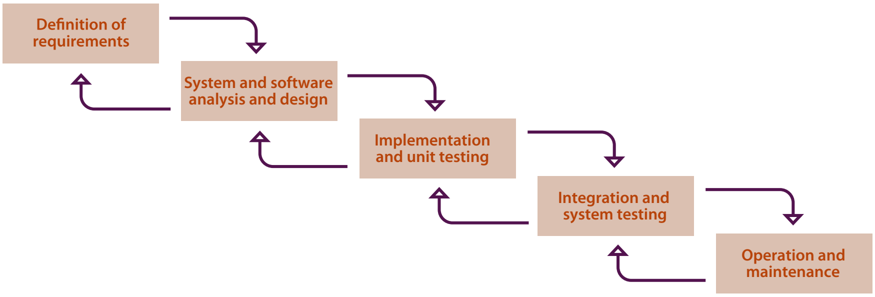

Fig. 2 Royce's Waterfall model (1970)

Fig. 3 Boehm's spiral model (1988)

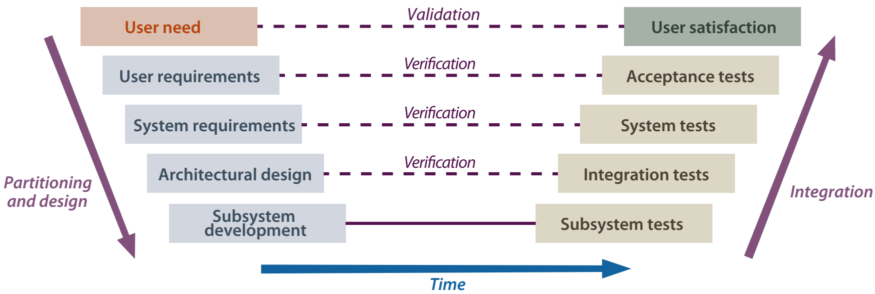

Fig. 4 Forsberg and Moog's "Vee" model (1992)

2.2 Technical Analysis and Simulation: Languages, Methods and Tools

As described in Pasquinelli et al. (2014), many types of models can be used in a model-based environment, and some are already widely used, especially in engineering disciplines. An initial classification limited to engineering activities may be organized into system-level models, engineering discipline models and collaboration models.

System-level models formally describe system-level views of system data (e.g., functional, architectural, behavioural, requirements). The Object Management Group standardized UML (Object Management Group 2015) (mainly for software) and SysML (Object Management Group 2013) (for systems). The xAF architectural framework (Rouhani et al. 2015) describes high-level (e.g., enterprise) architecture. Other examples include the ESA OCDT (de Koning et al. 2014) (for preliminary design) or VSEE (Rey 2013) (intended for entire lifecycle), the Thales ARCADIA approach (Roques 2016) and the TAS DEVICE model (Di Giorgio and Wiart 2012). CAD models define and maintain physical configurations, item arrangements, related interfaces and harness routing and are currently supported by many commercial tools.

Discipline-specific models are widely used in engineering for simulation and analysis. They represent a simplification of the real system from the perspective of a specific discipline. The geometry can be simplified for specific calculations and control. Continuous models can be discretized to solve problems using partial differential or differential algebraic equations. Software and logic models represent specific behaviours for implementation in system software or simulation of external operational entities.

Project collaboration models are also extensively used to manage workflow and change. Workflow models help define team tasks or work packages with associated input/output. Typically managed using PDM/PLM or corporate tools, they can sometimes be oriented to the formalization of contractual tasks rather than in support of daily work. Typically, such tools include authorization workflows and documentation management. For more technically oriented purposes, such models include the input/output definition from analysis and simulation and give control to a system architect/engineer for system analysis and simulation while gathering discipline-specific models. Change management models typically analyse relationships between existing models and can help provide an impact analysis in the case of a change.

Finally, optimization models typically connect different parametric models and enable finding the optimal solution according to objectives (Cencetti 2014).

As shown in Fig. 5, a centralized unique system model cannot exist because many models rely on its data and should be kept consistent. The system-level model could be a federation of models such as a SysML model or a Capella (Roques 2016) model for functional aspects (or an evolution based on semantics such as the

