Part I
Introduction and Setting the Scene

Dynamics of Long-Life Assets: The Editors' Intro

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Abstract The manufacturing industry is changing. Driven by a number of concurrent trends, including economic and political development, technological breakthroughs and social connectivity, the impacts on industry in general are fundamental. Companies need to find ways to adapt to this change in collaboration with actors across their value networks. For long-life industrial assets, i.e., industrial product-service systems, both economically and environmentally sustainable solutions become an imperative supported by new business models-based collaborative value creation. In an EU-funded research project twenty organisations including three research institutes, four universities and thirteen companies studied, developed and demonstrated ways to deal with the dynamics of long-life assets. The main findings are summarised in this book. This chapter provides a brief introduction to the topic and presents the structure of the rest of this book.

Keywords Digitalisation · Business model · Industrial product-services system · Technology adaptation · Asset · Dynamics

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S.N. Grösser et al. (eds.), *Dynamics of Long-Life Assets*,
DOI 10.1007/978-3-319-45438-2_1

1 Introduction

Digitalisation transforms industries globally. Companies, products and people have become increasingly connected and constantly accessible regardless of time or location. Combined with new technology innovations this gives rise to completely new products and services capable of adapting to specific customer needs. However, the demand for fast delivery of personalised solutions cannot be met by traditional, rigid supply chain structures. Instead, agile supply networks of highly specialised companies are emerging, adopting new, innovative business models. The growing technological complexity and speed of development requires a high level of specialisation. This emphasizes the need for collaboration on research and development between relevant actors to complement gaps in knowledge and innovation capacity, and to share risk and resources, especially in small and medium sized companies (Romero and Molina 2011). In a recent survey (KPMG 2015), more than three-quarters of the respondents said that partnerships will form the basis of innovation for their company.

In search of efficiency and flexibility, firms are driven to both form vertical and horizontal alliances, which in turn require a more strategic approach to integration and networking (Rothwell 1994). This extends to new ways of sharing revenues through the value network. Enabled by the digital transformation, a new performance economy is emerging, shifting the focus from selling products and services to selling measurable outcome and results, a change that will redefine the base of competition and industry structures (World Economic Forum 2015). Technology platforms and ecosystems of partnerships will take over large parts of the current business in the near future. For instance, the emerging Industry 4.0 supplier ecosystem is expected to reach €420 billion in value and ICT-based services are expected to account for more than 75% of all industrial services, amounting to nearly €17.5 billion in revenues by 2020 (Frost and Sullivan 2015). Knowledge has been seen as an asset for coping with the increasing complexity of inter-organisational value chains. Thus, continuous learning within and between organisations has become a key strategic requirement for building and sustaining future competitiveness (Bessant et al. 2003).

In parallel with technological development there is a growing concern about human impact on the environment and the limits of the global ecological capacity. This has led to political decisions and global agreements aiming at reducing ecological footprints. Research into key enabling technologies, such as new materials and manufacturing technologies, help reduce ecological footprints and comply with tightening regulations to, for example, reduce global warming or the use of non-renewable resources. Closed-loop life-cycles and circular economy business models appear as a viable solution to reduce environmental impacts. The European Commission has adopted an ambitious Circular Economy Package, which includes revised legislative proposals to stimulate Europe's transition towards a circular economy (European Commision 2015). A prerequisite for circular life-cycle models is a shift from a business logic based on products as the main bearer value to models based on life-cycle value shared through the value network (Tukker 2013). This requires new forms of collaboration and focusing on product based services to create end user benefit.

An industrial product-service system (IPSS or IPS^2) is an integrated product and service offering that delivers values in industrial applications, characterized by the integrated and mutually determined planning, development, provision and use of product and service shares (Meier et al. 2010). The majority of companies that have adopted the concept of industrial product-service systems offer the use of a product, but not the ownership of the respective product (Guidat et al. 2014). In business models where user value is based on system outcome instead of ownership OEMs are more prone to design for total life-cycle cost, which in turn tend to lead to longer life spans and focus on sustainable solutions (Sundin and Bras 2005). This includes better end-of-life management but also the dynamic adoption of changing customer demands and improved provider abilities along the life cycle (Meier et al. 2010).

High-investment industrial product-service systems face new challenges in this dynamic and highly competitive business environment. Due to high initial investment costs such systems are usually designed for relatively long life spans. Sustainability goals call for further extension of system life-cycles. At the same time personalised, targeted solutions and improvements based on new technologies push in the opposite direction (EFFRA 2013). Extending systems life-cycles require careful planning and close collaboration with end-users to ensure both ecological, economic and technical sustainability. Processes for continuously improving IPSS need to match the specific IPSS characteristics and value network structures (Schweitzer and Aurich 2010). Continuous performance monitoring and information exchange processes need to be established case by case.

Innovation has been identified as the most important asset for creating business value. Focus has already shifted from the own R&D department as the main source of innovation to include other in-house functions, and is now extending beyond corporate borders to involve other actors of the value chain, including end-users and other stakeholders. In the future, innovation will depend heavily on emerging ecosystems. This, again, requires new forms of collaboration, which includes also competing companies.

Efficient strategies must be developed to upgrade legacy product-service systems to meet new requirements and enable economically and ecologically viable system life-cycles. This requires new ways of collaboration and a comprehensive approach building on the combined knowledge of the actor network, exchange of knowledge between researchers and practitioners, and learning across industry domains.

2 Future-Proofing Industrial Product-Service Systems

In July 2013, twenty organisations representing research and industry across Europe signed an agreement with the European Commission to undertake a research project focusing on upgrading of capital intensive product-services to meet future demands of efficiency, performance and fitness for purpose. The project called “Innovative continuous upgrades of high investment product-services” was funded under the European Commission’s seventh Framework Program theme [FoF.NMP.2013-5] *Innovative design of personalised product-services and of their production processes based on collaborative environments*, short named *Use-it-Wisely*, and was part of the Factories of the Future public-private partnership in 2009. Public-private partnerships (or PPPs) were launched by the European Commission (executive of European Union or EU) as part of European Economic Recovery Plan presented in 2008.

The general objectives of the Factories of the Future PPP are to (EFFRA 2013):

– increase EU industrial competitiveness and sustainability in a global world through R&I activities for the timely development of new knowledge-based production technologies and systems;
– promote EU 2020 targets of a smart, green and inclusive economy;
– support EU industrial policy targets (EC industrial policy communication October 2012); and
– underpin EU trade and investment policy.

To meet these targets, the Use-it-Wisely (UIW) project set out to develop tools and models to help industry deal with change. The project focuses on continual improvement of products and services through a continuous upgrade activity based on a comprehensive approach involving multiple actors in a collaborative effort to improve product and services through small innovative upgrade increments.

The project targets industries dealing with high-investment products and services in general, not limited to any particular industry sector. The definition of ‘high-investment’ is therefore more linked to the rate of return than on the absolute value of the initial investment. A common characteristic of such systems is therefore a relative long operational life-cycle. During their life such systems must be maintained and regularly upgraded to meet requirements that were not known or anticipated when they were first designed.

Tools and methods developed in the project were implemented and tested in six separate pilot cases representing different industries: power turbines inspection, machinery, space mission, manufacturing lines, shipping and office furniture.

3 Content of the Book

The book is organised in three main parts. Part I gives an introduction to the specific challenge addressed in the book (Chapter "The Challenge") and presents the foundations of the UIW-approach (Chapter "The Use-it-Wisely (UIW) Approach"). Part II goes into more detail in some of the key topics of the approach: innovation management (Chapter "Innovation Management with an Emphasis on Co-creation"), systems and complexity management (Chapter "Complexity Management and System Dynamics Thinking"), environmental impact (Chapter "Managing the Life Cycle To Reduce Environmental Impacts"), virtual reality (Chapter "Virtual Reality and 3D Imaging to Support Collaborative Decision Making for Adaptation of Long-Life Assets"), human-centred design (Chapter "Operator-Oriented Product and Production Process Design for Manufacturing, Maintenance and Upgrading"), virtual communities (Chapter "Fostering a Community of Practice for Industrial Processes"), and system modelling (Chapter "Extending the System Model"). Part III describes six actual use cases where tools and technologies have been implemented and tested in the six different industry clusters: Service inspections power plant turbines (Chapter "Collaborative Management of Inspection Results in Power Plant Turbines"), upgrade business models of mobile rock crushers (Chapter "Rock Crusher Upgrade Business from a PLM Perspective"), collaborative information management in space systems development (Chapter "Space Systems Development"), adaptation of high variant automotive production systems (Chapter "Adaptation of High-Variant Automotive Production System Using a Collaborative Approach"), actor collaboration in maritime passenger vessel design (Chapter "Supporting the small-to-medium vessel industry"), and sustainable furniture business based on circular economy (Chapter "Sustainable Furniture That Grows with End-Users"). Finally, different upgrade business models defined based on an analysis of the pilot cases (Chapter "Comparing Industrial Cluster Cases to Define Upgrade Business Models for a Circular Economy").

