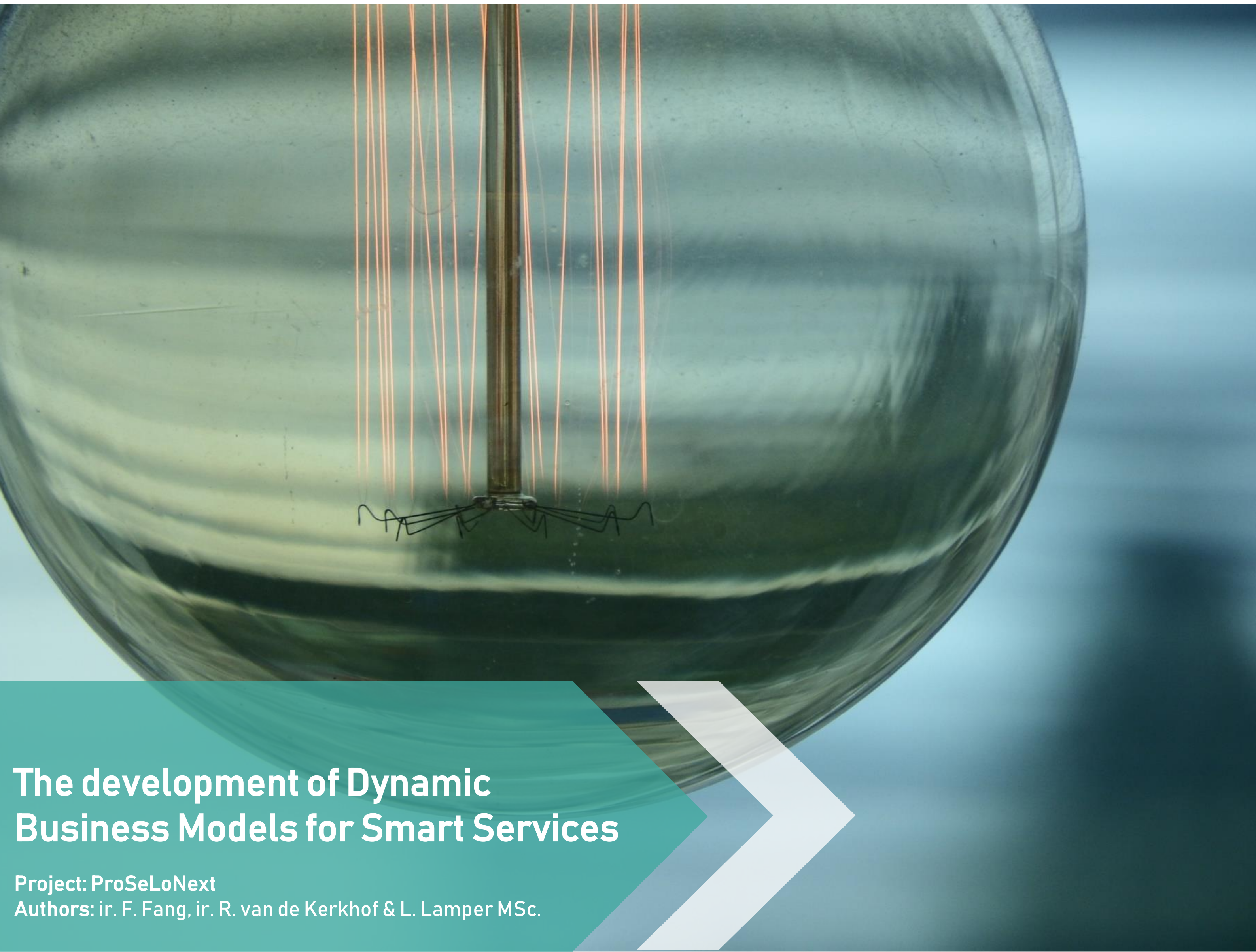

The development of Dynamic Business Models for Smart Services

Project: ProSeLoNext

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ASSET HEALTH DYNAMICS

TILBURG UNIVERSITY

Management Summary

The present digitization of industry provides unique opportunities for our society to make our equipment more reliable, better-performing, sustainable and environmental-friendly. Given the way in which our industrial ecosystems are organized, this calls for integrated collaborations between Original Equipment Manufacturers (OEMs) and their customers, Asset Owners (AOs). Such collaboration will not happen without sound business cases, agreed upon by all stakeholders and based on quantitative analyses. This manual describes an ongoing effort to develop a method that facilitates this collaboration process.

Servitization has increasingly attracted OEMs' attention over the last decades and it has become a global trend in the manufacturing industry with a third of large companies engaging in this transition process, in which they develops their capabilities to compete through services.

Smart Services, individually configurable data-based services that are usually delivered via intelligent objects, are an example of these services. In order to compete through Smart Services, OEMs have to meet several prerequisites, ranging from secured data transfers to smart service business models and a suited mind-set.

OEMs embarking in the servitization journey are bound to run into complexities. Along with technical and organizational complexities, dynamic complexities will render it difficult for OEMs to successfully deploy new smart services. Interrelations between key variables can be hard to grasp and are susceptible to change over time. Mapping these relations by using dynamic business modelling provides clear insights into how to overcome these complexities.

Dynamic business modelling is the process of generating business models through the system dynamics methodology. Business models, formal representations of how organizations operate, are brought onto a business model canvas through a stock-and flow framework. These so-called dynamic business models can be used as strategy simulation tools to explore how strategies, decisions and external phenomena interact to generate long-term behaviours of key performance variables, as well as to explain how and why outcomes change and potential unintended consequences occur.

Dynamic Business Modelling does not provide managers who are developing smart services the exact amount of profit their companies will earn in the near future. It does however give them an idea of the behaviour of the system, and which decisions have a positive or a negative impact on the outcome. Similar to the weather forecast, the forecasted outcome is bound to be wrong, as the simulation is merely a simplified version of reality. However, it does give you an idea whether you need a sweater or not. Creating a DBM is therefore a useful activity to ensure that your organisation gains more insight into this uncertain and dynamic journey of servitization.

It is perhaps ironic that a modelling approach such as System Dynamics, which was developed over sixty years ago, helps to innovate such a young and immature business activity as smart services. Then again, the great cooks always know their classics. Thus, keep turning the pages and build a solid dynamic business case for yourself!

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Chapter 1 Introduction

This is a manual for practitioners who are developing smart business services and are searching for a way to test the business case. The main purpose of this manual is to provide managers with a guideline of dynamic business modelling[1], which helps managers to design, calculate, and test the business model for a smart service. Thus, it enables managers to initiate a well-informed discussion in the management board and with their customers

Context

"Servitization" has increasingly attracted Original Equipment OEMs (OEMs)' attention over the last decades and it has become a global trend in the manufacturing industry with a third of large companies engaging in this transition process. Thanks to new developments in internet- and monitoring technologies, OEMs are able to provide smart and data-based services that bring great values to their customers. Managers, however, have found it difficult to create a compelling business rationale for smart services for capital goods, mainly due to technical-, organizational- and dynamic complexities [2].

In practice, most of the transitions from products to service lead to increased service offerings and higher cost, but not to correspondingly higher returns. Research has shown that around 80% of manufacturing companies have not been able to achieve a profitable transition towards smart services [3]. One of the main challenges of smart service providers is to find appropriate business models, which monetarize the value provided by analysing, visualizing and transferring data into new service concepts [4]. In addition, changing a business model requires senior-management commitment, as well as buy-in from key stakeholders. Asset owners for example, have to shift from purchasing a product to purchasing a service. Therefore, developing a proper business model is of great importance for managers that take the lead in the servitization transition.

Guide

We first introduce the concepts of servitization, smart services and business models in Chapter 2. In Chapter 3 we further discuss the methodology that can be used to develop dynamic business model (DBM) for smart services. In Chapter 4, a case study from the ProSeLoNext project is presented to show how the business modelling was conducted and how policy analysis can be done in order to develop a sound business case for a smart service. Alongside the manual, a "micro-world" model is developed based on learning from three models created in ProSeLoNext. This "micro-world" model is included in Chapter 4 to give the readers more insight into policy analysis.

For readers that are only interested in the guideline of dynamic business modelling, we recommend to start directly from Chapter 3. For readers who want to refresh their basic knowledge of System Dynamics before the journey of dynamic business modelling, we recommend to begin with section 2.3.4 in Chapter 2. For readers who are also interested in learning more on servitization, smart services and business models, we recommend to read from Chapter 2.

