Understanding the interplay between exploration and exploitation in the data-driven servitization of manufacturing firms

Daniel Jandt, Katja Laurischkat

Junior Professorship of Product-Service Systems
Faculty of Mechanical Engineering, Ruhr-University Bochum
Universitätsstraße 150, 44807 Bochum, Germany
☏ +49 (234) 32 27628, ✉ daniel.jandt@ruhr-uni-bochum.de

Abstract

In an age in which data becomes the new oil, data-driven servitization is meant to be the imperative for manufacturing firms. The analysis of the accumulated customer usage and process data reveals new insights for improving the efficiency of the service delivery system and creating innovative service offerings. Nevertheless, manufacturers often struggle to make appropriate use of data analytics. They cannot balance service innovations and operational optimizations with the consequence of either failing the customer needs or missing operational excellence. Thus, in order to be viable in both the short- and the long-term, a crucial trade-off has to be made between exploitative data analytics as an input for the delivery management and explorative data analytics as an input for the development management. To model this trade-off, the general theories of management cybernetics and organizational ambidexterity are combined with specific findings derived from research on data-driven servitization. In order to consolidate several theses and to investigate the resulting business dynamics, a formal model is deduced and validated against empirical findings of manufacturing firms undergoing data-driven servitization. The resulting contributions are twofold: On the one hand, different policies for the trade-off between exploitative and explorative data analytics can be evaluated on the basis of cybernetic performance measures. On the other hand, the existing literature concerning the trade-off between explorative and exploitative data analytics in the servitization of manufacturing firms is condensed into a system of differential equations which is characterized by consistence and parsimony.

Keywords

Solution thinking, organizational ambidexterity, management cybernetics

1. Introduction

Modern companies are increasingly looking at customer needs as a whole and are thus moving from simplistic products towards integrated systems of products and services. This paradigm shift is called servitization (Vandermerwe & Rada 1988). Taking into account the increasing role of information- and communication technology (ICT) and the resulting abundance of data, the interpretation capability to improve service delivery and service innovation gains importance. This paper sheds light on the interplay between data analytics for increasing operational efficiency and data analytics for identifying unmet customer service needs. Therefore, servitization is meant to be data-driven.

Consider the capital equipment manufacturer General Electric, whose evolution of data-driven servitization can be separated into three phases as shown in Figure 1.

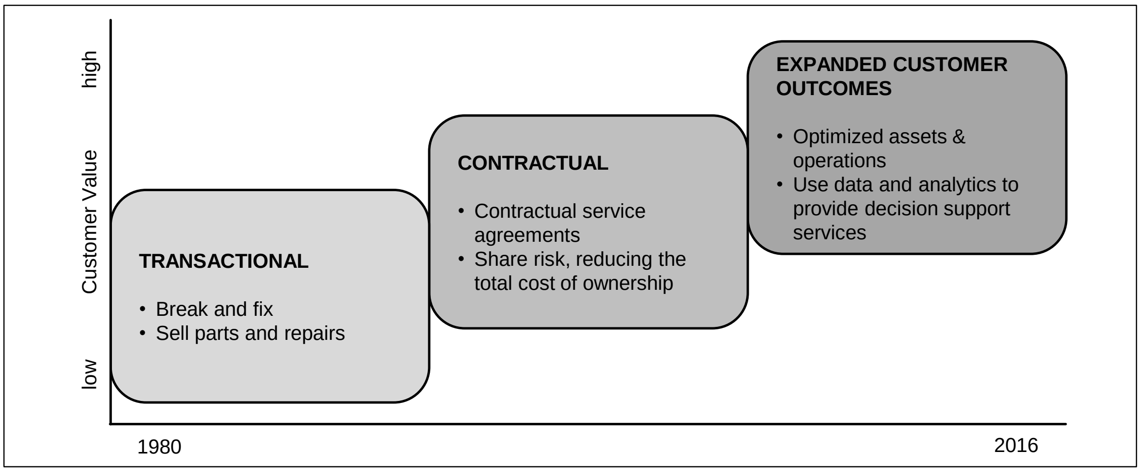

Figure 1: The evolution of GE service models (Iansiti and Lakhani 2014)

In the first phase, GE was offering product-related services which were only loosely dependent on customer processes. An example is the repair of a broken jet engine. In the second phase, GE offered long-term service agreements and so took over customer activities related to the product. Examples are power by the hour agreements in which GE uses remote monitoring to improve scheduled maintenance and thus guarantees the availability of a jet engine. In 2012, GE launched its Industrial Internet Initiative, which was the starting point of the third phase. Based on the software platform Predix, GE is now able to offer supplementary services in form of applications providing insights for operations and process optimizations (Agarwal & Brem 2015, Fitzgerald 2015, Weinman 2015). One of those is the flight efficiency service which offers fuel management, flight synchronisation and navigation. GE takes over value activities which are, for the most part, independent from their products. Dave Bartlett, CTO of GE Aviation, expressed the final step of data-driven servitization as follows: “We want Predix to become the Android or iOS of the machine world. We want it to become the language of the Industrial Internet” (Capgemini 2015, p. 4).

Despite the important theoretical and practical implications of understanding data-driven servitization, dynamic assessments of the transition paths that lead to becoming a solution provider are desperately missing and thus need to be researched (Velamuri et al. 2011). As most of the research in the field is descriptive, prescriptive methods that enable practitioners to assess the organizational transformation are lacking (Baines et al. 2009). Velamuri et al. (2011) underpin that the firm which can build, integrate, and reconfigure both internal and external competencies to address the needs of their customers the fastest will be most successful. Therefore, internal and external performance indices are necessary to evaluate a transition path. It is crucial to consider these measures of organizational performance in a dynamic rather than a static way (Hoverstadt 2008).

Additionally, the emergence of digital technologies and the resulting abundance of product usage and process data have an important impact on servitization and thus also need to be considered in terms of the dynamic assessment of transition paths (Eloranta & Turunen 2015, Boehm & Thomas 2013). Nevertheless, Lightfoot et al. (2013) claim that scholars still have “a limited awareness or appreciation of the use of information and communication technologies that are enabling many servitized manufacturers to deliver sophisticated product-centric service offerings” (p. 1421). This view is shared by Wuenderlich et al. (2015), who see the need for further exploration of the effect that data-driven servitization has on organizations. Grubic (2014) explicitly demands that the benefits of digital technologies for both the internal view of service delivery and the external view of service offerings have to be investigated in more detail.

The resulting challenge of balancing the internal and the external organizational performance has already been addressed in general theories of strategic management (Beer 1972, O’Reilly & Tushman 2008). Nevertheless, the specific literature on servitization lags behind the literature on strategic management “by approximately ten to 15 years” (Eloranta & Turunen 2015, p. 410). This limited use of theory and the resulting lack of extensive theoretical underpinning in the existing servitization literature can largely be attributed to the fact that a considerable part of the research has been conducted by researchers from various disciplines of engineering, where the use of theory and theory-building is not the primary focus of studies (Velamuri et al. 2011).

