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Managing Complexity in Product Service Systems and Smart Services

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Abstract

In the context of product service systems and smart services, the huge number of possible variants and dynamic market requirements present a challenge for service providers who want to stay profitable. The combination of variety and dynamic is called the complexity challenge. Among the main difficulty is to respond to the market's external variety and dynamic with the right flexibility without losing efficiency or effectiveness. This paper, motivated by a case study, focuses on selected difficulties posed by complex markets on the portfolio, product, process and resource level. It introduces a qualitative and quantitative model to manage a company's internal complexity according to the external complexity on all mentioned levels. In the introduction, the most relevant challenges posed by complex markets will be explained in detail. The second section covers the understanding of complexity management as a control loop. The third section then introduces a set of key figures that can be used to evaluate a company's internal complexity on a quantitative level. In the fourth section, a curve model that aims at representing the qualitative interconnections between these key figures to gain control of the complexity in product service systems and smart services will be presented.

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Keywords: Smart Services; product servic systems; variety; dynamic markets; complexity management; control loop; key figures; curve model

1. Introduction

When it comes to adding a service to a product, which can be seen as mandatory for smart products, the number of possible variants rises exponentially. As seen in the industrial services industry, the challenge for service providers is then characterized by two main features, namely a high variety and high dynamics. A high variety means that there are many similar yet distinct smart services available on the market and possibly even in the company's own portfolio. A high dynamic implies that these variants do not simply coexist, but they mutually influence one another through the customers' purchasing behaviour on the one hand and possibly some resources on the other hand. In addition, the smart service market is subject to constant and unpredictable change. These two characteristics – variety and dynamics – define complexity, stand opposed to effective corporate action and therefore pose a major challenge to the management of smart service providers [1]. A company that aims at being successful in such a complex market environment needs to be both flexible and efficient in its actions, which requires a systematic approach towards complexity management. Complexity management is concerned with finding strategies to react to the dynamics and variety of a complex market in a way that reduces ineffectiveness. Its ultimate aim is to find the optimum between the cost of diversity, variety and flexibility in the smart service portfolio and the benefit in the form of achievable prices or turnover. It is often seen that cost rises exponentially by adding more and more variants to a portfolio, but on the other hand the realized revenue often converges against a certain maximum. The target of each business must be a leveraged number of variants and variant change rates to fulfill the cost efficiency

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and flexibility requirements. The present paper introduces a model that can be used for managing complexity in product service systems and smart services. For this purpose, variant and complexity management approaches from the industrial good production have been adapted to the needs in the service industry. A descriptive submodel includes key figures that can be used to describe a company's complexity on four major levels, the portfolio, product, process and resource level. An evaluation submodel then provides curves that aim at representing the quantitative interconnections between these key figures. The four different levels allow to identify potential for optimization towards gaining the necessary flexibility without losing efficiency. Before these components of the model can be presented, however, the underlying understanding of the company as a set of intertwined control loops needs to be explained.

2. The company as a multi-level control loop

Most of the reviewed complexity management approaches for the industrial goods production are based on the idea that there is an optimum between high stock and high capacity utilization. Complexity management then has to identify the correct point of operations under the circumstances given by the market variety and dynamic. But, Services could not be stocked due to their immateriality. As a first step, this paper uses the idea of the service production model according to Corsten [2, 3, 4] with its three different layers of product, processes and resources/potentials. Further, the present paper understands a company and its complexity management in particular as a control loop.

A control loop is a closed and continuous sequence of events that aims at influencing a controlled variable through a constant succession of measuring, comparing and regulating so that the controlled variable reaches and remains at a desired value (see Fig. 1). A common control loop consists of

- A **control system** whose output variable is changed when the input variable is altered
- A **controller** that compares the controlled variable with the predefined target value and uses the result to determine the correcting variable and can be described by
- A **controlled variable** that is to be maintained at a predefined target value
- A **target value** that the controlled variable should follow
- A **correcting variable** that can be directly regulated and in turn influences the controlled variable – used to approach the controlled variable to the target value
- A **disturbance variable** – any variable other than the correcting variable that influences the controlled variable and is controlled outside the loop.

Merging the principles of a control loop and the four levels of service production results in intertwined levels in the form of a multi-level control loop. Due to the fact that a whole portfolio instead of one single product needs to be managed in the case of complexity management, a further layer regarding the structure of the portfolio has been added to the three existing service levels. If product service systems are covered in the evaluation according to the presented model, the physical products also need to be monitored on the portfolio level.