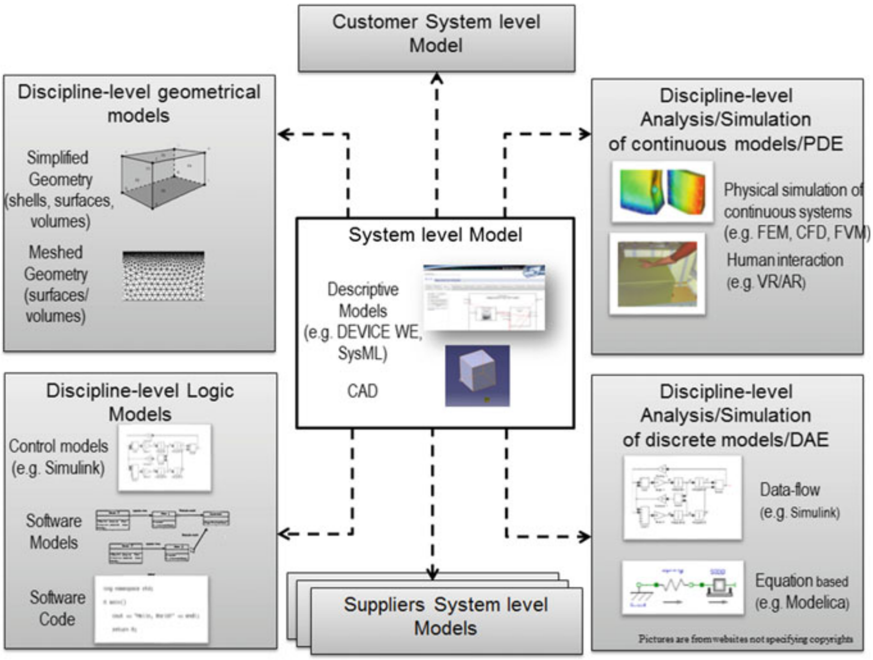

Fig. 5 Discipline-specific models rely on data and should be kept consistent

TAS DEVICE model) connected with the geometrical baseline (typical a CAD model).

The system-level information is mostly generated by discipline-level activities, providing analysis of requirements and evolution of the design in lower-level detail. Typically, discipline-level activities require a subset of the system model data and provide another subset of the system model data that is needed by other disciplines.

However, discipline-level models are not a subset of the system model. For instance, the geometry of a thermal model can be simplified with respect to a CAD model, excepting some items and including fictional items related to the simplification of the model for calculation purposes (especially in early phases and for some specific analyses). A mechanical FEM model includes more items than the CAD model meshes and has many properties that do not need to be shared. A software model could be mapped to system functions but it is not useful to share and maintain software-specific items (classes, protocols, etc.) in a central repository.

One typically overlooked aspect is the collaboration with different industrial tiers (i.e., customers and suppliers). In the case of model-based environments in industrial teams, a connection between models (with precise workflow and rule management) is essential for the highest profit from consistency control, clear flow of data between partners and control of impacts in the case of changes.

System/Architectural methods and initiatives are approached differently, from the SysML effort to provide a standardized language to other initiatives at company, project, or open communities levels (e.g., the DEVICE or Capella initiatives). The examples reported here were analysed during the UIW-project, leading to the study of custom solutions.

Systems Modelling Language (Object Management Group 2013) is a joint effort of the Object Management Group and INCOSE to standardize MBSE. SysML is a graphical modelling language with nine diagram types to model system requirements, functionality, behaviour and structure.

SysML (Fig. 6) has roots in Unified Model Language (UML), which is widely used in software and was designed to be exchanged with XMI. SysML is a methodology-agnostic and tool-agnostic open standard, implemented by many commercial and free tools. The OMG SysML and tool vendors form a dynamic community and the standard and tools are frequently updated. This effort is an ongoing process that started in 2001; OMG SysML specification 1.0 was released in 2007, and the latest version 1.4 of the standard was released in September 2015.

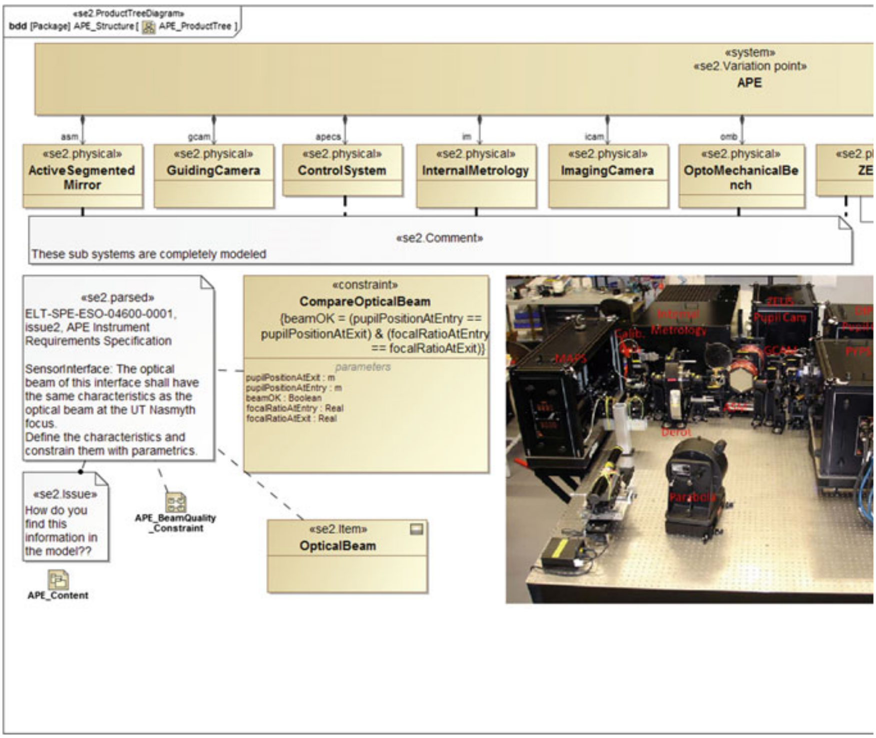

Fig. 6 A fragment of a structural SysML diagram (Karban et al. 2011)

Recent commercial tool vendor efforts have situated SysML at the centre of the MBSE approach (Fig. 7). Syndeia software for lifecycle management (Intercax 2016) claims to use the language to interconnect models between discipline-specific tools such as CAD, project management, requirement management, simulation, PLM and relational databases.