[1] *This manual assumes the readers have a basic understanding in System Dynamics (SD). For a basic course in SD, please refer to Strategy Dynamics [1]. In this manual we only explain the basic concepts of SD in section 2.3.4.*

Chapter 2 Servitization, smart services and business models

We first discuss the definition of servitization and the trend of servitization. Then we elaborate on possible motivations of OEMs undertaking servitization. After that the process of servitization, types of services that can be delivered and factors affecting readiness of an individual OEM for servitization are presented. In paragraph 2.2 smart services are explained. Then we elaborate what types of smart services OEMs can provide and what the prerequisites for providing smart services are. In the end we discuss the opportunities and challenges for OEMs to become smart service providers.

2.1 Servitization

2.1.1 What is servitization?

The term servitization was first introduced in 1988 [5]. Servitization was defined as "the increased offering of fuller market packages or 'bundles' of customer focused combinations of goods, services, support, self-service and knowledge in order to add value to core product offerings". Later research has established other definitions of servitization, but there is a broad agreement on the idea that servitization is a process of building revenue streams for OEMs from services [6].

"Servitization is a process in which an OEM develops its capabilities to compete through services."

2.1.2 The trend of servitization

Servitization has become a global trend among OEMs. Over a third of large OEMs worldwide offer services [7]. Within the western countries, around two thirds of the large OEMs are in the journey of servitization. A recent survey shows that 56% of the interviewed OEMs in the UK considered themselves as an intermediate or advanced service provider [8]. Other research, which involved interviewing 60 OEMs in Europe, concludes that 85% of the survey participants aim to deliver output-based services within three to five years, and 75% of the companies expect services to become a significant part of their business in the next three to five years [9]. Over 61% of the OEMs readily deliver some form of output based services. More than 200 U.S. executives participated in a nationwide survey conducted online in 2016 [10]. The research shows that around two thirds of the executives acknowledge the strategic importance of their service departments, while a similar percentage of executives consider them as revenue generators.

2.1.3 Motivations for servitization

Competitive motivation, demand-based motivation and economic motivation have been distinguished as reasons to engage in servitization [11]. With competitive motivation, OEMs might provide product related services to ensure the correct functioning of the product. OEMs might also provide customer service to improve the quality of customer relationship as a response to the general customer demand. To support the operational needs of customers and enable new revenue streams to be developed, OEMs may also provide services supporting business needs with economic motivations.

Figure 2.1 Motivations for servitization

Three types of motivation are identified from the customer's perspective [12]. Firstly, customers seek to improve the performance of a product or asset, while simultaneously reducing operating costs and risks. Secondly, through service from suppliers, customers aim to concentrate their energy and resources on core business activities. Thirdly, customers voice their desire to improve financial visibility and to transfer their fixed cost into variable costs that reflect revenue generation.

2.1.4 Different forms of servitization

Various forms of servitization can be found, ranging from products with services as an "add-on" to services with tangible goods as an "add-on" [13]. Servitization has been categorized into three levels [12].

(1) The ***base service level***: OEMs are offering service focused on product provisioning (e.g. equipment provisioning, spare part provisioning, and warranty). In principle, the service is considered as

necessity to support products. OEMs are set to compete based on their production competences (i.e. "we know how to build it").

(2) In the *intermediate service level*, OEMs provide services dedicated to the condition of a product or asset. Examples of service offered are scheduled maintenance, technical helpdesk service, repair, overhaul, delivery to site, operator training, condition monitoring and in-field service. In this case, service is viewed as added value to customers and OEMs have to not only exploit their production competences but also maintain the condition of products (i.e. because "we know how to build it, we know how to repair it").

(3) In the *advanced service level*, services are offered to achieve an outcome for customers delivered through performance of the product. Service is viewed as business by OEMs. In order to compete, OEMs have to transform their production competence into competence of managing a product's performance (i.e. because "we know how to build it, we know how to keep it operational"). An advanced service is a complex bundling of product and service, which might include revenue through usage, risk- and revenue sharing (e.g. performance incentives) and long-term contractual agreements (e.g. customer support agreement and rental agreement) [12].

As Figure 2.2 shows, the more advanced a service level, the higher the extent to which services are used to support customers. In similar fashion, economic benefits increase when services become more advanced, although risk and responsibility for OEMs increase simultaneously.

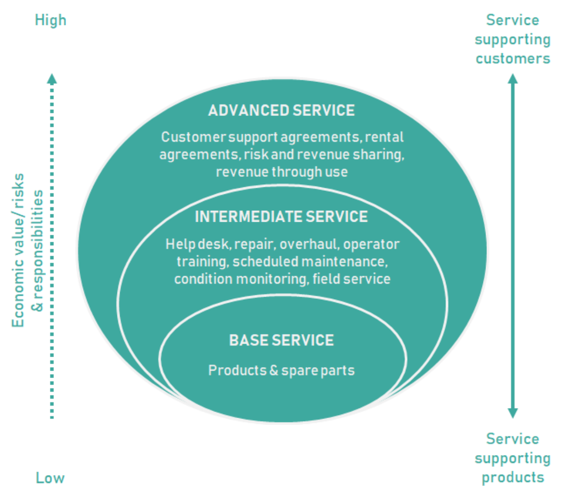

Figure 2.2 Product-service levels

2.1.5 Process of servitization

In general, servitization is a process in which an OEM develops its capabilities to compete through services. Figure 2.3 shows the servitization process an OEM might undergo. An OEM can experience servitization through transitioning from a regular pure-product supplier into a product supplier that increasingly acts as a service provider.

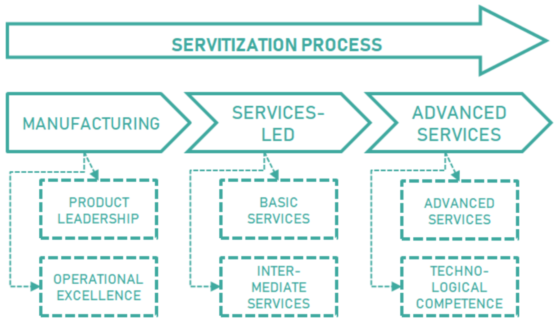

Figure 2.3 The process of servitization

2.2 Smart services

2.2.1 What are smart services?

Smart services are data-based, individually configurable bundles consisting of services, digital applications and technologies [4]. A smart service is usually delivered via an intelligent object that is able to sense its own condition and its surroundings and thus allows for real-time data collection, continuous communication and interactive feedback [14].

In general, smart services are associated with the following characteristics [15]:

(1) development of a connection between the physical and the digital world;
(2) aid provision in value creation and economic efficiency;
(3) extension of products and services to a digital level;
(4) transformation of a product into a part of service;
(5) transition from product centred to customer centred business models.

2.2.2 Smart service maturity

The maturity framework of smart services that is depicted in Figure 2.4 shows different maturity levels of smart services that OEMs might develop [4].

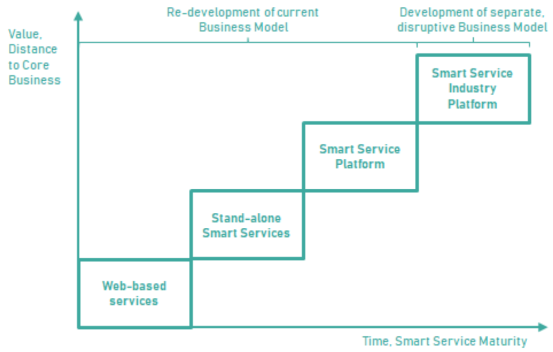

Figure 2.4 Smart Service Maturity

The first level is "*Web-based services*", which represents the first effort of OEMs towards digitalized service offerings. Examples of web-based services are online shops for ordering spare parts and filing electronic documents such as service reports, contracts or manuals. As web-based services are rather rudimentary versions of smart services, it might not fit all elements of above mentioned definition.

The second smart service maturity level is described as "*Stand-alone Smart Services*". At this level, OEMs begin to provide services that are based on machine data collected via sensors. A well-known example is condition monitoring. Based on the continuous collection and analysis of machine data for conspicuous patterns, OEMs are able to identify potential failures in advance and thus conduct preventive maintenance to prevent breakdowns of their plants and machines from happening.

At the third maturity level, "*Smart Service Platforms*", OEMs start to offer a wide range of smart services through their company platform. As a result of a portfolio of data-based and value added applications and service, the stand-alone smart service (e.g. condition monitoring) can evolve into a more integrated smart service (e.g. integrated performance cockpits, predictive maintenance solutions and fleet management systems).

The fourth smart service maturity level is "*Smart Service Industrial Platform*", which describes the opening of the company-specific smart service platform to other smart service providers and ecosystem stakeholders. These "Smart Service Industrial Platforms" serve as fully automated market places, where products, services, production capacities or data is traded between suppliers and consumers across company borders.