The chapters can be read independently but for understanding the concept of the approach is advisable to first read Sect. 1. References to relevant chapters inside the book will be given when needed. The book is linked to online resources maintained by the UIW-virtual community accessible at http://use-it-wisely.eu.

Acknowledgements The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement no 609027. The results are based on close collaboration between the 20 partners of the UIW-research project.

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The Challenge

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Abstract Industries involved in manufacturing and providing services for high-value, long-life products must address challenges related to upgrading their products once they are in operation. The aim of this chapter is to present some of those challenges, which have been addressed in the Use-it-Wisely (UIW) project using the tools and methods presented in this book. To outline these different challenges and how they are interrelated, an imaginary company is assumed, a European manufacturer producing high-investment equipment for customers worldwide. Their products are complex machinery with a long life cycle, and thus, an important part of the business is focused not only on manufacturing but also on inspection, maintenance, refurbishing, upgrading, and retirement. This chapter presents a brief description of its activities and business areas to highlight the main challenges that this company has to address in the current context of globalization, rapid change and high restrictions, together with other companies and stakeholders that define a value network. Finally, the chapter outlines how these challenges have been organized to discover key elements for addressing them. This organization is a result of the UIW-project.

Keywords Product lifecycle · High-investment products · Long-life products · Product upgrades · Product maintenance · Product reutilization · Customer involvement · System modelling · Business modelling · Technological support of collaboration

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S.N. Grösser et al. (eds.), *Dynamics of Long-Life Assets*,
DOI 10.1007/978-3-319-45438-2_2

1 Introduction

The Use-it-Wisely (UIW) Project gathers several important companies grouped into six industrial clusters, together with universities and other research institutions. They work in vastly different industries with the common goal of investigating new business models and opportunities based on innovative methods of managing continuous upgrades in different industrial product-service systems. These are high-investment, long-service-life, one-of-a-kind or highly customized products such as working machines, ships, trucks, power plant equipment, spacecraft or long-life furniture. These companies are facing important challenges due to global off-shoring, rapid business environment change, shrinking investment budgets, and environmental pressures (Schuh et al. 2011). These challenges can be addressed by creating added value by augmenting their products with agile knowledge-based, environmentally friendly post-manufacturing services. This was outlined in the Factories of the Future roadmap for Horizon 2020 (EFFRA 2013) and other platforms and networks focused on innovation in production, such as Manufuture (2006) or the Intelligent Manufacturing Systems (IMS) project (2011).

During the execution of the UIW-project, the industries involved worked together to describe common interests, visions and approaches to face the aforementioned challenges. Each of them has contributed specific solutions to their problems. Although these problems are specific, there are many commonalities that were captured during the UIW-project. To structure those contributions, we assume an imaginary company in which all these challenges are present. It is important to highlight that the challenges outlined are not the challenges of a single company. A whole network of stakeholders is implied in each of them, whose role is relevant. We have named this imaginary company "Eutopia[1] Ltd." and present these challenges in the next section.

2 Presenting the Challenges: A High-Investment Product Manufacturer

Let us imagine Eutopia Ltd., a global manufacturer based in Europe that produces high-investment equipment for customers worldwide. Eutopia is a large company with several thousand employees working in several plants in Europe and provides service to customers throughout the world. Its products are complex machinery with a long life cycle, and thus, an important part of the company business is focused on

[1]The name Eutopia is used as a combination of Europe and Utopia, from ancient Greek: "ou" (non) + "topos" (place), coined by T. More (and used as title of his book, 1516, about an imaginary island enjoying the utmost perfection in legal, social, and political systems). The word eutopia can also be understood from ancient Greek as "eu" (good) + "topos" (place). Eutopia would therefore be a desirable place to be, whether it exists or not.

the inspection, maintenance, refurbishing, upgrading, and retirement of their products as well as their manufacture. Its customers are companies running large facilities, which are subject to strict regulations and operate in a highly competitive environment with rapidly changing conditions. Moreover, many other companies provide products and services to Eutopia's customers, and collaboration and information sharing among them is necessary.

To be able to adapt to the high diversity and rapid changes in market conditions, Eutopia must tackle various problems in the entire product life cycle that involve different stakeholders and other associated companies that define a value network. The next paragraph summarizes these challenges.

2.1 Challenge 1: Involving Customers in Early Stages

Due to the high diversity of customer needs and the need to adapt to different environments, interaction with customers for ordering new units must be very flexible and allow a high level of customization. Moreover, some of the products produced by Eutopia are one-of-a-kind products specifically designed for one customer. Therefore, the company needs methods and tools for gathering high-level requirements from the final customers and enhancing the communication among all relevant stakeholders involved in the value generation process, including customers and other service companies.

Therefore, they must develop applications to enhance communication between stakeholders including customers because the first interaction is with them when a product is ordered. The basis of this system should be a product model that is built following a reference data model (meta-model) to store and interchange information about the product design, configurations, data for calculations and simulations. With this approach, the system could provide support for the initial choices among different design and configuration possibilities and associated prices. In Chapter "Space Systems Development", a similar challenge in the space industry, maintaining communication with the customer from the early stages in commercial space service development, is addressed.

This approach is so generic that this improvement in product modelling can serve as a standard for storing and interchanging any industrial information in multiple types of industries, e.g., large series, small series, or one-of-a-kind products (Eigner et al. 2014). Furthermore, Chapter "Extending the system model" describes extending the models to support different project activities throughout the product life cycle and maintaining control of system consistency.

2.2 Challenge 2: Factory Upgrading

A rapidly changing market leads to the necessity of continuously adapting and developing production systems (Lindskog et al. 2013). Therefore, factory upgrading as a mechanism to adapt to customer needs is another challenge Eutopia must address. However, modifying a manufacturing system requires complex plans and necessarily involves contributions from actors across the entire organization and beyond (Lindskog et al. 2016). All of the involved actors must collaborate and share a common understanding of the design, functions and performance of the current and future manufacturing systems.

One tool for supporting engineers in preventing mistakes and misunderstandings when working in redesigning an existing factory is virtual representation of products and manufacturing systems (Becker et al. 2005). Therefore, Eutopia is interested in developing applications to store technical information for the production system (3D models of the factory, live production data, etc.) and improving current work activities with a collaborative focus. Its goal is to improve the communication between actors from different departments to make technical decisions including positioning, allocation of work, maintenance, and planning of production-related activities using this information. Chapter "Virtual Reality and 3D Imaging to Support Collaborative Decision Making for Adaptation of Long-Life Assets" contains a more detailed elaboration of the use of virtual representations to improve understanding of existing systems and for facilitating collaboration and decision making in this context.

A particular challenge for a global manufacturer such as Eutopia is to harmonize and standardize the production processes within operations in multiple locations and markets to ensure best practices and the most efficient way of working. Hence, with virtual representations of their production sites, together with a rich collection of associated metadata, the upgrading process can be easily shared among different factories. This allows considering their multiple experiences to improve the collaborative decision making process that is required in modifying a manufacturing system. Chapter "Adaptation of High-Variant Automotive Production System Using a Collaborative Approach" presents an industrial case in a truck factory that addresses a similar challenge.

2.3 Challenge 3: Maintenance Management

Once the equipment is sold and in operation, periodic maintenance management is an important business area. Maintenance operations can be undertaken by Eutopia itself or through other service companies that are part of its network. Again, collaboration among the actors involved, which could include the customer, inspection companies, the manufacturer and other maintenance companies for repair or refurbishing depending on the inspection results, is a key challenge of paramount importance (Reyes-Lecuona et al. 2014).

In the case of inspections, the results for each unit sold that is in operation should be stored in Eutopia's information systems and linked to a product realization model built based on the aforementioned meta-model. There, all of the information relevant to the system context is identified and structured. In addition, it is necessary to develop collaborative applications to share and manage this information. Here, it is convenient to link all this information to the 3D geometry of the product.

This challenge has additional implications. In many cases, the product consists of a physical assembly of parts defining the product geometry. This assembly is usually hierarchical, with several levels of sub-assemblies. Maintenance work is usually focused on one sub-assembly or a specific part, and different maintenance services may be conducted different parts of the product or over an area or volume defined within the product geometry. Providing a user-centred design of the 3D interaction mechanisms is essential for a collaborative decision making tool (González-Toledo et al. 2015).

