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# Towards Mass Individualization: Life-Cycle Oriented Configuration of Time-Variable Product-Service Systems

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*Abstract*--**The objective of this article is to identify the requirements for product service systems (PSS) with non-predefined services due to unknown customer demands over the life cycle of the product and to identify the requirements to the non-predefined stakeholders of the PSS within a collaborative network due to unknown business processes/scenarios over the life cycle of the solution. Aim of this paper is to describe an approach for simultaneous life-cycle optimization of product-services and business processes within the network of stakeholders.**

**This paper presents an in-depth case study based on a network of OEMs, components suppliers and system suppliers of durable capital equipment, organized within a best practice network with focus on mass customization. Basis of the approach is an analysis of realized projects of the past in combination with strategic approaches of the future. The used approach is based on the findings of modularization of products and processes and is adopted to non-predefined business services and business processes.**

**The paper investigates PSS through an understanding of a service-enhanced product solution, consisting of tangible and intangible assets; the understanding of collaborative network as a process in which companies/stakeholders share information, resources and responsibilities towards a common goal (e.g. customer order).**

**The paper identifies the following recommendations for mass individualization-oriented companies**

- **how to enlarge their tangible assets (e.g. machines, smartphones etc.) with intangible assets (e.g. service engineering, product financing etc.) into service-enhanced products**
- **how to take into consideration changes in technology and market in order to adopt their products and their technologies to these changes over the whole product life cycle (PLC)**
- **how to find out the relevant processes to realize these service-enhanced products and how to realize these processes on a mass production level**
- **how to find the right network partners to overtake and to integrate these stakeholders with a maximum of efficiency**
- **how to control the whole product and process system over the whole life cycle with the use of a business intelligence solution**

**This paper provides further empirical evidence that the systematic creation of business services and the identification and integration of corresponding business processes cannot be treated as discrete stages but is evolutionary and requires a complex systems perspective. The approach is transfer-oriented, e.g. being based on a methodolgy and adopted to a special group of stakeholders (best-practice network).**

## I. INTRODUCTION

Many case studies show, that in the IT-branch new product-services go beyond the physical and service oriented concept. These product service systems are very successful, as they are designed to be always connected, self-learning, adaptive, intelligent and give the company many spaces to interact with the customer (e.g. through new Apps, etc.). In order to generate economic growth, also companies in other branches should focus on delivering solutions for current actually customer needs rather than offering simply static products-services. Especially through innovative enhanced services big revenues are expected.

This mass individualization concept can be addressed by embedding knowledge and new functions in highly-personalized innovative product-services. Through this functional extension again new business opportunities can result.

In mass-individualization, new product design and -development is fully linked to the concurrent design of the related business processes. Managing business processes and product-service systems through life-cyle in many cases is just possible within collaborative networks.

**Mass Customization** - The most fundamental principle of low-cost, high-volume customization is modularity, which enables the supplier to do only and exactly what each customer needs. Not only the product should be modular, the supporting processes also should be able to retain the modularity till the end when a customer exercises her choice. To achieve MC, companies can start from its product designs by introducing a common platform. Platform-based approach enables a number of product variants to be developed from a common platform, which can largely reduce the time and cost of new product development. Platform commonality means to standardize and share components among products. The manufacturing steps that result in the differentiation of products are postponed as late as possible. As a result, manufacturers produce a generic product and become more flexible and responsive to customer demand.

**Collaborative networks** - Developing in network is not a new issue - it has been done already for many decades. But frameworks are changing: the intensity of competition is growing due to globalization, the momentum of new technology development is increasing due to IT-usage, different technology fields are converging and offering new functions and performance within a decreasing life cycle of innovation and technology. Therefore, companies are forced to develop their offer (product-service systems) in collaborative networks which changing participants through time on a frequent way. Collaboration allows to work with business partners and – at the same time – compete in the market for customer's attention and share of their business. With the advances in information and communications technologies, the business community is encouraged to consider many different and innovative business models that bring together a judicious combination of collaboration and competition. This has implication on a company's business intelligence which is changing towards a "multi-company" Business Intelligence concept.

**Business Intelligence** - This subject deals with the challenge of life-cycle oriented configuration of business processes and service-enhanced products based on economical key figures. Thereby, one of the key challenges is that relevant actual, as well as historical data, has to be gathered from all network-partners and integrated on a syntactically and semantically layer. Within businesses, so-called Business Intelligence concepts deal with the extraction, transformation and storage of data from different source systems. Managing service oriented collaborative networks require research on "multi-company" Business Intelligence concepts. Thereby, several new aspects have to be considered:

- Managing business processes and service enhanced products in collaborative networks means that several stakeholders have their own focus and therefore their specific information demand. Because of that in a first step the information demand of the stakeholders has to be explored. This includes the aspects of information content and quality.
- Establishing Business Intelligence across company borders requires specific security policies. For example, the data ownership, the access authorization and the level of analysis options have to be specified for each stakeholder. Therefore, businesses usually establish organizational bodies, for example Business Intelligence Competence Centers (BICC). Within collaborative networks new forms of virtual BICCs are needed.
- Decision processes in collaborative networks are quite different compared to decision processes in single businesses. Therefore, the opportunities of Business Intelligence tools in collaborative networks have to be analysed.

In order to support managing life-cycle oriented configuration of business processes and service-enhanced products within collaborative networks, a proposal for a Business Intelligence concept is needed.

**Technology- and Market Cycles** – Dealing with heterogeneous technology- and market cycles in changing collaborative networks requires

- Picturing the actual state of the product-service system and the value of each component of this offer. Furthermore, the actual partner network and the relations between them and their value proposition concerning the offer needs to be identified and monitored.
- Identifying the relevant information base for establishing the most appropriate collaboration network based on potential future developments of markets and technologies.
- Formulating the cross-partner technology strategy based on the single technology strategies of the partner based on the actual and future requirements of the customer concerning the *cross-partner* offer.

The approach described in this paper aims at answering the question concerning the cross-partner technology strategy: „How do the changes in market (individualization) and technology influence the cross-partner offer of product service systems and which collaborative network (stakeholder and business processes) is then needed?“

*The use case "OEM - supplying durable capital equipment"*

The industry in Germany is well known as consisting of SMEs working in the area of durable capital equipment for special purpose, acting as OEM all over the world. These companies are directly affected by the trend to mass customization in combination with product service systems, i.e. their customers require customized product and service solutions all over the world.

The nature of capital equipment presents an ideal opportunity for packaging product and service as part of its core offering as it is characterised by large, high value, low volume production outputs.

Furthermore, durable manufactured goods result in utility over time and require services as they advance through their life cycle (acquisition, installation, operation, upgrades, decommission, etc.), they also have an associated cost of ownership beyond the original purchase price (spare parts, consumables, maintenance, etc.).

Historically, the focus has been on product-orientated service offerings including repair and maintenance. But in the last years companies have expanded their offering by introducing a number of use-orientated PSS solutions which can be characterised by:

- Whole-life support of the asset:
  Support in the economical acquisition, repair, maintenance and disposal of equipment from the time it is delivered to the customer, until it reaches end of life.
- Working availability of assets as a performance indicator:
  The company maintains and measure on a volume of equipment ready for use at any one time.
- Pricing based on a cost-per-unit of equipment use:
  A customer pays per unit of use, generally speaking the unit could be time, distance, depth, volume etc. depending on which measurement unit applies to the equipment and its usefulness.
- Different ownership options:
  The customer can choose whether to retain ownership of the equipment as capital assets, whether ot rent/lease equipment for certain periods of time or indeed not to have any ownership rights over the equipment. [55].

The approach of this paper can be described by the following example:

After the delivery and putting into operation of the equipment by the OEM, the customer normally asks for the service of maintenance due to a predefined schedule. The OEM will have to decide who to perform this service by doing this himself or charging a partner out of his network starting from the early beginning of the equipment operation time.