DEVICE (Distributed Environment for Virtual Integrated Collaborative Engineering) is a collector of Thales Alenia Space Italia internal research devoted to study, development, validation and proposal of new methodologies/tools to improve systems engineering and multidisciplinary collaboration since 2007 (Di Giorgio and Wiart 2012). This research was recently realigned with the Thales engineering environment deployed across all Thales business units and also partially deployed (for model-based system architecture tooling) since 2015 as the Capella open-source initiative under the Polarsys project (Blondelle et al. 2015).

The modelling portion of the DEVICE infrastructure is currently a customized conceptual meta-model that was conceived to be compatible with European standardization, e.g., ECSS-E-TM-10-23 and ECSS-E-TM-10-23 data models, which are not current standards but are meant to change significantly in the future. The end product is incrementally defined in terms of structure and behaviour with regards to

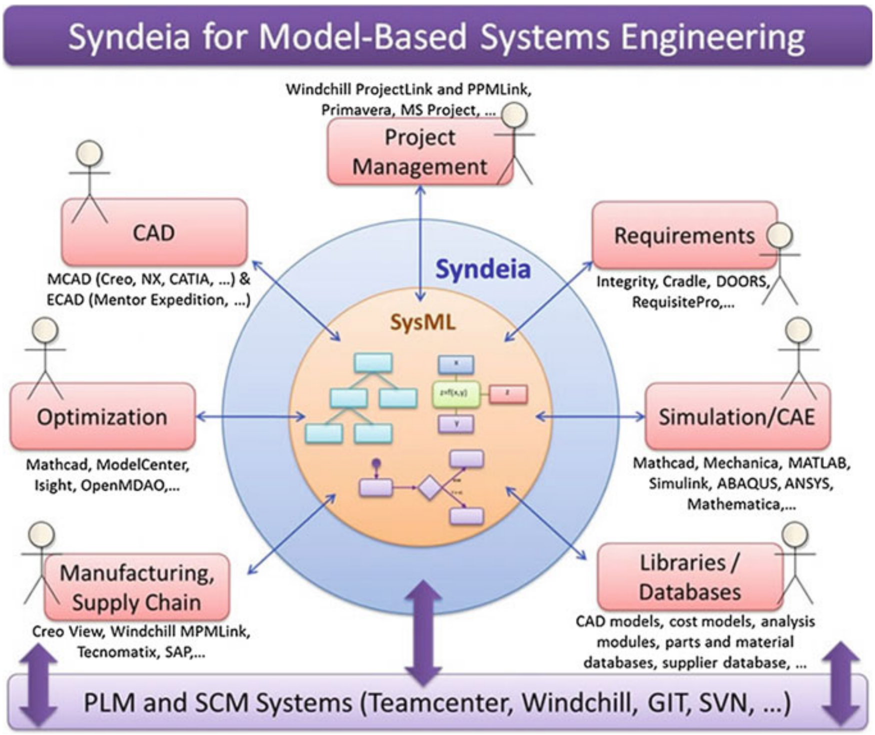

Fig. 7 SysML is in the centre of a tool-interconnection effort (Intercax 2016)

the lifecycle phase. Different design methods are allowed for logical and physical architectures, with relationships that allow precise semantics but do not create many different items. The defined semantics allow the product model to be used as a virtual model for simulation, allowing linkage with design tools, analysis models, test equipment and operational data.

The end product definition and verification are driven by requirements and reference scenarios, the requirements that are defined using models and are related to design items for automatic consistency checks. The scenarios consist of the definition of activities that will be performed in the in-flight utilization phase and during the production, integration, on-ground testing and logistics.

The UIW-project provided a cross-linked environment between the DEVICE research, typically validated in space activities and other domains and lifecycle activities that can enrich the existing models and approaches and inspire novel usage of standard tools such as SysML-based commercial tools or open source platforms such as Capella. The following section describes some of these results.

ARCADIA (Roques 2016) is a model-based engineering method for systems, hardware and software architectural design. It was developed by Thales between 2005 and 2010 through an iterative process involving operational architects from all Thales business domains. ARCADIA is the systems engineering methodology supported by the Capella tool (Roques 2016). This methodology was developed internally by the Thales Group and has been made open source. This methodology relies on several interconnected modelling levels:

- Needs understanding in operational analysis, i.e., an understanding of the operational environment that is independent from the existence of the system, and system analysis with objectives of defining the boundary of the system with respect to external actors and the system-level functions.
- Solution architectural design in terms of logical architecture, i.e., allocating the functions to logical components, physical architecture, i.e., defining how the system will be developed and built, allocating functions to hardware and software components, and detailing the interfaces, and end-product breakdown structure for managing industrial criteria and associating requirements and interfaces with configuration items

Figure 8 summarizes the ARCADIA Methodology. Other notable initiatives from the space field that have been used as references are the OCDT (https://ocdt.esa.int) and the VSEE (https://vsd.esa.int).

