Digital Engineering of Dynamic Business Models for Smart Product-Service Systems

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Abstract

Smart product-service systems offer new opportunities for the innovation of digital business models by integrating digitized product and service components. A key aspect of these intelligent solutions is the life cycle accompanying fulfilment of customer value. Consequently, the corresponding digital business models must dynamically adapt to changing customer requirements. Tools are necessary for the systematic development of dynamic business models that enable an analysis over time. Therefore, this paper presents the digital engineering of dynamic business models for smart product-service systems using system dynamics. In the context of a conceptual case study in the field of micro production, a supporting software tool in the form of a partial model library is introduced.

Keywords: smart product-service-system, industrial solutions, digital business models, system dynamics, feedback approach, business model engineering

1 Introduction

Traditional companies in industry often still focus on the production of products in the form of physical goods. [1,2] This is particularly true for the business-to-business (B2B) market in an industrial context, but can also be observed in the business-to-consumer (B2C) sector [3]. With increasing digitization and the advent of intelligent components, new opportunities and innovative solutions are increasingly emerging. They fundamentally change the traditional understanding of products and services (see Figure 1).

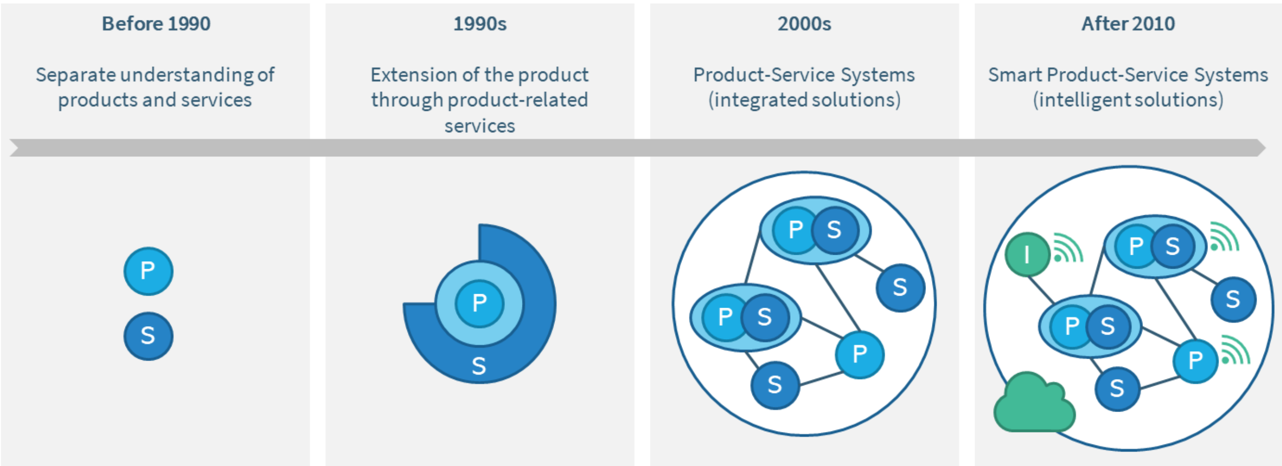

Figure 1: Transformation of the traditional product understanding [1,4,5]

Industrial companies have also begun to introduce various smart technologies embedded in these integrated offerings [6]. The use of smart technologies thus leads to a new type of product-service systems - the so-called smart product-service systems, which can be understood as intelligent solution offerings with a high focus on customer value. Advancing digital networking and the resulting potential in the context of Industry 4.0 result in a wide range of opportunities to offer such integrated solutions with smart components as a complete package. Through embedded software and electronics, integrated actuators and multi-sensor systems, these systems communicate with each other. They can autonomously adapt to different situations at system and component level, thereby achieving unprecedented benefits for both customers and supplier companies [7]. An increased shift from traditional product-oriented business models to integrated end-to-end solutions is a major challenge, especially for small and medium-sized enterprises. In many cases, the high level of cooperation required for this undertaking and the lack of digitization expertise prevent a successful migration to a solution provider of smart PSS [8]. Innovative business model engineering methods can provide initial support in mapping the structure and dynamics of the emerging dynamic business models for these complex systems.

2 Theoretical Foundations

2.1 Smart Product-Service Systems

Both in engineering as well as in economics literature, there is a variety of terms that describe the combination and integration of products and services. In addition to the practical designation of smart product-service systems (smart PSS) used within the scope of this paper, authors also use the terms industrial product-service systems (IPS2) [9,10], product-service systems (PSS) [11,12], hybrid products [13] and integrated solutions [14,15].

Smart PSS have their origin in traditional industrial PSS which are problem solutions tailored specifically to a customer, which consist of integrated product and service components which can be flexibly adapted to changing customer demands over the life cycle. [3,16] A PSS consists of different modules: [4,17–19]

- **Pure product modules** can be tangible goods or physical hardware, e.g. spare parts for a machine.
- **Pure service modules** are traditional services, e.g. the delivery of the spare parts.
- **Integrated modules** are customer-specific components of integrated products and services. There are multiple interdependencies between these components which results in a higher degree of dynamic complexity over the lifecycle.

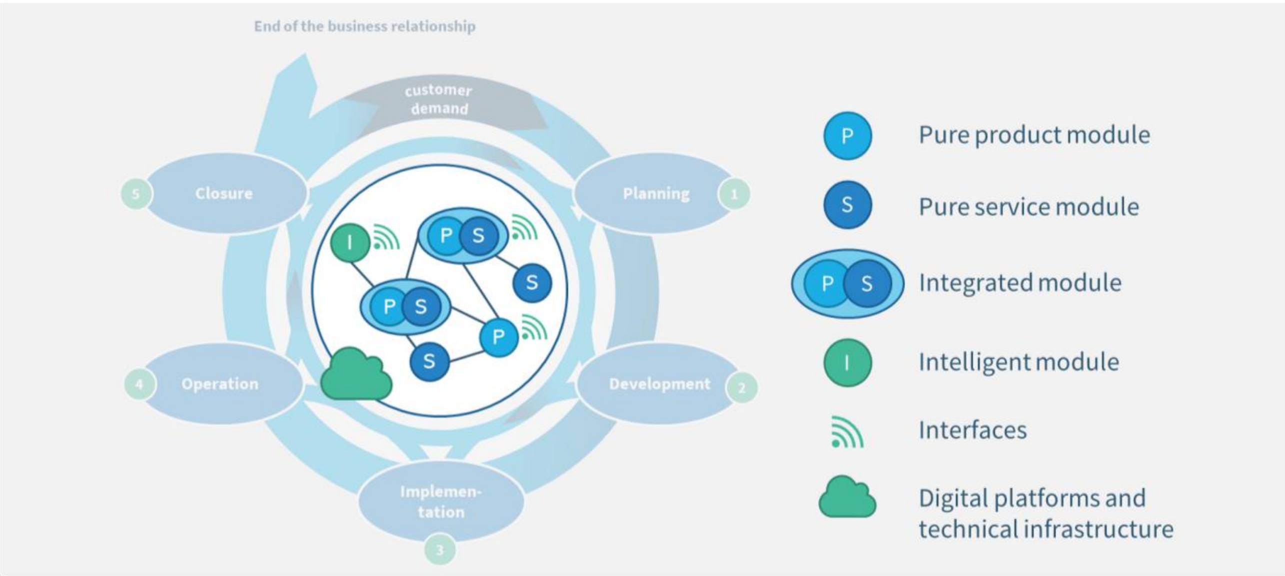

Figure 2: Modular design of smart product-service systems over the lifecycle [1,4,5,20]

In recent publications in the context of digital transformation, the terms "smart" and "digital" are increasingly being integrated into the definitional approaches [6,7,15,21–24]. As a result of technological advancements during digitalization, PSS are changing into smart PSS. As can be seen in figure 2, smart PSS have a more extensive modular structure. The specific configuration is based on the individual needs of a customer. Smart PSS have additional components [4,19]:

- **Intelligent modules** include components such as sensors, actuators, embedded systems, and software.

- **Interfaces** are another important component in smart PSS. Here, the existing modules of the smart PSS can be interconnected with other modules and actors in the overall system. This is also referred to as machine-to-machine communication or human-to-machine communication. Consequently, interfaces exist not only as technical interfaces between physical and software components. There are also interfaces to the service employees and machine operators. This makes coordination particularly difficult, since it is not a matter of unambiguously exchangeable data, but rather of providing interpretable information as well as simple and fast input mechanisms for these actors in the complex system. [25]
- **Digital platforms and technical infrastructure** are a key driver of smart PSS (e.g. cloud platforms). The goal of cloud-based provision of smart PSS is to provide each employee with precisely the production-relevant data that is needed for the respective work task [26]. The same applies to suppliers and customers. [27]

Due to these digitized modules smart PSS have more far-reaching capabilities. A smart PSS is not only continuously localizable, it also provides continuously retrievable production-relevant information [19]. In a traditional PSS, for example, classic maintenance is offered as a service. With a smart PSS, this becomes predictive maintenance - in other words, a smart service. Here, machine behavior is recorded by sensors and then analyzed. This information can in turn be used to feed algorithms for predicting malfunctions. Maintenance staff can then be dispatched in a targeted manner. [4,19,28] Based on this component-based understanding of the term, the following definition can be derived:

> *A **smart product-service system** (smart PSS) is a business-to-business-oriented, customer-specific bundle of digitized modules in the form of physical products and hardware, software, interfaces, and services, seamlessly integrated via a cloud platform to provide more value than the parts alone; it is characterized by an iterative and interactive problem-solving process in a customer-integrated value network, which extends over the entire lifecycle. A smart PSS facilitates the continuous adjustment of its components for changing customer requirements and provider capabilities, thus opening a continuum of innovative, dynamic business models that will ensure flexibility and adaptability in a long-term business relationship. [3,4]*

The definition shows that the fulfilment of customer value over the entire life cycle is a central aspect of smart PSS. They must adapt dynamically to changing customer requirements and provider capabilities.

2.2 Dynamic Business Models for Smart Product-Service-Systems

Many authors use a component-based description of business models to reduce complexity by means of partial models [29–33]. The component-based perspective facilitates the design and analysis of a business model's essential dimensions and can be helpful for a differentiated analysis [34]. For the classification of business models, these components are mapped in a structured way with the help of taxonomies or typologies [3].

To date, research has not reached a consensus with respect to the choice of partial models. Nevertheless, value proposition and revenue mechanism are often represented as partial models [3,35,36]. However, these systematization proposals are often based on only one line of business and are consequently not transferable to other industrial contexts [37]. For further analysis, appropriate partial models for smart PSS business models in industry will be discussed. Figure 3 illustrates the *partial models* with their components (white and blue) and the corresponding *relational components* (green) by means of a classification scheme [3,35].