Within the life time of the equipment, the customer might require the service of capability forecasting, e.g. advice on the optimal configuration of a group of equipment to ensure maximum equipment availability at minimum cost, e.g. due to an enlargement of activities of the customer.

This service was not predefined at the development and realization phase of the equipment – therefore, no service provider (close to the customer) is available yet.

Now the following tasks have to be solved:

- How can the business service “capability forecasting” be designed in a way that a maximum of customer individualization can be achieved by using the principles/advantages of mass production/standardization?
- How can the corresponding business processes/scenarios (i.e. actors, roles, data input-output etc.) be defined in order to have a maximum “fit-for purpose” of the provider/stakeholder of the requested business service into the existing collaborative network?
- What kind of technologies are actually “ready” for use in order to perform the required business service and which stakeholder in the collaborative network can already provide this technology on the required “readiness level”?
- What kind of information and data (“Industrial Intelligence”) is needed for the service provider for performing the required business service and for the stakeholders in the collaborative network to be sure that the complete business scenarios can be fulfilled properly?
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## II. REQUIREMENTS AND FRAMEWORK

To meet the above mentioned research questions, three dimensions have to be considered:

1. changes in technologies and markets,
2. changes in the collaborative network and
3. changes in the cross-partner product service system (PSS).

Those three dimensions are interdependent: Due to not predictable impulses from market (e.g.: “…the customer requests a new service”) or technology (e.g.: “…a new technology increases the performance of the PSS”) changes in the structure of the PSS (e.g.: a new service needs a new software to be added), in the collaborative network (e.g. a new partner is needed to provide the new service) and in the product service system (e.g.: a new product variant) with corresponding business processes (e.g. an additional new product development (NPD) process in order to realize the new product variant) can appear.

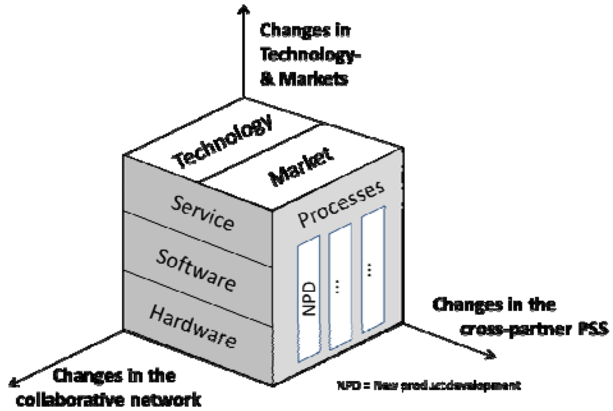


Figure 1: Framework

Therefore, following 3 dimensions needs to be considered in order meet the above mentioned research questions:

- **Changes in technology (cycles) and markets (customer requirements)**
- Changes in technology and/or market needs to be forecasted and monitored in order to ensure, that both, the offer and the collaborative network are designed on a future-proof way and that signals in the area of new technologies and markets can be sensed and implemented. Usually the integration of a new technologies influence several network partners. A new technology of a network partner can cause serious changes in the way another partner provides its contribution to the PSS. In some cases, network partner could get obsolete (e.g.: in an electric car, gearboxes are not necessary any more) or new partner needs to be found (e.g..: in an electric car, batteries are necessary). Therefore technology forecasting is a multidimensional issue. This means that the results of the technology forecasting of every network partner needs to be managed centrally in order to notice distinctive changes in an early stage.
- **Changes in cross-partner PSS and corresponding business processes**
  New business opportunities will be generated when providing increased added-value to users by integrating personalized innovative functions into traditional and high-tech products based on production and process standards (Mass Individualization). But considering the life cylce of products and corresponding services, a change can happen concerning the market required services and corresponding processes (e.g. the service of refillment of the battery in a electric car realized by the business process of a service provider exchanging the battery on request of the customer). The special requirement is how to configure these unknown (non-predefined) services and the corresponding unknown (non-predefined) business scenarios (i.e. processes, actors, information etc.). New concepts to configure these product service systems and the corresponding business scenarios are necessary.

- **Changes in the collaborative network**
  Creating PSS in collaboration networks requires a professional network management. Typically network configurations are characterized by independent partners where all of them act in different networks. Therefore on the one hand side loose and flexible structures are needed. On the other hand, typically PSS are highly complex systems which only fit together and reach high quality through a gapless information network. Therefore a close information exchange is necessary. Each partner has an information demand about features of the PSS. This information has to be provided from different network partners in the right manner – without providing confidential knowledge to all partners. Therefore, a major challenge in collaboration networks is creating concepts for distributing right information to the right partners. Because of the flexible network configuration, given as well as non-predefined stakeholders has to be considered within this concepts.

The integration of those 3 dimensions is a quite demanding task, as all three dimensione can change over time and are influencing the other dimesions. Therefore the following requirements for the framework can be deducted:

- The framework should support a successful integration of non-predefined services into an existing PSS
- The framework should depict essential components of customization and deployment for non-predefined PSS and non –predefined stakeholders
- The framework should reflect all relevant relations between the components and the stakeholders
- The framework should be easy-to-use by the target group and a basis for transfer into daily practice of collaborative networks.

In the following sections these three differentiating elements are described and related to each other.

*A. Technology cycles and market/customer requirements*

Concerning the technology cycles, it needs to be drawn attention on two different topics: first, the readiness of existing technologies and second the emerging of new technologies. Both are crucial, as improvements of existing technologies and the rise of new technologies can affect the offer and the collaborative network.

**1) Technology readiness**

For the evaluation of the state of the art of technologies, different models in literature and practice can be found [53, 60].

According to findings from biology – where after organisms go through an evolutionary development process – different life cycle models were developed for branches, markets, products and technologies.

To classify the technology readiness models and life cycle models, we distinguish between state- and time-based approaches.

Regarding the state-based models, the dynamics of the relevant state variables are considered to describe the technology readiness [21]. However, the technology readiness is a time-dependent factor, also if it is described by state-based models. Within these models, the time dimension is taken as inherent without showing it explicitly.

On the opposite, the time-based approaches map the retention time of the technology in the market [18] or the performance of the technology. Thereby the progress in technology development is mapped on a time line or over/by/with a time correlated variable (e.g. R&D effort).

Different approaches exist and are described in Table 1.

TABLE 1: EXISTING APPROACHES TO MAP TECHNOLOGY READINESS

| | |
|---|---|
| Technology readiness levels | Technology Readiness Levels (TRLs) were defined by the NASA in the late 1980s to support technology maturity assessments as an integral part of the technology planning process [41].<br>There are 9 TRLs defined [see (16], whereat the first Technology Readiness Level (TRL 1) signifies the lowest and the ninth Technology Readiness Level (TRL 9) the highest degree of readiness. To start the acquisition of a new technology, at least TRL 6 is recommended, for system development TRL 7 should be achieved [(General Accounting Office)]. |
| Roadmapping | a technology roadmap is a graphical representation of technologies and their link over time [(45)].<br>According to Kappel and Lauber it is possible to differentiate four different approaches of technology roadmapping with regard to their use case [26,38]:<br>• TRIZ-based technology roadmapping: Description of the development of the considered technologies over time<br>• Branch-orientated technology roadmapping: Description of the development of markets, branches and the relevant technologies over time<br>• Product-technology-roadmapping:Company-specific description of the development of products and technologies over time<br>• Integrated product and manufacturing technology roadmapping: Company-specific description of the development of market requirements, products, (product and manufacturing) technologies, etc. over time |
| Aster-model | According to Ardilio [2], the technology readiness depends on the application the technology is to be implemented in and on the single attribute of the technology.<br>Therefore, the application specific technology readiness model (Aster-model) identifies the readiness of a technology (on an attribute-level) for the technology implementation within a specific application.<br>The Aster-Model determine and map the application-specific readiness of technologies by decomposing both, the application and the technology into its provided resp. requested functions and performance- resp. requirements-profile. Furthermore, Ardilio maps the technology readiness for every single technology performance criteria. The technology readiness is not a single number, but a set of different criteria, describing the readiness of a technology for an specific application. |

**2) Technology forecasting in collaborative networks**

The task of identifying emerging technologies includes the technology identification as well as the technology foresight (prognosis) and the technology monitoring. Thus, companies are practicing technology foresight in terms of overall economic, social, political and legal aspects [39, 20, 44].