Chapter "Collaborative Management of Inspection Results in Power Plant Turbines" presents an industrial case in which a company working on inspections of power plant turbines addresses a similar challenge and a collaborative tool that has been developed to improve the decision-making process among the actors involved.

2.4 Challenge 4: In-Operation Upgrades Demanded by Customers

Once Eutopia's products are in operation, customers might require different upgrades to the equipment during its operating life, sometimes after a long operation time with possible unknown modifications. This is another challenge as well as a business opportunity. The challenge is to create modular upgrade solutions so that the same parts can be reused in many product models. The company must develop pre-engineered modules for these upgrades so it will be able to provide a machine upgrade service as a new business model [see Leino (2015) for a similar case description].

However, delivery of upgrade modules for physical assets in operation for a long time is not an easy task. It is necessary to build tools and methods to evaluate compatibility between upgrades and machines, prior to design, customization and delivery of upgrade offerings to customers. As the machine has possibly undergone modifications affecting its geometry after a long time in operation, it is necessary to track these changes to ensure that an upgrade module is compatible with a specific machine. This is not easy, as these products might not be under the producer's control after the sales process. In general, as in previous challenges, improvement of communication between actors is essential to interchange commercial and technical information as well as recording the actual state of each unit sold, including possible geometric changes.

Chapter "Rock Crusher Upgrade Business from a PLM Perspective" presents a similar industrial case in which novel digital technology is used to enable a new business model for upgrading old machines in the mining and construction industry. There, the innovative business model is based on clever engineering design solutions of the upgrade products and on digitalization of information flows for upgrade projects.

2.5 Challenge 5: Upgrades Driven by Changes in Regulations

There are many more reasons for upgrading equipment that is already in operation. Eutopia's products are subjected to strict regulations. Changes in these regulations, operational data, post-delivery inspections and surveys may lead to a decision that upgrading is necessary. In these cases, the actors involved in this process should have access to an information-rich technical metafile that includes all aspects of the product, including initial customer specifications, designs, trial data, inspection results, and required regulations that may change over time, necessitating an upgrade to extend the operating life of the product (Frangakis et al. 2014). Here, communication among different actors, including regulatory bodies, is essential.

Therefore, the upgrading process requires the company to develop tools and methods to improve the information flow and communication between actors and to exchange technical and legal information. The products should be transformed into meta-products that are accompanied by an information-rich environment.

Chapter "Supporting the Small-to-Medium Vessel Industry" presents an industrial case focused on the manufacture of small craft passenger vessels made of composite materials, which poses a similar challenge. This challenge is addressed by developing a set of tools that enables the storage of information on all aspects of a vessel's life cycle.

2.6 Challenge 6: Business Modelling Simulation and Innovation

Current rapid market changes force Eutopia to constantly generate new business models or adapt current business models to innovative ideas. To address these challenges, the company works on innovation management such as business model innovation using system dynamics simulation modelling (Groesser and Jovy 2016; Martinez-Moyano and Richardson 2013; Sterman 2000). Their objective is to produce estimations of costs and updates, thus following market dynamics in the context of increasing the duration of the life of the equipment in service. Such business model analyses allow the company to evaluate the effectiveness of various policy options under varying circumstances and to improve management decision-making.

In addition, such business model analyses could be extended with quantitative simulation models for estimation in the context of business model innovation (Rahmandad and Sterman 2012; Groesser and Jovy 2016). Simulating business cases in a systematic and reliable manner would allow for informed decisions to be made on which upgrades should be conducted.

Chapter "Complexity Management and System Dynamics Thinking" presents how to address this challenge using causal context models and how to extend them with quantitative models for performing estimations.

2.7 Challenge 7: Retirement and reutilization

Retirement of old equipment and reutilization of old components in new products is another challenge for Eutopia to achieve flexibility, adaptability, and modularity in its product designs as well as a high level of material reuse and hence sustainability. To achieve high levels of returned material, a new business model should be developed through new product-service strategies based on the Circular Economy (CE) paradigm (Tukker 2015; Lieder and Rashid 2016). In addition, Eutopia must respond to constant market developments and adjust their products, services, processes and business model while accounting for the required sustainability and flexibility of products. In this context, one question is how to retain the highest value of its investments.

To address this challenge, Eutopia has developed a causal context model (Groesser 2012) in which different variables and their relationships are identified (see Chapter "Complexity Management and System Dynamics Thinking"). The causal context model builds the foundation for a simulation-based business model analysis that can be used to simulate the effects of important business model decisions. This is done using a business simulator based on system dynamics modelling to reflect its product and service portfolio using CE scenarios.

Further, the company's approach is to develop a CE Check to support a modular, adaptable product design, creating the possibility of adapting (by upgrading, retrofitting or remanufacturing) the product while in use at the customer site, to prolong the lifespan of the product and meet changing final customer needs. A special focus is on modularity aspects that support the re-use of parts within and between product lines.

Chapter "Sustainable Furniture that Grows with End-Users" presents an industrial case in which this challenge is addressed in the context of sustainable furniture production.

3 Addressing the Challenges

The challenges we have presented as those faced by Eutopia Ltd. can be structured in a generic model around the upgrade initiation process. To manage and address these challenges, we can differentiate them into three domains: (1) innovation management and business models, (2) collaboration and data visualization, and (3) Actor-Product-Service modelling. Figure 1 shows the three domains related to the upgrade initiation process.

Market and data analysis using business forecasting models and tools can, from a strategic decision, initiate the upgrade of its product/service or business model. This decision can be supported by business simulation, made by management directly or be the result of a collaborative process to analyse simulation outputs. As an example, a simulator application could be used to study new product-service strategies based on the CE model or to allow the customer to be informed of the costs involved in different possible upgrades. In both cases, the outputs of these simulators will be the base upon which to choose what upgrades should be initiated.

The decision to initiate an upgrade could also arise from technical analysis of the situation. Collaboration management via models and applications that support this collaboration and the knowledge of product status through enhanced visualization can also drive an upgrade decision. As an example, a collaborative application that includes discussion management could help technicians to determine when initiation of an upgrade is necessary.

Both sources for an upgrade decision, based on strategic market estimation or the result of collaborative technical work, should rely on effective Actor-Product-Service models and tools to support decision making. These three domains are described in more detail below:

- **Actor-Product-Service Modelling domain**. Company applications must handle large amounts of information from different sources (3D scan data, CAD models, ad hoc process databases, etc.) A reference meta-model would provide a set of rules to develop specific Actor-Product-Service Models. This meta-model would contain recommendations on how to model information on product and services so that interfaces between different formats and tools are easier to maintain. Information about customers and other actors in the value network can also be included. This meta-model is general enough to serve as a standard for storing and interchanging any industrial information in multiple types of industries.
- **Collaboration and Data Visualization domain**. As noted in the previous section, a recurrent challenge is to improve the communication between different actors involved in the life cycle of products or services. To that end, several methods and tools might be implemented inside the collaboration management domain. These tools would be focused on enabling information flow, promoting collaborations in technical developments, and providing an easy and efficient method for making decisions. As mentioned before, the Actor-Product-Service model organizes all of the information related to the

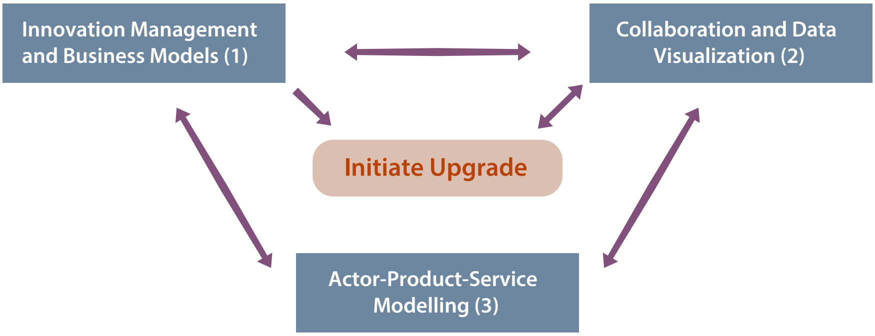

Fig. 1 The three UIW challenge domains and their relationship with the upgrade initiation process

product/service. This information can be used by the applications contained in this domain to offer: a collaborative environment (in which many actors can interchange technical, legal and commercial information), decision making support (providing a discussion management mechanism) and visualization of the product/service (using 3D models and specific diagrams). The collaboration management domain has two roles. First, this domain can work as the upgrade originator. In this case, actors use the collaboration management tools to study the problem and decide if it is worth initiating the upgrade or not. Second, this domain appears when an upgrade has been initiated and different actors must make technical decisions regarding modifications to the system of interest.