2.2.3 Prerequisites for smart services

In order to successfully become a smart service provider, it is essential that the following factors are present:

- the ability to understand customer needs and surrounding factors;
- the possession of smart data and platforms;
- The ability to integrate and process the data;
- The ability to change the company mind-set and current business models.

Prerequisites for smart services are [15]:

(1) to have developed ***smart and connected products***, which integrate electronic intelligence such as sensors, controllers, microprocessors and data storage chips with a wireless internet connection;
(2) to have encrypted and ***secured data collection, -transfers and -storage***;
(3) to have ***data analytics and data based intelligence*** for supported decision and solution finding; and
(4) to have adopted ***smart service business models and an accommodating mind-set*** by using customer centred and solution oriented approaches with higher service focus and pre-emptive acting to avoid unpleasant reactions from customers. As shown in Figure 2.4, the more advanced smart services OEMs offer, the more distant it is from their core business. This requires more radical changes to be made by OEMs in terms of their current business model (see section 2.3 for more information about business models).

Figure 2.5 Prerequisites for Smart Services (adapted from [15])

2.2.4 Opportunities and challenges

Opportunities

Smart services definitely bring opportunities for OEMs. Firstly, selling smart services as extensions to existing products/services brings financial benefits. New services bring in additional revenue for OEMs. As a result of usage of data for process optimization, costs are reduced and financial visibility is enhanced. Secondly, entering smart service business also gives OEMs competitive advantages. To be more specific, by using smart solutions such as condition monitoring, early alarms or predictive maintenance, efficiency can be improved. In addition, OEMs are able to make decisions with more ease and respond quickly to problems with the help of data analytics and data based intelligence. In addition, the productivity is increased because of automation, increased flexibility of work locations and enlarged mobility. The last benefit is the improved customer relationship, as OEMs are more capable of meeting customer needs and requirements by providing customer-centric and solution-oriented smart services.

Challenges

However, it is a challenging task to make the transition from being a product provider to being a smart service provider. First of all, OEMs have to cope with the *technical complexity* of the smart service, a trait that is often encountered. The deficit in technical knowledge is an important aspect that needs to be traversed. In addition, the lack of standards and interoperability in data makes it a challenging task for OEMs to collect and transfer data. On top of that, the issues regarding data ownership, security and privacy require special attention from OEMs during this process. Furthermore, the challenge in the area of data analytics and data based intelligence is the scarcity of skilled workers and knowledge. It is also difficult for OEMs to effectively acquire, manage and retain qualified human resources.

Secondly, OEMs in the process of becoming smart service providers also encounter challenges coming from *organizational complexities*. As discussed above, a smart service business requires a different mind-set and business model compared to traditional businesses. Changing these aspects is not straightforward. OEMs require a clear vision and experience to deal with resistance to change.

More specifically, the first organizational challenge is to harmonize different interests and perspectives from many internal stakeholders (Purchasing, Operations, Maintenance, Service, Sales, Finance, Human Resource and IT). Since the transition from product to service has different implications for every stakeholder. Functions such as aftersales service will experience major changes. While the aftersales department was possibly slightly overlooked, it will now become the heart of the business. Selling a product will no longer be considered sales, but pre-sales. Since pre-sales involves relationship management, the service engineer might have to become part of the sales force. To support this, the R&D departments that are traditionally focused on the development of the product will have to collaborate even more with software and data specialists to ensure that products are durable, are serviceable at low costs, and have the right data-delivery capabilities built in. Therefore, it requires a strong business model that is shaped around the services provided while explicitly addressing cultural issues.

"Selling a product will no longer be called sales, but pre-sales."

The second organizational challenge is to convince the customer base and again align different perspectives and interests. Purchasing smart services is substantially different from purchasing products. Whereas the latter is within the domain of the purchasing department, the former is decided upon in the boardroom. The offering and the conversations around it need to resonate with a range of stakeholders: Operations, Finance and IT need to agree on subjects as reliability, costs and technological integration. It is no longer sufficient to simply interact with the procurement officer and negotiate the price of a singular item.

While developing a new business model, the following question needs to be answered: "how can we develop and price a new service in a way that it delivers above-average margins and is of added value for our customers?" In many cases, OEMs that make the transition towards servitization, encounter unwilling customers who now have to pay for a service that in their eyes was free before.

OEMs have used service for marketing purposes. The inclusion of service also partly determined the price of product. OEMs are often used to working with cost-plus calculations, which does not work for smart services anymore; the insight into the cost of the activities required for services is often not there. Customers argue that OEMs also benefit from smart services (e.g. cost reduction and increased flexibility) [16]. According to the study mentioned in 2.1.2, 70% of companies that were interviewed raised the issue that their customers are initially not prepared to pay for services [9]. This is becoming increasingly challenging when OEMs encounter a traditional customer that still focuses on acquiring capital assets for which the total investment costs are as low as possible.

Thirdly, OEMs encounter challenges because of *dynamic complexity*: all these interrelations between customer needs and interests of internal stakeholders, installed base and service capacities evolve over time. Any static picture is bound to be changed as time passes. Getting the timing right is key to closing the deal on servitized offerings. Once sold, offerings develop over time, reflecting the customer's evolving needs and confidence, and take on a shape surprisingly different to their original form [9].

"Any static picture is bound to be changed as time passes."

To conclude, the move towards servitization requires a significant change in the applied business models. A substantial amount of OEMs do not yet see the bigger or dynamic picture. Although 75% of the interviewed expects to get a significant portion of their revenue from output- or outcome-based services rather than products in the next three years, an astounding 70% does not have a service strategy in place [9]. Around 80% has a good level of enabling technology and availability of data. However, they fail to utilize the potential of connecting these capabilities and using them to tap into the customer need – using them in an integrated way to build compelling offerings.

2.3 Business models

2.3.1 Business models

Business models, in general, have been defined as a description of an organization and how it functions in achieving its goals such as profitability, growth, innovation, social impact and value creation [17]. However, there is a lack of agreement among scholars on more operational definitions of a business model. There are three different interpretations of what a business model is. Business models are considered as attributes of real firms, cognitive or linguistic schemas, or formal conceptual representations of how an organization operates [18]. *In this manual, business models are regarded as formal representations of how an organization operates.*

2.3.2 Business model representations

There are two fundamental methods to present a business model. The first method offers a flow logic that considers value flows and activities. A prominent example for this is the e3-Value method [19]. The second method offers a system-level holistic view on the business logic of an economic entity or offering. A prominent example is the Business Model Canvas [20]. In this manual, the business model canvas method is used, as it is more widely applied in the practice than the e3-Value method.

Business model canvas

Seven basic building blocks make up a business model canvas:

(1) Key Partners
(2) Key Resources
(3) Value Proposition and Key Performance Indicators
(4) Key Processes
(5) Customer Segments
(6) Cost Structure
(7) Revenue Streams

2.3.3 Service business models

The business model canvas is a useful framework to represent how a company should operate to achieve its goal in traditional product selling business. The original business model canvas was not aimed for service business models, which means that the more important aspects regarding service business models such as the relationship orientation and co-creation of value should be integrated in the business model [21]. Service business models have to be developed with consideration of both the customers and service providers. The possibility of adapting to changing customer needs is one of the central characteristics of a service business model. The service business model must be able to change over time in order to handle the dynamic behaviour of the customers. OEMs must be able to adapt quickly to the changing requirements. This again proves that it is of utmost importance to develop a model that fits in the business context, and more importantly, a model that captures, creates and delivers value.