Technology foresight supports general and particularly technological decisions of the company and therefore also of the cross-partner technology strategy. The identification of relevant emerging technologies is focused on information about technology trends, opportunities and threats that have a far-reaching influence on the technology-related strategies and activities [39]. Thus, the perception and interpretation of weak signals related to technology is the guiding theme of this task [54].

The newer concepts of technology intelligence integrate considerations of the provision, the format and the assessment of technology-related information [54]. This information mostly will be originated from the research environment, due to different information sources. Weak signals often represent indicators for developments and trends that could become concrete opportunities for the offer of the company-specific technology strategy [54], and therefore also for the cross-partner strategy.

Technology forecasting in collaborative networks is a quite challenging task, as it requires the input and a synchronized involvement of all existing partner.

Dealing with heterogeneous technology- and market cycles in changing collaborative networks requires the picturing of the actual state of the product-service system on a technological level.

In order to identify relevant technologies for a future PSS, the technologies were translated into its functions (approach see Figure 2). This functional description supports the identification of potential new addressable markets and/or relevant substitution technologies with better performance ratio.

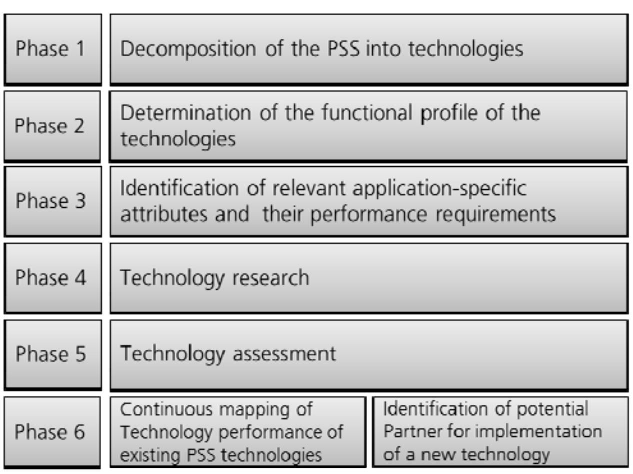


Figure 2: Approach for technology forecasting in collaborative networks

Furthermore, the actual partner network and the relations between them and their value proposition concerning the offer needs to be identified and monitored.

Due to changing requirements and/or new found technologies, the collaborative network needs to be enhanced by new partner or diminished from partner, which do not add value to the PSS anymore. Based on the actual and future requirements of the customer concerning the cross-partner, the cross-partner technology strategy will be formulated based on the single technology strategies of the partner.

*B. Integrated PSS and the corresponding business processes*

**1) The integration of non-predefined business services into a PSS as "smart engineering" solution**

The integrated development of PSS is based on a systems engineering approach, considering all influences to the development of a product solution. This includes all aspects of activities over the whole life cycle of the product, taking into consideration the mutual influence between product and process design. The product development process therefore no longer consists of parallel development processes for mechanical, electronical, software, service components which are linked together at the end, but comprises an integrated approach of all disciplines. This requires a synchronization of the different development models of the different disciplines, integrated by a model based development concept. The key is to focus on product and process functions and not on components in the first step of development.

This consists of the following characteristics:

- Integrative development models and description languages: model design free of redundancies, domain-overlapping
- Integrative methodological support: systems engineering
- Process-accompanying validation models: rapid prototyping, digital mock-up *enlargement of a "classic" PSS by non-predefined services requires an IT-driven adaptive Business Services*

Responding rapidly to changes of customer requests by non-predefined services, with timely service provision, is critical for the effective functioning and overall success of enhanced product service systems. To meet rapidly changing demands, businesses have become increasingly service-driven, both in the ways they interact with customers and partners, and in how they design and build their IT infrastructure.

The mass customization or personalization of product service systems can be achieved by efficient and agile orchestration mechanism for service composition which is based on scalable and highly-efficient service composition systems.

Simple computing services can be combined into more complex and versatile service- and application compositions. Thanks to the agile orchestration of individual services to processes (using an existing infrastructure i.e. existing fine granular services specifically designed to enhance the basic physical product), new and adaptive business processes can be used productively "on-the-fly" according to the customization needs of the product service systems.

A kind of rich ecosystem of services and service providers supporting product service systems has to emerge, forming a complex environment in which non-predefined services can be developed, tested, deployed and operated.

While this complex service environment provides many choices, at the same time it poses a great challenge to developers in charge of building resilient application architectures. To address the identified gap for product-service-systems an implementation of a mash-up between a market system, federated authentication system and distributed computing platforms must be possible.

A PSS-based framework and toolset is needed, that allow the development of interoperable applications independently of each other.

Such a toolset should minimize human involvement to the process of binding of interoperable services and mapping between the business functionalities and customer personalization needs.

The following technical preconditions have to be met by the tool-set:

- A loosely-coupled architecture supporting the PSS designed to meet the agile business services needs
- Building system-centric processes spanning products and services
- Potential to quickly expose processes as services
- Develop fine-grained integrated application and process control, i.e. with kind of combined product-service-configurator
- Deliver high performance execution for straight-through processing
- Enable run-time configuration capabilities into the service infrastructure

Finally a mechanism must be provided to allow for ad-hoc (at least with a short time-frame) creation of new and additional functionalities or core services. To this end concepts like Human-as-a-service (HaaS) and advanced third-party integration might introduced into the concept.

The future business environment will be characterized by open business service ecosystems where product providers can relatively easily enhance their product with new potential services, establish new flexible business models, based on an open market of business services to jointly utilize, and to rely on service interoperability utilities.

### 2) Smart organizations

To meet the requirement for a Life-cycle oriented configuration of business processes and service-enhanced products the collaborative network should be seen as a "smart organization".

In order to make valuable step towards intelligent services, companies and/or collaborative networks should not limit to the creation of specific services, but instead build-up flexible solutions that allows all members to create new services through orchestration of reusable collaborative approaches. Collaborative networks which are intended on the one hand to the PSS and on the other hand the corresponding business services over the product life cycle are facing the following requirements in addition to "time, target and budget":

- The adaptability to new product and process variants which require the integration and interoperability of the corresponding IT-systems
- The real-time ability to make information and data available to selected partners within the collaborative network
- The network ability to integrate different stakeholders and different business processes into the collaborative network

As a result, collaborative network-partner (as existing or new member of a smart organization) needs to be integrated into the whole life cycle of the PSS not only on the product level, but also on the IT-supported business process level. Therefore the whole collaborative network is affected by the IT-architecture of the total organization. This has to be kept in mind when e.g. using cloud-based Software as Service solutions for realizing selected business processes within the network.

As a result out of this, the following services and functionalities can be identified:

- Communication by networking of production units
- Comprehensive adjustment of resources, dates, materials etc.
- Comprehensive recognition of affected processes caused by changes
- Permanent controlling of all entities within the network affected by changes
- Integration of new process units into the existing work flows

### 3) Adaptive Business Scenarios

The enlargement of "classic" collaboration networks by non-predefined business processes re-quires adaptive Business Scenarios.

A business scenario is a complete description of a business task/problem, both in business and in architectural terms, which enables individual requirements to be viewed in relation to one another in the context of the overall problem.

A business scenario describes a business process or application, the business and technology environment, the people and computing components ("actors") to excute and the desired outcome of proper execution.