- **Innovation Management and Business Modelling (market and data analysis) domain**. Some of the aforementioned challenges require producing applications and models to perform predictions in the context of business innovation in a systematic and reliable manner to subsequently make decisions about which upgrades should be carried out. To model applications related with the market and data analysis, some generic structures must be defined (Lane and Smart 1996; Lane 1998; Paich 1985; Ulli-Beer et al. 2010). Some of these generic structures, which are basic structures of System Dynamics models, were created during the UIW-project. First, generic business model structures include major business elements with generic values. Then, using an inductive process, other generic structures can be extracted from causal context models. These generic structures should illustrate a basic understanding of upgrading and its effects for the company as well as for the users of upgradable assets. Generic structures are the first element of any System Dynamics model and allow practitioners to model their own upgrading challenges using the generic structures as a stepping stone for a more specific model applied to their challenge (Groesser and Jovy 2016).

4 Conclusion

This chapter introduced the main challenges that companies involved in producing, maintaining, and operating high-investment, long-life products must address due to global off-shoring, rapid business environment change, shrinking investment budgets, and environmental pressures. It is the result of an analysis conducted with the industrial partners of the UIW-project and has been presented as the unified story of an imaginary company, Eutopia Ltd. The idea behind this chapter is to present the challenges that have been addressed during this project in developing and testing new tools, methods and business models that build the remaining elements of the book. Companies with similar needs to those presented here as Eutopia's challenges could discover that the tools and methodologies presented in the remainder of this book are applicable to their business.

To address these challenges, actors should be involved in a collaborative process for producing upgrade innovations. In the next chapter, a generic framework for managing these system upgrades is formulated. This framework goes beyond the three-domain model outlined here and is designed to address the challenges presented in this chapter using an adaptation mechanism to manage factors influencing the upgrade design, a system model definition that integrates actor, product and service data, and a virtual collaboration environment to facilitate the interaction between actors.

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The Use-it-Wisely (UIW) Approach

Göran Granholm and Stefan N. Grösser

Abstract Industrial products and services must be continually upgraded to meet changing demands of enhanced functionality and performance. The digital transformation of industry, together with new emerging technologies, enables improved solutions but at the same time cause increasing complexity and interdependence between system components. New forms of collaboration across the value chain are necessary to deliver sustainable solutions to satisfy current and future needs. The UIW-approach builds on the idea of a continuous incremental upgrade process carried out in collaborative effort between actors and stakeholders with the common objective to achieve a sustainable project life-cycle. Based on this approach a conceptual framework is defined. The UIW-framework includes an adaptation mechanism designed to account for the diverse influence factors affecting the upgrade design, a multi-disciplinary system model definition integrating actor, product and service data, and a virtual collaboration environment to facilitate the interaction between actors and a collection of tools and methods to support the collective efforts. The UIW-framework is used as a template for system implementations in installations in various actor networks.

Keywords Industrial product-service system · Collaborative innovation · Innovation network · Circular economy · System upgrade · Business model · Systems engineering

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S.N. Grösser et al. (eds.), *Dynamics of Long-Life Assets*,
DOI 10.1007/978-3-319-45438-2_3

1 Introduction

The speed of technological development in concurrence with global economic development and short-term market volatility force companies to find new strategies to compete in the marketplace. The competitiveness of manufacturing firms will be increasingly linked to their ability to rapidly transfer developments in science and technology into their processes and products as well as adopting ideas developed both internally and externally (UNIDO 2013). Foresights of future markets and operating environments (Müller and Müller-Stewens 2009) become crucial when making decisions about investments in innovation and R&D of products and services that need to create value in the long-term.

The digital transformation of industry is profoundly changing the manufacturing of products, provision of services and structures of value creation in general and of individual businesses in particular. Advances in wireless communication combined with embedded sensor and computation technologies have changed the way humans and machines interact, shaping the concept of cyber-physical systems (Rajkumar et al. 2010). At the same time increased awareness of the effects of human activity on the environment has become an important factor affecting the design of new products as well as upgrade solutions. New business models based on the circular economy vision are being adopted in order to minimise waste and save resources through efficient reuse of material (Parker et al. 2015). A common denominator of much of the current development is the need for closer ties between the involved actors. This is driven both by the growing demand for customised products and services, and the increasing complexity of technical systems requiring cooperation between large numbers of experts and sub-contractors. To stay ahead in the competition, companies increasingly turn to innovation-led strategies and focus on improving R&D efficiency and value (OECD 2015). In a complex and highly interdependent business environment innovation involves a wide range of actors, including firms, entrepreneurs, foundations and non-profit organisations, universities, scientific institutes, public sector agencies, citizens, and consumers, often working in close collaboration. Managing this collaboration becomes an important target (see also Hurni and Groesser, Chapter "Innovation Management with an Emphasis on Co-creation" in this book).

1.1 System Obsolescence and Decay of Use Value Require Change

Systems are designed based on available knowledge to fulfil current and future needs. The objective is to produce value during the system life-cycle to cover investment costs and profit expectations. To sustain their value when markets and user needs change, products and services need to be continually maintained, upgraded and improved. High-investment assets with long payback periods, e.g., a production system for a car manufacturer, can provide specific challenges as complete replacements are infrequent and the value of using the system (use value) might become significantly reduced. The capability of suppliers to retain or increase the use value of the asset throughout its planned service life becomes an important, perhaps even decisive, factor for customers' investments decisions.

All technical systems will face a gradual decay of their use value over time. This value degradation is due to both internal factors, such as wear and tear leading to increasing maintenance costs and interrupted operation, and external factors, such as changing market demands, new technologies, and alternative solutions. A further external factor is component obsolescence, i.e., the redesign required as replacement components become obsolete. To account for such obsolescence, systems undergo major upgrades (Engel and Browning 2006).

Technical solutions are often designed to meet current requirements without emphasizing enough that systems inevitably evolve with time (Schulz and Fricke 1999). Moreover, factors that are difficult to measure or deal with are often neglected due to time or cost pressures. Fink et al. (2004) have identified three main traps to avoid when planning for the future: (1) suppression of uncertainty, (2) suppression of complexity, and (3) suppression of change. Avoiding dealing with difficult issues may speed up decision making, but does not eliminate risk, and shifts more difficult decisions to a later point in time. Thus, delaying decisions makes it impossible to manage risks in a systematic and effective way.

Investment decisions have to be made based on information about the future that is inherently uncertain. Managing risk and uncertainty associated with design solutions requires considerable effort. Systems thinking and tools for modelling complexity and causal dependencies (e.g. Anderson and Johnson 1997) may be used to help strategic planning and management by building a common understanding of the implications on the design task and possible future developments (see also Groesser, Chapter "Complexity Management and System Dynamics Thinking" in this book).

1.2 Adapting to Change in Markets and Environment

Companies need well-defined strategies to ensure effective adaptation to change. According to Schulz et al. (2000), the major drivers of future development are marketplace dynamics, technological evolution, and variety of environments. Marketplace dynamics can be observed as new markets emerge and existing ones change or converge with others. On the supplier side, new actors appear introducing new offerings, often by employing new, most often digital, business models. On the customer side demands for individualised solutions call for a higher degree of responsiveness and customer adaptation, which in turn require increased agility of design and production processes. Fast technological evolution brings up new opportunities, but also introduces challenges when system life-cycles are longer than the life-cycles of technologies that the systems are built on. This is especially the case for industrial product-service systems (IPSS) (cf. the definition in Chapter "Dynamics of Long-Life Assets: The Editors' Intro" of this book), and leads to increasing maintenance costs and expensive upgrades replacing old technologies with new ones. Variety of environments refers to the increasing variety and complexity of technical systems where individual components must be able to adapt to operate as part of different system compositions, i.e., systems of systems (Schulz et al. 2000).

Changes to end products frequently also require changes to the production lines and manufacturing systems, while service changes may require adopting new business models. Thus, changeability requirements may have to target simultaneously the product or service, the way it is manufactured, and the complete value network delivering the value added. Sharing of tasks and resources across various forms of collaboration networks can provide improved capacity to change due to smaller, more agile operators and flexibility of the collaboration network itself. Efficient operation of the supplier network requires a flexible information architecture that supports decentralized collaborative processes (Gunasekaran et al. 2008).

In order to meet future change demands, changeability features must be premeditated and built into the IPSS. Different technological approaches have been developed for this purpose. A quantitative method to model adaptability cost and value fluctuations of given system architectures has been proposed by Engel and Browning (2006).

In parallel with system properties that allow for future change, a streamlined process to support effective adaptation is required to achieve agile adaptation. Companies are increasingly moving from linear product life-cycle process with decoupled supplier and customer views (Fig. 1) to an integrated product-service life-cycle based on a continuous collaboration between actors (Fig. 2).