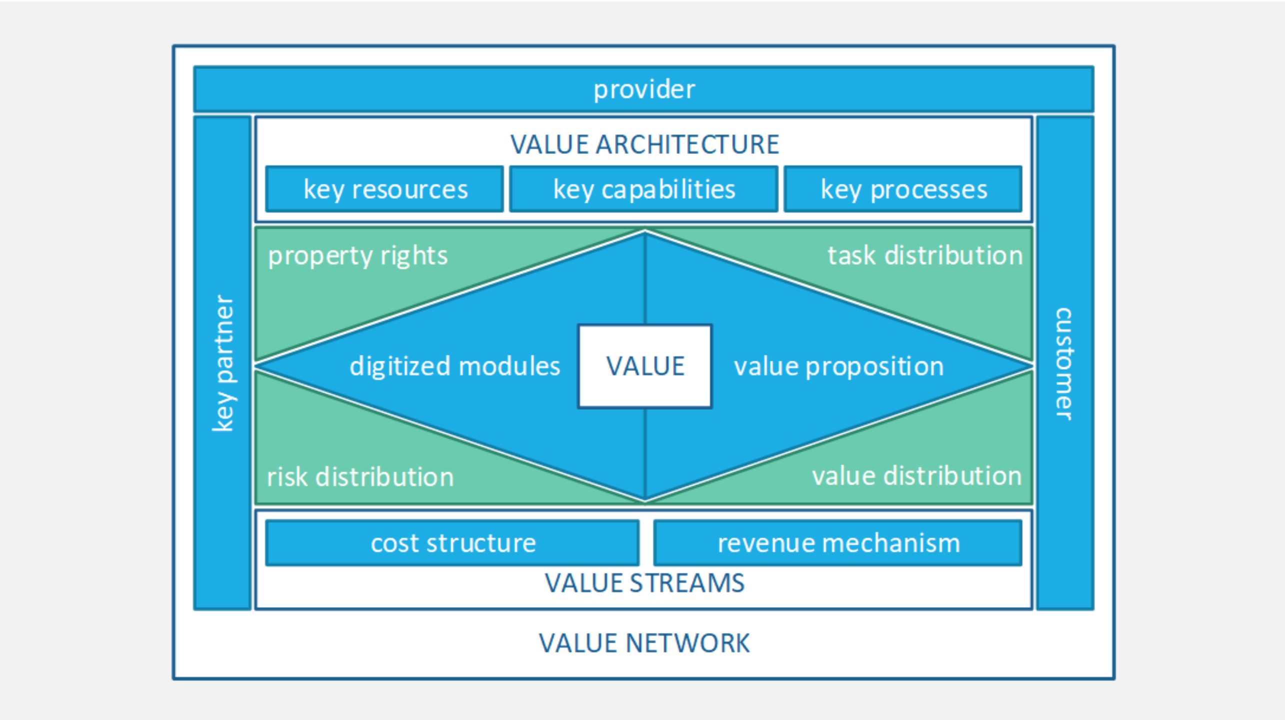

Figure 3: Business Model Components [3,35].

Value. The partial model value defines, through which combination of digitized modules (e.g. physical products, services and/or information) the value is generated for the customer. This combination comprises different digitized artefacts in the form of physical hardware, software, and services.

Value architecture. The partial model value architecture describes how value and benefits are generated for the customer by the allocation of key resources, capabilities, and processes. Key resources are combined with key processes to provide services. For this purpose, key capabilities are required, which are provided by the partners in the value network.

Value network. Customers, providers, and key partners are assigned to the partial model value network. The duties and corresponding tasks of the involved parties in the value network are strongly related to the value which must be provided to the customer. The task distribution and process responsibility regarding the life cycle activities is set in the value network of the business model.

Value streams. The partial model value streams includes the cost structure and the revenue mechanism. The number and distribution of key processes affect the cost structure. The issue of revenue for the provider or the payment for the customer is closely linked to the question of value and risks. This is not just a payment for the value generated for the customer, but often also a compensation for the risks the provider bears.

To clarify the relationships between the four partial models and their components, we need to consider *relational components* that regulate the important aspects of the business relationship.

Property rights. The relational component property rights defines the ownership and possession of key material resources (e.g. tools) and physical products (e.g. machines) in the value network. Thus, the ownership structure has a decisive influence on the cost structure of the business model. However, data security issues can also be assigned to this component. This raises the question of who has data sovereignty or ownership of the generated data in the business model.

Value distribution. The value distribution is in turn influenced by the cost structure and assigns the values generated by the business model to the parties in the value network, taking risk distribution into account.

Risk distribution. The risk distribution determines which actor in the value network bears which risk in the creation of value and is thus closely related to the distribution of tasks and the value proposition. The assumption of risks is compensated by the value distribution. Data security aspects are also considered in risk distribution.

Task distribution. The task distribution defines the mapping of key processes in the value network and thus also affects the value distribution.

Business models may take different forms depending on the value proposition. The value proposition as a core aspect of the business model determines the distribution of processes and activities between the provider and the customer. Following Rese et al., a continuous understanding of business models is a basis for comprehensively considering the variety of possible forms of business models. The continuum formed by the business models is shown in Figure 4.

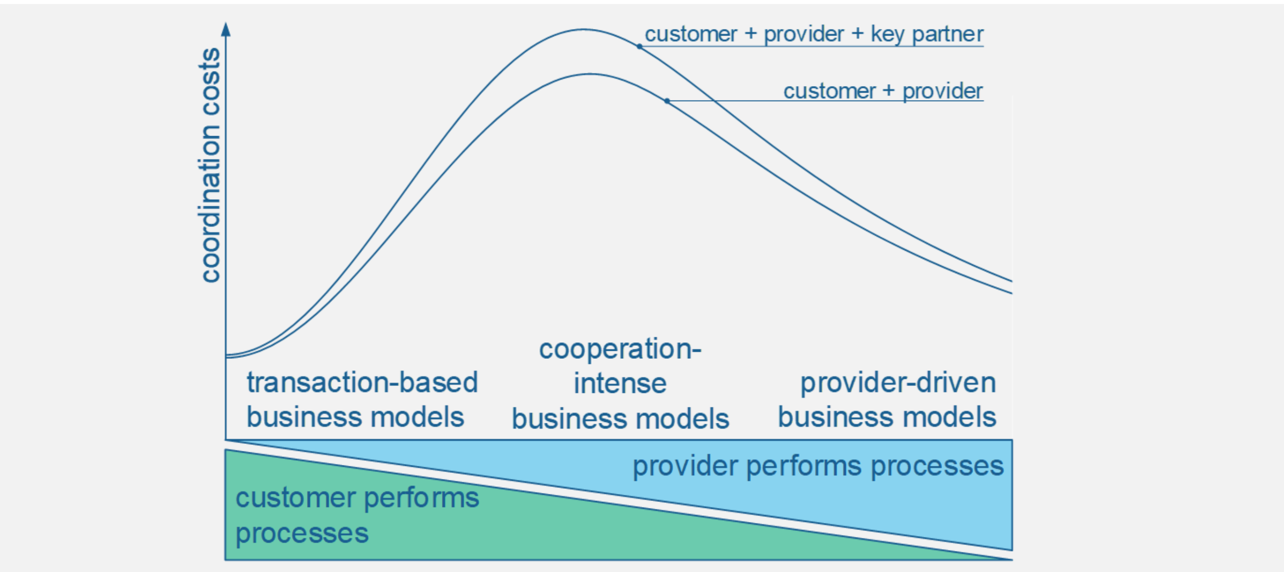

Figure 4: Dynamic Business Model Continuum [3,38].

In traditional business models, individual product or services are sold on a transaction basis. In these transaction-based business models, one can speak of low-intensity collaboration, since the customer is responsible for implementing the process. On the opposite side of the continuum, there are provider-driven business models, where the provider takes responsibility for most of its customers' processes. Here, one can also speak of a rather low intensity of cooperation. The business models between these two extremes are characterised by a high degree of collaboration. In these models, customer, and provider as well as their key partners assume activities in the value chain. Therefore, close cooperation and coordination is needed, requiring an intensive and trustful relationship. To account for these relationship aspects accordingly, these types of models are referred to as cooperation-intense business models [3,38]. The definition of the term smart PSS business model can be derived from these special features:

> *A **smart PSS business model** is an aggregated description of a customer-specific, value-oriented solution and is defined by the business relationship between a provider, its potential key partners, and a customer. A business model involves four partial models: value, value architecture, value streams, and value network. Their dependencies are specified through the four relational components: property rights, task distribution, risk distribution, and value distribution. The characteristics of these components are determined by the capability profiles of the parties in the value network. As a dynamic system of interdependent components, a business model can be adapted over its entire life cycle to changing customer requirements and provider capabilities. It forms a continuum that can include transaction-based, cooperation-intense and provider-driven business model variants, depending on the degree of collaboration of the involved parties. [3]*

3 Digital Engineering of Dynamic Business Models

3.1 Business Model Engineering Methodology

The structured feedback approach of business model engineering structures the activity sequence of the methodology at a higher level and thus defines the methods integration (see figure 5). The iterative procedure model links two cycles for business model design and business model analysis. *Business Model Design* includes the five phases: (1) define business concept, (2) define flexibility options, (3) select partial model attributes, (4) concretize partial models as well as (5) create dynamic business model prototype through a digital support tool for qualitative and quantitative business model development. The second cycle of *business model analysis* involves dynamic modeling using System Dynamics. It also consists of five iterative phases: (1) articulate problem and model purpose, (2) concretize dynamic problem (3) formulate simulation model, (4) simulate, validate and test as well as (5) analyze, evaluate, and document [39,40].

