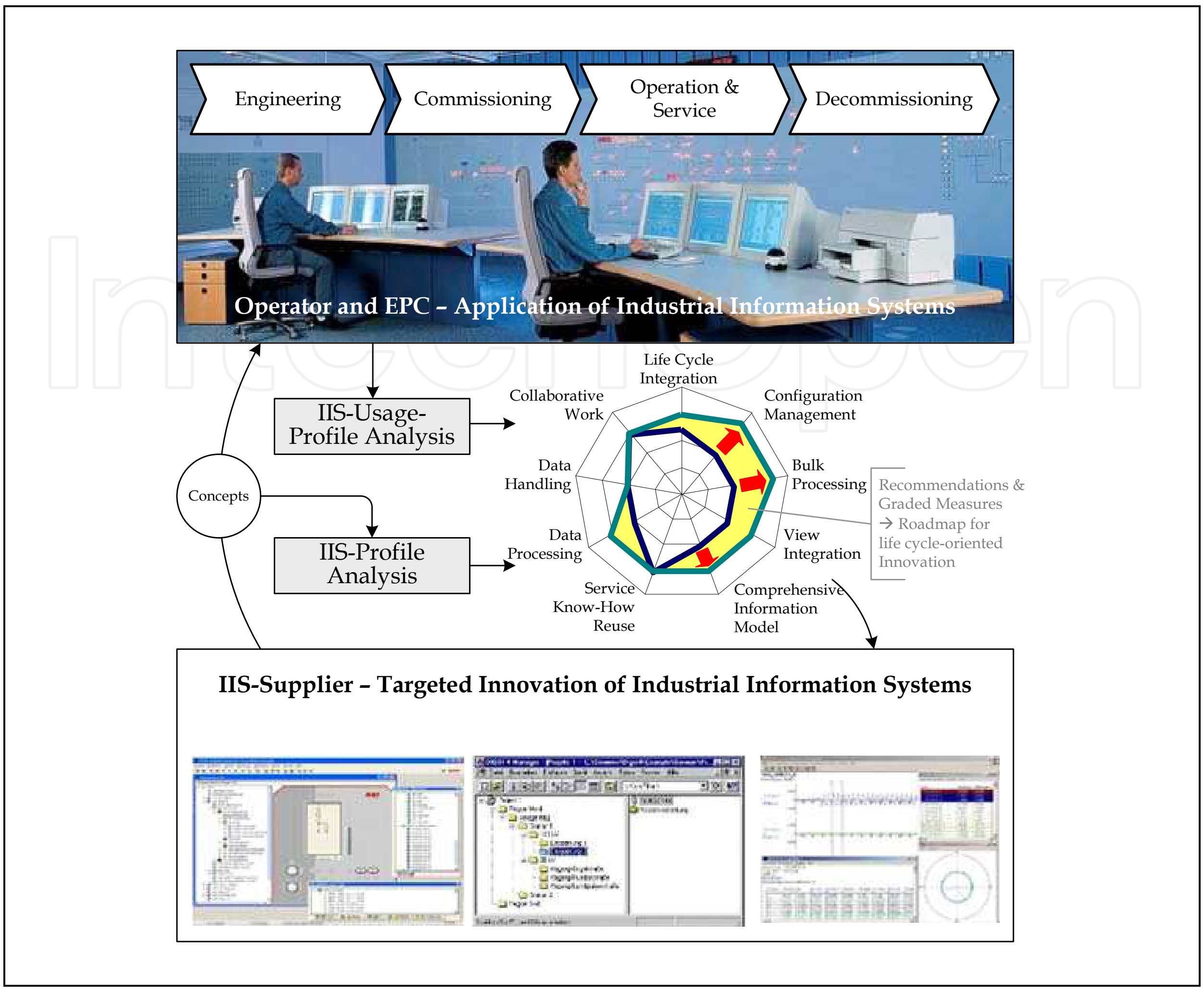

Fig. 10. Complementary methods for use of Siemens Challenge Reference Model

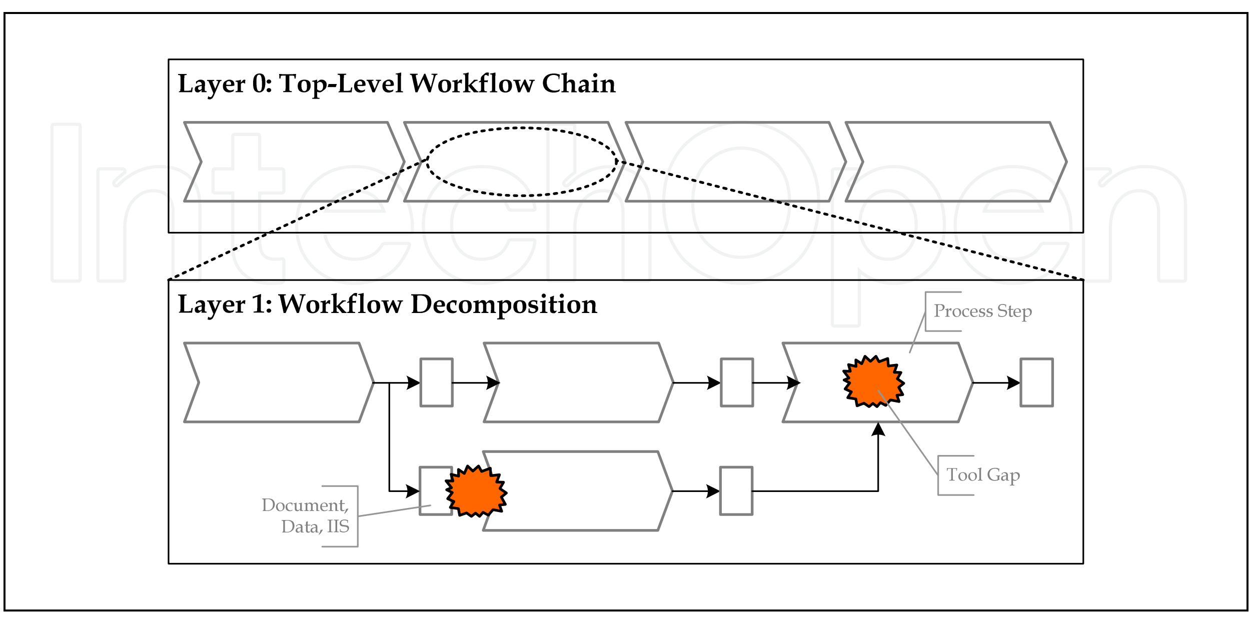

Fig. 11. Modeling of user workflows

Subsequently, using a standard list of questions and an interactively created workflow model, an IIS-Usage-Profile is created that contains existing strengths and weaknesses, as well as the expectations of the user for future concepts. The Challenges serve as an structuring perspective during workshops with users for a systematic examination of all important aspects. Existing Best Practices from the concept catalog are used, in order to put the requirements and expectations of the users into concrete terms, to illustrate them to the users; and possibly to limit them. For example, it is not meaningful to strive for the highest level of Best Practices when it is not required by the user's task, because with an increasing degree of freedom and number of possible settings, there is a simultaneous increase of time and energy needed for learning the ropes of the IIS.

The described two methods complement each other in order, on the one hand, to highlight principal (existing or planned) possibilities and concepts of IIS, and on the other hand, building on those, on the basis of developed IIS-Usage-Profiles and expectations, to develop life cycle-oriented innovation steps and roadmaps based on the idea of the Digital Factory. The results are summarized compactly at the highest level in a clearly arranged graphical representation. Individual levels represent how comprehensively the Industrial Information System supports the user. Through comparison with the current IIS-Profile, the appropriate adjustments for increasing the productivity can be identified and corresponding optimization measures can be derived. Figure 10 shows the combination of the two methods.