Considering these scientific shortcomings the research gap is formulated as follows:
There is an insufficient understanding of the firm performance which results from the interplay between the exploitation and exploration of service business opportunities under regard of an increasing amount of data.
To achieve a dynamic assessment of potential transition paths, the specific findings of servitization have to be underpinned by relevant approaches of strategic management. Consequently, the aim is to deduce a dynamic model that links strategic and information aspects of firms and explains the behavior of manufacturers during servitization.

2. Data-driven servitization

Research activities relevant to constructing this kind of model deal with aspects such as the service transition continuum, the evolution of the firm capabilities, the impact of ICT and the firm performance. The following findings will be considered in the model.

First, the transformation of a manufacturing firm into a solution provider can ideal-typically be described as a continuum from services supporting the supplier's product (SSP) to services supporting the client's actions (SSC). The main goal of SSP is to ensure the proper functioning of the product and to facilitate the client's access to it. In contrast, by offering SSC suppliers explore how services support particular client initiatives and advance the mission of the customer organization. When a firm expands its service portfolio from SSP to SSC, extended knowledge of the client's operations is crucial (Mathieu 2001). Thus, the ideal-typical continuum shown in Figure 2 is used to define the transition trajectory of manufacturing firms becoming solution providers. On the left side, the services are mainly based on knowledge about the product and are predominantly independent of customer processes. In the middle, the manufacturer takes over the majority of product-dependent activities and aligns them with adjacent customer activities. Therefore, knowledge about both the product and the customer processes is necessary. To the right, the service innovations are derived from insights about the customer processes. In this case, the knowledge about the product is of minor relevance and does not provide considerable sources for innovative services.

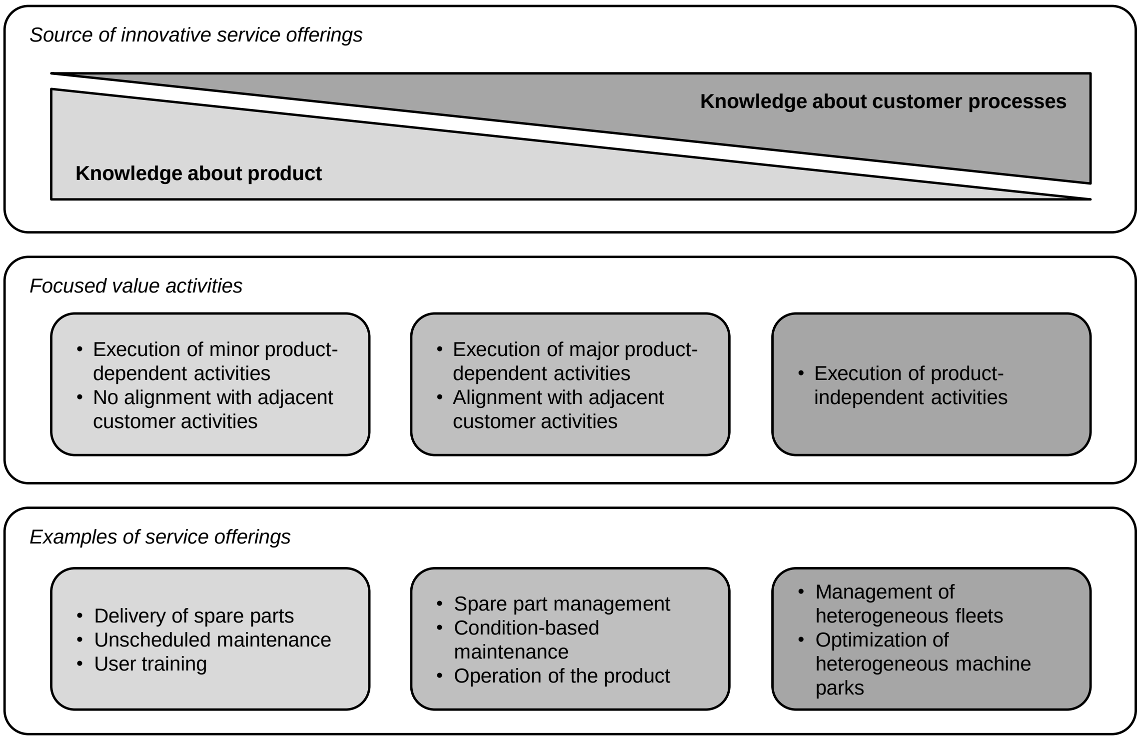

Figure 2: Continuum of data-driven servitization

Second, moving through this service continuum, several organizational capabilities and resources have to be provided. Examples for resources are the service sales force and distribution network, as well as the field service organization. Exemplary capabilities are the execution risk assessment and mitigation capability or the design-to-service capability (Ulaga & Reinartz 2011). In the context of data-driven servitization, the use of customer usage and process data plays a crucial role. Therefore, interpretation capabilities are necessary to derive actionable insights from the accumulated data. (Parida et al. 2014, Ulaga & Reinartz 2011)

Third, ICT is crucial for both the development and the delivery of services. It enables the remote monitoring of machines and thus a fine-grained registration of their use. On the one hand, the efficiency of the service delivery system can be increased (Grubic 2014, Kowalkowski et al. 2013). Predictive maintenance can for instance increase the efficiency of achieving guaranteed machine availability. On the other hand, ICT supports the development of innovative service offerings. Insights for service innovations can be gained from the accumulated product usage and process data (Allmendinger & Lombreglia 2005, Opresnik & Taisch 2015). An analysis of customer usage and process data can for example help to recognize latent potentials for achieving efficiency gains of the customer processes.

Finally, the alignment of the above mentioned resources and capabilities has direct impact on the firm performance. Thus, several researchers have investigated the influence of the organizational transformation on a firm’s economic measures (Eggert et al. 2014, Kastalli and Van Looy 2013, Neely 2008). According to the change process, a worse-before-better effect is constituted until the investments into the service business pay off. Once the manufacturer has successfully established an efficient service organization, the profitability increases.

These four distinctive aspects of data-driven servitization have to be considered while developing and validating a System Dynamics model that offers management support for balancing exploration and exploitation. In the following section, the specific findings of data-driven servitization will be complemented by general findings from the field of organizational ambidexterity and organizational cybernetics. Afterwards, the considered literature will be condensed into a causal loop structure.

3. General management theories

During data-driven servitization organizations have to expand their service offer while at the same time they need to be able to deliver the existing service in an efficient way. This crucial trade-off has already been addressed by general literature of organizational ambidexterity and organizational cybernetics.

On the one hand, exploration, exploitation and ambidexterity themselves are central terms of organizational ambidexterity. Exploration relates to subjects such as search, variation, risk taking, experimentation, play flexibility, discovery and innovation.

However, exploitation includes such concepts as refinement, choice, production, efficiency, selection, implementation and execution (March 1991). Ambidexterity combines both aspects (O'Reilly and Tushman 2008). On the other hand, development management, delivery management and corporate governance are crucial terms of organizational cybernetics, and they are used in a very similar way to the terms of organizational ambidexterity. An explanation by Hoverstadt (2008), based on the strategic gap, is given on the left side of Table 1. The advantage of organizational cybernetics is the very precise definition of the various management functions. Additional, Beer (1972) defined three performance indices which make the several management functions tangible. To avoid terminological obscurities, those three indices were partially renamed. The terminology used in this paper is given on the right side of Table 1. Furthermore, the synergies between System Dynamics and organizational cybernetics have already been outlined by Schwaninger and Pérez Ríos (2008).