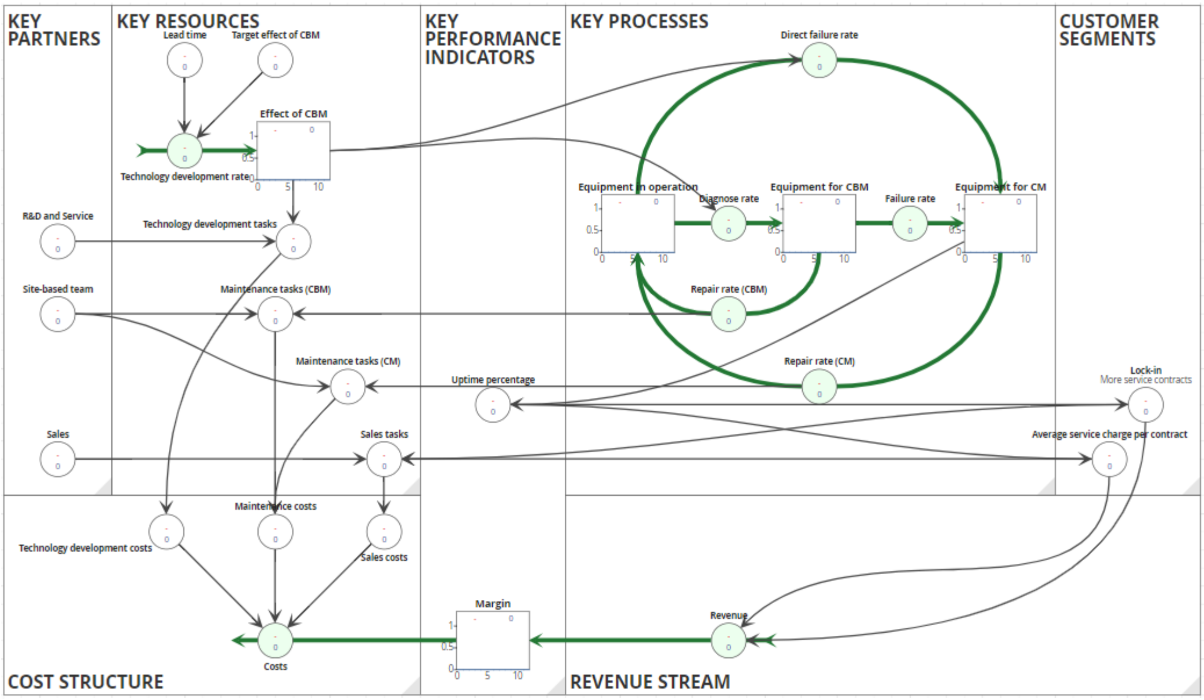

Figure 2.6 Business Model Canvas containing a generic maintenance structure

Achieving value for the customer and fulfilling demand over the entire life cycle is a central aspect of a service business model. Due to the associated uncertainty and the feedback characteristics in the service life cycle, long-term contracts remain incomplete, since contingency is often omitted. Dealing with uncertainty, in terms of high complexity and dynamism, is therefore one of the key challenges in developing such service business models. Dynamic business modelling can help to achieve design and development of such models.

2.3.4 Dynamic business modelling

What is dynamic business modelling?

A dynamic business model is a strategic tool that combines the conventional business model canvas with system dynamics modelling [17]. System dynamics modelling is an approach for capturing the dynamic aspects of complex social and managerial systems [22][23].

System dynamics modelling

(1) *Business structure:* system dynamic models are notably useful for helping managers to solve specific managerial problems, as they are developed by ***mapping structures of business systems***, which aids in understanding complex business processes.

(2) *Causal interactions:* through the ***quantification of the causal interactions***, where a set of equations is developed that lays the groundwork for simulating possible system behaviour over time, it helps managers to discover dynamic aspects of the system [24].

(3) *Feedback loops:* within system dynamic models, a business system is viewed as a system that entails multiple ***closed feedback loops***. This system encompasses all the main variables associated with the phenomenon under observation. There are two types of feedback loops: positive/reinforcing feedback loops and negative/balancing feedback loops. The positive/reinforcing feedback loop represent virtuous or vicious cycles related to a growth or decline process of a business system, while the negative/balancing feedback loop is related to goal-seeking behaviour in a business system.

(4) *Stock-and-flow diagrams:* after identification of feedback loops, the main variables of the business system are converted into stock-and-flow diagrams by using a system dynamic simulation software package. These diagrams enable decision-makers to ***simulate the behaviour of the observed business system*** over time [23][25].

(5) *Calibration:* a system dynamic model is calibrated by ***comparing simulation output to empirical business data***. The structure of the model and parameter estimates based on assumptions is refined if discrepancies or inconsistencies exist between the output and real data.

(6) *Policy analysis:* After calibration, *"what if"-analyses* can be conducted to see how Key Performance Indicators would change in response to different policies [26][27]. These simulation experiments are particularly valuable when real experimentation is too costly, which is often the case in practice. The simulations allow managers to discover how complex business system work and aid in identifying high leverage points [28].

A complete tutorial about System Dynamics Modelling and more information about the method we advise to use can be found in the Appendix.

Why dynamic business modelling?

Dynamic business modelling generates a holistic perspective of all relevant elements in a service business model, including the causal links between them. This holistic approach takes into account all aspects: feedback loops, accumulation, time delays, and nonlinear interplay. These aspects are necessary in order to capture the dynamics of business processes [23].

In addition, dynamic business modelling provides the possibility to engage both internal and external stakeholders. It simultaneously provides a shared understanding and (internal) alignment of interests. Engaging stakeholders can improve both the accuracy and the legitimacy of the model, while it simultaneously fosters the alignment of key players' mental models and the group's consensus about what actions to take in order to co-create value [29]. Subsequently, the new established group consensus may result in both new understandings of the potential causes and effects of system behaviour and the fine-tuning of the assumptions for the associated model calibration [30][31].

Lastly, dynamic business modelling allows for experimentation to predict dynamic implications of policies to determine whether an intervention will improve or worsen the current situation [32]. In practice, OEMs can explore these models and simulate alternative scenarios.

"Dynamic business modelling allows for experimentation to predict dynamic implications of policies to determine whether an intervention will improve or worsen the current situation."

In conclusion, dynamic business models can be used as strategy simulation tools to explore how strategies, decisions and external phenomena interact to generate long-term behaviour of key performance variables, as well as to explain how and why outcomes change and potential unintended consequences occur. Dynamic business models provide methodological support for managers in turning ideas into formal conceptual representations that show the impact of aforementioned ideas. With the help of the model, managers are able to comprehend the complexity of the dynamic systems, after which optimal business policies can be designed and developed by experimenting with the models [17].

Chapter 3 Methodology for development of dynamic business models

Two possible questions that might be asked by managers who seek to build a sound business case for a smart service themselves are: with whom do we need to develop this? And how do we develop it? In this chapter we address these two questions by elaborating upon the dynamic business modelling team and the modelling process.

3.1 Dynamic business modelling team

A common method that is used to develop SD models is Group Model Building [33]. To successfully develop dynamic smart service business models, it is essential to have a diverse group modelling team. Participants from different disciplines with varying competences and qualifications can provide different insights that are particularly helpful in the group modelling process. Since a customer-centric business model requires the analysis and integration of customer requirements, the presence of policy makers and managers from the customers is strongly recommended [2].

Generally speaking, there are at least four stakeholders that together form the natural project composition for modelling engagements. The project team consists of [34]:

(1) the modeller (managers who want to develop DBMs for smart services themselves can also act as the project manager: responsible for project planning and progress);
(2) the project sponsor (often someone from higher management);
(3) line managers and support staff from relevant departments for smart services (e.g. maintenance, customer support, system engineering etc.).
(4) key stakeholders from customer side.

For different purposes, three groups should be created: a steering team, a reference team and a contact group. The steering team normally consist of the project manager (in this case also the modeller) and the project sponsor. This group convenes only at certain key stages of the project to review the progress and decide on the next actions. The reference group consists of two or three managers who are active in project design. Whenever the modeller wishes to have an informal session with effective decision making, the reference group is to be convened. Support staff and the line managers dealing with the front line issues, but who are not part of the reference group, are in the contact group. Most of time they are invited for group modelling sessions, as their in-depth knowledge about parts of the issue from regularly dealing with it is extremely useful. These line managers are also often crucial for successful implementation of the recommendations.

3.2 Dynamic business modelling process

Three distinct phases are necessary to develop DBMs (see Figure 3.1 for key phases, steps, activities, engagement, deliverables and durations of the dynamic business building process). Phase 1 is the design of dynamic business model, which consists of Scoping and Problem Conceptualization. The aim of this phase is to understand and describe business problems and develop a conceptual model that explains the possible causes of the business problems. Phase 2 concerns the engineering of a DBM, which consists of Technical Design and Policy Analysis. During this phase, the developed conceptual model from phase 1 is provided with equations and parameter values. In addition, a variety of diagnostic simulations are conducted. Phase 3 revolves around the dissemination of the knowledge learned from the DBM. During this phase, problem insights and recommendations are documented (e.g. final reports and management presentations) and the SD model is transformed with a simulator (e.g. a "micro-world") to enable communication of the insights in workshops.

3.2.1 DBM design

The design of DBM consists of two phases: *Scoping* and *Problem conceptualization*. The former focuses on identifying the problem situation, while the latter seeks to map the relevant feedback structure (causal loop diagram or stock & flow diagram) in order to conceptualize business problems.