In recent years, more than 15 Industrial Information Systems were classified by Siemens Corporate Technology with the IIS-Profile method. Among these were commercially available tools, such as Freelance 800F from ABB, but also, tools of Siemens AG like Comos® (see for instance Maurmaier et al., 2008) or SIMATIC PCS 7. It can be seen, that IIS-suppliers follow different strategies in addressing Challenges in production system projects via concepts.

Further on, for several automation solution suppliers an IIS-Usage-Profile analysis was executed to model and visualize the actual user's workflow in relation to the IIS used, and to show strengths, weaknesses and improvement potentials of these and as well user expectations towards Industrial Information Systems.

6. Conclusion

Changed basic conditions and trends, postulated as such across various industries, demand from suppliers of automation solutions for production systems like Siemens AG to choose new paths in order to reduce the total cost of ownership and to increase the total value of production systems. The most important are

- to establish efficient integrated engineering processes and methods based on mechatronic components
- to provide standardized solutions for production systems (reusable work results) including adequate libraries
- to offer an integrated view on the production system over all life cycle phases and crafts

based on efficient and integrated Industrial Information Systems.

These new paths are combined within the idea of the Digital Factory, where for instance the production system is engineered entirely in a virtual way first, before the real production system is realized. According to Siemens AG, integrated engineering for mechanics, electrics and automation will be available in ten to 15 years not only but especially for automotive industry.

In addition, the continuous and integrated provision of digital information over the whole production system life cycle based on mechatronic components enables to consider dependencies between various life cycle phases in advance. For instance, maintenance and condition monitoring activities for the operation and service phase of a production system can already be prepared during the engineering phase in a virtual way (Wucherer, 2006).

As an overall result it can be stated that suitable and integrated Industrial Information Systems, which are designed to realize the idea of the Digital Factory are crucial for the future success of all stakeholders of production systems. As a consequence, Industrial Information Systems have to be innovated in an adequate way. The method for the life cycle-oriented innovation of Industrial Information Systems introduced in this chapter allows for a targeted evaluation and innovation of IIS with the aim to realize the ideas of the Digital Factory in an evolutionary way.

The core of the presented method is built by the Siemens Challenge Reference Model, which operationalizes the knowledge on concepts used to cope with the challenges in industrial project business. This reference model integrates both the knowledge on life cycle phase-specific concepts and life cycle- and craft-spanning dependencies. With the help of the IIS-Profile-Analysis and IIS-Usage-Profile-Analysis which both use the Siemens Challenge Reference Model, IIS-suppliers as well as users of Industrial Information Systems have essential benefits, which are for instance

- status quo analyses of Industrial Information Systems as a basis for life cycle-oriented innovation
- competitor analyses, i.e. comparison of different Industrial Information Systems of various IIS-suppliers in order to generate unique selling points
- basis for selection and purchasing activities for users

On the road to realizing the Digital Factory, the stepwise innovation of Industrial Information Systems according to the introduced innovation method along the life cycle of a production system generates short and mid term benefits for all stakeholders of production systems. For the engineering and commissioning phase, following benefits can be described, for instance

- reduced engineering and reduced time-to-operation
- easy overview of complete project
- high quality of technical information
- flexible concurrent engineering
- reduced technical risks
- reduced commissioning time and costs
- reduced engineering and commissioning effort by standardized and compatible technical solutions
- faster start up by better diagnostic data of equipment and reduced effort for failure and malfunction fixing.

In addition, there are several benefits for the operation and service phase, too, for instance

- availability of engineering and diagnostic data for production system elements
- reduced production system down-times applying intelligent maintenance strategies

- fast failure fixing
- access to all relevant production system data for decision making.

Due to the fact that the introduced method already considers and describes life cycle- and craft-spanning dependencies of production systems within the Siemens Challenge Reference Model and the complementary described methods of a IIS-Profile-Analysis and IIS-Usage-Profile-Analysis, it can finally be stated, that a stepwise innovation of Industrial Information Systems according to this presented approach enables a stepwise realization of the vision of a Digital Factory.

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