Table 1: Cybernetic management functions and performance indices

Terms of organizational cybernetics according to Hoverstadt (2008)		**Performance indices in the System Dynamics model**
Management function	**Description**	
Development management	„Opening up the strategic gap", based on information on environment and future	Latency
Delivery management	„Closing the strategic gap", based on performance information from Operations	Efficiency
Corporate governance	„Balancing the capabilities of the organization as it is now, in its current operating environment, against the demands that it needs to address in its environment and in the future"	Ambidexterity

In comparison to organizational ambidexterity, the past two decades have provided a considerably small number of studies dealing with organizational cybernetics. Thus, the theory of organizational ambidexterity bears the advantage of numerous current empirical analyses. Moreover, some authors have already linked specific results of data-driven servitization to the theory of exploration and exploitation. Schuh et al. (2015) examine the impact of information feedback from service processes on service excellence and innovation capabilities. Yet, they see a need to validate their results in terms of robustness and transferability. Fischer et al. (2010) focus on sensing and seizing of service opportunities and maintaining service competitiveness. Nevertheless, these studies do not capture ambidexterity, although the authors hold the view that company performance can benefit from ambidexterity in the long term. Due to these shortcomings, the initially defined research gap can be confirmed. While combining the advantages of the theories of organizational ambidexterity (numerous current empirical research) and organizational cybernetics (precise definition of management functions and performance indices), some terms have to be defined before developing a simulation model.

The actually performed **services** give information about the number of service activities which are really performed by the service delivery system. The **capacity** of the service delivery system determines how many service activities could be performed by using all possible insights for process improvement that could be derived from the existing data. The **potentiality** of the service delivery system describes the service activities which could be performed by using all possible insights for novel service offerings that could be developed from the existing data. Besides these measures, there are three indices which allow a conclusion about the management. The **efficiency** describes the ration of the actually performed services and the capacity of the service delivery system. Thus, it is a measure for the delivery management. The **latency** describes the ratio of the capacity of the service delivery system and the potentiality of the service delivery system, hence being a measure for the development management. The **ambidexterity** is the product of latency and efficiency and therefore a measurement for the corporate governance. Figure 3 depicts the relations between the measures and indices.

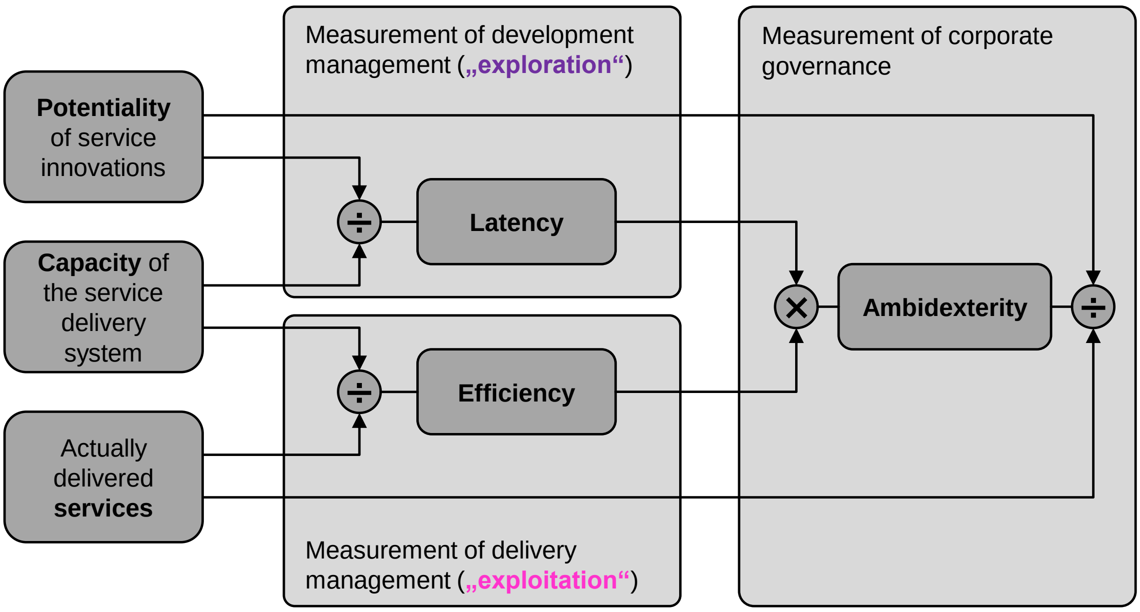

Figure 3: Performance indices according to Beer (1972)

In the following, a simple example is given to illustrate the cybernetic performance indices: A firm actually delivers 70 service activities. When the delivery management does a perfect job, recognizes and implements all possible process improvements from their stored data and thus achieves operational excellence, the firm could deliver 100 service activities. This 100 service activities constitute the capacity of the firm. When the development management also does a perfect job and derives all possible insights for service innovations from their stored data, the firm could deliver even 125 service activities. Consequently, right now the firm’s efficiency is 70% and the latency is 80%. The resulting ambidexterity is 56%. Due to the fact that data which enhance both service delivery and innovation accumulate over time it is evident that a dynamic view is indispensable to support managerial decision making.

4. The applicability of System Dynamics as a research method

In order to show how System Dynamics can be applied to the identified research gap, the interplay between the service business development and the service delivery system is depicted in a causal loop diagram in Figure 4. The four feedback loops were derived from literature on data-driven servitization. The exponential growth of data due to servitization is explained in Opresnik & Taisch (2015, p. 175): "Servitization can be thought of as a data intensive process. With new virtualizations of assets, new [product–service] compositions and, especially, through [product–service] usage, the volume of these data increases exponentially." Additionally, Kowalkowski et al. (2013) mention that increased service process efficiency and the development of competitive services are "highly interrelated and can provide positive feedback loops to each other" (p. 511). Thus, the stock of customer usage and process data reinforces two loops, namely **exploration** and **exploitation**. The **customer satisfaction** causes a balancing feedback and is described in Baines & Lightfoot (2013, p. 84): "An equilibrium therefore appears between the manufacturer and its customers; a balance is reached where the competences of the manufacturer are thoroughly exploited and yet those of the customer remain distinctive." The **operational excellence** is an obvious limit for the growth of the actual services. The trade-off between exploration and exploitation is emphasized in Kowalkowski et al. (2015, p. 66): "[…] our first assumption emphasizes the importance of *balancing expansion and standardization activities* […]." Therefore, the two exogenous variables **explorative** and **exploitative analytics** can be defined.