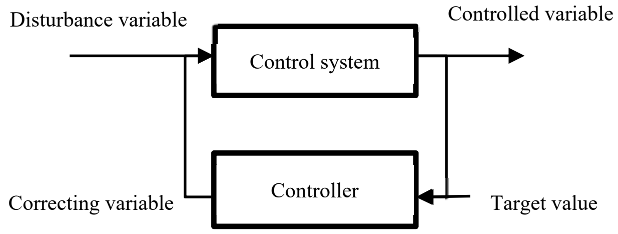

Fig. 1. Elements and key indicators of a control loop

In general, each commercial action on a market can be understood as a control loop. The market itself represents the control system, but the acting enterprises are control units with the aim to control the market. Transforming this picture into the specific complexity management case, the market remains the control system and the company under consideration represents the controller. The market complexity affects the company as an external complexity. By changing offered prices and sales volumes, the company in turn tries to affect the market. Of course, the potential prices and sales volumes are highly influenced by cost, margin and resource capacities on the other hand. To map exactly this in the presented model, the company itself is divided into the four declared levels of portfolio, products, processes and resources (for a simplified graphic representation see Fig. 2).

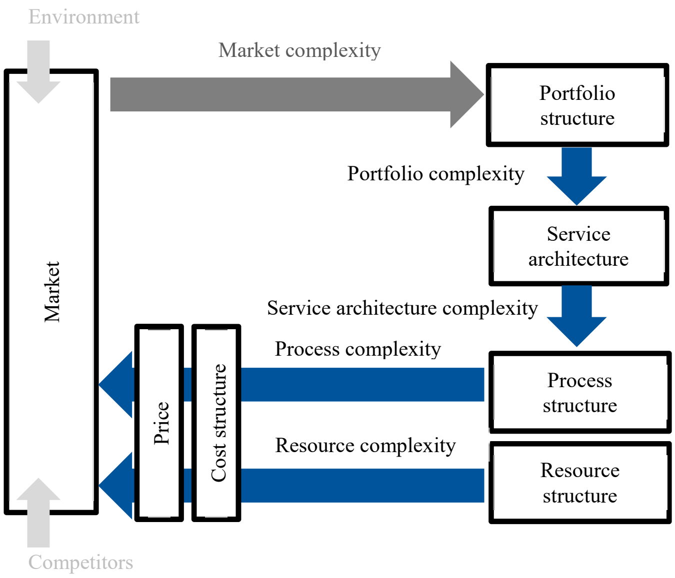

Fig. 2. Graphic representation of a control loop

The first partial control loop is a company's portfolio. Here, the complexity of the market represents the disturbance variable. This complexity affects the actual turnover or market share of the portfolio, the controlled variable of the loop, through the customers' purchasing behaviour. The actual turnover or market share is compared to the target value, the desired turnover or market share. Complexity management acts as the controller of the loop in the form of business development by altering the structure of the portfolio – the correcting variable – in a way that brings the actual turnover or market share closer to the target value. The reference point is always the variety and dynamic of the market.

The second partial control loop is the architecture of individual smart services. Here, the portfolio structure acts as the disturbance variable while the structure of individual smart services within the portfolio can be understood as the control system. Like in the first partial loop, the achieved turnover or market share represents the controlled variable of the system while a predefined target turnover or market share represents the target value. Again, complexity management acts as the controller of the system by making changes to the structure of individual smart services – the service structure thus acts as the correcting variable on this level.

The third partial control loop can be found on the process level. Especially in services, the processes ensure that a result is generated. Here, the correcting variable of the second level, the structure of individual services, acts as the disturbance variable. The process structure, the control system of the level, is often subject to change when the structure of individual services is changed. The actual process times represent the controlled variable, while predefined target times function as the target value of the system. Upon comparing these process times, complexity management needs to act as the controller of the system by making changes to the process structure, which can be understood as the correcting variable of this level.

The fourth and last partial control loop can be found on the resource level. Like on the process level, the structure of individual services represents the disturbance variable of this loop. The control system is the operational management who selects the resources, while the controlled variable and the target value take the shape of actual or desired cost rates. Like on the previous level, complexity management acts as the controller of the system by revaluating and adapting the resource selection, which functions as the correcting variable of the system.

Between the last two partial control loops and the market, prices and cost structures are two more factors that need to be included in the overall control loop. While these do not create new control loops, the costs are a product out of process time and cost rate. In addition, the product management and sales department top a margin on the cost to determine the offered price, though it is not guaranteed that the full sales volume will be sold at the target price.

The control loop model of complexity management explained above forms the basis of the model for managing complexity in smart services. The model consists of three components, namely a set of key figures, a curve model and a cost accounting approach. Both the key figures and the curve model will be explained in greater detail in the following sections.