The relevance of business scenarios cannot be determined by the current operational business practices of single companies, but rather by their contribution to identify the "backbone" (models, infrastructure, tools, and processes) for a new way of doing business in a collaborative net-worked environment.

In other words, the selected scenarios should help in creating the conditions to get prepared to effectively doing business in a different way.

Under this perspective, it is also important to consider the need for base or "enabling" scenarios, which just create the proper conditions for the development of enhanced scenarios that are appealing to an end-user more directly.

For instance, while for end-user companies it might be relevant to have a scenario focused on the formation of goal-oriented networks (in response to a business opportunity), it is also clear that the agility of the consortium formation process very much depends on the existence of a long-term strategic network that promoted the preparedness of its members for collaboration.

Therefore, the effectiveness of the mentioned scenario depends on the consideration of an "enabler" scenario focused on the management of long-term networks or business ecosystems.

In this context, the following business scenarios are considered:

1. Management of long-term collaborative network
2. Formation of goal-oriented collaborative network
3. Co-design and co-innovation support
4. Base operation and management of product servicing
5. Advanced supervision services for the collaborative network
6. Shared Resources Repository Management
7. Product portfolio management
8. Semi-automated Learning-based Decision Support.

Scenarios 1, 3, and 6 have a kind of "enabler" nature, while the others more directly address end-user.

As a result out of this, our framework consists of 3 dimensions:

- Integrated PSS plus corresponding business processes, enlarged by non-predefined services and non-predefined business scenarios
- collaboration network of stakeholders for PSS, enlarged by an integration scheme for non-predefined stakeholders
- life cycle oriented changes of technology and market influencing PSS and business processes.

### *C. Network Management and Industrial intelligence*

One of the preliminary tasks of network management is, as depicted in chapter 1, the information management. Because of the critical role of information, this paper focusses on the information demand and information supply within collaboration networks. First of all, from the perspective of ICT the network partners must be considered separately since it is assumed that all of them have their own historically emerged IT infrastructure. Regarding businesses, the IT infrastructure can be subdivided into three layers, [43] : planning, execution, and control layer.

Within industrial enterprises the planning layer contains engineering and economic oriented IT systems. As studies show, these systems have to be considered separately because it is not unusual that those categories are "two worlds" within a business [36] . On the one hand, in business units like R&D and manufacturing, there are product-orientated applications in use that support several early phases of the innovation process. These systems are commonly called "computer aided …" (CAx), e.g. CAD, CAE or Computer Aided Quality (CAQ) [14, 52, 63] . With the aid of these systems the engineering tasks are supported. In the given case, these systems are relevant because they contain relevant information about the product itself, e.g. specifications, bill of materials (engineering view) and assemblies. On the other hand, economic orientated systems like Enterprise Resource Planning (ERP) systems promise an integrated support for all kinds of transactional processes within an enterprise. Usually, MRP (Manufacturing-Ressource-Planning)-II-and ERP-based scheduling and capacity planning is conducted on a macroscopic level that is both long term and product-orientated [43, 46, 22] . In the given case, the systems contain relevant information about customer interactions, contracts, costs and other key performance indicators.

The third category are ingredients of the execution and control layers. Relevant tasks in these two layers include scheduling and planning on an atomic level, real-time process control, and active process control. In the given case, these systems are important because they handle right-time data about the value-creating processes. In practice, Manufacturing Execution Systems (MES) attempt to address these layers in an integrated approach [30] . They originate from the data collection technologies of the early 1980s. Initially, production environments were characterized by unrelated data gathering components. With the rise of integrated concepts like Computer Integrated Manufacturing (CIM), individual tasks were not any longer seen as independent but rather related to a value creating process. This led to benefits resulting from data integration. But the CIM concept was unable to achieve acceptance because of several reasons [30] .

Later, the vision of CIM was replaced by integrated data collection systems that concentrated on defined functional scopes, e.g. production, quality management or product data management (PDM) and later on product lifecycle management (PLM) [15, 28] . But it has to be remarked that it still fell short of achieving a satisfying degree of integration that is needed for lifecycle transparency. This is due to the fact that the integration of engineering oriented IT-systems (e.g. PLM) and economic oriented IT-systems (e.g. ERP) is still insufficient [35].

Therefore, a fourth layer called Business Intelligence (BI) is increasingly relevant in the given con-text. BI denotes integrated approaches to support decision-makers and is usually associated with data warehouse systems (DWHs) that provide an integrated, subject-orientated, time-variant and non-volatile repository for diverse analytic and reporting applications (e.g. for OLAP analysis, data mining, balanced scorecards etc.) [23, 29, 4, 5, 48]. In respect of the context, two major contributors have to be considered: While Inmon stands for a strongly centralized, application-independent approach [23] , Kimball and Ross propose a more decentralized data management, which is held together semantically by the use of shared dimensions ("dimensional bus") [29] . While first approaches focused on not time-critical economic key figures, actual approaches contain the building of "Operational Data Stores" (ODS) to integrate transactional data from multiple sources.. However, the neglecting of engineering data is still a limitation of current BI concepts [31].

Current frameworks organize BI in several layers: the data provisioning layer (extraction, transformation and loading (ETL)), the data storage layer (data warehouse), the logic layer and the access layer [5, 24, 58] (cf. Figure 3). ETL processes extract data from several sources, transform them syntactically and semantically and load them into data warehouse systems [23] . The data storage layer contains one or more data stores. The data stores are sometimes separated due to different data scopes, e.g. financial data warehouses and customer orientated data warehouses or divergent requirements like timeliness, e.g. ODS [25, 29]. Core data warehouses are typically not used as direct sources for analysis systems [23, 5]. Multi-dimensionally modeled data marts in combination with a core data warehouse are known as the "hub-and-spoke approach" [3]. The logic layer focuses on data analysis systems like data mining and OLAP [5] . Within the data access layer all relevant components and functions are presented to the user in an integrated and personalized manner [5] . As mentioned above, BI is largely limited to providing integrated economical information. Therefore, an enhanced BI concept has been developed which is based on economical and engineering data. This concept which is depicted in fig. 2 is called Industrial Intelligence (II) [37]. It includes technologies and procedures to extract data from engineering oriented IT systems e.g. CAx as well as transformation concepts. Thereby it is possible to build product oriented DWHs which are the foundation pillar of integrated and product life cycle oriented analyses. Industrial Intelligence research is recently focused on achieving transparency of product life cycles within businesses. Therefore, in the given case the concept of Industrial Intelligence has to be extended by multi-company data-sources to support decision makers within dynamic value creating networks.

## III. APPROACH: SMART NETWORK CIRCLE

In *product engineering*, modularization is presented in various forms. Its basic principle is to define modules and their interfaces so that they can be reused for different products.

In *software engineering*, the problem of creating modules and reusing them is known as software product lines. To enable a directed reuse, a domain-specific basis of applications is necessary.

The objective of *service engineering* is to enable a systematic development and design of services by providing various methods, process models and tools [11]. In service development, the benefits of modularization and reuse are recognized. The reuse of undifferentiating service components leads to an increase in profitability.