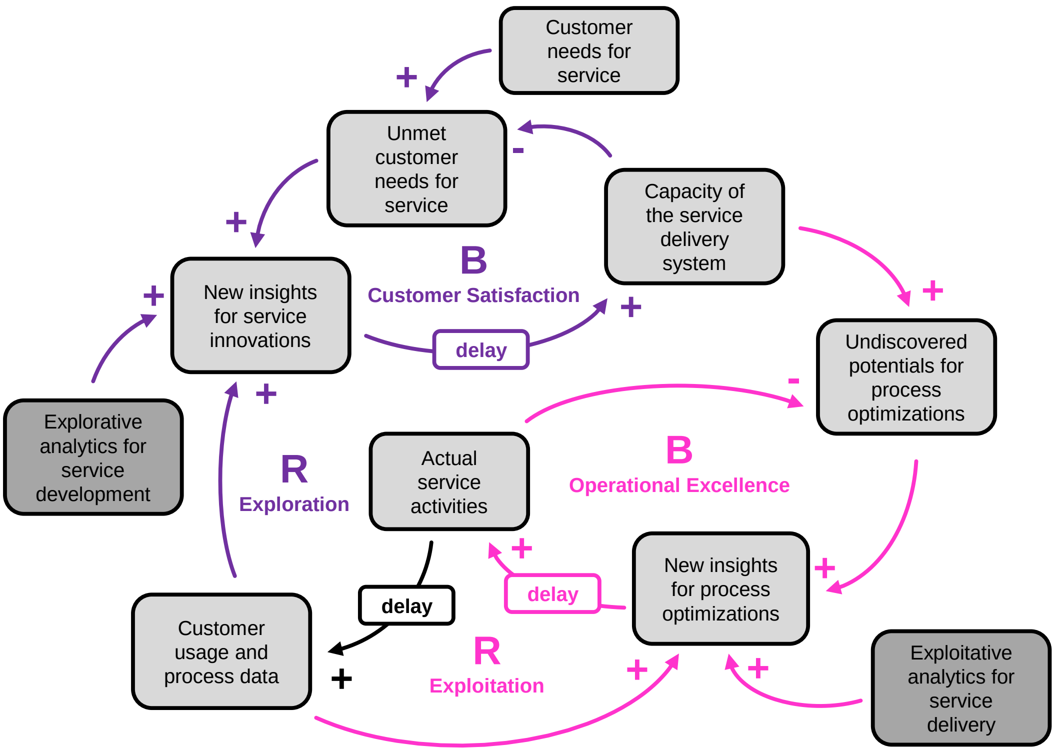

Figure 4: Interplay between exploration and exploitation

Due to the identified feedback structures in data-driven servitization, System Dynamics is an appropriate methodology to map the structure that causes the difficulty to assess trade-off between exploration and exploitation during the transformation from a manufacturing firm to a solution provider. Beside this fit between the research object and the research method, the research method must be able to build a theory that closes the gap between literature on servitization and the literature on strategic management. The advantages of model-based theory building with System Dynamics have been pointed out by several authors (Davis et al. 2007, Schwaninger & Grösser 2008). First, formal models are easy to refute. The theory, respectively the model, is a mathematical representation of reality and there is no possibility for textual attenuations to conceal theoretical insufficiencies. Second, formal models are both precise and clear. Therefore, hypotheses can easily be developed from the theory. Third, formal models are characterized by parsimony and simplicity. In contrast to a textual description, they are able to express complex circumstances in just a few lines of source code. Considering these advantages, model-based theory building is an appropriate research method to consolidate the existing literature on data-driven servitization.

Model-based theory building with System Dynamics has already been applied to several research topics that are close to data-driven servitization, such as dynamic capabilities and organizational change. Table 2 gives an overview of relevant literature and the number of stocks in the models as a rough estimation of their complexity. It is remarkable that especially the three latest models tend to have a very simple structure. Rahmandad (2015) justifies simple models by arguing that they allow a clear focus on the trade-offs managers are facing. For this reason, the model presented in the following section is as simple as possible and contains only three stocks.

Table 2: Publications of System Dynamics modelling of theories

Author and year	**Title**	**Number of stocks**
Sterman (1985)	The Growth of Knowledge: Testing a Theory of Scientific Revolutions with a Formal Model	6
Sastry (1997)	Problems and Paradoxes in a Model of Punctuated Organizational Change	4 (extension: 5)
Rudolph & Repenning (2002)	Disaster Dynamics: Understanding the Role of Quantity in Organizational Collapse	1
Repenning (2002)	A Simulation-Based Approach to Understanding the Dynamics of Innovation Implementation	2
Rahmandad (2012)	Impact of Growth Opportunities and Competition on Firm-Level Capability Development Trade-offs	2

5. Formal description of the model

This section gives the formal mathematical description of the simulation model. Figure 5 gives an overview of the stock and flow diagram which has been implemented in the multimethod simulation software AnyLogic® 7.3.5 University Researcher.