In the linear product-based process ownership is handed over in a delivery-acquisition transaction, which causes a disruption in the flow of product life-cycle data. This can be due to incompatibility between product data management systems or practices, or because of unwillingness to share data between customer and supplier organisation. In addition, direct personal communication and

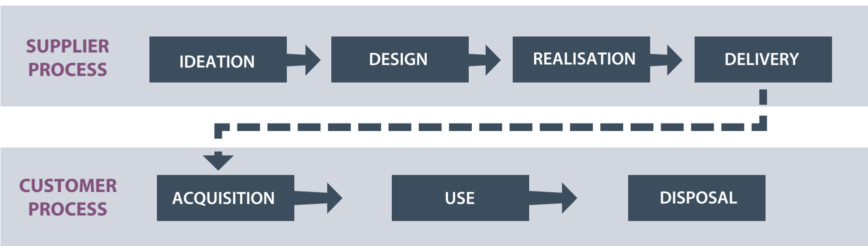

Fig. 1 Linear product life-cycle process with decoupled supplier and customer views

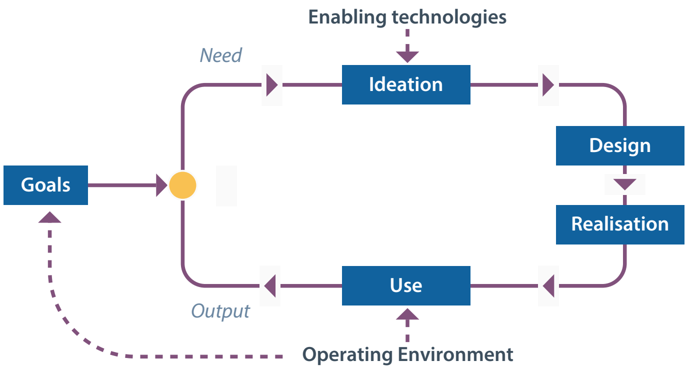

Fig. 2 Integrated customer-supplier product-service life-cycle process

exchange of tacit product knowledge between individuals across company borders is reduced in a life-cycle product model.

Figure 2 shows an integrated collaborative product-service life-cycle process. The main aim of the supplier is not to maximise profit in a single product delivery but to deliver end-user value, for instance as guaranteed up-time or system output. This requires business models focused on the sharing of revenues between the actors contributing to generating the output. As such models are typically based on service provision instead of transfer of ownership, delivery and acquisition sub-processes have been removed. Focusing on end-user value instead of product value creates a shared interest among the actors to maximise the output and to reduce life-cycle costs. This motivates systematic maintenance and continuous adaptation to change: alterations in the operating environment, such as increased production cost, changed market demand and new competition, force the user to set new business goals. The gap between current output and the new goals creates a need to modify the system.

The integrated collaborative product-service life-cycle process model builds on sharing of data across the actor network. Ideally all life-cycle data is accumulated in a shared database. The information on change in system status as well as changes in operating environment or user needs are available as input for successive system updates. This requires closer ties between customer and supplier, and provides a basis for defining structures for networked collaboration for continuous adaptation of industrial product-service systems.

1.3 The Use-it-Wisely Project

The Use-it-Wisely (UIW) research project focuses on continuous upgrade of high-investment industrial product-services (IPSS). The goal of the project was to develop an approach to support systematic adaptation to changing needs by developing business models and technologies to support collaborative efforts to sustain and improve high-investment IPSS. This chapter describes the research methodology used and the fundamental principles of the approach.

1.4 Structure of the Chapter

The chapter is divided into four parts: the introduction in Sect. 1 describes the background including the need and main drivers behind the Use-It-Wisely project idea. Section 2 describes the research methodology applied in the project. Section 3 discusses the main principles of the approach. Section 4 presents an outline of the solution nurtured with brief introductions to six pilot cases.

2 Research Methodology

The research was based on a continuous dialog between theory and practice. Theoretical knowledge and science-based methodologies were applied to analyse actual pilot cases. The project took place from September 2013 until November 2016. Feedback and results from practical implementation and testing was recorded and analysed. Six different industries were included in the research, each with a different upgrade case. The gradual progress of the pilot cases was presented and discussed in ten meetings and several workshops within the project. Sharing information and experience between seemingly unrelated pilot cases from different industries served to identify similarities especially in the problem space. The research setting was based on the assumption that creativity is fostered by exposure to groups of people with apparently unrelated tasks and knowledge. This assumption is supported by numerous studies showing that people connected across groups are more familiar with alternative ways of thinking and new ideas emerge from selection and synthesis across the structural holes between groups (Burt 2011). The following outlines the research setting and the research process applied in the UIW-project.

2.1 Research Setting

The focus of research was the transition from a linear product-service delivery process to an integrated, continuous process of small-step incremental upgrade innovations based on close collaboration within value chains. The research hinges on two basic assumptions: small upgrade increments and actor collaboration. The reasoning for both is presented in Table 1.

Table 1 Rationale behind the main research assumptions

Assumption	Rationale
Small upgrade increments	Reduced financial risk due to smaller investment Reduced technical risk due to smaller changes Shorter disruptions Shorter implementation time leading to faster response times and enhanced upgrade agility Reduced environmental impact due to extended use of major system parts
Actor collaboration	Important system knowledge exists outside of the corporate borders, on multiple levels System defect, deficiencies and changing user needs are communicated directly and proactively across the network Sustained actor involvement leads to deeper engagement and firm actor networks, building trust and loyalty between partners

Table 2 Industrial clusters included in the study and their primary research target

Cluster	Industry sector	Primary research target
1	Energy production	Turbine service inspection
2	Heavy machinery	Upgrade service for mobile rock crushers
3	Aerospace	Integrated system data management
4	Automotive	Production line configuration
5	Shipbuilding	Value chain collaboration
6	Furniture	Circular economy business model for office furniture

To ensure a wide applicability of the results, companies from six different industries were included in the study: energy production, heavy machinery, aerospace, automotive, shipbuilding and furniture. For each of the six industries, a cluster was formed, consisting of two to four organisations representing parts of the value network. One organisation responsible for technical and scientific research was included in each cluster. The clusters defined their own use cases based on identified needs or foreseen business potential. The use cases included specific research targets including maintenance inspection, upgrade service development, model-based systems engineering, and circular economy. Table 2 presents the industry sector and primary research target of the six clusters. The cluster cases are presented in more detail in Section III of this book.

We included these industries not because of their differences, but because of their commonality. Common between the six industry clusters and their use cases was the focus on IPSS. Another commonality was that the product-services could be classified as "high-investment", at least in relation to the size of client businesses, or to the expected rate of return on investment in the system. This definition of high-investment product-services implies relatively long life-cycles, due to long repayment periods and relatively small financial assets available for complete system recommissioning. In some cases, the push towards long life-cycle solutions was due to potential risks and complications associated with complete system replacement, such as incompatibility with connected legacy systems or unacceptably long service disruptions. The need to further extending life-cycles could also be caused by environmental motives, driven by user requirements or societal push. Inherently long system life-cycles and the push for further life cycle extension motivate the need for repeated system upgrades.

Within each cluster the viewpoints of a broad range of actors, such as design engineers, service personnel, sales staff, managers, decision makers, and end users, were taken into account to create comprehensive systems views. The broad scope of the study allowed for applications supporting both a horizontal integration, i.e., through the life-cycle, and vertical integration, i.e., “shop-floor to top-floor”. In addition, the collaboration between research and practice as well as between seemingly unrelated industries proved beneficial and provided new viewpoints to identified problems (Fox and Groesser 2016). This observation is in line with previous research supporting the hypothesis that good ideas emerges from the intersection of diverse social worlds, i.e., across “structural holes” in knowledge networks (Burt 2011).

The research setting, including the six industry clusters, different research targets and multiple actor viewpoints, provided the material to study applications on two different levels: first, on a generic level to analyse commonalities across the clusters and conceptually develop the UIW-approach for dealing with shared issues. And second, on a cluster-specific level to analyse individual use cases to provide bespoke solutions based on the tools and methods of the UIW-framework. This two-level approach was designed to ensure the applicability and practice-orientation of the UIW-approach and the transferability of specific solutions to other industries facing similar challenges.

2.2 Research Process

The research followed an iterative approach. The cluster cases were analysed to identify specific challenges and business opportunities and to extract commonalities. The goal was to apply a holistic approach to discover latent mechanisms and causal dependencies that could affect the outcome of introduced change, and eventually the success of suggested upgrades. Rich pictures were used to facilitate communication between actors on different levels and to create a shared view of the target case. Business perspectives were analysed using causal context models and system dynamics (SD) modelling to be able to identify influence factors and causal relationships (see Groesser, Chapter “Complexity Management and System Dynamics Thinking” in this book).