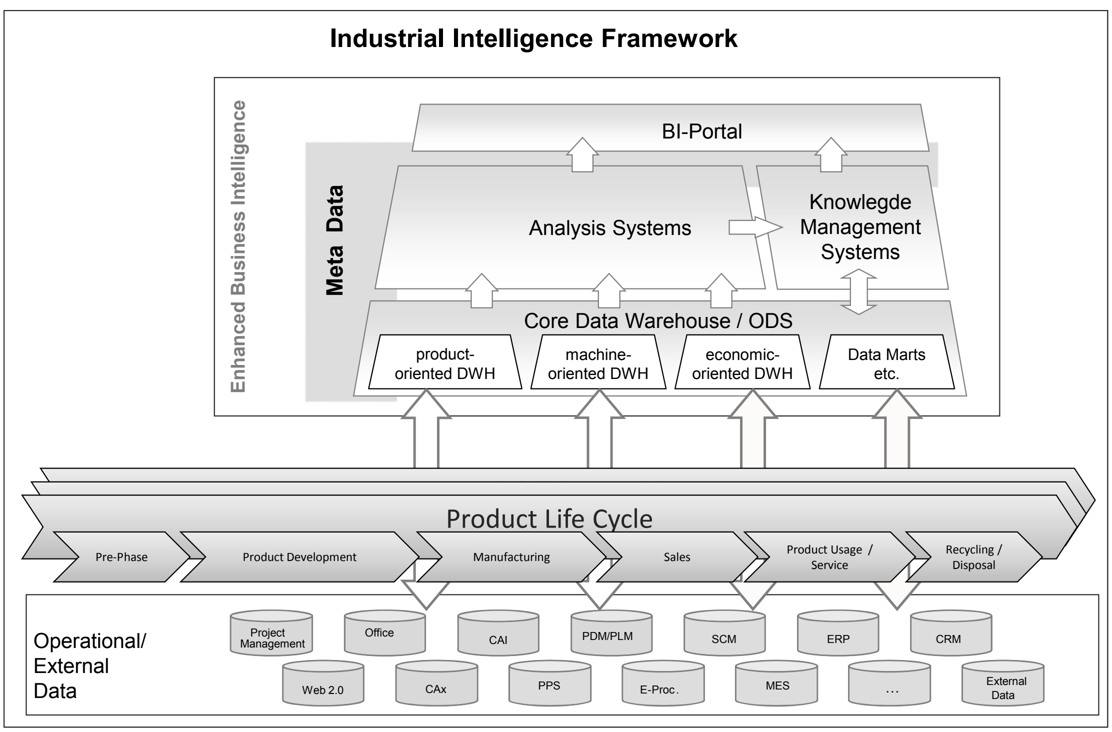


Figure 3: Industrial Intelligence framework (Source: Adopted from [27]

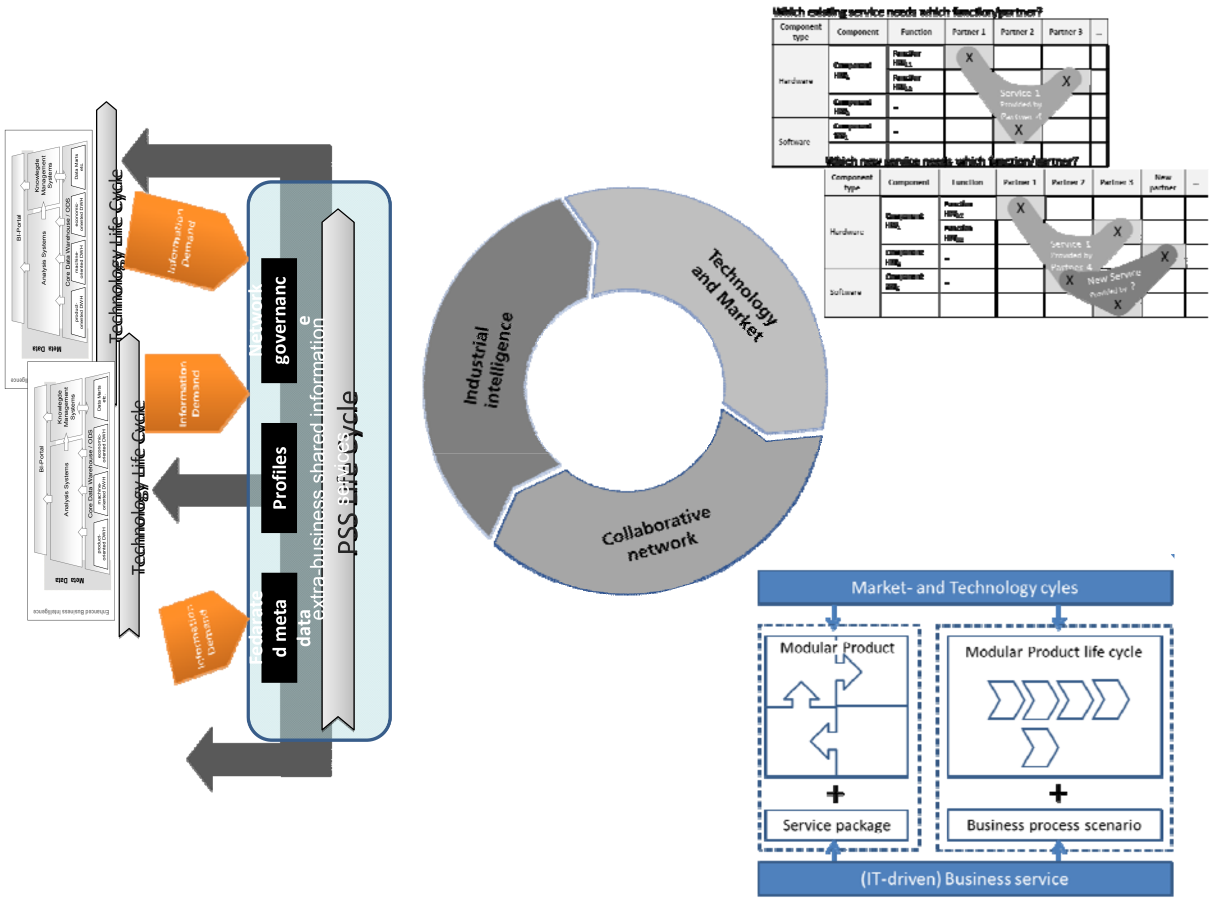


Figure 4: Integration of business services and business processes/scenarios

The Approach will be described in detail in following chapter.

*A. Technology cycles and market/customer requirements in collaborative networks*

The approach for the determination of the application-specific technology readiness is divided in five phases (see Figure 4**Error! Reference source not found.**):

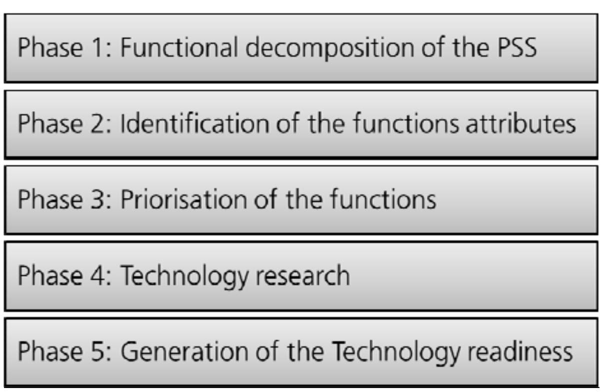


Figure 5: Phases for the determination of the application-specific technology readiness

**Phase 1: Functional decomposition of the PSS**

Aim is to identify the independencies between the functions, technologies and network partner in order to understand which partner will be influenced by a potential change of a technology.

Therefore, the PSS to be observed will be decomposed concerning its technologies and thereafter concerning its functions. Within a PSS "Display", for example the technology "OLED" can be found. This technology fulfills the function „emitting light". The functions will be subdivided into overall-function and sub-functions which can be defined as follows [60]:

- The **overall-function** provides the overall effect of all underlying sub-functions.
- **Sub-functions** where defined as functions, whose interactions result in an overall effect.

Between overall- and sub-functions, logical, physical, technological and/or organization-related correlations persist, which – in their addition – lead to a functional structure [42,1].

The outcome of this phase results into am matrix, which visualize the relation between PSS and partner on a functional basis (see Figure 6).