3. Key figures for managing complexity

As mentioned above, companies need to act in a flexible and efficient manner in order to be able to succeed in a complex market. The present paper aims at making a company's complexity management measurable by presenting a quantitative way to express both the flexibility and the efficiency of a company on all relevant levels from portfolio to resources. For this purpose, all four levels of the control loop explained above are regarded separately, and for each level, two key figures will be defined. The first of these key figures describes a company's efficiency on the respective level at a fixed point in time. The second key figure on the other hand quantifies the capability of change from one point in time to another – in this case, a company's flexibility on the level in question. This distinction results in a total of eight key figures, all of which will be introduced below. The aim of the presented model is to quantify the interdependence between the efficiency indicator and the flexibility indicator in a non-linear way at a later stage.

On the level of the portfolio structure, the number of smart service variants can be used to quantify a company's complexity management. The first key figure, the portfolio efficiency, can be defined as the ratio between the numbers of requested and offered service variants. The resulting quotient reaches its best value when each variant has been sold at least once. The portfolio flexibility, on the other hand, can be quantified as the ratio between the number of new variants in the portfolio and the number of new variants on the market, scaled to the number of competitors. The resulting quotient takes values between 0 and 1, with 1 representing the greatest flexibility. Technically it is possible for the value of the flexibility indicator to become bigger than 1, but to identify weaknesses in the complexity management of a business, it is not necessary to measure such an over performance. The reason is simple: too much flexibility definitely has an impact on efficiency.

$$\eta_{eff,PF} = \frac{requested\ variants}{offered\ variants} \tag{1}$$

$$\eta_{flex,PF} = \frac{new\ variants\ in\ the\ portfolio}{\frac{new\ variants\ on\ the\ market}{number\ of\ competitors}} \tag{2}$$

On the service architecture level, key indicators can be used to quantify the flexibility and efficiency of individual physical products, services and smart services. The overarching aim here is to find out how big the share of standard partial services is and to identify possible starting points for increasing the number of standard services in order to reduce costs. Product efficiency can be defined as the ratio between the costs of standard partial services and the costs of all partial services, multiplied by the portfolio efficiency. The correcting factor in the denominator ensures that the resulting value is not influenced by the efficiency on the portfolio level. The product flexibility can be defined as the ratio between the number of changed standard partial services and the overall number of changed service variants within the portfolio.

$$\eta_{eff,PD} = \frac{costs_{standard\ partial\ services}}{\eta_{eff,PF}\ x\ costs_{all\ partial\ services}} \quad (3)$$

$$\eta_{flex,PD} = \frac{changed\ standard\ partial\ services}{changed\ variants} \quad (4)$$

On the level of process structure, the overall aim is to find out how large the processing time in standard processes is and to identify starting points where more standardized processes can be used in order to reduce costs. For this purpose, process efficiency and process flexibility can be quantified using the following key indicators. Process efficiency can be defined as the ratio between the processing time of standard processes and the processing capacities for all processes, multiplied by the previously calculated product efficiency. Again, the correcting factor in the denominator ensures that the resulting value is not influenced by actions taken on the previous levels. Process flexibility, on the other hand, can be expressed as the quotient from the number of changed processes and the number of changed partial services.

$$\eta_{eff,PZ} = \frac{time_{standard\ processes}}{\eta_{eff,PD}\ x\ processing\ capacities_{all\ processes}} \quad (5)$$

$$\eta_{flex,PZ} = \frac{changed\ processes}{changed\ partial\ services} \quad (6)$$

Finally, efficiency and flexibility can also be quantified on the resource level. The overall goal of this level is to determine the proportion of resource stagnation and to identify where more standardized resources can be used to reduce costs. Resource efficiency is defined as the ratio of the cost rate of standard resources and the cost rate of all resources, multiplied by the value obtained for process efficiency using the equation above. This correcting factor makes sure that the value obtained can be understood to represent the efficiency on the resource level only. Resource flexibility can be understood as the quotient of the number of changed resources and the number of changed processes.

$$\eta_{eff,RS} = \frac{cost\ rate_{standard\ resources}}{\eta_{eff,PZ}\ x\ cost\ rate_{all\ resources}} \quad (7)$$

$$\eta_{flex,RS} = \frac{changed\ resources}{changed\ processes} \quad (8)$$

On each of the four levels in question, efficiency and flexibility can be understood as two dimensions of complexity management that span a plane. This plane can be used to create a graphic representation of the values obtained for the key indicators introduced above. A combination of all four planes results in a graphic overview of all key indicators (see Fig. 3). In each plane, there is an optimum between efficiency and flexibility. A hypothetical optimum that would represent a state

Fig. 3. Structure of key indicators

of perfect flexibility and full efficiency on all four levels lies in the centre of the graphic. However, as the four levels are free of overlaps, this state not achievable. Instead, the real optimum needs to be found separately on each level.