In successive iterations analysis was refined and tools for further enhancing collaboration and data management were developed. Virtual and augmented reality techniques were selected to develop collaboration applications facilitating communication between various actors. To deal with upcoming research or development issues of interest across clusters, dedicated task forces were set up as needed.

The topics of these task forces ranged from overall system architecture and implementation mock-ups to data modelling, simulation and use of individual software tools. The task force concept provided improved agility to work in a result-oriented way on defined topics on their own schedule. The iterative approach applied in the project enabled a continuous interplay between conceptual and empirical methods. It also facilitated a continuous collaboration between researchers and practitioners in different stages of development.

The results of the iterative development process were collected and reported by each of the clusters. The generic tools and methods used for the analysis of the use cases and the experience from applying specific technologies in the implementation of technical solutions targeting concrete development needs were collected to form the foundation of the UIW-approach to support innovative upgrades of high-investment product-services. The final stage included a sequence of on-site demonstrations of the pilot cases. The final UIW-approach is described in detail in Sect. 4.

Figure 3 shows the research process covering areas of theory and research, cross-domain collaboration and knowledge creation, and application in specific industry networks.

The research covered three main areas of activities: research (A), collaboration (B), and application (C). Research activities targeting the general approach (A.1) deal with the basic, theoretical foundation of UIW and strived to ensure that methodologies applied in various activities are founded on scientific evidence. They also aimed to facilitate the transfer of new knowledge to practice. The principles of the general approach are presented in Sect. 3. Based on relevant general research topics, a number of focus areas were selected (A.2) to support the development of shared knowledge, tools and methods (B.2) and to populate the Use-it-Wisely "tool box". Current focus areas and corresponding tools are described in Section II of this book. A community of practise (B.1) consisting of project partners was engaged with collaboration across industry and between research and practice. The community maintained collaboration across selected focus areas and contributed to developing shared knowledge and tools (B.2). With the help of the community of

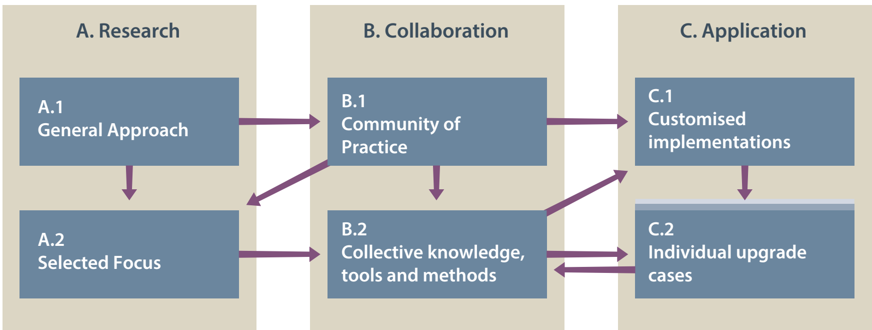

Fig. 3 Research process for the UIW-project

practice and the generic tools and methods were customised and implemented to meet the needs of specific actor networks (C.1). The adapted tool-box was then used in individual upgrade development cases (C.2).

3 Principles of the UIW-Approach

In the following, we introduce six principles which provide a foundation for the UIW-approach.

3.1 A Holistic System View

Transitioning from a product-based economy to models based on provision user value or output requires new forms of collaboration. Instead of focusing on revenues from individual sales transactions along the value chain service-based models must find ways to maximise total end-user value. This requires a thorough understanding of the business drivers and implications of both the end user and of the contributors in the value network. It also requires an understanding of the technical components of the system and of new emerging technologies that may impact future system implementations, markets and competitors. Making the right decisions with regard to system design, upgrade interventions and business model development must be based on a holistic systems view. Creating and evolving a comprehensive, shared view requires the combined efforts of the involved actors. Various tools can be used to model causes and effects of alternative decisions. These are described in more detail in Chapter "Complexity Management and System Dynamics Thinking" of this book.

3.2 Continual Improvement

The principle of continuous improvement has gained much attention since Imai introduced the approach called Kaizen (Imai 1986). This approach focuses on efficiency based in the identification, reduction and elimination of sub-optimal processes based on continuous and immediate feedback. However, continual improvement of all aspects of a firm's activities is necessary for meeting the challenges of evolving environments and changing customer needs (Bessant and Caffyn 1997). This includes the capability to continually renew and improve product and service offerings. To enable continuous improvement organisations need to manage their innovation process effectively and make sure that it is fed with a constant steam of good ideas and solutions (Brennan and Dooley 2005).

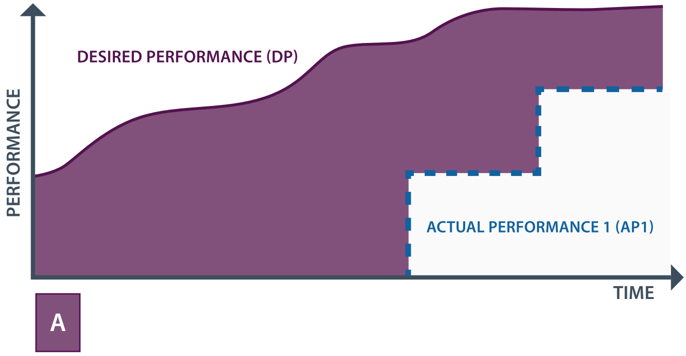

Fig. 4 Meeting increased performance demands through discrete upgrade increments

The idea behind a continual upgrade strategy is to initiate and implement relatively small but frequent change increments to minimise the gap between customers' desired performance and the actual system performance (Fig. 4).

Figure 4 shows two curves: desired performance (DP) and actual performance 1 (AP1). DP is the performance of an IPSS as desired by the owner or user of the IPSS. This performance increases over time in waves. Reasons are new technological developments or new demand and requirements of final customers. AP1 is the performance the current installed IPPS can provide. AP1 is improved by two stepwise increments. The decision to improve the actual performance, i.e., the decisions to upgrade the assets by investing depend on multiple factors; for example, ease of upgradability of the asset, the direct cost and benefits of upgrading, and the (more indirect) potential loss in customer and market share, if the IPSS is not upgraded. Figure 4 shows a large area A which represents the "area of loss" due to not upgrading frequently. In the figure, it is assumed that the two upgrading increments cannot improve the performance to the latest DP but that there is a significant gap.

With the UIW-approach, the IPSS can be upgraded more frequently as Fig. 5 shows. The objective of the UIW-framework is to minimize the area of loss, i.e., the area between the DP and actual performance by using continual, i.e., more frequent and smaller improvements. As Fig. 5 indicates, AP2 is much closer to DP as AP1. The previous "area of loss" A could be reduced to the area A'. In other words, the UW-approach aims to avoid the loss of area B.

3.3 Integrative Flexibility

Due to the continuously changing settings and the variety of networks firms will have to be involved in, it is not possible to develop a fixed solution capable of meeting all needs. Therefore, the solution must be flexible. It must be capable of adapting to various scenarios and it must be capable of evolving over time.

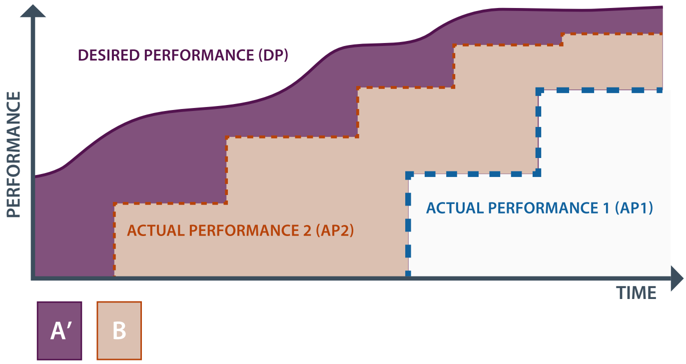

Fig. 5 Meeting increased performance demands through more frequent discrete upgrade increments

The UIW-approach is aiming to serve a wide range of industries and diverse upgrade needs. The approach is by design generic to provide sufficient flexibility to adapt to different use cases and scenarios in manufacturing industry at large. The tools and methods described in the approach are selected to serve a variety of user groups in each application case. This is necessary to enable actors across the value network to contribute effectively to the upgrade process bringing in knowledge and experience beyond what is available in traditional R&D teams.

The UIW-approach is also designed to cover a broad range of functions, including business development and decision making, engineering data management and life cycle support. Thus, it supports an integration of functions both horizontally across the life-cycle and vertically "from shop-floor to top-floor".