PHASES	STEPS	ACTIVITIES	ENGAGEMENT	DELIVERABLES	DURATION
DYNAMIC BUSINESS MODEL DESIGN 	SCOPING	• UNDERSTAND COMPLEXITIES/ISSUES • DESCRIBE BUSINESS SITUATION (TIME HORIZON, LEVEL OF AGGREGATION AND PROBLEM BOUNDARY) • FRAME THE ASSIGNMENT (PROJECT GOAL, SCOPE AND PLAN) • CREATE STEERING GROUP AND CLIENT PROJECT TEAM	• PROJECT KICK-OFF MEETING WITH STEERING GROUP • (SEMI-) STRUCTURED INTERVIEWS	• PROBLEM DEFINITION • PROJECT PLAN	2-8 WEEKS
	PROBLEM CONCEPTUALIZATION	• IDENTIFY KEY ELEMENTS, POTENTIAL CAUSES OF PROBLEM, STRATEGIC TRADE-OFFS AND OPTIONS • DEVELOP CONCEPTUAL MODEL	• INFORMAL BRAINSTORMING • (SEMI-) STRUCTURED INTERVIEWS • GROUP MODELLING SESSION	• WORKBOOK(S) • CONCEPTUAL MODEL • PROBLEM INSIGHTS	4-12 WEEKS
DYNAMIC BUSINESS MODEL ENGINEERING 	TECHNICAL DESIGN	• FIND FACTS (RELEVANT BUSINESS DATA) • DEVELOP QUANTIFIED MODEL (MATHEMATICAL EQUATIONS AND PARAMETER QUANTIFICATION) • CALIBRATE & VALIDATE MODEL	• DATA COLLECTION INTERVIEWS • GROUP MODELLING SESSION	• WORKBOOK(S) • QUANTIFIED MODEL • PROBLEM INSIGHTS	4-12 WEEKS
	POLICY ANALYSIS	• DESIGN POLICIES • EVALUATE POLICIES	• (SEMI-) STRUCTURED INTERVIEWS • GROUP MODELLING SESSION	• PROBLEM INSIGHTS AND RECOMMENDATIONS	2-8 WEEKS
DYNAMIC BUSINESS MODEL DISSEMINATION 	COMMUNICATION	• RECOMMEND ON POLICY IMPLEMENTATION • DISSEMINATE INSIGHTS	• MANAGEMENT PRESENTATION • CONCLUDING MEETING • FORMAL REPORTING	• FINAL REPORT • MODEL DOCUMENTATION	2-8 WEEKS

Figure 3.1 Business Modelling

Scoping

Developing DBMs requires brainstorming or divergent thinking in order to determine whether factors or variables should be included in or excluded from a system's boundary [35]. This can be achieved by nominal group techniques, in which brainstorming first takes place individually, after which the individual ideas are discussed and clustered by the group. This makes verbal dominancy by a part of the group or group thinking less likely [29].

Step 1: understand the business problem through individual and/or informal small group meetings (two to three people) with key internal and external stakeholders.

Step 2: form the steering group and reference group.

Step 3: describe the business situation by defining the time horizon, level of aggregation and system boundaries of the problem.

Step 4: frame the assignment of dynamic business modelling by establishing the goal of the project and determining the feasibility of the project (project scope and plan).

This phase ends with a well-defined problem definition and a project plan for going forward.

Problem conceptualization

Step 1: define business model configurations. The business model canvas can be used as a navigation system to make a blueprint of the business model structure.

Step 2: identify key strategic trade-offs and options with the reference group through informal brainstorming sessions.

Step 3: identify relevant line managers and support staff, and form the contact group.

Step 4: identify key elements (relevant variables and parameters), and the potential cause of problems (relationship between variables) through individual semi-structured interviews with relevant line managers and support staff.

Step 5: develop causal loop- and stock & flow diagrams based on interviews and test and improve the conceptual model in a follow-up group modelling session with the reference group and people in the contact group who have been interviewed. This step can be messy but is crucial. Extensive development of the model without group interaction abates stakeholders' ownership and creativity [35]. Stakeholders' ownership is pivotal in seeing SD models as "boundary-objects" [35][37].

Working towards a shared understanding of the problem comes with obstacles. Complementary and competing views from participants need to be understood in order to harmonize all different views and opinions so that a solution for the problem may be found. During this phase, it is fair to say that the quality of modelling process is even more important than the quality of the model itself.

"Working towards a shared understanding of the problem comes with obstacles."

The deliverables in this phase are the conceptual business model and the revised project plan. A feedback workbook can be used in the process to facilitate communication and provide problem insights and preliminary recommendations.

3.2.2 DBM engineering

Technical design

DBM engineering entails a step of technical design, which involves quantitative modelling and simulation in a continuous design, validation and implementation cycle. This work is carried out by a model project manager who has modelling skills and at least one person from the reference team who has specific knowledge about the value-oriented solution for the customer specific business model [2]. Throughout this phase, "classical system dynamics simulation modelling", mostly "in expert mode" is conducted. For a while, the quality of the model becomes more important than the quality of the discussion. To create a robust and well-calibrated model, several steps have to be taken [35].

Step 1: collect business data through individual data collection interviews with relevant line managers and staff from the contact group.

Step 2: quantify the conceptual models by determining mathematical equations, quantifying parameters and specifying scenarios.

Step 3: calibrate and validate the quantified model by checking the parameter values, estimating unknown/uncertain model parameters and comparing the model with the real system. A group modelling session with all relevant stakeholders is necessary to further accommodate the calibration and validation of the quantified model.

Policy analysis

During the policy analysis, the quality of the modelling process and the model itself are of equal importance. In an iterative process, policies are designed, tested and improved, while individual interviews continue. A group policy analysis session is required to define the preferred policies collectively with all stakeholders [25][29][30]. It consists of two steps:

Step 1: design policies by conducting sensitivity analyses and scenario analyses. Starting from the base case scenario, different policies can be generated by changing decision variables. Examples of decision variables that can be changed are initial values, delay lengths, maximum acceptable values and learning curve strength. The model can be run to experience the differences in outcome to see which changes have substantial impact.

Step 2: define criteria for policy evaluation, evaluate the identified policies and assess the alternative policies.

During this phase, some extra individual interviews can be done to further calibrate the model. A group modelling session is required to derive the optimal policy collectively with all stakeholders. The deliverables of the two phases are a formalized business model and business policy evaluation criteria.

Evaluating the policies is a good way to determine how the improvement process is shaped and moulded. Criteria including but not limited to feasibility, costs, quality, service level, reliability, availability and safety can all be considered as determining factors in a policy analysis. Assessing the policies through a multiple criteria analysis might be a good way to reach the most desirable policies.

3.2.3 DBM dissemination

After Phase 2, the stakeholders who were involved in the development of the model should feel high ownership of this model. However, that is only a small subset of all the people involved. Communicating the findings in a language without simulation jargon to the broader organization is essential for implementation.

Communication

Step 1: Derive normative recommendation on policy implementations and communicate to the project team through management presentations and formal reporting.

Step 2: Transfer the quantified model into a so called "micro-world" version of model to share insights of the DBM to the project team and to a wider audience. In contrast to the previously mentioned "boundary-objects", "micro-worlds" focus on the problem instead of the process [37], as it is developed specifically for learning purpose. Technical advances in simulation packages make it possible to run such a simplified version of the simulation models through an internet browser, without specialized hardware or software requirements [1]

Chapter 4 Case study and the DBM for smart services

This manual was developed as a work package within the PROSELO NEXT Research Programme [38], which is a larger applied research project with leading Dutch OEMs and Dutch Universities on board. It is sponsored by DINALOG, a Dutch government entity aimed at promoting innovations in logistics, such as spare part management [38]. Within the business modelling work package, three case studies were conducted with industrial companies: an OEM producing complex printing equipment, a service provider for aerospace maintenance and an OEM producing semiconductor manufacturing equipment. The method was originally based on a combination of (1) existing business modelling methods, (2) knowledge from the field of industrial maintenance and services and (3) the system dynamics modelling method for managerial decision-making. In each of the case studies the method was refined and better tailored towards the specific industry application of smart maintenance services. This section highlights steps and results from one of these cases, with the semiconductor OEM. Within this case study, the third phase, knowledge dissemination, is still ongoing at the time of writing and falls out of the scope of the research project, so the case description focuses on the first two phases in section 4.1. To further disseminate the knowledge created in ProSeLoNext, a micro-world is developed based on the three models mentioned above. This micro-world provides risk free learning environments for participants to experience issues in the journey of servitization. In section 4.2, we will introduce the micro-world model and explain how policies concerning smart services can be analysed and designed, and how an optimal policy for both OEMs and their customers can be derived from different scenarios.

4.1 Case study: The road to Full Service Premium at ASML

4.1.1 DBM Design

Scoping

The smart services that ASML provides are a set of practices called "Full Service". ASML, as the OEM, provides all customer related services, including accommodation and follow-up of scheduled and unscheduled 'downs' respectively. "Down" means a period in which the equipment is inactive, which is very costly for ASML's customers, semiconductor manufacturers. This "down" can either be scheduled (maintenance or inactivity) or unscheduled (failure, damage). Three different service levels are established to harmonize goals with the customer (see Figure 4.1).