The four levels of portfolio-, product-, process- and resource structure may be free of overlaps, but as becomes obvious when regarding the control loop model, these levels are by no means independent from one another. This implies that the key indicators presented above are not independent from one another either. The quality and quantity of these interdependencies, however, are not instantly visible. In the following section of the present paper, a curve model that aims at representing the interdependencies between the individual key indicators will be introduced.

4. Representing interdependencies in a curve model

In many sources, the interdependence between variety and costs is assumed to be linear, but it is clear that this assumption is not suitable if, as often observed, the costs exponentially explode with the number of variants. The presented model would like to open the door for the idea of using the nonlinear C_{Norm}-function which has been developed by Nyhuis and Wiendahl [5].

$$|x|^c + |y|^c = 1$$

They used this approach for describing the nonlinear interdependencies between resource efficiency and stock efficiency. To make use of the function in a two-dimensional problem, it has to be parameterized.

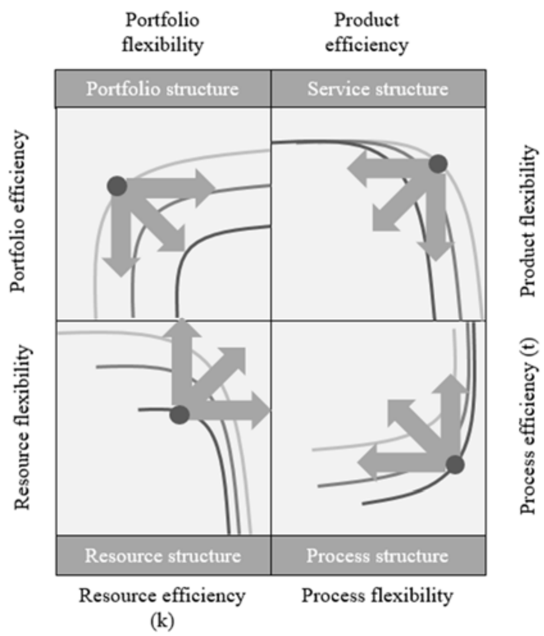

Fig. 3. Structure of key indicators

At first, an ideal linear correlation is identified. This is divided into two sections, the first being a section of proportional growth until the maximum of efficiency. Per definition, efficiency could not get bigger than 1, so afterwards in the second section the correlation stays constantly at the same value. Both sections together form the ideal curve.

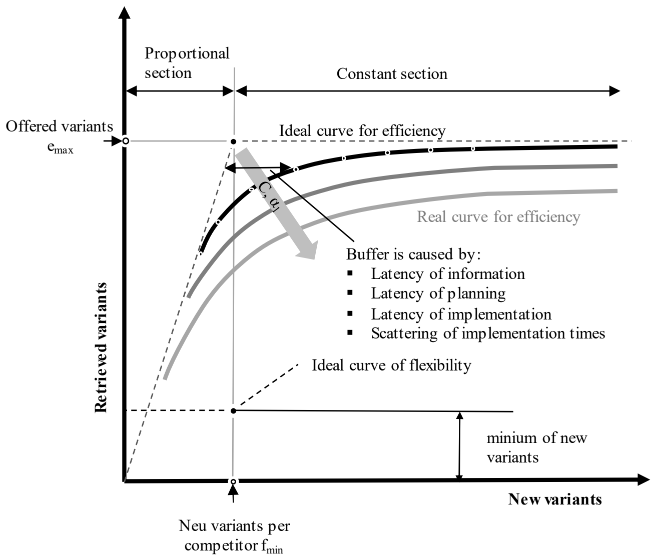

Fig. 4. The difference between ideal and real curve in the complexity model

Secondly, the nonlinear C_{Norm}-function is placed through an actual working point of the system. By knowing that the ends of the C_{Norm}-function and the ideal function need to be identical, correction factors for compression and glazing can be deduced. Consequently, the difference between the ideal curve and the identified curve on the basis of the C_{Norm}-function is forming a better assumption for a realistic curve. The difference could be explained by friction losses in the system. Most common forms of appearance are latency of information, decision-making or implementation.

The result of these two steps is presented exemplarily in Fig.4 for the first level of the portfolio structure. Once the number of retrieved and new variants is determined in comparison to the offered variants and the average number of new variants by each competitor, the correction factors C for compression and α_1 can be deduced. For optimization, exactly these two parameters need to be influenced to improve the level of complexity management.

5. Outlook

In the further research work, it will be investigated whether the two correction factors can be used in a dynamic cost calculation model or not. The whole model and its submodels will be tested in several case studies, especially in the case study that sparked the motivational impulse.

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