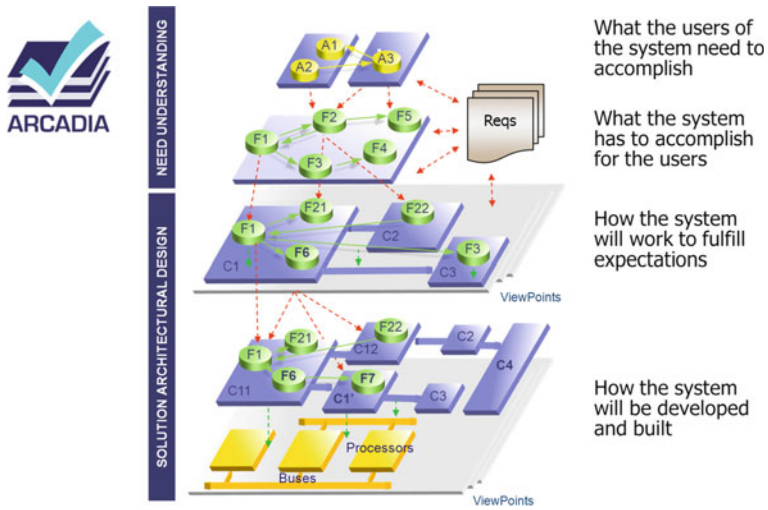

Fig. 8 The ARCADIA methodology (Roques 2016)

3 Extending the System Model to Cover the Entire Lifecycle

Three main gaps were identified in the ideal integrated methodology shown in Fig. 5: (1) integration of system modelling with simulation, (2) use of system modelling across the entire lifecycle and between different activities, and (3) tool limitations: security, data exchange, collaboration and user culture. A quick overview of such gaps is provided below.

Different issues can arise when system modelling methodologies are integrated in simulation environments. Development of the proper interfaces is strongly affected by the manner in which the integration is implemented within the overall design and analysis process. A clear understanding of the overall process and the related infrastructure can reduce issues that arise as development proceeds. A clear conceptual framework is fundamental to support modelling activities because it paves the way for effective exploitation of available resources.

Each of the existing methodologies is based on a specific data structure developed for specific applications, reducing the possibility of re-using the related environments within other contexts or domains.

The integration of simulation environments and system modelling frameworks can be approached in different manners depending on the final objectives and on the specific workflow that characterizes the company. Technical simulations can be used to investigate the product performance based on available data; the management of this information affects the integration architecture. The potential solutions can change based on the tools and required capabilities. Multidisciplinary analyses can be supported using dedicated platforms to manage the results generated by simulation tools.

The exploitation of technical simulations is strictly related to the capabilities of external analysis platforms. System modelling environments can be used to store the representative project information whereas simulation platforms use such data to set up and execute analyses. The data exchange across different environments represents a challenging process because it is often difficult to integrate information from different sources in a straightforward manner. Currently, different tools support system modelling, but there is a gap between the available information and analysis capabilities (sensitivity analysis, optimization, uncertainty quantification, and parameter estimation). Object-oriented solutions can enhance the advantages of a unique environment for modelling and technical simulations and can reduce the efforts required for consistency verification when the data are exchanged directly with an external process manager. The gap between simulation tools and modelling environments can be mitigated if a common conceptual infrastructure is defined. Such integration can be realized only if the platforms and related methodologies are clear and well-posed.

The improvements related to a successful MBSE method on a system engineer/architect level can be jeopardized by an ineffective connection with discipline-level work, especially for data exchanged between different disciplines and managed for consistency at a system level.

SysML, ARCADIA, UML, xAF and other frameworks rely on a data model that was created for specific purposes and was not intended to serve for the entire lifecycle or for all engineering activities. Moreover, such methods (and related tools) were initially developed to support SE activities and not for an asynchronous collaboration between different team members using different tools. Recent advancements in such model-based methods and tools have attempted to overcome this limitation. However, the lack of semantics (for simulation use) is still an issue in many methods and it often necessitates ad hoc solutions, e.g., with a specific profile for the SysML. In such cases, the standardization is often replaced by vendor-level, company-level or project-level profiling.

Many different companies and institutions already rely on MBSE solutions, SysML-based (Spangelo et al. 2012) or custom (Di Giorgio and Wiart 2012), and almost all large enterprises rely on legacy systems that include relevant data for past and current projects.

Currently, the system modelling–simulation connection is an open area in which many improvements can be made, especially with the objective of an improved rapid response to the customer.

System modelling across the lifecycle

Systems engineering is often regarded as an approach to provide system solutions but after deployment other disciplines such as project management are more prevalent. MBSE has followed this view and focuses on the initial concept and development stages, i.e., on the as-designed system rather than on the as-built system.

SysML, the main example of ongoing MBSE standardization, has a similar bias, lacking clear semantics to differentiate views of the system at different life-cycle stages. This limits the adoption of MBSE for the management of stages beyond concept and development. It also limits the mapping and interchange of information between tools across the life-cycle. One example is the configuration management of as-designed system components that can model design evolution versus configuration management of the as-built system components that can model system part maintenance and replacement. The link between the as-designed and the as-built statuses of a system is often at the frontier between tools and is often not explicitly managed in any of them.

Moreover, a typical Vee cycle should be supported by different types of tooling and methods for the relevant activities performed at each stage. In the space field, concept and feasibility studies conducted at the beginning of the typical life-cycle often rely on parametric models for early sizing and analysis to understand the system-level feasibility of the proposed solution.

In later phases of system and product definition (phases A/B in the European space standardization), a more complex industrial team is formed and more complex analysis is required. Moving towards the detailed definition and production phases, the overall consistency should be managed at different levels and the management of changes and requirements becomes more formal and controlled to assure the highest product quality and reduce risks. In serial production, the product and component variants and the ever-growing trend of customization increase the complexity. Modelling of product features, options and variants is not directly addressed in this chapter but their application is essential to any type of production, including one-of-a-kind, because they allow re-use of components that generates savings. The operational and disposal phases are typically supported by models to support the users, operators, maintenance and anomaly investigation teams (Fig. 9).