3.4 Collaborative Innovation

The capacity to innovate determines a firm's capability to survive in the global competition and meet the challenges of changing markets. In search for competitive strength firms have developed new strategies involving external resources in product design and customer adaptation. This is based on the insight that important knowledge about the product, and especially of its use, resides outside of the corporate boundaries.

End-user collaboration is frequent in consumer products and services where users are asked to provide feedback on designs, or mobilised in collaborative ideation about future products or services. This goes beyond traditional requirements management processes based on an elicitation of user needs and specified sets of requirements. Hienerth et al. (2014) have studied the efficiency of user vs. producer innovation and found that even an uncoordinated group of users can be as or more efficient than the specialized producer innovators. Companies can also seek increased innovation capacity in collaboration with each other. However, collaborative innovation is more common in radical innovation than in continuous improvement (Chapman and Corso 2005).

The need for increased collaboration across the value network is also a direct consequence of the shift towards a service-dominant business logic where value is determined by the consumer and produced as a collaborative effort of the value network (Vargo et al. 2008). Opening parts of a firm's innovation process to external actors is a strategic decision with important implications on, for instance, operational cost, value and knowledge creation, intellectual rights management. The decision should therefore be guided by careful analysis of technical and financial viability of different types and levels of collaboration. However, open, collaborative innovation models are fundamentally different from traditional organisation centred ones especially with respect to where in the network knowledge is accumulated and innovation created (Lakhani et al. 2012). This requires a new mode of thinking where shared knowledge is regarded as a competitive advantage of the collaboration network instead of a strategic in-house asset.

3.5 Sustainability

Increasing awareness of human activities on nature as a global habitat, as well as the depletion of natural resources has put increasing pressures on manufacturers to ensure environmental sustainability of their products and services. The requirements are enforced by public opinion driving market forces, and by international treaties and legislation. As a result, sustainability turns from a cost driver to an opportunity for companies leading the development.

The trend of sustainable product development is shifting from reduce, reuse and recycle to include also recover, redesign and remanufacture, and leading to the implementation of multiple generation life-cycle products (Go et al. 2015). This defines a transition from linear life-cycle process to a process based on a circular economy (Ellen MacArthur Foundation 2013). More details can be found in Pajula et al. in Chapter "Managing the Life Cycle to Reduce Environmental Impacts" of this book.

Environmental sustainability is a driver for new products and markets based on new environmental friendly technologies. On the other hand, sustainability goals also motivate life extension of existing systems (EFFRA 2013). Thus, sustainability improvement becomes an important upgrade objective.

Extending operational life cycles contribute to ecological values by postponing energy- and material-intensive system renewals, provided that the system can be operated in an environmentally sustainable manner.

3.6 Model-Based Engineering and Data Management

The growing complexity of technical systems calls for high levels of specialisation. Complex, interlinked systems of systems (SoS), therefore, have to rely on a close collaboration between a large number of actors across the value chain. Managing complex engineering processes involving multiple actors requires a systematic approach and efficient data management. The quantity of system documentation generated over the life-cycle of complex engineering artefacts quickly becomes unmanageable for human operators and may lead to design errors, expensive rework and added risk. Model-based systems engineering (MBSE) approaches aim to reduce and eventually replace document-centred system data management. Transitioning from human-readable text based information to model-based representations makes it possible to automate design tasks and ensure data consistency. Human readable (e.g. graphical) system modelling notations may also help communication across diverse design disciplines and between actors with different native languages (Vitech Corporation 2011). System data must also be managed in a reliable way while ensuring security and confidentiality of sensitive data from various collaborating parties. Chapter "Extending the System Model" of this book deals in more detail with the question of system modelling in complex design environments.

4 The UIW-Approach Supports Continuous Upgrades

To deal with the challenge of meeting the changing needs of an increasing group of customers requesting personalized solutions and life-cycle support, a generic approach for managing system upgrades of IPSS has been developed. The purpose of the approach is to facilitate a life-long upgrade process of IPSS aiming to extend the profitable service-life by enabling continuous adaptation to changing requirements. The approach combines theory knowledge, best practice and supporting tools and technologies.

The underlying idea is that successful IPSS upgrades require a comprehensive approach where the design of individual upgrade steps is not only based on single customer needs and feasibility analysis, but on a holistic understanding of the system in relation to the dynamic environment. This requires capturing extensive system knowledge form a wide spectrum of actors, including customers, end users, designers, operators, and marketing staff. The approach combines this comprehensive system knowledge with theory knowledge of experts with access to relevant tools, methods, and technologies for system analysis, decision making and process support.

The UIW-approach supports a collaborative innovation and design process in which each upgrade step is based on close interaction and knowledge sharing between involved actors. Through this collaboration, knowledge about the systems performance as well as changes to the operating environment, market changes, and other external factors are systematically collected and shared. At the core of the collective knowledge base is a generic representation of an upgrade innovation process (Fig. 6). The process supports collaborative and concurrent upgrade innovation. Collaborative innovation involves engaging actors, such as workers, designers, end uses, managers and sales staff, in a collaborative effort to solve identified problems. In the first phase problem solving involves identifying problems and their root causes, and finding possible solutions through creative ideation. The purpose of the ideas is to take the system from its current state ("as is") to a desirable future state ("to be").

The collaborative ideation produces ideas and suggested solutions to transform the system from the current state to a desirable future state. The proposed solutions are tested in the analytic cycle using simulation and analysis tools. The results of the simulations may show that the ideas are insufficient to transform the system to the target state. The discrepancy between the target future state and the simulated future state provide input to further ideation and refinement of proposed solutions. The simulations may also show that the future target state is unrealistic, given the existing system parameters, in which case a re-evaluation of possible target stages is necessary.

The process described in Fig. 6 applies two separate modes of thinking: the ideation cycle represent the fast, intuitive and associative "System 1" thinking and the analytic cycle represents the slow and analytic "System 2" (Kahneman 2011). Separating the two modes of thinking aims to enable, on the one hand, a creative ideation process free from the restrictions of premature analysis and rejection, and on the other hand an analytic cycle with an abundant flow of input in the form of new ideas. The ideation and analytic cycles, although separated, run in parallel forming a concurrent engineering environment where solutions and ideas are thoroughly tested before proceeding to production and implementation. The integration of key actors in the process ensures that upgrade solutions are not only tested for technical and economic feasibility, but also evaluated against the needs and system knowledge of end users.

The UIW-approach comprises three main elements: the UIW-framework; the UIW-web platform, and; the UIW-virtual community. These are introduced next.

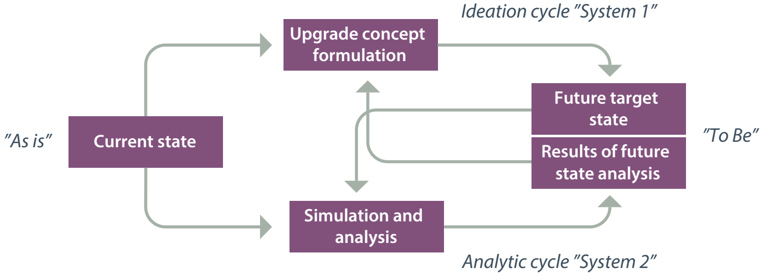

Fig. 6 Collaborative upgrade innovation process

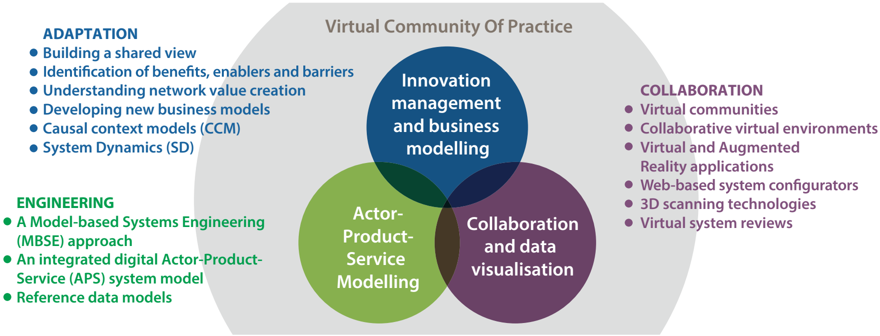

Fig. 7 The UIW-framework

4.1 The UIW-Framework

The purpose of the UIW-framework is to support a comprehensive approach to a continuous innovation process for a life-long adaptation of industrial product-service systems by outlining a generic solution to be further specified and implemented in actual use cases. The framework covers three main areas: adaptation, collaboration and engineering. Reflecting the analysis of the imaginary industrial company in Chapter "The Challenge", the UIW-framework describes three complementary sets of modelling solutions targeting the application areas. A number of tools and methods are suggested in each of the model categories. Figure 7 shows a schematic overview of the UIW-framework indicating tools and methods associated with the different sections.