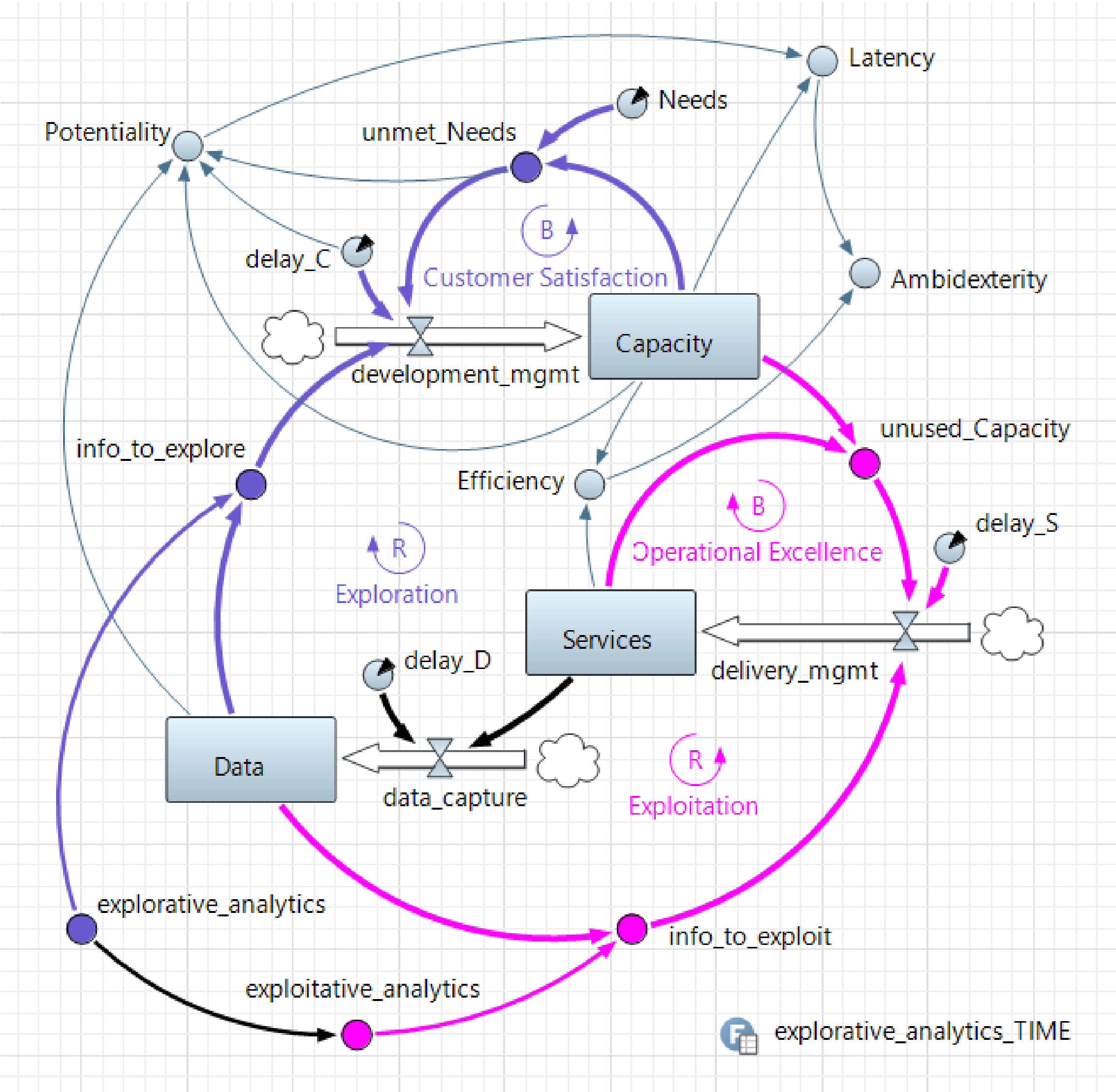

Figure 5: Overview of the model

The model contains two S-shaped growth mechanisms as described by Sterman (2000). On the one hand, data-based exploration reinforces development management, while customer satisfaction balances development management. On the other hand, data-based exploitation reinforces delivery management, while operational excellence balances delivery management. These two mechanisms are linked by the accumulated product usage and process data. Depending on the trade-off made between exploration and exploitation, the cybernetic performance indices report how ambidextrous the organization is at each point of data-driven servitization.

Trade-off between exploration and exploitation:

The resources of a firm are scarce. For this reason, a trade-off has to be made between data analytics for the purpose of exploration and data analytics for the purpose of exploitation. To model this central trade-off rigorously, the following definition is made for the effort of a firm to use exploitative data analytics:

$$\text{exploitative\_analytics} = 1 - \text{explorative\_analytics}$$

For the simulation of a firm's ambidexterity during data-driven servitization, the effort for the use of explorative data analytics is given as a table function and thus as an exogenous variable describing the firm's policy created by the corporate governance. The explorative and exploitative data analytics directly influence the development management and the delivery management, which are described in the following two subsections.

Development management:

The unmet customer needs are the difference between the customers' needs for service and the actual service offering, which is quantified as the capacity of the service delivery system:

$$\text{unmet\_Needs(t)} = \text{Needs} - \text{Capacity(t)}$$

The information resulting from the interpretation of the customer usage and process data for the exploration of new service offerings can be defined as the product of the total amount of data and the effort of explorative analytics:

$$\text{info\_to\_explore(t)} = \text{Data(t)} * \text{explorative\_analytics(t)}$$

This information has to be multiplied with the unmet customer needs in order to determine the novel insights for extending the capacity of the service delivery system to deliver innovative services. This value has to be divided through the time the development management needs to increase the capacity of the service delivery system.

$$\text{development\_mgmt(t)} = \frac{\text{unmet\_Needs(t)} * \text{info\_to\_explore(t)}}{\text{delay\_C}} = \frac{\text{dCapacity(t)}}{\text{dt}}$$

The capacity of the service delivery system can be described as the accumulation of the efforts of the development management over time:

$$\text{Capacity(t)} = \text{Capacity(0)} + \int_0^{T} \text{development\_mgmt(t)}\,\text{dt}$$

The structure of the delivery management is similar to the structure of the development management despite the fact that the carrying capacity is not constant but variable.

Delivery management:

The unused capacity is the difference between the capacity of the service delivery system resulting from the development management and the actually delivered services:

$$\mathrm{unused\_Capacity(t) = Capacity(t) - Services(t)}$$

The information gained from the interpretation of the customer usage and process data for the exploitation of process optimization opportunities can be defined as the product of the total amount of data and the effort of exploitative analytics:

$$\mathrm{info\_to\_exploit(t) = Data(t) * exploitative\_analytics(t)}$$

This information has to be multiplied with the unused capacity to determine the novel insights to increase the actually delivered service activities. Those must in turn be divided through the time the delivery management needs to increase the actually delivered services.

$$\mathrm{delivery\_mgmt(t)} = \frac{\mathrm{unused\_Capacity(t) * info\_to\_exploit(t)}}{\mathrm{delay\_S}} = \frac{\mathrm{dServices(t)}}{\mathrm{dt}}$$

The capacity of the service delivery system can be described as the accumulation of the efforts of the delivery management over time:

$$\mathrm{Services(t) = Services(0)} + \int_0^{\mathrm{T}} \mathrm{delivery\_mgmt(t)\,dt}$$

In this way, both management functions have been defined as balancing loops that maximize exploration and exploitation under restriction of available information.

Data capture from service activities:

During the delivery of services customer usage and process data can be captured. The ratio between actually performed service activities and the captured data is:

$$\mathrm{data\_capture(t)} = \frac{\mathrm{Services(t)}}{\mathrm{delay\_D}} = \frac{\mathrm{dData(t)}}{\mathrm{dt}}$$

Due to the fact that stored data accumulate over time, the resulting stock of data can be described as follows:

$$\mathrm{Data(t) = Data(0)} + \int_0^{\mathrm{T}} \mathrm{data\_capture(t)\,dt}$$

This stock is impacting both the development and the delivery management and so reinforces exploration and exploitation.

Potentiality and cybernetic performance indices:

Potentiality is dependent on the captured data of a firm and the remaining unmet customer needs. Both are determining factors for the potential of service innovations. Furthermore, potentiality contains the capacity respectively the already met customer needs and is dependent on the delay of the development management.

$$Potentiality(t) = \frac{Data(t) * unmet\_Needs(t)}{delay\_C} + Capacity(t)$$

The three cybernetic performance indices can be expressed by analytical equations, which have already been introduced in the third section. First, Latency describes the ratio of already focused customer needs and the potentiality. Thus, it displays how engaged a firm strives to meet unmet customer needs.

$$Latency(t) = \frac{Capacity(t)}{Potentiality(t)}$$

Second, efficiency describes the ratio of actually performed services and the capacity of the service delivery system.

$$Efficiency(t) = \frac{Services(t)}{Capacity(t)}$$

Third, ambidexterity shows how well the organization is balancing its exploitation and exploration potentials. Thus, it is the product of latency and efficiency.

$$Ambidexterity(t) = Latency(t) * Efficiency(t)$$

The dependency of ambidexterity on latency and efficiency is illustrated in Figure 6.