The analysis of the potential system- and product-level model-based activities is performed from a project lifecycle point of view and could be called "vertical", viewed as a sequence diagram, with time progressing from the top to the bottom. There is also a horizontal perspective that should be considered as each activity runs in parallel to activities in other projects or even in other companies involved in the project. This issue has two main associated topics to consider:

1. Collaboration: in model-based systems engineering, the capability of IT tools to exchange models and synchronize them with limited effort by the user is essential for effectiveness and efficiency. Security issues should also be considered to avoid spreading sensitive company knowledge outside of authorized boundaries. Moreover, the use of common rules, object libraries and conventions is essential to assure an effective collaboration and reduce related risks.
2. Return of experience: experience gained in other projects or activities should be appropriately incorporated into the current activity. The MBSE approach can

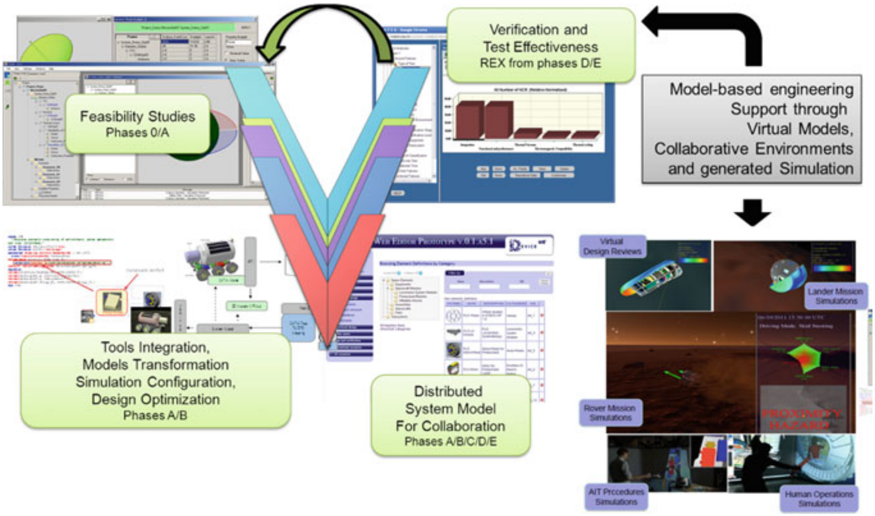

Fig. 9 Model-based usage across the lifecycle (Pasquinelli et al. 2014)

generate a large amount of data that, in contrast to the classic document-based approach, can be processed in a more effective manner.

Tool limitations: security, data exchange, collaboration and user culture

In many cases, the limitations are not in the methodology or languages but in the tools, toolchains and complexity of the information system networking in a multifaceted industrial scenario. There are three main factors that limit the seamless adoption of a tool by an end-user:

- Overwhelming complexity: if managing the data in the tool or understanding the user interface requires more time and mental effort than usual, the end-user may be reluctant to adopt new approaches. This is often the case with MBSE methodologies and tools. Simplified user interfaces, complexity management through different levels of detail, and easy navigation and immediate visualization are key aspects to consider.
- Annoying constraints: each company must take preventive action to avoid unwanted flow of sensitive data, propagation of human errors or negative impacts on company performance and security. This is typically translated into necessary constraints that are considered annoying limits by the end user. Tools that allow more fine-grained control of the flow of information may ease the constraints and improve overall security.
- Demanding collaboration and different cultures: collaboration among different users and stakeholders is typically a source of misunderstanding and requires well established processes and procedures. Even when consolidated in practice

due to past experience, any change brings new risk and should be disseminated correctly. When using different tools, this also translates into interface and compatibility issues (between both tools and people).

4 Proposed Extensions

Three main extensions to the current modelling solutions can fill these gaps:

(1) Extending the current data models with knowledge-oriented and simulation-oriented concepts, leading to the definition of an executable virtual product.
(2) Extending the current data models to include all statuses of a product (in PLM, from as-required to as-designed, as-analysed, as-built, and as-maintained), closing the gap between early engineering studies, detailed engineering tasks, production, testing, operations and maintenance.
(3) Extending the data models, related tooling and current processes to derive the system definition as a set of engineering services and related connections to project and company management.

4.1 Knowledge- and Simulation-Oriented Concepts

There are two main needs in the modelling and simulation field: (1) a modelling methodology that is generic enough to not constrain the solution definition, and (2) a modelling methodology that is specific enough to allow data to be univocally interpreted.

For example, SysML responds to the first need but is lacking in the second need, so a typical user specializes and customizes the language to meet their needs. The current trends (e.g., use of ontologies, the semantic web, and more detailed data models) respond to the second need but their definition and interpretation is often limited to IT experts. A potential solution is to decouple the two needs so that (1) generic concepts (such as the fact that a product is composed of other products and may be interfaced with other products) could be defined in a generic modelling methodology, adopted across different industrial domains and types of expertise, and (2) specific concepts are standardized at a community level (a community may be related to a specific industrial domain, a specific scientific field, or to a specific project or team).