Through iterations, the structure and the dynamic behavior of the developed business models can be continuously adapted and revised until an adequate business model with an appropriate problem-solving strategy exists. Further business models in the design process will first be examined on a generic and abstract level. Subsequently, the business model analysis is performed on a more (problem-)specific and detailed level. [3,41] The results of the analysis of the dynamic behavior of business models can be systematically stored in a partial model library (see section 3.2). In this way, the business model specific experience and knowledge of the methodology and the corresponding business modelling projects is systematically documented and can be used for new developments or adaptations of business models for smart PSS. In the context of integrating the two methods, business model engineering is defined as follows: [3]

> ***Business model engineering*** *refers to the methods and model-based design and analysis of dynamic business models for smart PSS in terms of a structured problem-solving process. An iterative procedure model with domain-specific activities thereby promotes the division of labor in heterogeneous teams and as a result generates an understanding of the business models structure and dynamics. As a result-oriented methodology, business model engineering supports both the development of fundamentally new business models as well as the adaptation of existing ones by flexibly configuring interdependent business model components and partial models.[3]*

As a result of the method, dynamic business models are created that enable problem-related simulations for decision support. In this respect, they act as a simplified replacement reality and as catalysts in an iterative model development and learning process. [39,40,42]

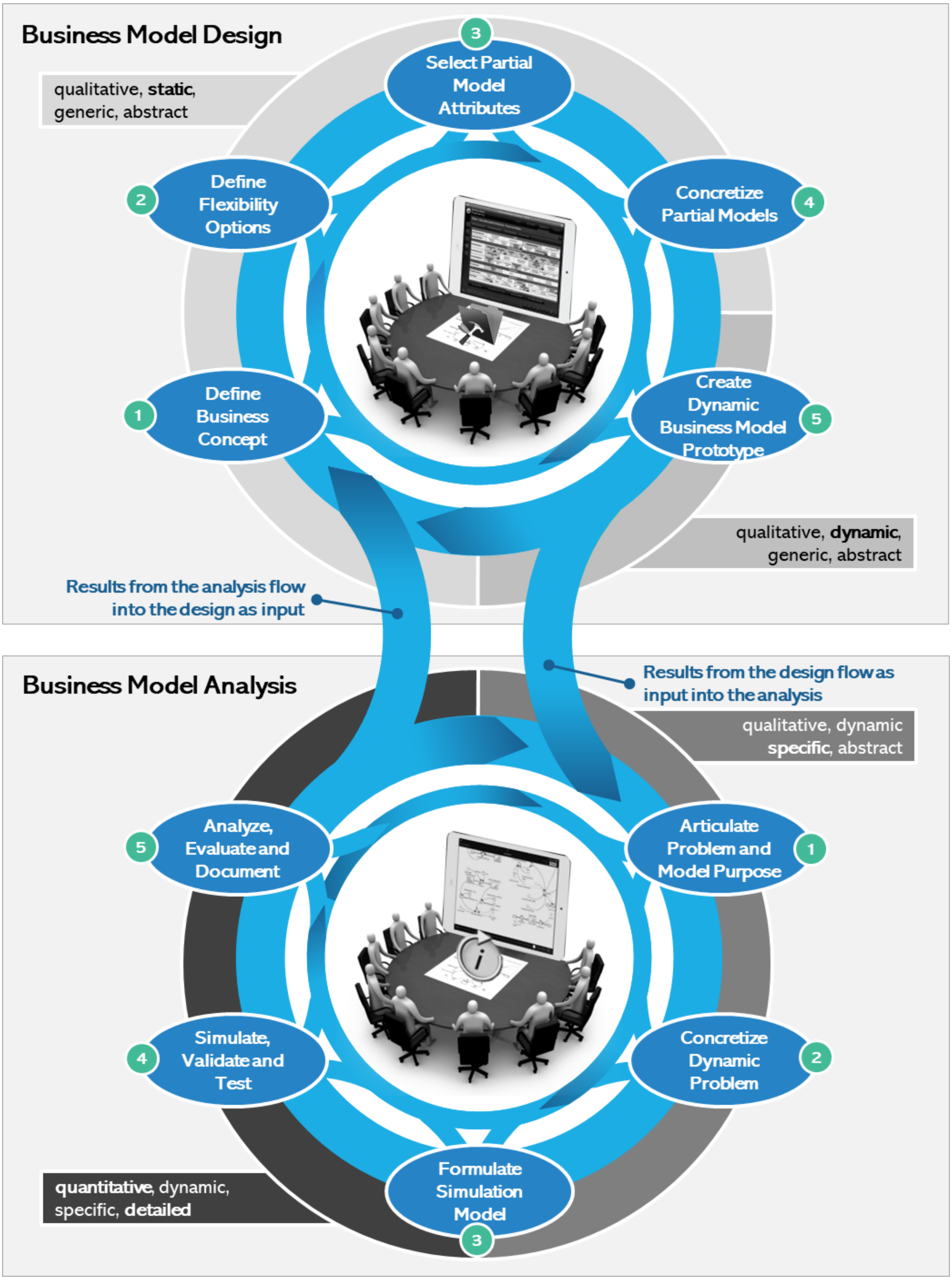

Figure 5: Iterative Business Model Engineering Procedure [3,38].

3.2 Digitization of the Business Model Engineering Methodology

The business model engineering process is supported by a prototypical, database-driven software tool to ensure a structured and economical application of the methodology. [43] It also integrates the steps for the traditional system dynamics modelling process. In addition, the different model elements (System Dynamics modules from *isee systems iThink/Stella*) can be managed and documented in a partial model library. The basis for the software prototype is the relational database system FileMaker, which also allows a use on mobile devices such as the iPad. Thus, an intuitive, role-specific support of the modelling teams is possible, for example in modelling workshops. Figure 6 shows the graphical user interface (GUI) of the prototype. There, in step 4 in the design cycle (left), the business model morphology is displayed as a result. By integrating and connecting the Stella/iThink simulation software via the XMILE standard [44], it is possible to include learning environments and a documentation of the model. The application and documented models can be used in workshops und lectures to communicate the findings of modelling projects.

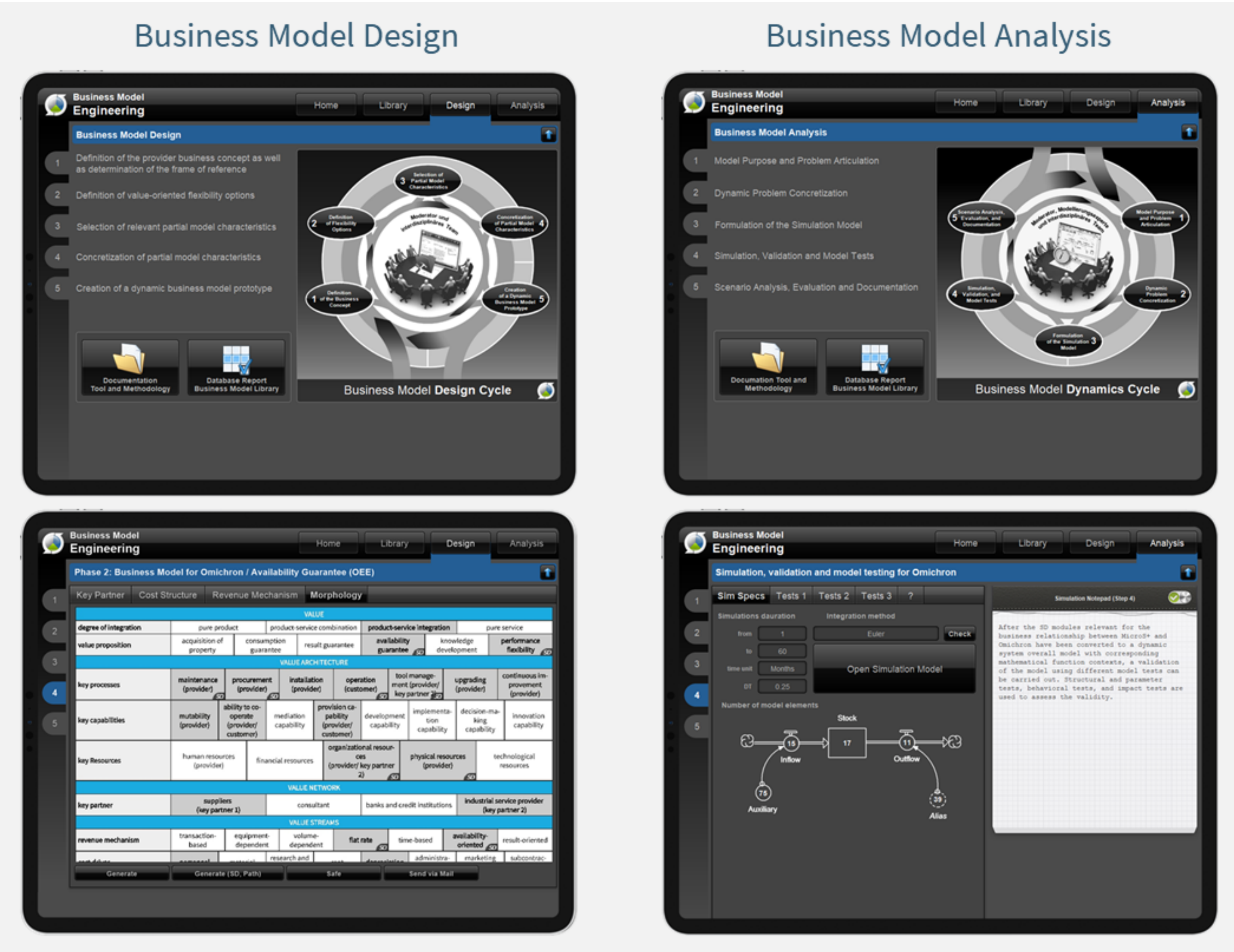

Figure 6: Business Model Engineering Software Prototype – Business Model Design with Morphological Box (left), Business Model Analysis with System Dynamics Documentation (right) [3,38].

3.3 Integration, Suitability and Relevance of System Dynamics

For the realization of a methodology for the design and analysis of dynamic business models for smart PSS, it is indispensable to integrate techniques and tools that enable a view over time. However, smart PSS and their business models require not only this lifecycle-spanning, dynamic perspective, but also the confident handling of a high level of complexity in an interdisciplinary environment. SD is particularly suited for handling complex problems with a large number of interdependent variables that exhibit dynamic, non-linear behavior. In the understanding of this paper, the dynamic problem character is given by the consideration of dynamic business models over long-term business relationships. Both the short-term and long-term consequences of the development and adaptation of business models over time are examined. This cross-life-cycle view allows crucial quantitative and qualitative aspects to be described by time courses, e.g., the know-how build-up of employees or the development of revenue streams. Furthermore, a smart PSS is a complex, socio-technical system that is characterized by feedbacks. These feedbacks are characterized by the existence of cause-effect relationships that form a loop (with a time lag). This situation is also present in the present work. Against the background of the variety of possible variations of business model characteristics in the business model continuum, similar or identical problems can occur repeatedly. These problems develop however always in the context of a specific provider-customer relationship and are beyond that feedback-driven. Therefore, these cannot always be permanently addressed with established repair routines. To make such problems manageable, the case-specific feedback structures need to be analyzed and understood. In this respect, SD can make an important contribution to knowledge with decision-support techniques and tools, especially in the business model analysis cycle.

4 Conceptual Case Study: Micro Production

4.1 Business Concept: Micro Production

This section describes the application of the method based on a conceptual case study in the field of microproduction. [3,45] It focuses on fundamental modelling structures and their dynamic correlations. A series of simulation runs is performed to support the management's decision process in finding an adequate strategy for the implementation of a new business model.

Since microproduction is still a relatively young branch of mechanical engineering, comprehensive application know-how is not yet available. Thus, there are major entry barriers for potential customers at the present time, as the establishment of comprehensive standard solutions, e.g., in tool management, measurement technology or maintenance, has yet to be achieved. The solution-oriented integration of such services can therefore create additional added value for the user of the technology. The realization of an adequate value proposition requires innovative business models that offer the customer investment security through the benefit-oriented integration of products and services. However, the number of value-added components plays a subordinate role for the customer if the needs and the value proposition offered do not fully coincide. To make the added value for the customer clear, the customer benefits must therefore also be communicated through the systematic description of dynamic business models. A suitable application area for micro production manufacturing processes is the watch industry, which is characterized by a high demand for innovative manufacturing processes to produce filigree mechanical components with the smallest dimensions. This need is demonstrated in the following using an exemplary supplier-customer relationship.