**1. Which partner is providing which function?**

| Component type | Component | Function | Partner 1 | Partner 2 | Partner 3 | ... |
|---|---|---|---|---|---|---|
| Hardware | Component $HW_1$ | Function $HW_{11}$ | X | | | |
| | | Function $HW_{12}$ | | | X | |
| | Component $HW_2$ | .. | | | | |
| Software | Component $SW_1$ | .. | | X | | |
| | | | | | | |

Figure 6: PSS/network partner-matrix

Services in general are provided by a partner using Hard- and software components of the PSS. In a next step, the provided Services will be mapped within this matrix.

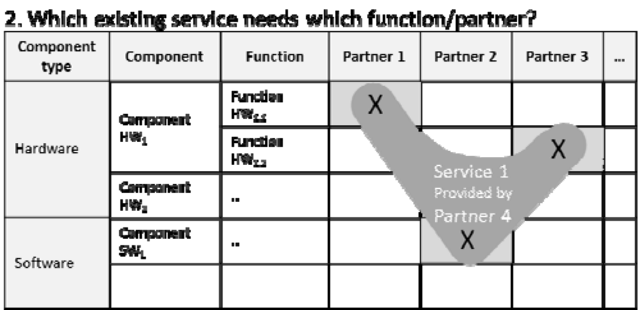


Figure 7: PSS/network partner-matrix with existing services

**Phase 2: Identification of the functions attributes**

Based on the PSS, relevant attributes and the specific performance requirement are to be identified.

For each attribute the function(s) which influences its performance was identified. For the OLED technology, the attribute “Lifetime” or “brightness” can be identified.

In a next step, technological parameters are to be assigned to the attributes. For the lifetime of an OLED, the user-oriented parameter “month” is rather difficult to map on a technological level, whereas the parameter “permeability of oxygen”– which describes the same matter from a technological point of view – is much easier to map.

In the next step, the actual performance of the attributes has to be investigated. In the OLED example the attribute “brightness” for technology is 500 cd/$m^2$.

**Phase 3: Priorisation of the functions**

It is a quite demanding task to forecast all technologies of a PSS. Therefore the technologies need to be prioritized concerning the value they provides to the customer. The higher the value a technology provides is, the more relevant a shift in this technology. Therefore, for those technologies a forecasting is necessary.

**Phase 4: Technology research**

In this phase new relevant technology for a better fulfillment of the attribute(s) have to be identified. [2, 34] describes effective methods for the technology research. Beside relevant technologies also their performance profile and relevant technology experts need to be identified.

Based on the priorized functions, technology trends and relevant technology experts need to be identified. Therefore the following activities need to be conducted:

- Scanning of the technology landscape within the scientific area,
- Determination of leading experts and lead projects in applied science,
- Survey of identified experts, thereby also identification of „white spots“ and detection of additional, interesting issues and experts,
- Evaluation of the results and discussion with the client.

The integration of the external point of view through experts depicts a substantial extension for many companies, which previously were highly focused to the inside-out-monitoring. Within the evaluation of new technologies, the market side is implied explicitly and the attempt to estimate future markets. The participating experts of the research facilities identify the technologies which are relevant for the collaborative network and evaluate them, based on the technology requirement profile. Within a common workshop, concrete ideas for products, suggestions and recommendations for actions as a foundation for managerial decisions and product-oriented decisions concerning the future are worked out. Furthermore a network with potential new cooperation partner will be obtained. This enables the access to their technology know how and builds the fundament for the research and development cooperation. The use of methods of the innovation- and technology management supports a structured approach taking into account the market aspects.

**Phase 5: Generation of the Technology readiness**

In this phase the readiness of an attractive technology will be generated.

Therefore, for every relevant attribute the performance will be monitored continuously in order to map the dynamic of development. Therefore technology experts will be consulted concerning the past, actual and the predicted performance of the single attributes.

*B. Integrated PSS and the corresponding business processes in collaboration networks*

**1) Approach for life-cycle optimization of product-services**

The approach presented in this paper follows the concept of modularization as used for the single components of a PSS – but taking into consideration that the product service is not yet defined when the product itself gets defined.

The modularization concept requires a 3 step approach to create technically and economically useful modules:

- Identification of functions

- Classification of components
- deployment of modules

The actual state of PSS and collaborative network will be mapped. Therefore, the PSS is subdivided into its single components which consist of hardware, software and services. Those components were described into a functional terminology.

Based on the components, the provider of these functions will be mapped and summarized into the collaborative network. As result, a function/ collaborative partner-matrix will be elaborated (Figure 8).

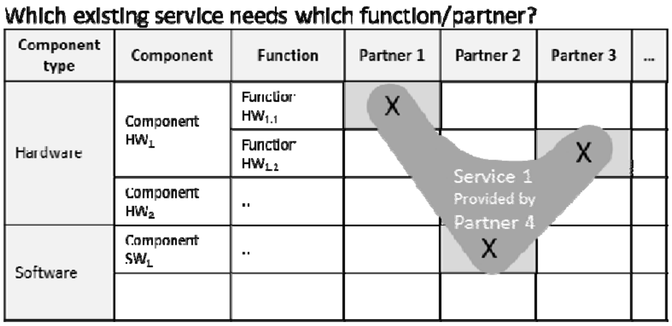


Figure 8: Function/collaborative partner-matrix with existing services

To explain this with an example based on the use case described:

After the delivery and putting into operation of the equipment by the OEM, the customer normally asks for the service of maintenance due to a predefined schedule. The OEM will have to decide who to perform this service by doing this himself or charging a partner out of his network starting from the early beginning of the equipment operation time.

If a new Service will arise (e.g. by customer-demand), this service will be mapped into this Function/collaborative partner-matrix (see Figure 9).

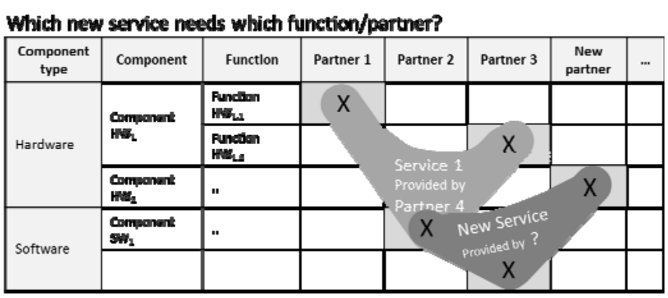


Figure 9: Function/collaborative partner-matrix with new services

In a next step, it needs to be decided who will perform this new service. There are principally three options:

- doing this by themself,
- charging an existing partner out of the network or
- acquiring a new partner.

Within the life time of the equipment, the customer might require the service of capability forecasting, e.g. advice on the optimal configuration of a group of equipment to ensure maximum equipment availability at minimum cost, e.g. due to an enlargement of activities of the customer.

This service was not predefined at the development and realization phase of the equipment – therefore, no service provider (close to the customer) is available yet.

To get this product service integrated into the existing product-services, the following modularization approach can be used:

1. Identification of the necessary business service functions which have to be fulfilled and evaluation of their importance by using the KANO-model.
   For the service of capability forecasting, this could be:
   - Basic needs: capability of the equipment (parts per hour)
   - Performance needs: optimizing the capability by use of simulation system
   - Excitement needs: optimizing the capability via Internet-based remote diagnosis and control

2. Classification and standardization of different business service components for the service and combining the components to different bundles (e.g. standard bundle, optional bundle, customized bundle).
   For the service of capability forecasting, this could be:
   - Standard bundle: stand-alone software component for rolling forecasting of capability based on daily OEE-data
   - Optional bundle: software component integrated into ERP-system and using additional data as e.g. production forecast
   - Customized bundle: customized personal consulting advice for capability optimization required on a call-by-call basis.