This approach can also replace the current standardization in document-based approaches. The end purpose is to produce models with items whose semantics can be understood by any target user and can be interpreted univocally by a machine (e.g., a simulation software code). This would allow a transition between a view of the MBSE as a model-based description of a system and related systems engineering data to a view of MBSE as the definition of a virtual product that can be interpreted and executed throughout the life-cycle, with capabilities related to a specific definition level of detail, input between users and the different product variants.

4.2 From Definitions to Realizations

Current data model support in MBSE tools– and the prevalent standardization effort of SysML-lacks explicit support for including the status of a product, from as-required to as-designed, as-analysed, as-built and as-maintained. This can be an obstacle for data interchange among tools employed throughout the product life-cycle (such as PLM tools). Using the example of the mass of a system component, a component may have an as-required mass, an as-designed mass and an as-measured mass. All three must be stored and tracked throughout the system life-cycle.

A first step is differentiating between component definitions and component realizations. Each component definition can be realized many times and each component realization corresponds to only one component definition. This difference is made explicit by recent MBSE efforts (Rey 2013) promising but still focused on a specific industrial sector, biased by the specificities of one-of-a-kind-products.

For example, the design of a product can be modelled by a component definition. The product can be realized (manufactured) many times. Examples of component realizations and definitions are the manufactured units and their designs. The component definitions can have an associated as-designed mass and component realizations can have an associated as-measured mass. Design upgrades can be modelled as component definition versions and product upgrades due to maintenance can be modelled by component realization versions.

4.3 Service-Based Engineering

The conceptual infrastructure that defines the data structure of a system model has a key role in the management of the available information. A clear representation of all possible data sources and their relations is fundamental for designing an effective system. The development of modelling processes in which the customer is increasingly involved within the design activity shows promising capabilities for the near future. Customer-in-the-loop strategies highlight interesting benefits regarding the expected system performance and a better exploitation of available resources. A clear and deeper involvement of the customer in the decision-making process can help generate a product that is better aligned with market expectations.

This aspect is common to different markets and the same approach can be used, with minor changes, across different domains.

These considerations highlight how a conceptual infrastructure for service modelling can help include additional scenarios in the context of system definition. The development of the objects and the relationships that characterize a service can enhance the communication between customers and system designers. This vision of the customer-in-the-loop strategy can be pursued through application of a model-based philosophy, providing all the features and benefits that aid in the definition of a system project. The related data structure can be used to drive information exchange between stakeholders and track of the current baseline and changes in a consistent manner.

5 Conclusion

The experiments conducted in UIW, especially those in the space and ship building domains, show interesting results for the extension of system models. Extensions include web-based collaboration, the connection with simulation and virtual reality, and the use of services and probes. However, the experience with causal context models, the circular economy model and other strategic/company level models should be linked with technical choices, collaboration aspects, project management and company strategy. Models that relate economic and strategic domains are often difficult to formalize, but a clear integration of the related concepts with the current system model can greatly enhance the lifecycle process.

Extending the model to include maintenance activities yielded interesting and promising results. Additional details are presented in Chapter "Collaborative Management of Inspection Results in Power plant Turbines" in the context of maintenance of power plant turbines. Efforts for harmonizing the product structure from the assembly point of view with alternate methods of structuring information derived from the maintenance processes have shown improvements in communication and information sharing among the different actors involved. However, extending the system model to cover both the product and the service views would require changes to the companies' information systems. However, such a step and the adoption of an MBSE approach, which is not the case for some traditional industries, are required to ensure the convergence of the actual practice towards a more effective data management solution.

The UIW-experience allowed determination of the common issues among different design processes. Such problems can be faced with a more effective design approach, and a model-based philosophy can provide useful tools to mitigate the current situation. Additional features can be integrated within the system model to cover common areas among different companies. For example, a well-formalized system model can pave the way for tools and techniques that can support the decision-making process. Currently, system solutions and design choices are strictly dependent on the context and seldom can all the knowledge elaborated during these processes be re-used in other projects. It is often difficult to track the rationales that drive a design choice because it is difficult to formalize how such information can be defined. An extension of the system model to include such aspects can improve the design process across different industry domains, especially with respect to company strategies and objectives. The system data can be exploited in a more effective manner if defined properly following the pattern of a formalized system model. In this manner, the information collected in a project can be re-used in another one with less effort than the traditional approaches. Company expertise can also be managed in a more consistent manner to help correlate all available information for product design.

For example, the decision-making process can take advantage of a model-based approach because optimizations, trade-offs or sensitivity analyses can be performed consistently with the available system data. Another interesting advantage is that all the related information for optimization, trade-off or sensitivity analyses is not only helpful for the current design but can be re-used in the future because it follows the structured data representation of a common system model. However, such an extension of the system model requires a clear understanding of the current optimization or sensitivity analyses practices so that the largest number of design scenarios is covered. The variety of optimization or sensitivity analyses scenarios is generally broad due to the characteristics of the computational models, inputs and outputs.

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Part III
From Theory to Practice

Collaborative Management of Inspection Results in Power Plant Turbines

Daniel Gonzalez-Toledo, Maria Cuevas-Rodriguez and Susana Flores-Holgado

Abstract This chapter presents an industrial case study that investigates a collaborative tool for use in the fossil and nuclear power plant industries. The tool makes the results of technical inspections on fossil and nuclear power plants available to all stakeholders and assists in the post-inspection decision-making process by highlighting decisions that minimise the outage duration and prolong the turbine's service life. Before development commenced, an actor-product-service (APS) model was employed to establish the problem, the process of which is presented in this chapter. This model describes the relationships between the elements that the system must store and manage. In this particular industrial case, the APS model defines the product as the power plant turbine and the service as technical inspections. Henceforth, this model describes the relation between the inspection tasks and results and the turbine parts that are inspected. In addition, the APS model allows the application to work jointly with the product and the service, representing the information in a way closer to the mental model of each user profile, which should result in an improvement in productivity.