This case study serves two major objectives. First, is to describe the introduced digital business model engineering approach by using System Dynamics in a practical perspective. Second, is to demonstrate how System Dynamics can be integrated in a holistic approach for the engineering of dynamic business models for smart PSS.

The watch manufacturer Omichron previously relied exclusively on mechanical watches in the mid-priced segment and in the future would like to offer especially high quality and structurally complex, mechanical chronographs in the high-price segment. Due to the high individuality of these high-priced watches, the independent production of clock mechanisms is required. Since Omichron was previously a purchaser of externally manufactured clock mechanisms, the development and production of clockwork plates is not part of the core competence of this watch manufacturing company. Accordingly, they do not have the technical expertise in micro-production for the independent production of clockwork plates.

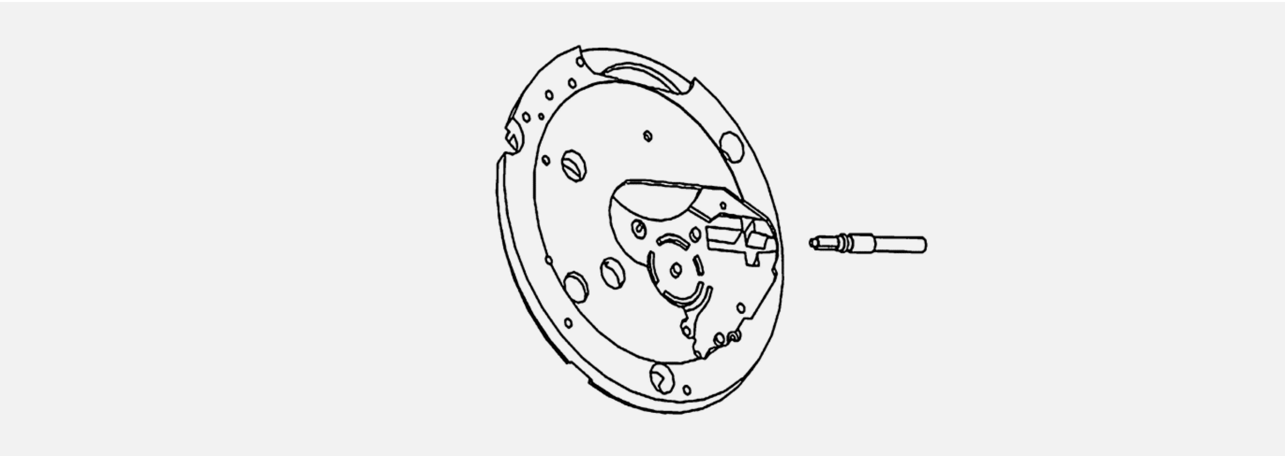

Figure 7: Clockwork Plate [45]

From this strategic realignment, a very specific requirement profile resulted that requires working with a solution provider in the field of micro-production technology. Omichron commissioned the provider company MicroS+, which has the required key skills for implementing the desired manufacturing process for the customer. The provider company MicroS+ has established itself over many years from a manufacturer of micro-milling machines to a solutions provider of smart PSS. The company offers its customers highly individual complete solutions for the development, implementation, distribution, and integration of micro-production processes into existing production processes. MicroS+ has been operating for many years in a market which is characterized by an increasing demand for micro-system solutions. Due to the complexity of these integrated offerings, there are few competitors in the market. New competitors entering the market can therefore be entirely ruled out for the further consideration of this business relationship. Under consideration of these assumptions, the business relationship between these two partners is observed in detail in the following.

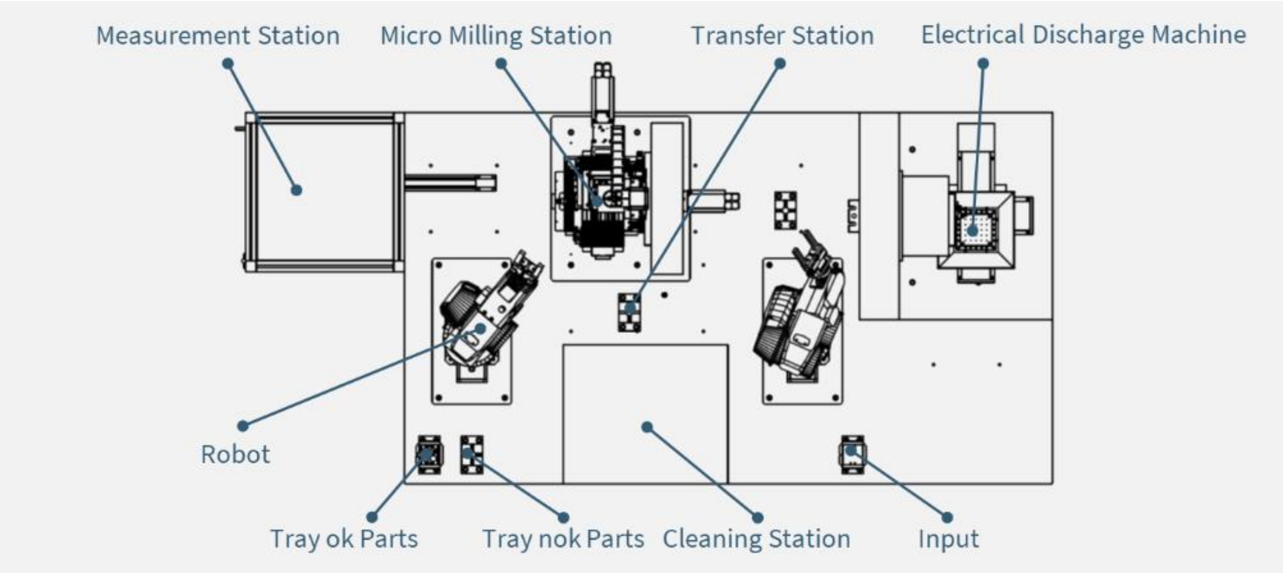

Figure 8: Flexible micro production engineering manufacturing system [45]

4.2 Business model design

4.2.1 Definition of the Business Concept

First, we will look at the definition of the business concept of MicroS+, which is aligned towards the strategic business objectives of the provider company. The business concept includes the provider-side solution space for implementing future business models. [3,41] The company offers both, products, and services as well as system and integration services. For example, flexible micro-production technology manufacturing systems are offered to produce clockwork components that include integrated services units. Beyond traditional ownership acquisition, further value propositions are also offered to the customer, e. g., availability and result guarantee or knowledge development to increase technical manufacturing expertise.

VALUE								
degree of integration	pure product	product-service combination	product-service integration	pure service				
value proposition	acquisition of property	consumption guarantee	result guarantee	availability guarantee	knowledge development	performance flexibility		
VALUE ARCHITECTURE								
key processes	maintenance	procurement	installation	operation	tool management	upgrading	continuous improvement	
key capabilities	mutability	ability to cooperate	mediation capability	provision capability	development capability	implementation capability	decision-making capability	innovation capability
Key Resources	human resources	financial resources	organizational resources	physical resources	technological resources			
VALUE NETWORK								
key partner	suppliers	consultant	banks and credit institutions	industrial service provider				
VALUE STREAMS								
revenue mechanism	transaction-based	equipment-dependent	volume-dependent	flat rate	time-based	availability-oriented	result-oriented	
cost driver	Personal	material	research and development	rent	depreciation	administration	marketing and Sales	subcontracting

Figure 9: Partial Model Characteristics of the Business Concept

property rights							
ownership	provider		customer		key partner		
possession	provider	customer	key partner	temporarily in possession of the provider	temporarily in possession of the customer	temporarily in possession of a key partner	
task distribution							
service initiation	provider		customer		key partner		
type of task distribution	customer-initiated (transaction-based)		cooperation-intense		provider-driven		
risk distribution							
operational risks	sales risk	procurement risk	provision risk	personnel risk	IT risk	availability risk	result risk
value distribution							
type of value distribution	gross distribution without cost allocation			net distribution with cost allocation			
cost allocation	originator		hybrid combination		risk bearer		

Figure 10: Characteristics of Relational Components

4.2.2 Definition of Flexibility Options

The choice of a suitable business model depends largely on the capability profiles of both parties as well as the definition of appropriate flexibility options. [46] To date, Omichron does not possess the capabilities to operate a micro-milling machine and to create the necessary environment for this. Several uncertainties result from this deficit in expertise. To build up the technical know-how for micro production at the customer's site, a provider-driven business model is initially used as a basis, in which the provider takes over all manufacturing processes. It is the responsibility of MicroS+ to provide qualified staff to ensure the implementation of accompanying production processes and the production of the agreed range of parts (1. flexibility option: provision of provider personnel). The provider guarantees the production result (2. flexibility option: result guarantee) and charges by units produced (3. flexibility option: unit revenue).

Primary Flexibility Options	**Secondary Flexibility Options**
1. Provision of provider personnel	4. Availability guarantee
2. Result guarantee	5. OEE optimization (if required)
3. Unit revenue	6. Automation (if required)

Table 1: Flexibility Options

Once the expertise is available for the machine operation with the customer, a business model can change to a collaboration-intensive business model with availability guarantee (4. flexibility option: availability guarantee). In doing this, the provider must minimize the risk of failure for the components of the micro-milling station, the failure of which impairs the operation of the entire production system. In this setting, the customer is offered as an option the optimization of the Overall Equipment Effectiveness (OEE) [47] as a measure of the added value of the manufacturing system (5. flexibility option: OEE optimization). In addition, the possibility of increasing capacity by means of robot-based automation is offered (6. flexibility option: automation). Flexibility options 5 and 6 are activated by the customer if required. Thus, an incremental adjustment of the cooperation-intensive business model is possible.

4.2.3 Selection of Partial Model Characteristics

Based on the flexibility options, the business relationship is now divided into several stages, for each of which the relevant partial model characteristics are selected using the morphological box. [3,41,46]

The *initial phase* is a provider-driven business model. This includes the product-service integration of complex, production-related capital goods (micro-milling machine) as well as function-creating, function-preserving, and training services. These services generate integrated value propositions with the characteristics result guarantee and expertise-building. The value proposition of the results guarantee can be quantified via the units that are to be produced (clockwork plates). Figure 11 shows the respective partial model characteristics. The characteristics marked with "SD" are taken as a basis for the system dynamic modeling (P - provider MicroS+, C - customer Omichron, KP 1 - key partner 1 spindle supplier). SD modules can be stored in the partial model library of the digital support tool.