Established actor networks select the best tools on a case-by-case basis to set up a dedicated upgrade innovation platform for a specific IPSS. The tools are then adapted, modified or extended to meet the specific needs in each case. Both the use and the adaptation of the tools may require special skills which may be offered by members of the Community of Practice. New, modified or extended tools are returned to expand the platform and to serve future needs. The following sections describe the model categories in more detail.

4.1.1 Innovation Management and Business Modelling

The purpose of innovation management and business modelling is to support the continual adaptation of the system in order to find optimal upgrade solutions to meet changing needs and exploit new opportunities. The key element is a shared understanding of the business dynamics of the upgrade case. This includes identifying influential actors, their motives and capabilities, and understanding how value is created and shared within the network. Rich pictures, Causal Context Models (CCM) and System Dynamics (SD) simulation can be used as tools (see Groesser, Chapter "Complexity Management and System Dynamics Thinking" in this book). The model emphasizes a shared effort between the actors to learn about system dependencies and the effect of change. A comprehensive, shared view on actor roles and interests, as well as an understanding of the effects of potential future development, help establishing new competitive business models. The adaptation model can later be used to identify and simulate the effects changes in the business environment, thus supporting decision making in later stages of the systems life-cycle.

The UIW-web-platform includes resources for constructing a bespoke adaptation model, in the form of a selection of model exemplars. These exemplars can be extended and configured to meet specific requirements of actual upgrade cases. The platform also provides resources in the form of expert support on setting up and working with the models.

4.1.2 Collaboration and Data Visualisation

One of the key elements of the UIW-approach is a close and continuous interaction between involved actors. This is supported by digital tools for collaboration and data visualisation. Collaboration between diverse groups of actors with different interest, motives and professional background differs substantially from collaboration between individuals of in-house R&D teams or other established networks of a more stable nature. In addition to social or professional distribution actors may also be spatially distributed, separated by distance, time zones or language barriers. To enable efficient communication and active collaboration between network actors the framework suggests various tools for shared virtual system representations based on Virtual Reality (VR) and Augmented Reality(AR) and tools for retrieving the and presenting necessary 3D information. Current internet-based communication solutions offer multiple options for establishing collaboration networks capable of operating effectively regardless of physical distance. VR and AR technologies can be used to provide users with a realistic and interactive virtual representation of target system or the operating environment, making it possible to try out and comment on suggested upgrade solutions. The use of visualisation techniques based on virtual and augmented reality to create shared views is presented in Chapter "Virtual Reality and 3D Imaging to Support Collaborative Decision Making for Adaptation of Long-Life Assets" and was implemented in several pilot cases presented in Part III of this book.

In addition to technological solutions the UIW-framework also contains guidelines for establishing and maintaining active actor communities or virtual Communities of Practice (CoP). CoPs are seen as an efficient way to foster a continuous dialog between actors to share knowledge and support the generation of new ideas. The collaboration model should enable an ongoing exchange of information through the system life, also between individual upgrade increments. Principles for establishing successful CoPs are treated in Chapter "Fostering a Community of Practice for Industrial Processes".

4.1.3 Actor-Product-Service Modelling

Designing complex product-service systems require the combined efforts of large engineering teams and a diversity of different domain experts. When the system undergoes repeated upgrades during their life-cycle a well-managed engineering process is necessary. The UIW-framework strongly supports the use of shared digital system models to capture all system life-cycle data to enable efficient collaborative engineering based on MBSE principles. An extension of the product-centric data model is proposed. The extended actor-product-service (APS) system model includes data relating to actors and product-based service. Reference data models have been developed, but actual implementations must be designed separately in each case to account for specific needs and requirements of individual actors. Especially technical restrictions or incompatibility issues between different data systems used by various actors may limit the implementation of an optimal shared APS system model. Transitioning from a document-based design process to a MBSE approach promises to facilitate automation of design information by introducing a more generic, symbolic system representation, overcoming the limitations of written text is described in Chapter "Extending the System Model".

5 The UIW-Web Platform

The purpose of the UIW-web platform is to work as a public front-end combining the outcomes of the project and making them available to external audiences. The platform also provides access to expert knowledge and services related to the implementation of the tools and models in future upgrade cases and hosts a virtual community of practice within which members can share their experience and generate new knowledge in a continuous collaboration process.

UIW-web platform acts as a broker of information and services relating to the upgrading of industrial product-service systems. The platform website is available at http://use-it-wisely.eu.

6 UIW-Virtual Community

The UIW-virtual community brings together suppliers, customers, engineering experts and researchers focusing on upgrades of high-investment product-services. The community combines theory and practice knowledge across various fields of industry, and presents tools and methods applied in documented reference cases. The purpose of the virtual community is to ensure continuous development of the UIW-framework and to contribute to the accumulation of shared knowledge and resources. The combined resources generated through the sustained activities of the multi-domain collaborative community of practice are collected in a pool of collective knowledge, tools and methods accessible through the UIW-web platform. The community also provides access to information or expert services relating to the application of the various methods.

7 Reference Cases

The UIW-framework is an abstract building on the main idea of involving actors in a collaborative effort to sustain and create IPSS through upgrading. Practical implementation of the framework is supported through a community platform that provides access to knowledge and tools as well as expert advice to assist companies set up their own collaboration networks and toolsets to specific needs. The community platform is maintained at http://use-it-wisely.eu. The localised implementations of the framework may target a single product-service development case, a specific business area or build on the collaboration of a network with a shared interest looking for new opportunities. The objective may be technical improvement, taking advantage of new technology opportunities of business model innovation. Thus, all implementation instances will have their own characteristics with different adaptation systems, APS system models and virtual collaboration spaces. The use of the framework in dedicated update innovation projects improves existing tools and models, and generates new knowledge. Voluntary sharing this generated knowledge through the community platform contributes to the common knowledge base and promotes cross disciplinary learning shared across industry domains. Part III of this book presents implementation of the UIW-framework in six industry clusters.

8 Conclusions

Global competition in manufacturing industry and industrial services increase as emerging economies enter the market, and communication and logistics channels develop. Customers take advantage of the new opportunities and require solutions adapted to specific needs at competitive costs. Environmental sustainability becomes a high priority driven by legislation and social pressures. Companies need to find new ways to maintain their competitive advantage in the changing business landscape.

One way of approaching the challenges is to shift focus from tangible products to customer benefit. Rather than just offering add-on services there is a shift towards service-dominant business models where value is provided primarily as services or resources. This shift of business logic has important implications on how firms collaborate with the customer and other actors. The creation and utilisation of knowledge outside of traditional corporate boundaries becomes a prime target.

The volatile market with fast moving market entrants and a continuous stream of new technologies poses specific challenges to well established industries supplying high-investment products with high long expected life-cycles. To meet changing requirements in different phases of the operational life, these systems need to be continually upgraded. Efficient maintenance and upgrade services may also enable an extended life-cycle, which brings savings to customers and contribute to environmental sustainability objectives.

In the UIW-project, co-funded by the European Commission and twenty companies, universities and research organisations, a generic approach was developed for enabling effective upgrade innovation and customer adaptation. The UIW-approach is based on close actor collaboration, a shared, holistic system view and effective information management to support life-cycle sustainability based on frequent, demand-led upgrade increments. Based on this approach a conceptual framework was created to help companies develop their upgrade innovation processes. The UIW-framework builds on three corner stones: an adaptation mechanism, consisting of tools and methods for a holistic view of influence factors and causal dependencies to support decision making and creation of upgrade strategies; an actor-product-service system model, integrating product and actor data with a model-based systems engineering approach for a comprehensive and up-to-date digital system representation throughout the life-cycle; and a collaborative virtual environment, to support upgrade innovation by connecting actors in a collaborative effort independent of location.

The UIW-framework is supported by a collection of selected tools and methods, best practice information and selected reference cases made available through a community web site. The site is maintained by a virtual community bringing together practitioners and researchers in a continuing effort to further develop tools and methods and build on the collective knowledge of the community. The framework does not describe a strict process or prescribe specific tools to be used. Instead, it proposes a number of viewpoints and suggests tools and methods to support analysis, decision making and collaboration based on the previous research knowledge and practical experience from the pilot cases. This makes the framework agile to adjust to upgrade cases beyond those treated in the current project and to other sectors of industry. The framework itself is intended to be extended and upgraded based on resources and experience gained from future case studies.

The approach and related tools were tested in six clusters representing a broad variety of industries. Some examples of the tools and their use in the process are presented in Part II of this book. Industrial implementation cases are presented in Part III.

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