Keywords Collaborative tools · 3D interaction · 3D viewer · Web-based application · Inspection services · Turbine maintenance

D. Gonzalez-Toledo (✉) · M. Cuevas-Rodriguez
DIANA Research Group, Departamento de Tecnología Electrónica,
ETSI Telecomunicación, Universidad de Málaga, Malaga, Spain
e-mail: dgonzalezt@uma.es

M. Cuevas-Rodriguez
e-mail: mariacuevas@uma.es

S. Flores-Holgado
Materials and Life Management, Tecnatom, San Sebastián de los Reyes, Spain
e-mail: sflores@tecnatom.es

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1 Introduction

Tecnatom is an engineering company that provides services to a number of markets, including the nuclear energy, combined cycle and thermal, aircraft and aerospace, transport, and petrochemical markets. The company's main activity is performing inspection services and training operation personnel by means of full-scope simulators to support plant operations.

As part of the evaluation of the structural integrity of nuclear power plants' components and industrial facilities in general, Tecnatom performs inspections and tests based on applicable standards. Once an inspection has been carried out, the results are recorded, transmitted and evaluated. When defects are detected, the flow of information becomes crucial because there are many actors involved, including the companies that design, supervise and manufacture the turbines; the companies that perform the inspections; engineering companies; the power plant managers; and maintenance and repair companies. It is essential that those involved understand the problem, share information, analyse the results and propose a solution in the shortest amount of time possible.

Within the UIW-context, this industrial case is centred on the power plant steam turbine (Fig. 1). Turbines are long-lasting, high-investment components whose operation directly affects power generation and hence productivity. A collaborative tool that manages the inspections carried out on turbine components and the results has the potential to contribute to improving company services.

1.1 Company Necessities

During the last 15 years, Tecnatom has developed and successfully established a software tool to manage inspections and testing plans and the results of such inspections in several Spanish power plants. The system also stores all the

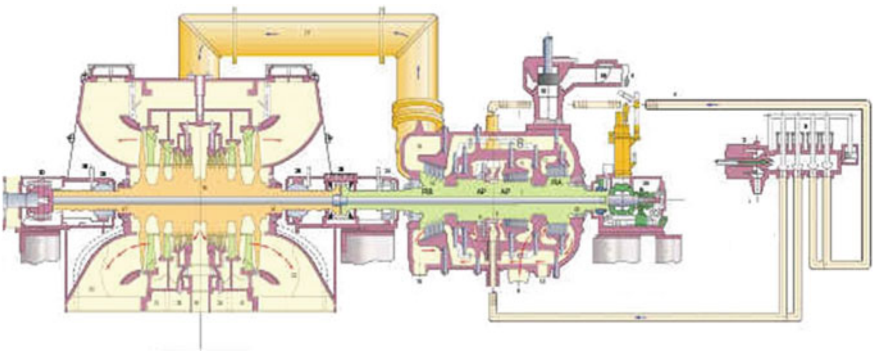


Fig. 1 Typical turbine-generator set scheme

information required by technicians to fulfil inspection tasks, including inspection and maintenance procedures; information regarding inspection areas, techniques, and frequencies for each component; and 2D drawings of systems and components. Figure 2 shows a schematic diagram of the information flow managed by the system.

Although the system has had prolonged success, some users have suggested that improvements are needed to obtain a more reliable tool and provide added-value services in a collaborative environment by supporting the decision-making process throughout the life cycle of power plants components. This updated application would allow designers and engineers to analyse the problem, propose a definitive solution and even modify the design to avoid similar problems in future versions of the product.