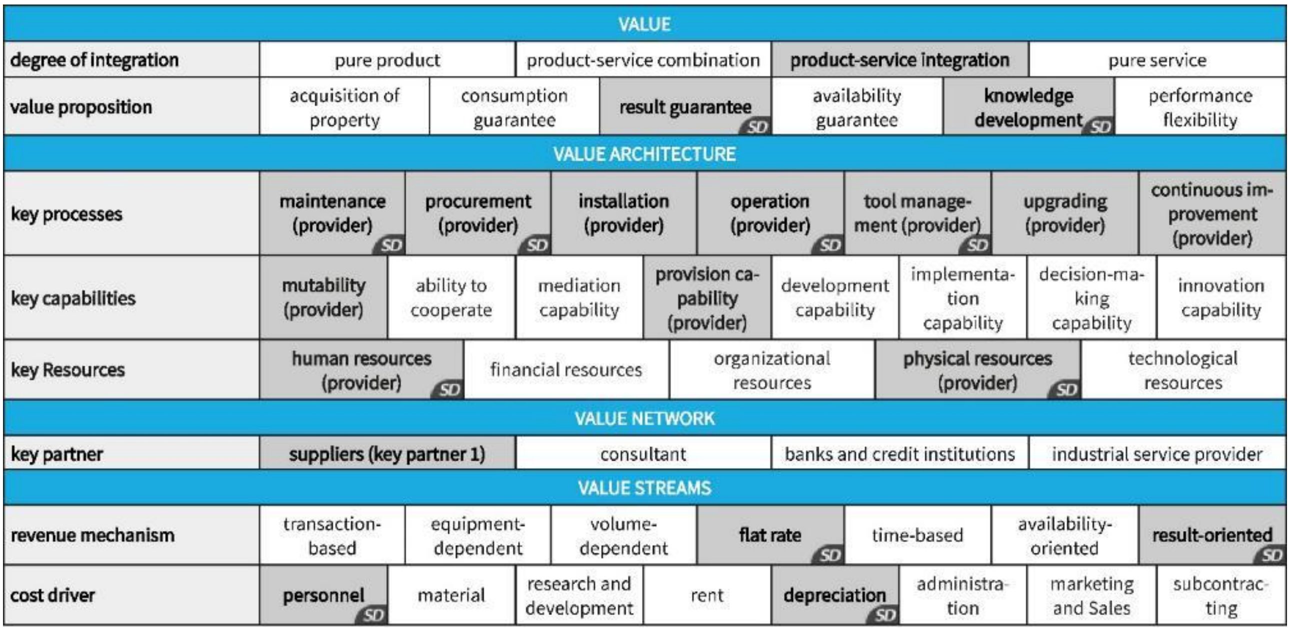

Figure 11: Partial Model Characteristics and SD-Modules (Initial Business Model Phase)

As part of the results guarantee by MicroS+, risk minimization is implemented for the customer because market and revenue risks are assumed by the provider. Moreover, the necessary customer expertise for clockwork manufacturing is provided. In addition, the provider is responsible for all key processes such as installation, procurement, maintenance, operation, and tool management (see figure 11).

VALUE								
degree of integration	pure product	product-service combination	**product-service integration**	pure service				
value proposition	acquisition of property	consumption guarantee	result guarantee	**availability guarantee** SD	knowledge development	**performance flexibility** SD		
VALUE ARCHITECTURE								
key processes	**maintenance (provider)** SD	**procurement (provider)** SD	**installation (provider)**	**operation (customer)** SD	**tool management (provider/ key partner 2)** SD	**upgrading (provider)**	**continuous improvement (provider)**	
key capabilities	**mutability (provider)**	**ability to co-operate (provider/ customer)**	mediation capability	**provision capability (provider/ customer)**	development capability	implementation capability	decision-making capability	innovation capability
key Resources	human resources (provider)	financial resources	**organizational resources (provider/ key partner 2)** SD	**physical resources (provider)** SD	technological resources			
VALUE NETWORK								
key partner	**suppliers (key partner 1)**	consultant	banks and credit institutions	**industrial service provider (key partner 2)**				
VALUE STREAMS								
revenue mechanism	transaction-based	equipment-dependent	volume-dependent	**flat rate** SD	time-based	**availability-oriented** SD	result-oriented	
cost driver	**personnel** SD	material	research and development	rent	**depreciation** SD	administration	marketing and Sales	subcontracting

Figure 12: Partial Model Characteristics (Second Business Model Phase)

In the *second phase* of the business model, the provider guarantees the *availability* of the micro-milling station. Thus, function-preserving, optimizing, and advisory services are the priority. The value contribution is quantified using the OEE ratio. Key processes are divided between the parties. The customer now independently assumes operation of the micro-milling machine. The monthly fee is supplemented by availability-based billing, depending on the OEE ratio. An industrial service can be activated for tool management if required.

4.2.4 Concretization of Business Model Characteristics

To specify the relational aspects of the business relationship in the value network, the relational components of the business model phases are specified. For this purpose, the task, risk, and value distribution, as well as property rights, are determined in the value network. Furthermore, the cost structure and revenue mechanism are determined by quantification of fixed and variable components. In the initial phase of the business relationship, the flexible manufacturing system remains the property of the provider. However, since this is integrated at Omichron's production site, it is in the possession of the customer. The service initiation takes place in a provider-driven business model solely by the provider. Due to the results-oriented revenue mechanism, the provider also bears the sales risk in addition to the production risk.

property rights							
ownership	**provider**	customer	key partner				
possession	provider	**customer**	key partner	temporarily in possession of the provider	temporarily in possession of the customer	temporarily in possession of a key partner	
task distribution							
service initiation	**provider**	customer	key partner				
type of task distribution	customer-initiated (transaction-based)	cooperation-intense	**provider-driven**				
risk distribution							
operational risks	**sales risk (provider)**	procurement risk (provider)	provision risk (provider)	**personnel risk (provider)**	IT risk (provider)	**availability risk (provider)**	**result risk (provider)**
value distribution							
type of value distribution	**gross distribution without cost allocation**	net distribution with cost allocation					
cost allocation	originator	**hybrid combination**	risk bearer				

Figure 13: Characteristics of Relational Components (Initial Phase)

In the second business model phase a cooperation-intense business model with availability guarantee, the flexible manufacturing system remains the property of the provider and in the possession of the customer. The service initiation continues to occur by the provider because it guarantees the availability of the production system. The acquisition of the availability risk through the provider is directly reflected in the availability-oriented revenue mechanism. The sales risk is now, however, solely with the customer.

property rights							
ownership	**provider**	customer	key partner				
possession	provider	**customer**	key partner	temporarily in possession of the provider	temporarily in possession of the customer	temporarily in possession of a key partner	
task distribution							
service initiation	**provider**	customer	key partner				
type of task distribution	customer-initiated (transaction-based)	**cooperation-intense**	provider-driven				
risk distribution							
operational risks	sales risk (customer)	procurement risk (customer)	**provision risk (provider/ customer)**	personnel risk (provider)	IT risk (provider/ customer)	**availability risk (provider)**	result risk (customer)
value distribution							
type of value distribution	gross distribution without cost allocation	**net distribution with cost allocation**					
cost allocation	originator	**hybrid combination**	risk bearer				

Figure 14: Characteristics of Relational Components (Second Phase)

4.2.5 Creating a Dynamic Business Model Prototype

As a result of the iterative design process, there is now a qualitative description of the business relationship. The result originating from the partial model characteristics selected for each activity converts the corresponding SD modules from the partial model library into a generic business model with SD modules. Building on that, the dynamic behavior of the business model can now be analyzed.

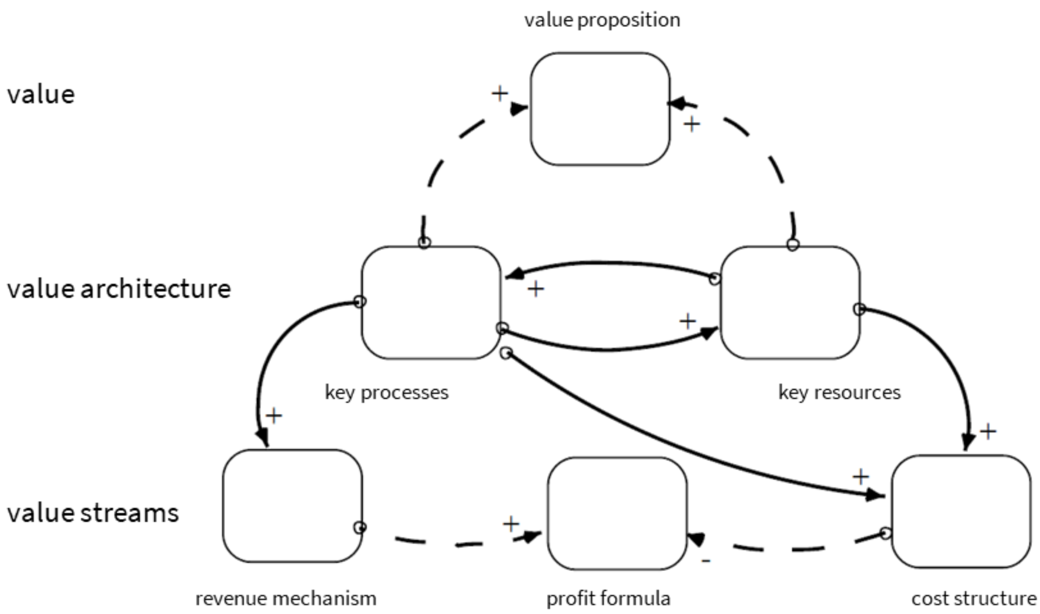

Figure 15: Sub-System Diagram

4.3 Business Model Analysis

4.3.1 Model Purpose and Problem Articulation

When designing the business model, two basic business model phases were defined for the business relationship between Omichron and MicroS+. In the first phase, the customer develops the application of the expertise. In the second phase, the provider guarantees the availability of the flexible manufacturing system. In this setting, three problem areas are examined that include questions about the business model change in addition to phase-specific questions and issues.

1. What are the implications of machine failures for the result-oriented revenue mechanism in the initial phase of the business model? How must the earnings mechanism be designed to distribute earnings risk appropriately among the parties in the business relationship?
2. What impact does a collapse in organizational availability have on the value generated in the business model?

To define the problem border, systemically important variables are endogenized. This is done by the problem border diagram shown in Table 2, where endogenous, exogenous, and excluded variables are differentiated.

Endogenous	**Exogenous**	**Excluded**
Stock of manufactured movement plates	Movement plate orders	Competitors
Maintenance order backlog	Maintenance personnel of the supplier	Key partner personnel
Operator personnel of the customer	Operator personnel of the supplier	Labor market

Application know-how and experience of the customer	flexible manufacturing system (with micro milling station)	Capital market
Production tooling inventory		
Raw materials inventory		
Revenue		
Costs		

Table 2: Flexibility Options

4.3.2 Dynamic Problem Concretization

Specific partial model characteristics have already been identified in the design of the business model for the business relationship between MicroS+ and Omichron. For further investigation, six SD modules are used as a basis: value proposition, key processes, key resources, revenue mechanism, cost structure, and values. The relationships between the variables and the basic feedback structure in the business model are exemplified in Figure 16 using a causal loop diagram. Due to the generic business model prototype, there are already predefined SD modules in the form of stock flow diagrams, which are made available automatically by means of the partial model library.