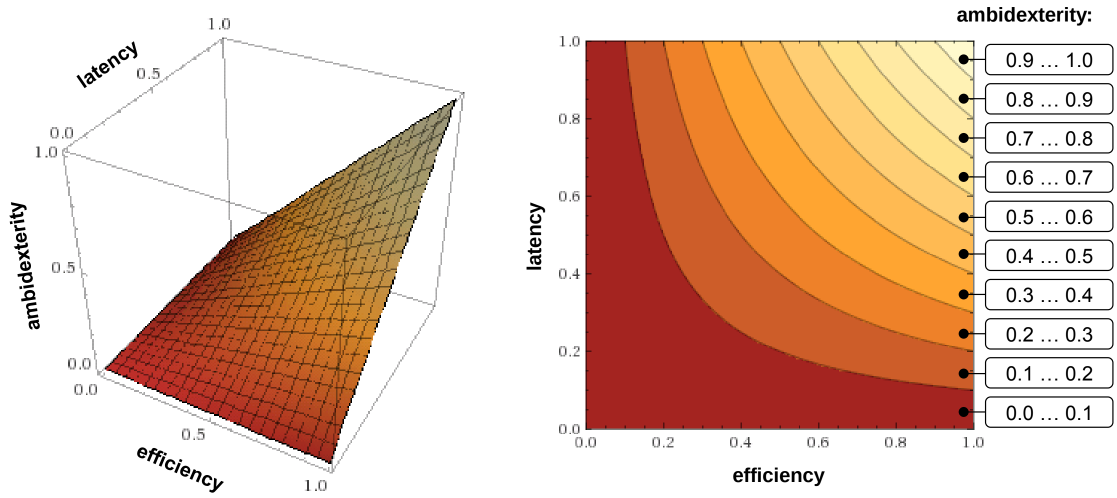

Figure 6: Relationship of the three cybernetic performance indices

6. Validation of the model

In this section, the model is validated against empirical findings. In regard of the behavior-reproduction test according to Forrester & Senge (1980), a typical trajectory of a manufacturer becoming a solution provider is considered.

At the starting point of the simulation, the manufacturer offers services supporting the product. During the first time period (0 <= t < 20), he consolidates these basic services and expands his service offering only incrementally (exploitation 98%, exploration 2%). Afterwards (20 <= t < 30), the manufacturer starts to develop and offer more sophisticated service offerings (exploitation 50%, exploration 50%). This phase of radical change is followed by a phase of consolidating the service delivery system (30 <= t < 60), which is characterized by an incremental expansion of the service offering (exploitation 98%, exploration 2%). The last phase (60 <= t < 100) represents the firm's digital transformation. Based on strong ICT, the manufacturer accelerates his innovation cycles and so improves his offerings and delivery system simultaneously.

For simplicity, the customer needs for service are assumed to be constant. Initially, the capacity of the service delivery system is only 10% of the customer needs, whereby the actually performed services are only 8% of the customer needs. In line with Meier & Massberg (2004), the development management's delay in building up more capacity is higher than the delivery management's delay in realizing more service activities. The delay of the data capture is only about 10% of the management delays. This delay also expresses the relationship between actually performed service activities and captured data points, so that the unit has to be extended by the corresponding fraction. The entire parametrization and the initial values of the model are shown in Table 3.

Table 3: Parametrization of the model

Variables	Value	Units
Needs	100	Service Activities
Capacity(t=0)	10	Service Activities
Services(t=0)	8	Service Activities
Data(t=0)	45	Data Points
delay_C	600	Months
delay_S	400	Months
delay_D	50	Months*(Service Activities/Data Points)
explorative_analytics(t)	0.02 (0 <= t < 20) 0.50 (20 <= t < 30) 0.02 (30 <= t < 60) 0.50 (60 <= t < 100)	1/Data Points
exploitative_analytics(t)	dynamic	1/Data Points
info_to_explore(t)	dynamic	Dimensionless
info_to_exploit(t)	dynamic	Dimensionless
Potentiality	dynamic	Service Activities

The simulation results can be seen in Figure 7. The upper plot depicts the actually delivered service activities, the capacity of the service delivery system, the potentiality for service innovations and the customer needs for service. These variables all share the unit service activities. Furthermore, the graph shows the exponential growth of the captured product usage and process data with the unit data points. Through the parametrization of the model it becomes apparent that although the data explode, the number of services converges against the customer needs. The middle plot shows the three cybernetic performance indices of the manufacturer, which are dimensionless. The lower plot illustrates the realized policy concerning the trade-off between exploration and exploitation. For reasons of clarity the negative value of the effort of exploitative data analytics is plotted. In the following, these results are discussed in detail.

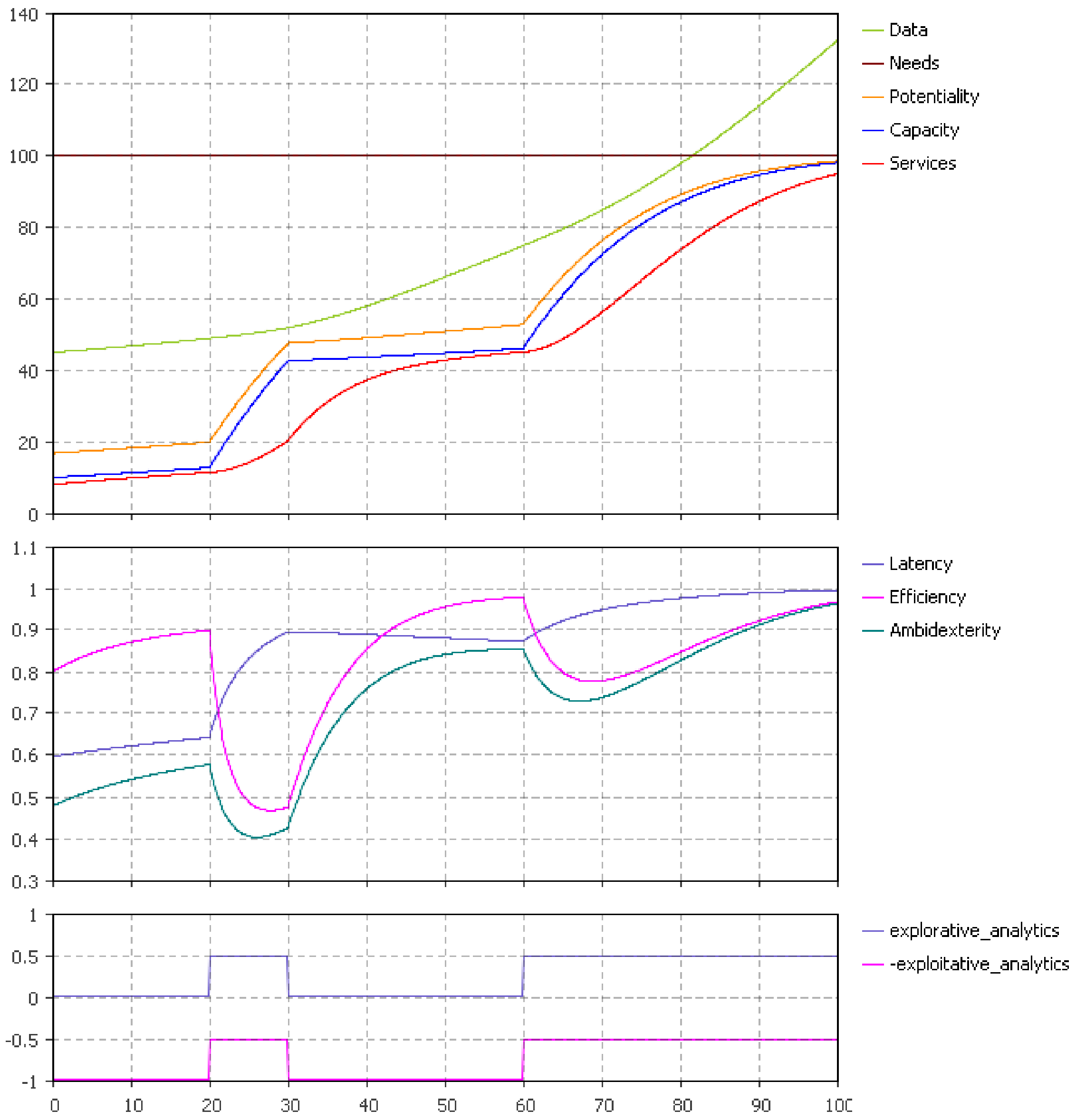

Figure 7: Response of the system for two distinctive phases of exploration

Being a manufacturer and offering services as add-ons to the product (0 <= t < 20)