Problem conceptualization

System dynamics modelling was used to identify the road towards the most ambitious level of "Full Service Premium" (FSP). It targets both productivity (higher per-system availability to enable higher output) and predictability (less variations among systems), so that the system performance can be guaranteed.

Managers from a range of departments were interviewed to gather information, collect data and form assumptions on Full Service Premium practices. The Snowball strategy was applied to identify relevant departments subsequently. Individual interviews were first conducted with managers in Customer Supply Chain Management, followed by interviews with managers in Customer Support, Business Line Marketing and System Engineering. A group modelling session was held with interviewees to generate research questions, test and refine the conceptual model and finally identify scenarios. The date requirements and project plan were also discussed in the session.

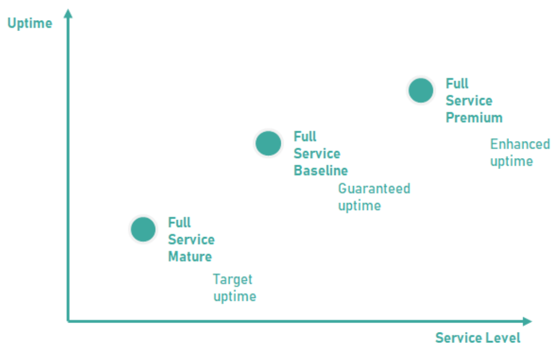

Figure 4.1 Full Service Levels

4.1.2 DBM Engineering

Technical design

The simulation model developed consisted of three main building blocks:

(1) the mechanisms of scheduled and unscheduled downs;
(2) the uptime percentage calculations; and
(3) the bonus/malus calculation.

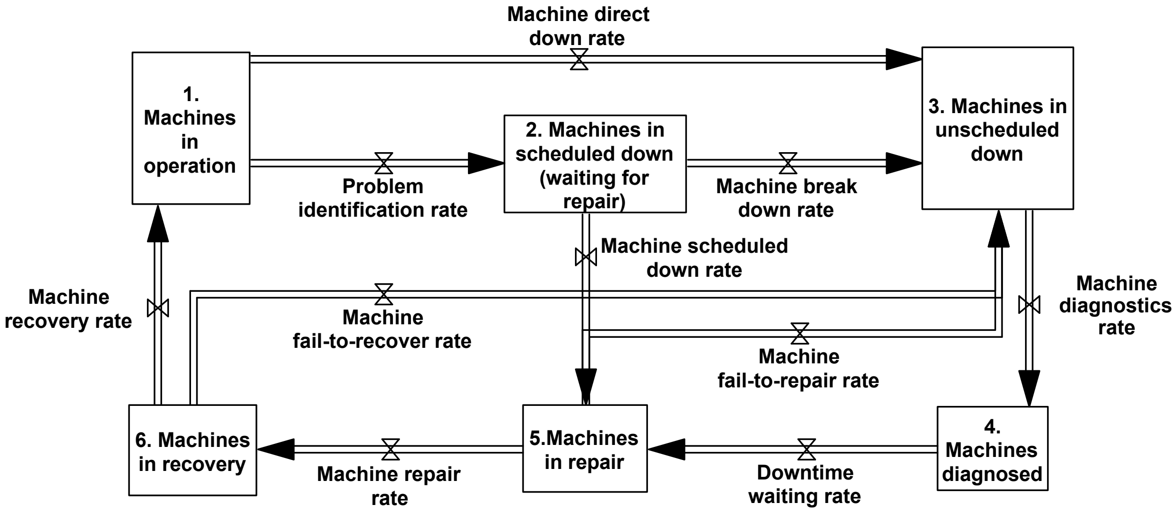

Figure 4.2 Machine stages at ASML

Figure 4.2 illustrates the *first* building block concerning the course of scheduled and unscheduled downs. The OEM has identified six different states in which machines can be found:

(1) in operation;
(2) in scheduled down;
(3) unscheduled down;
(4) diagnosed (but not yet repaired);
(5) in repair; and
(6) in recovery (bringing the machine back in full production mode).

If all goes according to plan, a machine will follow the (1) → (2) → (5) → (6) trajectory. Machines that encounter unscheduled downs require diagnosis before anything can be repaired. It is not uncommon for stage (4) to accumulate up to eight hours, since "Downtime Waiting for Parts/Tools" (DTWP/T) is a relatively unpredictable variable.

The *second* building block concerns the uptime. The uptime is calculated through "Machines in Operation"/"Number of Machines", which reflect productivity. When the numerator increases ("Machines in Operation"), the uptime percentage will do so as well.

The *third* building block incorporates the bonus/malus calculation, which is related to predictability. ASML draws up agreements with its customers on the guaranteed service level. If the uptime exceeds the guaranteed service level, ASML will receive increased payments. When the uptime dips below the guaranteed service level, ASML will reimburse the customer.

In this step, several individual interviews with managers and staff from abovementioned departments were conducted to collect relevant historical data such as time distribution for scheduled downs and unscheduled downs and Fail-to-repair data et cetera. The model was calibrated against these historical datasets. In addition, a group modelling session was hosted to collect extra data, further validate and refine the quantified model.

Policy analysis

Six different scenarios were developed and tested in order to identify which policies would substantially improve both productivity and predictability. Each of these scenarios affected different flow rates in the model.

- Scenario 1: turn unscheduled downs into scheduled downs
- Scenario 2: improve the Diagnostics phase
- Scenario 3: improve the Recovery phase
- Scenario 4: improve the Down Time Waiting for Parts/Tools (DTWP/T) phase
- Scenario 5: consider the interactions between Scenario 2 and Scenario 4
- Scenario 6: improve Mean Time Between Interrupts (MTBI)

The policy analysis indicates that combining scenarios 1, 3 and 6 sequentially leads to the most desirable results. An uptime increase and lower costs are the results of combining the policies. However, upon closer scrutiny that scenario worked in the model, but was not feasible in the business. Therefore, another slightly less ambitious policy combination was selected, which is a combination of scenarios 3, 5 and 6. In this case the uptime will increase slightly less compared to the base case but with lower costs.

In this step, individual interviews with managers and staff from relevant departments continued to generate and improve policies. In the end, a group modelling session was organized to collectively determine the optimal policies. A possible implementation was also discussed in the meeting.

4.2 Dynamic Business Model for Smart Services

4.2.1 Introduction

In the journey of servitization, the OEM might ask questions: "Should I invest in smart services?" "If so, how fast should I go with smart services?" and "What level of sophistication do I have to provide with smart services?" The micro-world in this manual is developed particularly to address these questions. As discussed in section 2.1.4, there are different levels of services that the OEM can provide. In this model, we assume that the OEM, besides selling product and spare parts, is able to provide three levels of services:

(1) maintenance service (corrective and preventive maintenance);
(2) monitoring service (providing advice for preventive maintenance);
(3) integrated service combining monitoring and maintenance.

With this model, we aim to find out whether adding the smart service condition monitoring can be beneficial for OEMs and their customers. In addition we determine what the optimal combination of different service levels is and how the performance of condition monitoring affects the profitability of the smart service.

4.2.2 The micro-world model

The micro-world model (which can be found [here]) consists of components as a business model canvas described in section 2.3.

(1) Value proposition and key performance indicators
The central value proposition provided by OEMs in this model to their customers is to maintain a high percentage of product uptime ("Average availability"). The products of OEMs provide value when they are available for use by the customers. Two key performance indicators are "CBM performance: Type I error" and "CBM performance: Type II error". The Type I error refers to the percentage of products that is maintained because the monitoring equipment detected flaws, while in reality, maintenance is not necessary yet (a so-called 'false positive'). The percentage of Type I errors can be decreased by investing in more sophisticated equipment. Type II errors occur when a product breaks down without the monitoring equipment detecting any flaws just beforehand. The percentage of Type II errors can be decreased by investing in more sophisticated equipment.

(2) Key resources
OEMs require in order to create value are all capacity related. Production capacity is required to manufacture products and spare parts. Maintenance capacity (human capital and tools) is required to perform corrective and preventive maintenance, while monitoring capacity (human capital, systems, tools) is required to analyse the data and provide advice regarding maintenance.

(3) Key processes
The key processes include manufacturing of products and spare parts and the activities associated with maintenance and monitoring through which OEMs strive to secure a high availability of products for their customers.

(4) Customer segments
For this business model we have distinguished two types of customers. Customers who buy products and customers who buy services. In addition, four different service offerings are proposed:

- provision of spare parts (A);
- maintenance service (B1);
- monitoring service (B2);
- integrated service of monitoring & maintenance (B3).