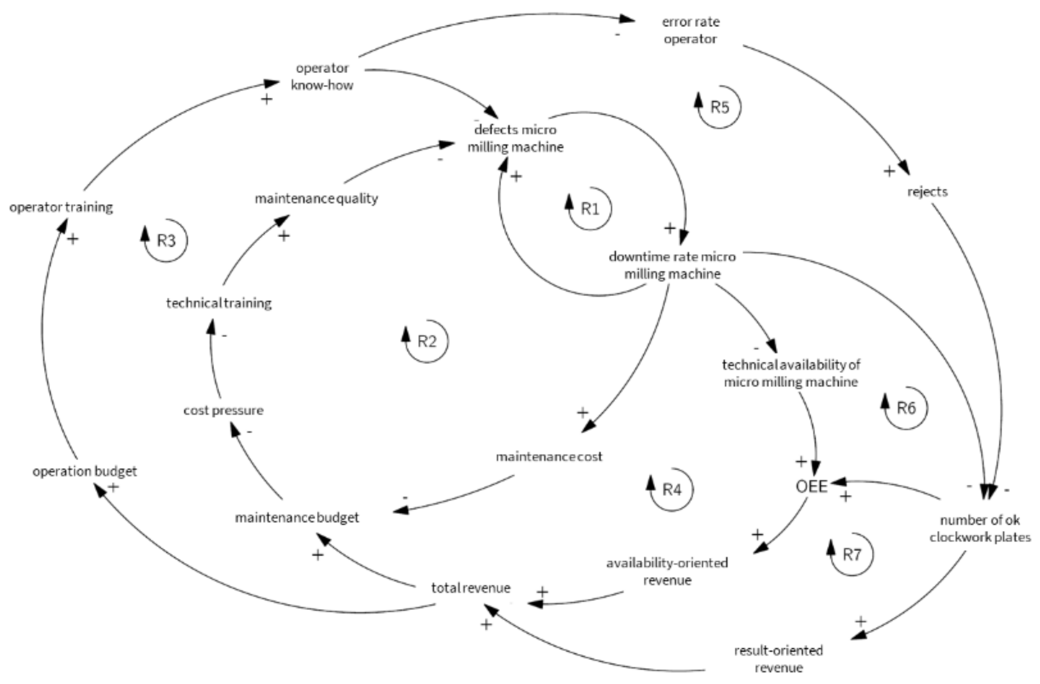

Figure 16: Causal Loop Diagram

4.3.3 Formulation of the Simulation Model

The components are now specified by mathematical function relationships and initialization of the stocks. In this way, there is a comprehensive system of equations in which every problem-relevant component of the business model is described by an equation. The value architecture consists of the components key processes, key resources, and key capabilities. The key processes operating, tool management, maintenance, and procurement of raw materials in stock flow diagrams are transferred.

The key process operation is shown in Figure 17. For the examined business model, incoming orders for clockwork plates are used. In the scenario, a rise in demand is anticipated at the end of the term, which can be activated via an auxiliary variable and thus influence the order rate. The resulting order backlog reduces gradually over time. The production rate for clockwork plates is restricted by the key resources tools, raw materials, and operating personnel, as well as the product component micro-milling machine. Using the minimum function, the resulting production rate is determined, in which the resource is taken as a basis with the largest bottleneck of the calculation. The manufactured clockwork plates then go into stock for quality control. A subdivision in error-free and erroneous clockwork is carried out in accordance with the error rate occurring during production.

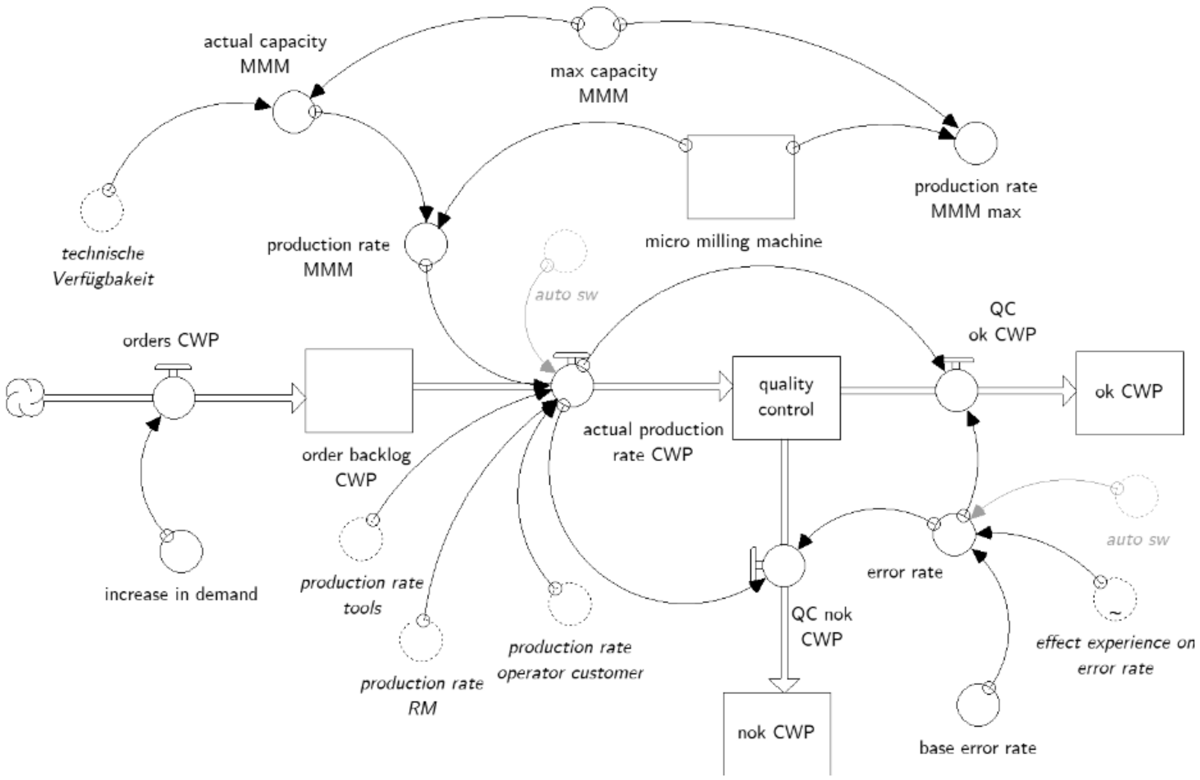

Figure 17: Key Process Operation

In figure 18 tool management is presented as another key process that can be run on demand by an external key partner. Based on the orders of clockwork plates from the key process operation, the cutting tools required for manufacturing are ordered considering the replenishment lead time according to the available stock of tools. Used milling tools are disposed of at the end of their operating life. Reprocessing is not provided. The tool-specific production rate that goes into the key process operation results from the capacity of the tools and the stock of tools.

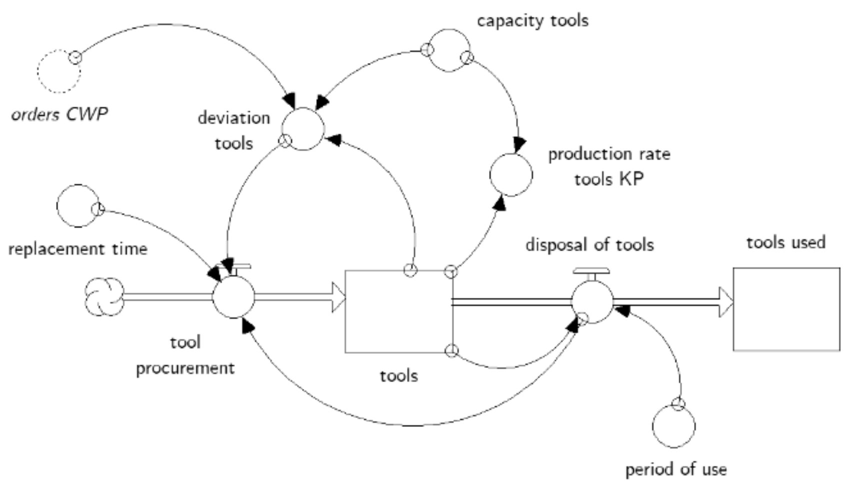

Figure 18: Key process Tool management by key partners

Furthermore, key resources must be considered for modelling the value architecture. The structure of the application expertise is relevant through training for the customer's operating personnel for the case study. This aspect is reflected in the SD module of key resource operating personnel of the customer in figure 19 The knowledge structure is displayed here to the operator personnel by using an aging chain. Using the constant training duration, trained operators are generated via the training rate of operator candidates. Once the required knowledge level is reached, the model automatically changes to a cooperation-intensive business model. Once the business model has changed, the customer is solely responsible for the operation. Accordingly, operating personnel develops in addition to the existing technical hands-on experience and knowledge, which over time has an (increasingly positive) impact on the production and quality rate.

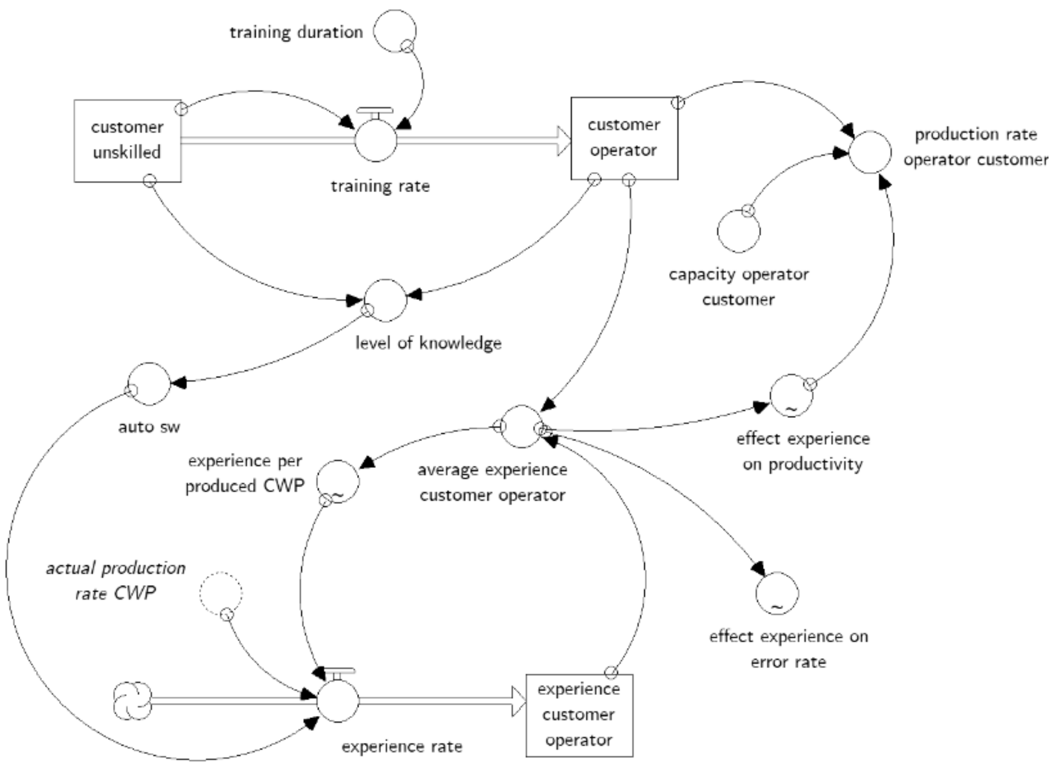

Figure 19: Key resource operator personnel of the customer

The value proposition is essential for a business model and is quantified in this model by means of various indicators. In the case of availability-oriented value proposition, the OEE figure is crucial, which is defined by the performance, quality, and availability index of the product. These factors are determined by various variables from existing SD modules for the key processes operation, tool management, and maintenance. Figure 20 presents these relationships in an SD module. The number of produced clockwork plates from the key process operation is critical for the result-oriented value proposition, for which the number of flawlessly crafted clockwork plates is crucial. The development of the application expertise associated with this value proposition structure can be illustrated via the auxiliary variable level of knowledge.