This first phase relates to the time before the distinct servitization of the manufacturer. There is a high potentiality because of the accumulated product usage and process data from the past of the firm as a manufacturer and the huge amount of unmet customer needs for service. The firm consolidates its basic installed base services and thus achieves gains in efficiency. The latency is improved by incremental extensions of the basic service offerings. Nevertheless, due to both the fact that the company does not use their stored product usage and process data extensively and the huge amount of unmet customer needs, the latency is extremely low. According to these shortcomings, the ambidexterity of the firm is low, too. This unused potential for competitive advantages is the motif of the existing literature on servitization (Fischer et al. 2012, Lightfoot et al. 2013, Oliva & Kallenberg 2003, Vandermerwe & Rada 1988).

The big step towards integrated product and service solutions (20 <= t < 30)

In this phase, manufacturers start to offer long-term service agreements to their customers. In this way, they are able to monetize their product know-how and gain knowledge about customer processes. Due to this large expansion of the service capacity, the latency increases massively, because the accumulated data are used for innovations and so more and more customer needs are met. Besides this positive effect, this phase is characterized by a strong decrease in efficiency, because the delivery management struggles to fulfil the service offerings developed by the development management. Literature on servitization named this often observed worse-before-better effect “Service Paradox” (Benedettini et al. 2015, Gebauer et al. 2005, Gebauer 2003).

Getting used to being a solution provider (30 <= t < 60)

After the important move towards servitization, the delivery management increases efficiency in delivering the services leading to higher profits (Neely 2008). At this point, latency is slowly decreasing: Through long-term service agreements and the related customer proximity new knowledge about the customer processes is available. This knowledge provides potentials for supplementary service innovations beyond the bare product.

Going digital with supplementary services (60 <= t < 100)

To create and capture value from supplementary services, digital technologies are of crucial importance. While the ability of delivering long-term service agreements was the critical factor of the big step towards servitization, the ability of identifying latent customer needs constitutes the key element of the digital transformation. There is an exponential increase of business opportunities according to the digital transformation (Weitzman 1998), but it is getting harder and harder to identify unmet customer needs. The simulation predicts a less distinctive slope of performance during the digital transformation because of the previously gained firmness of the service delivery system.

7. Conclusion and future research

The initial research gap stated that there is an insufficient understanding of the firm performance that results from the interplay between the exploitation and exploration of service business opportunities under regard of an increasing amount of data. Based on System Dynamics-based theory building, several findings in the field of data driven-servitization can be consolidated and underpinned by general theories of organizational ambidexterity and organizational cybernetics. The resulting model can be validated against empirical findings and constitutes a first step into a System Dynamics-based theory that links data-driven servitization with general organizational theories. Due to the necessity of implemented simplifications, some aspects of the model should undergo further investigations.

First, in order to model the fundamental structure of ambidexterity in the context of data-driven servitization, the trade-off between exploitation and exploration has been modeled discretely. However, System Dynamics-based research on dynamic capabilities has shown the continuous change of capabilities (Rahmandad 2012). Therefore, the extension of the model by accumulations representing the capabilities of explorative and exploitative data analytics should be considered. Second, the customer needs for service have been assumed as constant, which was appropriate for investigating the fundamental transformation of a manufacturer becoming a solution provider. This static endpoint of data-driven servitization is in line with existing System Dynamics-based research on organizational change (Sastry 1997). Nevertheless, customer needs for service vary over time. The more servitized the firm is, the more important this aspect becomes. Therefore, erosion of capabilities may be considered in future research (Rahmandad & Repenning 2016). Potential ideas are changes in the optimal orientation of the service offerings and the obsolescence of the stored data. Third, the captured data were assumed homogeneous, as they were meant to model the evolution of a firm's knowledge on developing and delivering services. Nevertheless, the data captured by basic product-related services differ clearly from the data that are captured by advanced digital services. Thus, future research should focus on the relationship between the service portfolio and the knowledge gained by the analytics of customer usage and process data (Chen et al. 2012). Fourth, the cybernetic performance indices offer a comprehensible frame to describe the interplay between exploration and exploitation. Yet, empirical research on these indices is scarce. Latest advancements in ambidexterity should hence be considered in more detail, as the impact of exploration and exploitation on firm performance has already been investigated in general (Boumgarden et al. 2012).

All in all, this paper outlines the synergies between organizational ambidexterity, organizational cybernetics and the methodology of System Dynamics for theory building in data-driven servitization. Consequently, the implications of Schwaninger & Pérez Ríos (2008) and Schwaninger & Grösser (2008) can be used to full advantage.

References

Agarwal N, Brem A. 2015. Strategic Business Transformation through Technology Convergence: Implications from General Electric's Industrial Internet Initiative. *International Journal of Technology Management* **67**(2-4): 196–214.

Allmendinger G, Lombreglia R (2005). Four Strategies for the Age of Smart Services. *Harvard Business Review* **83**(10): 131–145.

Baines T, Lightfoot H. 2013. *Made to Serve: How Manufacturers Can Compete through Servitization and Product-Service Systems.* John Wiley & Sons: Chichester.

Baines T, Lightfoot H, Benedettini O, Kay J. 2009. The Servitization of Manufacturing: A Review of Literature and Reflection on Future Challenges. *Journal of Manufacturing Technology Management* **20**(5): 547–567.

Beer S. 1972. *Brain of the Firm. 2nd Edition*. John Wiley & Sons: Chichester.

Benedettini O, Neely A, Swink M. 2015. Why Do Servitized Firms Fail? A Risk-Based Explanation. *International Journal of Operations & Production Management* **35**(6): 946–979.

Boehm M, Thomas O. 2013. Looking beyond the Rim of One's Teacup: A Multidisciplinary Literature Review of Product-Service Systems in Information Systems, Business Management, and Engineering & Design. *Journal of Cleaner Production* **51**: 245–260.

Boumgarden P, Nickerson J, Zenger TR. 2012. Sailing into the Wind: Exploring the Relationships among Ambidexterity, Vacillation, and Organizational Performance. *Strategic Management Journal* **33**: 587–610.

Capgemini Consulting 2015. Going Digital: General Electric and its Digital Transformation.

Chen H, Chiang RHL, Storey VC. Business Intelligence and Analytics: From Big Data to Big Impact. *MIS Quarterly* **36**(4): 1165–118.

Daft RL, Weick KE. 1984. Toward a Model of Organizations as Interpretation Systems. *Academy of Management Review* **9**(2): 284–295.