The services (B2 and B3), where monitoring is included, are considered smart services.

(5) Cost structure
The OEM's costs are rooted in fixed costs for capacity and the costs associated with increasing or decreasing capacity. Variable costs are made up of manufacturing costs, service costs (maintenance service and monitoring service) and costs for installing monitoring systems. Part of the customer's costs is payment towards the OEM.

(6) Revenue streams

The OEM's revenue is generated from selling the aforementioned products and services, while in addition, the customer partially covers the installation costs for the monitoring system. In turn, customers generate revenue from using the product.

4.2.3 Policy analysis

To determine under which conditions a smart service is beneficial for both the OEM and its customer, six decision variables have been identified with which different scenarios can be simulated:

(1) % of products with service A: spare parts: The percentage of products for which the OEM will provide spare parts as a service;
(2) % of products with service B1: Maintenance: The percentage of products for which the OEM provides corrective and scheduled maintenance;
(3) % of products with service B2: monitoring: The percentage of products for which the OEM provides a monitoring service to continuously check the condition of the products and give advices on maintenance activities;
(4) % of products with service B3: monitoring & maintenance: the OEM provides an integrated service including both the monitoring service and the maintenance required to guarantee availability;
(5) CBM performance: Type I error; and
(6) CBM performance: Type II error.

Scenarios

By setting up different values for decision variables, seven scenarios are developed in this model. The profitability of each scenario is then calculated to see under which conditions a smart service is beneficial for the OEM and its customers.

Scenario 1 – Products *(the base case)*

Make sure that all decision variables are set at 0. In this base case, the OEM only sells products without any additional service. Over 25 years, the base case accumulates a profit of €120 million for the OEM. The total amount of profit for the customers settles around €5,76 billion.

Scenario 2 – Addition of spare part sales *(service A)*

Ensure that the value of "% of products with service A: spare parts" is 100. The remainder of the decision variables stays the same in comparison with the base case. In this scenario, the OEM is selling both products and spare parts. Adding the sales of spare parts can increase the profit up to almost €180 million over 25 years. This is an increase of 60 million compared to the base case policy. The amount of profit for customers remains the same, as we assume that the prices of spare parts from competitors are somewhat equal.

Scenario 3 – Provision of maintenance *(service A and service B1)*

Set the value of "% of products with service B1: maintenance" at 100, and make sure that the other decision variables remain the same as in scenario 2. In this scenario, the OEM provides maintenance service in addition to selling products and spare parts. The addition of maintenance service leads to a slight increase of profit compared to scenario 2, namely €185 million. The amount of profit for customers remains the same, as we assume that the maintenance costs for customers are the same, no matter which party provides the maintenance.

Scenario 4 – Provision of monitoring services *(service A + service B2)*

For this scenario, put the value of "% of products with service B2: monitoring" at 100 while the value of both CBM performance: Type I error and CBM performance:

Scenarios	Services	Total profit for OEM	Total profit for customers
Scenario 1	Products	€ 120 m	€ 5,75 b
Scenario 2	Products and spare parts	€ 180 m	€ 5,76 b
Scenario 3	Products, spare parts and maintenance	€ 185 m	€ 5,76 b
Scenario 4	Products, spare parts and monitoring service	€ 234 m	€ 6,89 b
Scenario 5	Products, spare parts and integrated CBM	€ 235 m	€ 6,89 b
Scenario 6	Products, spare parts and advanced monitoring service	€ 219 m	€ 7,15 b
Scenario 7	Products, spare parts and advanced integrated CBM	€ 219 m	€ 7,15 b

Table 4.1 Results of different scenarios

Type II error should be at 20. The rest of the decision variables remain the same as the scenario 2. In this scenario, the OEM sells products and spare parts and provides monitoring service for its customer. The fourth scenario drastically increases the revenues and profits made by both the OEM and the customers. The additional monitoring service ensures that the OEM's profit rises to almost €234 million, while more than 6000 prevented breakdowns result in additional profit for customers up to a grand total of €6,89 billion.

Scenario 5 – Provision of integrated CBM *(service A + service B3)*

Scenario 5 combines B1 and B2, so the value of "% of products with service B3: monitoring & maintenance" should be at 100, while both CBM performance: Type I error and CBM performance: Type II error should remain at 20. In scenario 5, the OEM offers an integrated service with a combination of monitoring service and maintenance. Profit for the OEM accumulates to over €235 million. Adding maintenance service to monitoring only increases profit by €1 million compared to scenario 4. The reason is that the monitoring service has reduced the need for maintenance service and spare parts. Figure 4.3 shows that revenue from maintenance service and spare parts both decrease, when adding monitoring service.

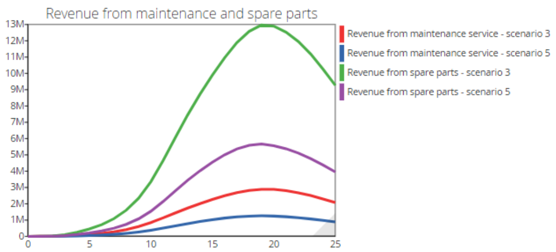

Figure 4.3 Revenue from maintenance and spare parts

The total profit for the customers approximates €6,89 billion. It remains the same with scenario 4. As we assume that the customer uses other parties' service and the cost and performance of the service are the same with the OEM.

Scenario 6 – Provision of advanced monitoring services *(service A + service B2, CBM performance Types I & II: 5%)*

With the values of both CBM performances Types I & II equal to 5, the quality of the monitoring equipment is increased. Hence, the availability of products also increases. It results in €7,15 billion profit for customers. This is a difference of over €250 million compared to scenario 4. On the flip side, the OEM's profit is slightly lower with total amount just edging €219 million. *In this model we did not calculate extra costs for the OEM to improve the monitoring performance. If one were to add this to the model, the additional value can be added to one of the monitoring cost variables*. Finally, the improvement of the monitoring service leads to less breakdowns, after which the demand for spare parts decreases, as seen in Figure 4.4. This results in less profit for the OEM.

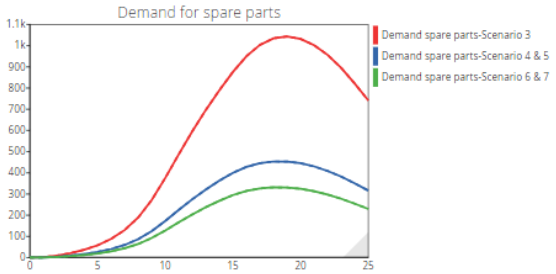

Figure 4.4 Demand for spare parts

Scenario 7 – Provision of advanced integrated CBM *(service A + service B3: CBM performance Types I & II: 5%)*

Keep the values of both CBM performance Types I & II equal at 5 and the value "% of products with service B3: monitoring & maintenance" at 100. In this scenario, the OEM increases the performance of monitoring service compared to scenario 5, and it also adds maintenance service to monitoring service. In a similar fashion as scenario 6, the total amount of profit for the customers reaches €7,16 billion. However, the profit for the OEM is merely €219 million, which, although similar to scenario 6, is €16 million lower than in comparison with scenario 5. The main cause of this drop is the improvement in monitoring performance, which reduces the demand for spare parts and maintenance service (see Figure 4.4 and Figure 4.6).

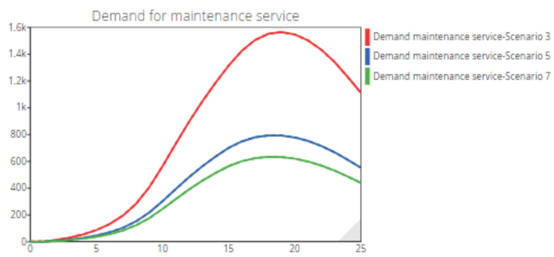

Figure 4.5 Demand for maintenance service

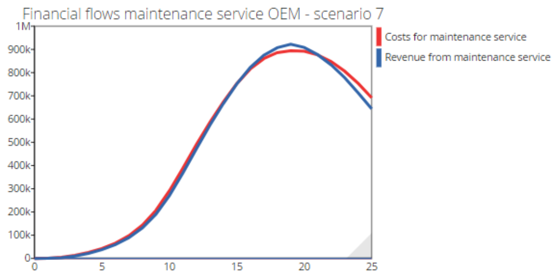

Figure 4.6 Financial flows maintenance service OEM - scenario 7

Conclusion

Through the scenario analysis we can conclude that the following three points.

1. Providing smart services is profitable for both the OEM and the customer

The model shows that adding smart service (monitoring service) is beneficial for both the OEM and its customer. By comparing scenarios 4-7 with scenario 3, we see that by providing monitoring service the OEM and its customer experience larger profits than just selling spare parts and maintenance service (see Table 4.1). To illustrate this, scenario 4 results in almost €50 million more by providing monitoring services, opposed to scenario 3 which solely covers maintenance services.