3. Creating a business service module with well-defined interfaces to existing PSS solutions, including IT-integration and KPI-feedback.
   For the service of capability forecasting, this could be:
   - product interface: identification of performance parameters of the whole equipment (e.g. motor power, tool temperature etc.) – business service: installation of a sensor system to measure the OEE of the whole equipment
   - Service interface: the schedule of equipment maintenance is automatically delivered to the business service provider - business service: the performance optimization of the key components (e.g. motor) and the maintenance of the equipment is done at the same time in order to reduce equipment down times

In total, the interfaces for product, software and services are defined by using an interface matrix in order to make sure that new services will fit to the existing ones (see Figure 10).

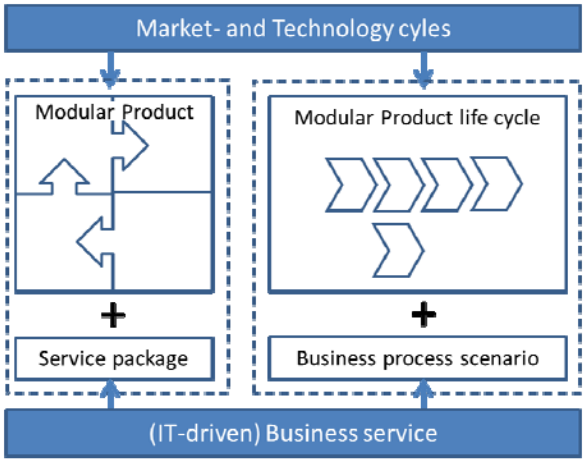


Figure 10: Modularization of PSS and business processes/scenarios

The basis for this modularization approach is a set of design rules for product, software and service engineering which will be used as obligatory requirements specification to any new service supplier.

**2) Approach for life-cycle optimization of business processes and scenarios**

In product engineering, the simultaneous development of modular products together with modular processes is state-of-the-art knowledge. Therefore our approach for creating non-predefined business processes and business scenarios is also based on this modular concept – but taking into consideration that the service provider, i.e. the new partner in the collaborative network, is not yet identified.

This new partner has to fulfil the following requirements:

- The ability to perform the requested business service
- The ability to fit into the existing collaborative network

In order to find the right partner for the requested service, we use the same 3-step concept for modularization as for the business services:

1. Identification of the necessary business scenario functions which have to be fulfilled and evaluation of their importance by using the KANO-model.
   These functions now relate at least to the 2 main processes of realizing PSS:
   - the product development process and
   - the order fulfilment process.

   Business scenario functions for the product development process are e.g.:
   Requirements engineering, Idea generation, configuration management, ramp up management, life cycle management

   Business scenario functions for the order fulfilment process are e.g.:
   Engineering change management, material and logistics management, information management, supply chain management

   Following the 3-step approach of functions – components – modules, now for business scenarios, the first step functions will be realized:
   For both processes different business scenario functions are defined and evaluated following the KANO-model.

   a) for the product development process: e.g. requirements engineering
      - basic need: workflow of service development tasks
      - performance need: use of templates for describing the workflow
      - excitement need: modelling of workflow with BPMN

      For the business process capability forecasting a function could be:
      Basic need workflow: tasks for creating a reliable capability forecasting based on business intelligence and technology and market developments (e.g. customer orders a high volume product and a low volume product – high volume to be produced on a non-stop running equipment in-house, low volume to be produced on demand by an external supplier)

   b) for the order fulfilment process: e.g. engineering change management
      - basic need: workflow for handling of change requests
      - performance need: use of templates for risk analysis of change requests
      - excitement need: modelling of workflow with BPMN

      For the business process capability forecasting a function could be:
      Basic need workflow: tasks to be done if requested capability changes not within the estimated ranges (e.g. high volume customer stops his orders on a short notice basis – necessary tasks to be done for capability adjustment (machine close down etc.)

2. Classification and standardization of different business scenario components for the service and combining the components to different bundles (e.g. standard bundle, optional bundle, customized bundle).
   - Standard bundle: processes, actors, data input/output to be defined for each service
   - Optional bundle: processes, actors, data input/output to be chosen out of a configuration box

- Customized bundle: processes, actors, data input/output: to be defined on request of a stakeholder

For the business process capability forecasting,

- a standard components bundle could be:
  - processes: information about reduced volume sent by customer via Electronic Data Interchange-adaption of machine capability
  - actors: ERP-System and production manager
  - data input and output: old production volume – new production volume
- a customized components bundle could be:
  - processes: consulting for the customers about possibilities of adapting the capability
  - actors: ERP-system and consultant
  - data input and output: forecast planning in combination with forecast simulation

3. Creating a business scenario module with well-defined interfaces to existing business scenarios, including IT-integration and KPI-feedback.
   The business scenario modules will describe all the defined business scenarios of the collaborative network in order to make sure that a new stakeholder can be integrated easily.
   The following 3 modules are assumed to be basically relevant in order to enable the collaborative network work efficiently:
   - Customer Relationship Management – Module: basic data of all stakeholders
   - Configuration Management – Module: basic relationships between products, services, processes
   - Enterprise Resource Planning – Module: basic workflow and data exchange for product development process and order fulfilment process.

   For the business process capability forecasting modules could be:
   - Customer Relationship Management: history about capability requirements of the past (different products, different volumes, different manufacturing processes)
   - Configuration Management: plug-in module of manufacturing machine + parts feeder + control interface
   - Enterprise Resource Planning: capability module of all required resources (tangible and non-tangible assets) including all required planning data for plug-in or take-out
     Each module must be able to be integrated into the existing IT-infrastructure (cloud-based platform) and into the existing BI-system of the collaborative network (following the rules of Enterprise Application Integration and Business Intelligence Integration).

The basis for this modularization approach is a set of design rules for the business scenarios (i.e. processes, actors and data input/output) which will be used as obligatory requirements specification to any new stakeholder within the collaborative network.

### *C. Network management and Industrial Intelligence in collaborative networks*

In chapter III.A and III.B several scenarios are introduced. All of them contain a solution space and therefore a bunch of decisions which have to be made (e.g. technology choice, network partner selection). These decisions need sound information about the context and possible impacts (e.g. KPIs). Regarding decision support within industrial companies, concepts based on Business Intelligence have been established so far (cf. chapter II.C). But the Current Business Intelligence concepts respectively Industrial Intelligence concepts are usually limited to intra business decision support. In the given context, the product lifecycle of PSS is orchestrated from multi network partners. All ingredients are based on their own lifecycle. Therefore, each network partner needs to have industrial intelligence to manage the lifecycle of his components. However, there is also a need to have transparency for planning, organizing and controlling the entire product life cycle of PSS. Therefore, within Collaborative Networks a federated Industrial Intelligence framework is needed which shares information between the network partners. A first concept is depicted in Figure 11.

The basis of federated Industrial Intelligence is to deploy the right information in the right matter to network partners. Therefore, it has to face several challenges:

- First of all, network partners can also be competitors in other fields. Hence, it has to be ensured that the shared information are exactly filtered to the necessary ones. This is given for the information content as well as the nature of information. The result is that if there are more than two network partners, the information cannot be shared over an information bus with all collaboration partners. It always has to be specified information sharing between two partners. Especially in dynamic network collaborations it seems thus useful to establish “information services” which can be subscribed by network partners with the approval of the information owner; a basis for defining “information services” may be information demand profiles.
- Secondly, shared information is based on the technology life cycle of the information provider. Therefore, the shared information has to be mapped to an inter-collaborative network given product lifecycle (cf. Figure 11). This will make it possible for each network partner to map the information on his technology life cycle.
- Third, the management of the entire product life cycle makes it necessary to establish Industrial Intelligence governance. Unpublished research activities show that it is good practice to implement virtual Industrial Intelligence committees. Collaborative network wide indicators have to be defined and operationalized within