Davis JP, Eisenhardt KM, Bingham CB. 2007. Developing Theory through Simulation Methods. *Academy of Management Review* **32**(2): 480–499.

Eggert A, Hogreve J, Ulaga W, Münkhoff E. 2014. Revenue and Profit Implications of Industrial Service Strategies. *Journal of Service Research* **17**(1): 23–39.

Eloranta V, Turunen T. 2015. Seeking Competitive Advantage with Service Infusion: A Systematic Literature Review. *Journal of Service Management* **26**(3): 394–425.

Fischer T, Gebauer H, Fleisch E. 2012. *Service Business Development: Strategies for Value Creation in Manufacturing Firms*. Cambridge University Press: Cambridge.

Fischer T, Gebauer H, Gregory M, Ren G, Fleisch E. 2010. Exploitation or Exploration in Service Business Development? Insights from a Dynamic Capabilities Perspective. *Journal of Service Management* **21**(5): 591–624.

Fitzgerald M. 2015. Gone Fishing — For Data. *MIT Sloan Management Review* **56**(3).

Forrester JW, Senge PM. 1980. Tests for building confidence in System Dynamics models. *TIMS Studies in the Management Sciences* **14**: 209–228.

Gebauer H. 2003. A Simulation-Based Approach to Understanding the Dynamics of the Transition from Product Manufacturer into Service Provider. *Proceedings of the 2003 International System Dynamics Conference*. New York, USA.

Gebauer H, Fleisch E, Friedli T. 2005. Overcoming the Service Paradox in Manufacturing Companies. *European Management Journal* **23**(1): 14–26.

Grubic T. 2014. Servitization and Remote Monitoring Technology: A Literature Review and Research Agenda. *Journal of Manufacturing Technology Management* **25**(1): 100–124.

Hoverstadt P. 2008. *The Fractal Organization: Creating Sustainable Organizations with the Viable System Model*. John Wiley & Sons: Chichester.

Iansiti M, Lakhani KR. 2014. Digital Ubiquity: How Connections, Sensors, and Data Are Revolutionizing Business. *Harvard Business Review* **92**(11): 91–99.

Kastalli, IV, Van Looy B. 2013. Servitization: Disentangling the Impact of Service Business Model Innovation on Manufacturing Firm Performance. *Journal of Operations Management* **31**(4): 169–180.

Kowalkowski C, Kindström D, Gebauer H. 2013. ICT as a Catalyst for Service Business Orientation. *Journal of Business & Industrial Marketing* **28**(6): 506–513.

Kowalkowski C, Windahl C, Kindström D, Gebauer H. 2015. What Service Transition? Rethinking Established Assumptions about Manufacturers' Service-Led Growth Strategies. *Industrial Marketing Management* **45**: 59–69.

Lightfoot H, Baines T, Smart P. 2013. The Servitization of Manufacturing: A Systematic Literature Review of Interdependent Trends. *International Journal of Operations & Production Management* **33**(11-12): 1408–1434.

March JG. 1991. Exploration and Exploitation in Organizational Learning. *Organization Science* **2**(1): 71–87.

Meier H, Massberg W. 2004. Life Cycle-Based Service Design for Innovative Business Models. *CIRP Annals – Manufacturing Technology* **53**(1): 393–396.

Neely A. 2008. Exploring the Financial Consequences of the Servitization of Manufacturing. *Operations Management Research* **1**(2): 103–118.

Oliva R, Kallenberg R. 2003. Managing the Transition from Products to Services. *International Journal of Service Industry Management* **14**(2): 160–172.

Opresnik D, Taisch M. 2015. The Value of Big Data in Servitization. *International Journal of Production Economics* **165**: 174–184.

O'Reilly CA, Tushman ML. 2008. Ambidexterity as a Dynamic Capability: Resolving the Innovator's Dilemma. *Research in Organizational Behavior* **28**: 185–206.

Parida V, Sjödin DR, Wincent J, Kohtamäki M. 2014. Mastering the Transition to Product-Service Provision. Insights into Business Models, Learning Activities, and Capabilities. *Research-Technology Management* **57**(3): 44–52.

Rahmandad H, Repenning N. 2016. Capability Erosion Dynamics. *Strategic Management Journal* **37**: 649–672.

Rahmandad H. 2015. Connecting Strategy and System Dynamics: An Example and Lessons Learned. *System Dynamics Review* **31**(3): 149–172.

Rahmandad H. 2012. Impact of Growth Opportunities and Competition on Firm-Level Capability Development Trade-offs. *Organization Science* **23**(1): 138–154.

Repenning NP. 2002. A Simulation-Based Approach to Understanding the Dynamics of Innovation Implementation. *Organization Science* **13**(2): 109–127.

Rudolph JW, Repenning NP. 2002 Disaster Dynamics: Understanding the Role of Quantity in Organizational Collapse. *Administrative Science Quarterly* **47**: 1–30.

Sastry MA. 1997. Problems and Paradoxes in a Model of Punctual Organizational Change. *Administrative Science Quarterly* **42**: 237–275.

Schuh G, Gudergan G, Feige BA, Buschmeyer A, Krechting D. 2015. Business Transformation in the Manufacturing Industry: How Information Acquisition, Analysis, Usage and Distribution Affects the Success of Lifecycle-Product-Service-Systems. *Proceedings of the 7th CIRP Conference on Industrial Product-Service Systems*. Saint-Étienne, France.

Schwaninger M, Grösser S. 2008. System Dynamics as Model-Based Theory Building. *Systems Research and Behavioral Science* **25**: 447–465.

Schwaninger M, Pérez Ríos J. 2008. System Dynamics and Cybernetics: A Synergetic Pair. *System Dynamics Review* **24**(2): 145–174.

Sterman JD. 1985. The Growth of Knowledge: Testing a Theory of Scientific Revolutions with a Formal Model. *Technological Forecasting and Social Change* **28**(2): 93–122.

Sterman JD. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw-Hill: Boston.

Ulaga W, Reinartz WJ. 2011. Hybrid Offerings: How Manufacturing Firms Combine Goods and Services Successfully. *Journal of Marketing* **75**: 5–23.

Vandermerwe S, Rada J. 1988. Servitization of Business: Adding Value by Adding Services. *European Management Journal* **6**(4): 314–324.

Velamuri VK, Neyer AK, Möslein KM. 2011. Hybrid Value Creation: A Systematic Review of an Evolving Research Area. *Journal für Betriebswirtschaft* **61**: 3–35.

Weinman J. 2015. *Digital Disciplines: Attaining Market Leadership via the Cloud, Big Data, Social, Mobile, and the Internet of Things*. John Wiley & Sons: Hoboken, NJ.

Weitzman ML. 1998. Recombinant Growth. *The Quarterly Journal of Economics* **113**(2): 331–360.

Windahl C, Lakemond N. 2010. Integrated Solutions from a Service-Centered Perspective: Applicability and Limitations in the Capital Goods Industry. *Industrial Marketing Management* **39**(8): 1278–1290.

Wuenderlich NV, Heinonen K, Ostrom AL, Patricio L, Sousa R, Voss C, Lemmink JG. 2015. “Futurizing” Smart Service: Implications for Service Researchers and Managers. *Journal of Services Marketing* **29**(6-7): 442–447.