2. Smart services have a negative impact on traditional maintenance services

By comparing scenario 4 and 6 with scenario 3, we discover that providing monitoring service dramatically reduces the demand for spare parts (see the profits of selling spare parts in Figure 4.4). Moreover, by comparing scenario 5 and 7 with scenario 3, we conclude that providing monitoring service also has a negative impact on demand of maintenance activities. If the OEM provides a monitoring service with a higher performance, the negative impact on the demand for spare parts and maintenance activities will increase. If the benefits do not outweigh the costs for the OEM, a possibility is to change the acquisition structure for the AOs or increase the prices.

3. An integrated smart service requires a new payment model.

For the OEM the best situation is scenario 5, where the OEM provides an integrated service with monitoring and maintenance under the monitoring performance level of 20% of Type I error & Type II error. It generates a profit of €235 million over a 25-year-span, and can therefore be considered the most profitable scenario. Scenarios 6 and 7 are more beneficial for the customers, where they achieve the highest profit with a grand total of €7,15 billion. In these two scenarios, the monitoring performance level is increased and allows 5% of Type I & Type II errors at most. It is interesting to see that the OEM and the customer have different best scenarios. In this model, we assume that the OEM charges its customer separately on monitoring service and maintenance service, even when the OEM provides integrated smart services with a combination of monitoring and maintenance. This results in a situation where an improvement in monitoring performance is beneficial for the customer but not for the OEM. Comparing scenario 5 and 7 shows that an improvement in monitoring performance brings an increase in profit of 260 million for the customer, but a decrease in profit of 16 million for the OEM. Solely seen from the OEM's perspective, providing the advance service is not recommendable. But if we see this from a supply chain perspective, over €240 million becomes available. One of the solutions is to share the profit or cost between two parties. A new payment model that links incentives to performances is needed in case of an integrated smart service to ensure that all parties can benefit from the additional profit.

Disclaimer:

Values used in the model are not representative for any OEM or customer. However the model can be adjusted and the historical data can be applied to fit the specific situation in the participant company.

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Appendix

Sysdea Tutorial

The browser-based modelling application Sysdea is a suitable environment for developing a "micro-world". The modeller can share a link to the model with all interested parties. The recipients can then modify values in the "micro-world" and learn about dynamic behaviour which determines the outcome of the model.

The Sysdea app can be accessed here: link 1.

Useful tutorial videos that explain how Sysdea works can be found here: link 2 or here: link 3.

The Sysdea manual can be found here: link 4.

The application is relatively straightforward to use. Variables, stocks, flows, functions, charts and tables can be added by either right-clicking in the page or pressing the corresponding key-binds.

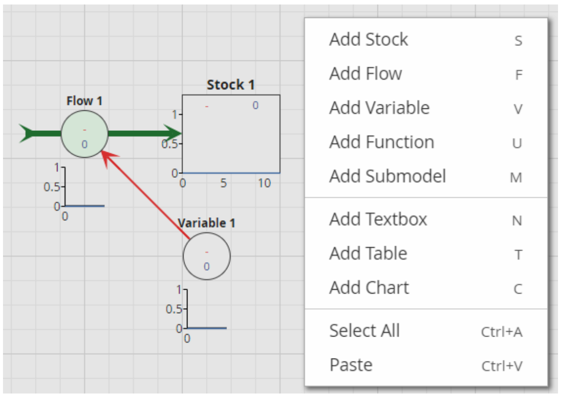

Figure 0.1 Model building in Sysdea

Stock variables

A stock denotes the level or rate at which a certain part of the system is on any given time period. Stocks accumulate through inflows and deplete through outflows. Every time period, the stock's new value is determined by the previous value plus the change from the last time period. An example for the maintenance model is the stock "Profit". The stock accumulates over time through the "Revenue" that is flowing in, however the "Costs" that are made are subtracted from the stock. The structure of the stock and flow can be found here.

In Figure 0.2, the behaviour of the stock "Profit" is displayed for a year. The initial value of "Profit" is 100.000. Every month, the "Costs" are fixed at 20.000. The "Revenue" is variable. As for the level of "Profit", it increases when "Revenue" exceeds "Costs", while it decreases when "Costs" exceeds "Revenue". Stocks do not necessarily have to be tangible or financial. Intangible concepts like customer satisfaction are also examples of stocks, as they are not solely based on other variables but stem from the 'memory' of the previous values, slightly adapted through new experiences.

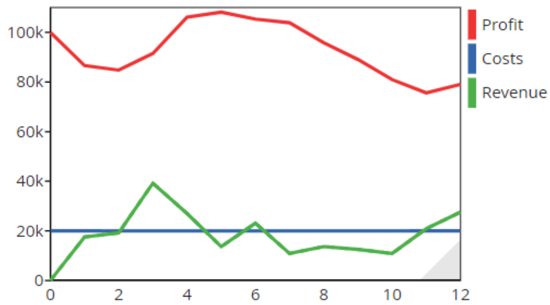

Figure 0.2 Stock-and-flow behaviour example

Flow variables

As previously mentioned, flows have a direct impact on the stocks. Every time period, a flow has a value impact on a stock. In the previous example, the height of the Revenue is "sketched" in this case, while the costs are fixed at 20.000. Normally, both costs and revenue are dependent on multiple factors. These factors can be determined by input variables or values that are not within the system's boundaries (in that case, the flow has either a source or a sink).

Input variables

Input variables are values that influence the model, but do not show the same behaviour as stocks or flows. Variables can either be constants or formulas. In the maintenance model shown in Figure 2.6, "Lead time" is (in this case) an example of a value. It has a fixed value and is not influenced by surrounding factors. A different example is "Maintenance tasks (CBM)". This variable is determined by the values of "Site-based team" and "Repair rate (CBM)" and the value can therefore change every time period.

In this small model about service contracts, the impact of variables and feedback can be seen in the height of the stocks "Customers" and "Profit".

Input variables have an impact on the flows that determine the height of the stock. If "Price per contract" increases c.p., the revenue increases and hence "Profit" increase.

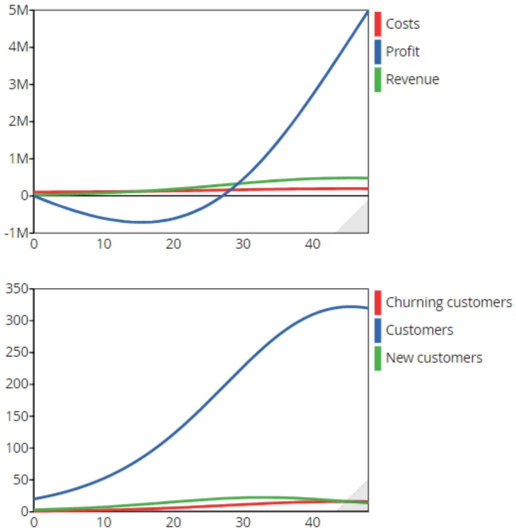

Figure 0.3 Profit- and Customer-trajectory

Connectors

Connectors or arrows are added to portray the causal connection between stocks, flows and variables. If a model becomes to cluttered, connectors can be removed to make the model more clear, however, it becomes more difficult to see the active connections.

Sensitivity analysis

A sensitivity analysis consists of running the simulation multiple times, while changing variables in the model, ceteris paribus (all other variables being equal). The results can be compared in graphs, which show the differences in outcome when certain variables are increased or decreased. Figure 0.4 shows an example of a sensitivity analysis.

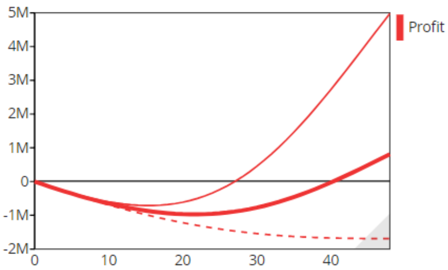

Figure 0.4 Example of a sensitivity analysis

The graph shows the outcome of "Profit" when "Churn rate" is slightly altered. The base-case ("Churn rate" = 5%) is displayed by the thin line. After nine time periods, the organization start to profit. Increasing "Churn rate" to 10% (dotted line) shows that through the first four years, the costs will always exceed the revenue. If "Churn rate" is set at 7,5%, "Profit" becomes a positive value after around 40 months. More information about creating these comparison runs can be found here.

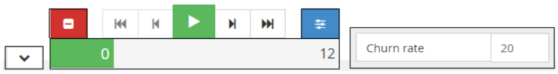

Figure 0.5 Comparison run menu

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