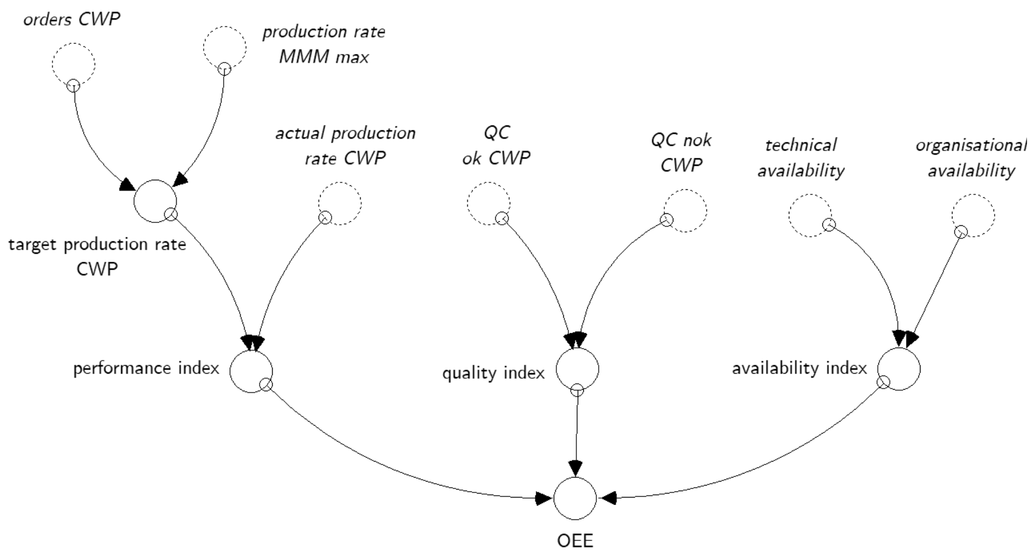

Figure 20: Quantification of the value proposition

In close relation to the value proposition, the revenue mechanism must be defined. Figure 21 integrates the results and availability-oriented revenue mechanism. The number of flawlessly crafted clockwork plates is used for the results-oriented revenue mechanism. The variable part of the revenue mechanism is realized by multiplying with a unit price (CPU - cost per unit). The procedure for the availability-based revenue mechanism is analogous.

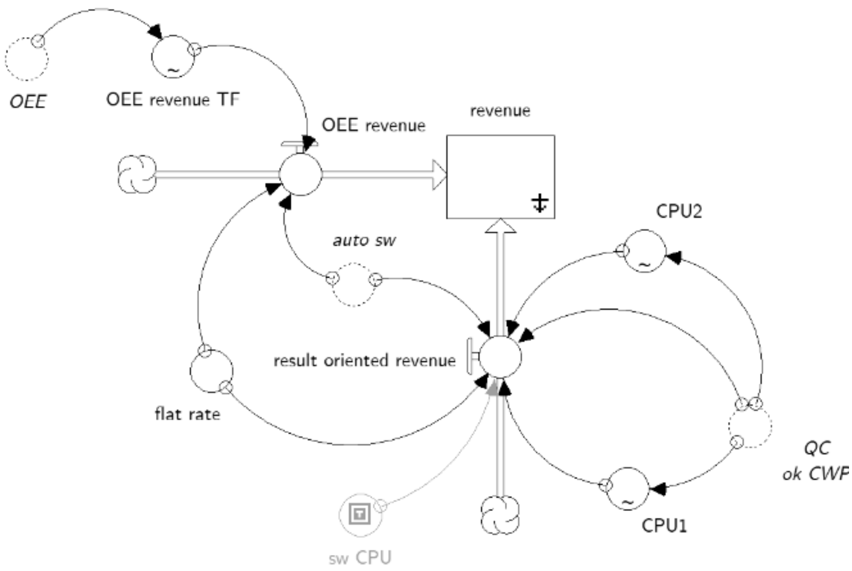

Figure 21: Revenue mechanism

The dependence of the revenue mechanism of the OEE figure is displayed via a table function. In addition to these variable revenue components, a fixed income component is additionally provided in the form of a flat rate.

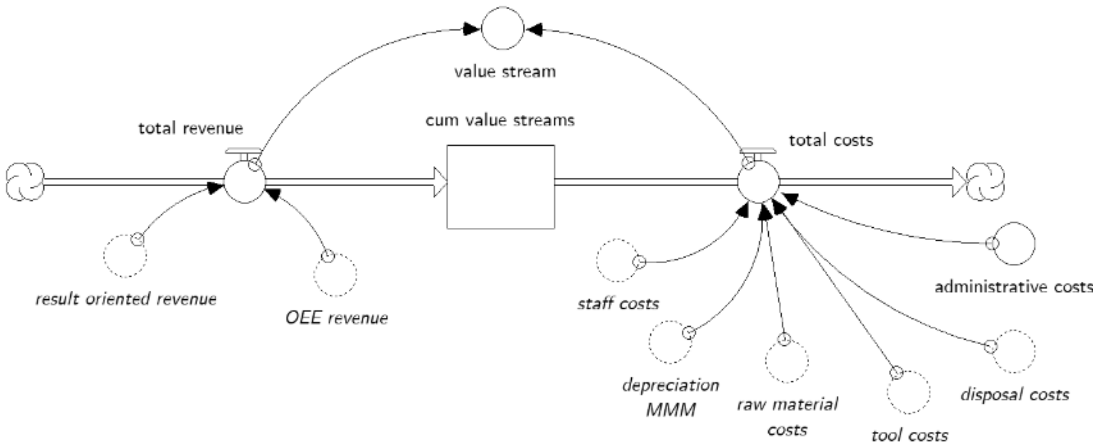

Figure 22: Value Streams

Another essential component for determining the values generated in the business model is the cost structure. In the cost structure, several variables from the general model are analogous to the revenue mechanism, e.g. the raw material costs are derived from the number of used raw materials. Figure 22 summarizes important cost elements in the SD module values. The revenue generated by the revenue mechanism yields are compared with the costs here. Thus, as part of the scenario analysis, statements can be made on the profitability of the business model.

4.3.4 Simulation, Validation, and Model Tests

After the SD modules relevant for the business relationship between MicroS+ and Omichron have been converted to a dynamic system overall model with corresponding mathematical function contexts, a validation of the model using different model tests can be carried out. Structural and parameter tests, behavioral tests, and impact tests are used to assess the validity. A detailed description of the performed model tests of this case study research can be found in [3]. The data in the present scenario originate from a demonstrator project of the Collaborative Research Center Transregion 29 for Industrial Product-Service Systems [18]. A detailed description and documentation of the models can be found in the book Business Model Engineering by Boßlau [3].

4.3.5 Scenario Analysis, Evaluation, and Documentation

With the validated SD model, a series of simulation runs can be performed to answer the above-defined research questions. First a simulation of a baseline scenario is carried out for the presentation of an ideal profile of the business relationship. Finally, a threat scenario will be comparatively contrasted.

The simulation of the baseline scenario extends over a period of five years, while the integration step is one month. The model includes in total 118 variables. In the following, only the model sizes that in their chronological consequence are of essential importance in the context of model purpose and problem articulation are presented graphically for coping with complexity.

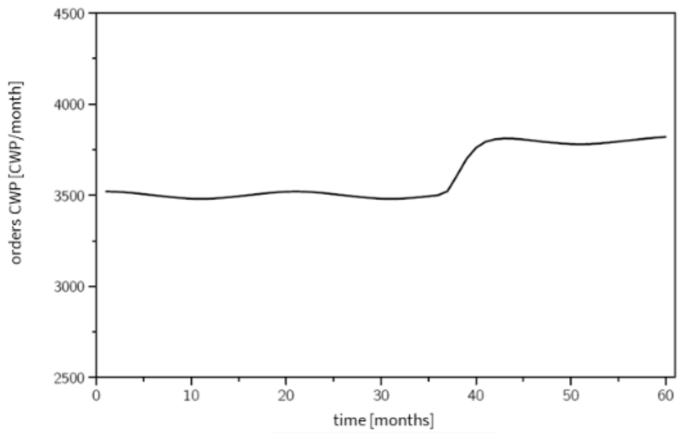

Figure 23: Baseline Scenario Orders

To quantify the value proposition, the focus is on the following sizes: Number of flawlessly crafted clockwork plates (initial business model phase), knowledge level (initial business model phase), OEE figure (secondary business model phase). To illustrate the value of the business model, the following variables are also analyzed: revenue, costs, and values (profit and loss). The number of orders (figure 23) provide the starting point for the development of these values and in the first three years is at an average of 3,500 clockwork plates per month. This order quantity is compatible with the maximum engine capacity of the micro-milling station of 3,850 clockwork plates per month. In the last two years of the business relationship, there is a demand increase to approximately 3,800 clockwork plates per month, which must still be dealt with. Moreover, the initial values for stocks and constants are valid for the baseline scenario.

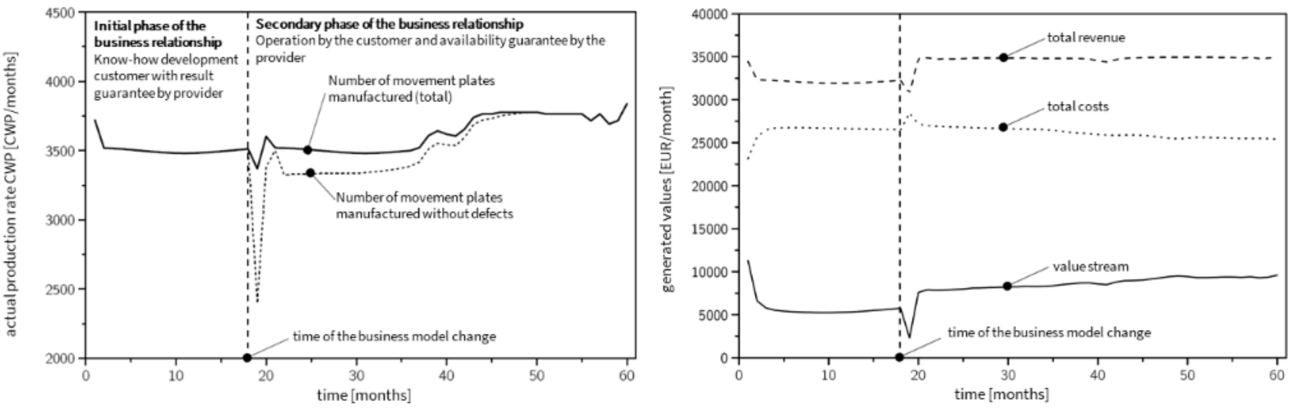

Figure 24: Baseline scenario Production Rate (left) and Generated Values (right)

Figure 24 shows the production rate that results from the incoming orders. Since the order stock has an initial value of 50 clockwork plates and allows the existing capacity processing of more than 3,500 clockwork plates, the production rate is marginal in the initial phase of the business relationship in the first month on the incoming orders; however, in the end it aligns itself exactly with the order income. Due to the long-term experience of the provider, exclusively faultless clockwork plates are made in the initial phase of the business relationship.