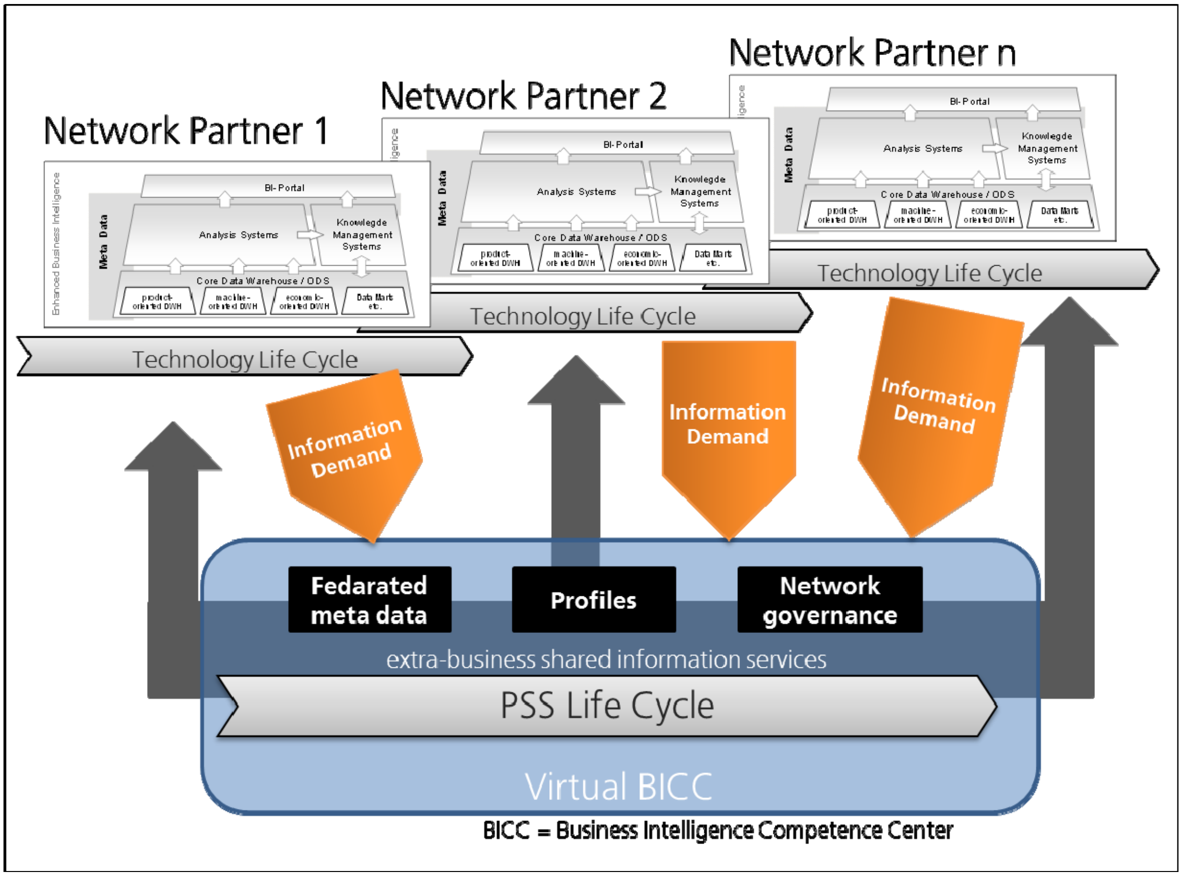


Figure 11: Federated Industrial Intelligence Framework for Collaborative Networks

the governance committees. Collaborative-wide meta data also has to be specified to ensure data quality and semantic compatibility. The required meta data results from the information demand profiles of the network partners.

In the given example, the information demand of each partner depends on the interaction between components and functions (cf. chapter III.A). For example, the software partner has to have information about the actual hardware configuration as well as the expected life-cycle of the hardware. At the same time, the hardware partner need to know technology based process changes or software update cycles. As mentioned above, the information demand profiles are various in the same way as the network partners change. For example, two or more software partners provide Apps for different hardware configurations or customers. In this case, all software partners ask for information about their hardware configuration. Therefore the hardware partner has to provide different information to each of the software partners.

The example has so far shown extra business shared information services between two partners. But there is also a demand for decision support regarding the whole DSS life cycle. For example, the leading company wants to have comparing information about different configurations. Therefore, information from all network partners have to be shared in the same semantically way. The virtual BICC has therefore to define the meta data as well as the security guidelines to prevent information abuse.

## IV. CONCLUSIONS AND OUTLOOK

New product-services nowadays go beyond the physical and service oriented concept, since they are designed in order to be always connected, self-learning, adapting and intelligent. In order to generate economic growth, manufacturers should focus on delivering solutions for customer needs rather than simply products (or product-services) for their customers. Therefore, new business opportunities will be generated when providing increased added-value to users by integrating personalized innovative functions into traditional and high-tech products based on production and process standards (Mass Individualization).

This **business challenge** can be addressed by embedding more and more knowledge into highly-personalized innovative product-service systems (PSS) (i.e. service-enhanced products). This will provide improved value-added services for a wide range of users, but with personalization aspects so as to consider individual demands. Product development should take place through a collaboration within the product ecosystem, involving multiple companies and actors, in order to offer the high-value personalized product-services to users. This collaborative network is described by a set of relevant business scenarios, focusing on complex, highly customized service-enhanced products and the corresponding business processes.

Therefore the **aim** of this paper was to describe an approach for simultaneous life-cycle optimization of product-services and business processes within the network of stakeholders – by identifying the requirements for PSS with non-predefined services due to unknown customer wishes during the life cycle of the product and by identifying the requirements to the non-predefined stakeholders of the PSS within a collaborative network due to unknown business processes/scenarios during the life cycle of the solution.

The **systematic approach** presented in this paper is based on the findings of modularization of products and processes being adopted to non-predefined business services and business processes within a dynamic value creating network of stakeholders. This core approach gets enlarged on the one hand by a customized application of specific technology readiness and forecasting models and one the other hand by a federated framework for Industrial Intelligence for dealing with the extraction, transformation and storage of data from different source systems.

It was shown by the **use case** of manufacturers of durable capital equipment how non-predefined business services can be developed systematically and how the corresponding business processes and scenarios can get adopted to these services. This results in a corresponding specification of business services and a specification of business processes which can be linked together within a function-collaborative-partner matrix. The described federated Industrial Intelligence system will deploy the requested data by using existing network software solutions (e.g. cloud-based platform) to ensure the data and information exchange. The described application specific technology readiness system will deploy the necessary information about market and technology developments also by using the software platform solution.

Furthermore we assume in this paper that this approach to configure products, processes, technologies and the whole supply chain/network is basically valid for product service systems due to their orientation towards the customer/individualization of solutions. But there is a basic need to customize the approach itself, e.g. depending of market, technology, customers etc., the different parameters for modularization of business services and corresponding business processes have to be identified. The target must be to create a "*my mass individualization approach"* based on the above mentioned parameters.

This goes in combination with the practical realization of the so created business services and business processes. For practical use, business services and business processes have to be realized by IT-driven services to make the collaboration net-work efficiently. This requires a working solution of all the aspects of Enterprise Application Integration, Service Oriented Architecture, cloud-based software platforms etc. Up to now, there are single solutions available, but not yet on a level of an "ebusiness standard"; this will be a basic requirement in order to easily adopt non-predefined business services and non-predefined business processes.

*Outlook*

The approach described in this paper is not a linear solution with fixed starting and ending points; on the contrary, this is a circle approach characterized by a mutual influence of technology & market requirements, data & Information exchange (Industrial Intelligence) and business services creation. Therefore, further research work should concentrate on adding the additional dimension of life cycle to the described approach.

Furthermore, the approach described is focused on the market pull (customer driven) perspective due to the actual development in the market towards open innovation/mass customization scenarios. Besides the fact that market pull and technology push are always linked together in highly innovative product service systems, there is a difference in creating the customized "my mass individualization approach". Therefore, further research should take into consideration the difference in the way of realization of customized solutions either driven by the market or driven by technology.

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