The business model changes after a period of 18 months to an availability-oriented value proposition once the customer Omichron has developed the expertise to operate the micro-milling process independently from the provider. The change of the business model is triggered by the auxiliary variable level of knowledge in the SD model. By varying the duration of training, in this way the time of the business model change can be influenced. After the business model changes, operation is carried out by the customer.

Due to the customer's lack of experience, there is initially a slight drop in the production rate. In addition, the low application experience of the customer in the operation also affects the error rate. Accordingly, the number of error-free manufactured clockwork plates initially is below the overall production rate, but with increasing application experience it approaches the desired target value. This results in an improvement of the quality factor that flows into the indicator OEE. In the last two years there has been an increase in demand in clockwork plates (figure 24 left). Due to slight variations in tool availability, the required order quantity cannot be manufactured in full. The production rate, however, levelled off at the higher level.

Figure 24 (right) shows the values generated in the business model. The course of the revenue in the result-based mechanism results from the number of flawlessly crafted clockwork plates (course before the business model changes). After the business model change, the OEE figure will be calculated using a table function. Consequently, the increase in demand at the end of the business relationship and the consequent increase in production rate are not visible in the revenue. Only the positive development of the quality factor that flows into the OEE figure leads to a slight increase in revenue. In total, positive values (profits) are generated via the business relationship. A solid financial position can therefore be assumed in the baseline scenario.

Threat scenario: Equipment failure and decline of organizational availability

In the threat scenario we will first show what impact machine faults on the generated values of the business model can have in the initial business model phase. For the second business model phase with availability guarantee, the tool availability is no longer given. Other initial values from the baseline scenario are, however, maintained. The equipment failure aspect is implemented in the SD module key process maintenance. The start time, duration, and intensity of the failure can be specified there via auxiliary variables. This has a negative effect on the machine capacity for the chosen dates. There will also be additional costs for repairing the machine that flow into the values model. In figure 25 the resulting downturn in the number of manufactured clockwork plates in the initial phase of the business model is depicted.

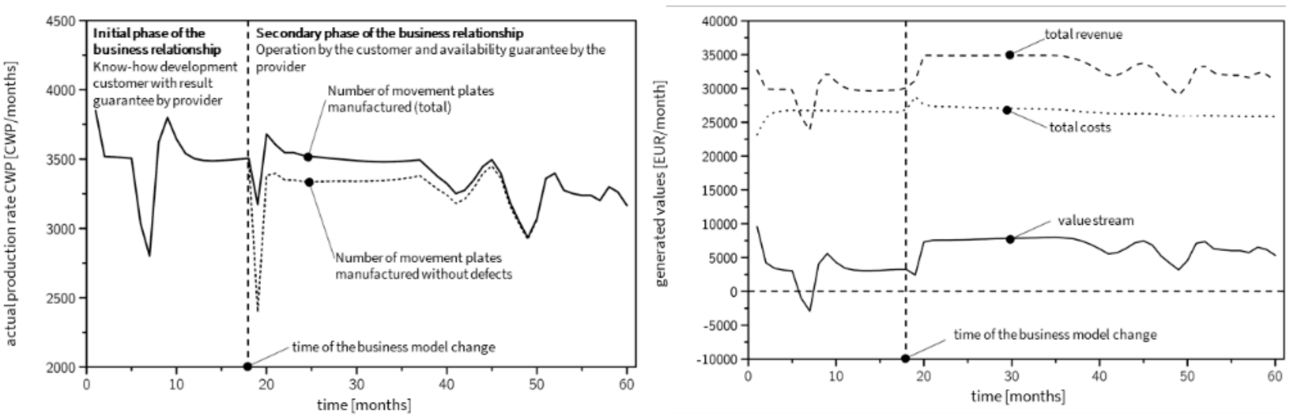

Figure 25: Threat Scenario Production Rate (left) and Generated Values (right)

In addition to machine failure, a decrease in tool availability is assumed in the second business model phase because the provider is initially responsible for the supply of tools. This aspect is mapped in the SD module key resource tools. As a result, there is a reduction in the OEE, which is reflected directly in availability-oriented revenue mechanism. In addition, there is a significant reduction in the production rate (Figure 26 left) in the secondary phase of the business relationship. Figure 26 (right) shows the resulting course of the values model. In the initial phase, losses are generated because the costs exceed the targeted results-based revenues. Although no negative result is achieved in the secondary phase, a slightly negative trend is nevertheless evident with fluctuations in total revenue and also in the value stream generated. Although this development is still acceptable from the supplier's point of view, the reduced tool availability cannot be accepted from the customer's point of view due to the increased demand for movement plates.

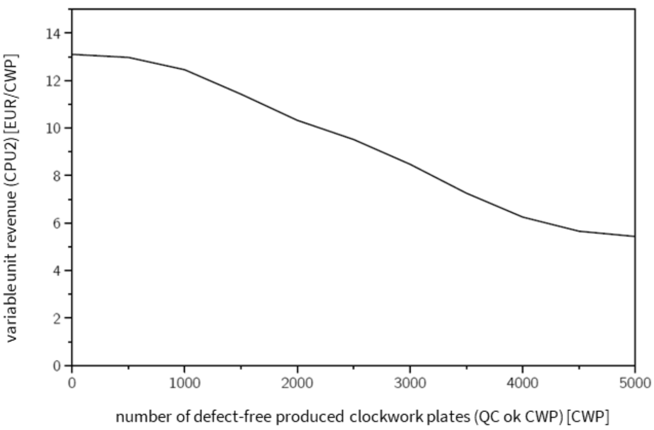

Figure 26: Variable Unit Revenue – Cost per Unit (CPU)

To distribute the result of risk appropriate to the parties in the business relationship, a periodically variable revenue mechanism can be implemented via a staggered unit of revenue. Relatively higher unit revenues will thus be calculated for lower production volumes. To avert the threat scenarios in the initial business model phase, the revenue mechanism is thus implemented with the revenue unit shown in Figure 28.

Despite the existing downturn in the number of manufactured clockwork plates (Figure 27 left), loss can be avoided by adjusting the revenue mechanism (Figure 27 right) in the initial phase of the business relationship. Moreover, a key partner for tool management is included in the value network to ensure organizational availability. In the SD model, the key process tool management module is activated by key partner. The required milling tools for manufacturing are automatically re-ordered according to the available stock of tools based on the existing orders for clockwork plates.

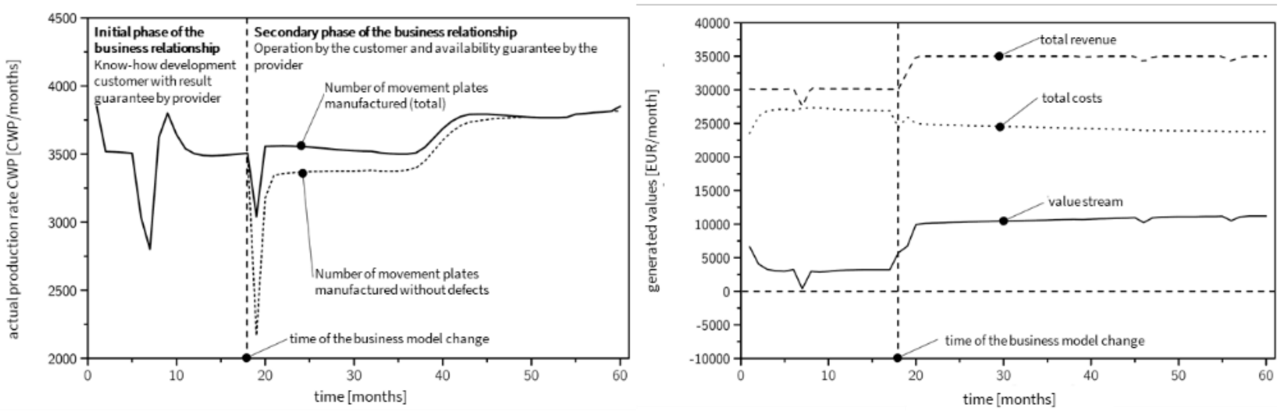

Figure 27: Defense Strategy Production Rate (left) and Generated Values (right)

In Figure 27 (right) it is apparent from the course of the number of manufactured clockwork plates that the requested number of clockwork plates can be manufactured by consulting with the key partner. In addition, the OEE figure reaches a high level, thus causing a continuous and solid course of revenue streams.

5 Conclusion and Future Research

Smart PSS offerings are a key competitive factor for companies in the mechanical and plant engineering industry. However, to be able to deliver these integrated solutions, it is necessary to develop appropriate business models that can be adapted through the business relationship. In this paper, the methodology of business model engineering for the design and analysis of dynamic business models for smart PSS was presented for this.

Considering the challenges of digitalization, an increased shift from traditional product-oriented business models to integrated overall solutions in the form of smart PSS is most likely. However, the required high intensity cooperation for this has to date prevented the successful migration to a solutions provider in many cases. The demonstrated digital business model engineering approach can provide initial important support to map the structure and dynamics of the resulting business models.

For the future, there are still more open questions for research and industrial application. The combination of smart services and products is becoming increasingly interesting for the manufacturing industry.

Comprehensive data analyses can provide good support for further optimization. A number of questions arise: How can fear of contact be reduced and how can data-based decisions be increasingly used in production? How can data experts support production with their approaches and results? Certainly, the combination of process and data experts will continue to be the right approach here in the future.

Figure 28: Application and Validation of the Methodology in Teaching and Practice

However, the results of this research open new research opportunities, in relation to the life cycle of overarching management of innovative business models. Extensibility is ensured by additional components due to the methodical construction of business model engineering. Thus, integration in the existing methodology will be possible in the future without any problems. Based on this framework, further scientific work can be developed, for instance, an empirical review of the benefits of various business models under different framework conditions. In addition, the methodological framework presented will be integrated into IU International University's online teaching programs (lecture and project: smart PSS and System Dynamics) and will continue to be validated and tested with industrial partners in case studies.

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