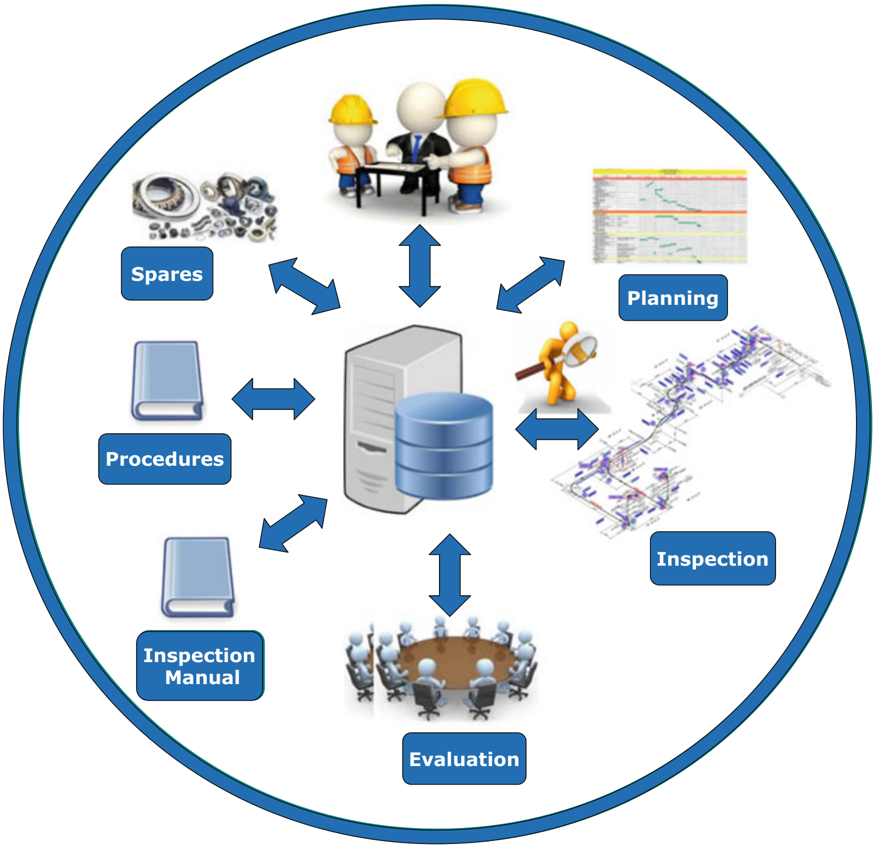


Fig. 2 Flow of information and working team

In relation to the Tecnatom industrial case, added-value services would be the 3D visualisation of the whole turbine and 3D interaction with turbine components (Bowman et al. 2004), along with relevant information about the turbine, linked to the 3D model (Elmqvist and Tsigas 2008). These services would allow the user to more quickly assess the situation when a problem arises, resulting in the optimal solution in a short period of time. In addition, the system could create an environment that allows decisions to be made among all the stakeholders in a collaborative way while registering and storing the comments and the agreed solution for future use. This would allow comparisons to be made when issues arise with similar components by taking into account lessons learned or previously stored operating experiences.

In summary, the main goal of this industrial case is to investigate the different possibilities and technologies for the development of an innovative collaborative prototype system that will work as a decision support tool for the life-cycle management of power plant steam turbines. Taking into account the company requirements, the aim of this industrial case study is to provide (1) interactive 3D models of the turbines, (2) visualisation of augmented information in the 3D models to understand the structure and issues, (3) information linked to the 3D model regarding the inspection results and (4) a discussion management tool to share information and comments related to inspection results.

1.2 Industrial Case Approach in the Use-It-Wisely Project Context

In Chapter “The Use-It-Wisely (UIW) Approach” of this book, common challenges of industrial cases were identified and organised within a framework (see Chapter “The Use-It-Wisely (UIW) Approach”, Fig. 7) that contains three different domains: (1) market and data analysis, (2) collaboration management and (3) actor-product-service (APS) modelling. These three domains cover the challenges that manufacturing industries such as Tecnatom experience in providing services for high value, long-life products related to the upgrade initiating process.

Considering the company needs presented in the previous subsection, the challenges to be addressed can be allocated into two framework domains: APS modelling and collaboration management. The APS modelling domain organises all the information related to the turbine (the product), the inspections tasks and results (the service), whereas the collaboration management domain includes a discussion management tool to assist in optimal decision-making and a 3D application that depicts the inspection process, allowing for the visualisation and management of a turbine’s technical information in a 3D interactive environment.

2 Modelling the Problem, from Theory Towards Implementation

To improve the management of inspection results in power plant turbines using the collaborative tool, the industrial case problem must be modelled. Therefore, this section aims to describe the specifications related to the industrial case problems, including a brief summary of the system use cases and requirements in the first sub-section, the APS model in the second sub-section, and the proposed implementation approach and system architecture in the third subsection. A conceptual prototype of the tool and a description of the industrial case can also be found in Reyes-Lecuona et al. (2014).

2.1 Requirements and Use Cases

This section describes an industrial use-case model of the system that can solve the problem of information flow among actors involved in the overall management of turbine inspections. In this industrial case, these actors are an inspection team (in charge of planning and performing inspections and informing on the results), an engineering team (in charge of analysing results and inputting them into the model), a plant team (representing different technicians and workers from the power plant) and administrators (technicians who are in charge of managing the model to create, edit, complete and adjust instantiations of each turbine with the Tecnatom databases).

A wide list of requirements has been defined to specify the system in a technical way. These include requirements related to how the system represents the inspection results and links them to the 3D model of the turbine, as well as the requirement for visualisation and discussion management tools. These requirements are associated with a set of system use cases, which are listed below.

- *Activity login*. The system identifies every actor before giving the actor access to the system to control which information and functionalities are available.
- *Inspection result input*. The Tecnatom inspection team inputs the results of an inspection into the system. If needed, the actor opens and prepares a discussion related to these results.
- *Visualising information*. The actors navigate through the turbine model, obtaining information about the different parts of the turbine, specific inspection data (defects/flaws, repairs performed, etc.) or information related to the corrective maintenance of a specific part. The actors visualise this information supported by the 3D geometry of the turbine.
- *Input location and size of defects*. When flaws are discovered during an inspection, their position and size can be registered into the model. Inspectors are able to graphically sketch the location of the defects using the system.

- *Management of discussions*. The actors can collaborate in a discussion related to a registered inspection point. The actors may add proposals to the discussion and relate it to other discussions until it is closed by an authorised actor.

2.2 Actor Product Service Model

From a high-level perspective, the APS model aims to describe the different business elements of the company and the relationships between them. These elements refer to both human and non-human factors. In other words, the APS model aims to detail the relationships between the workers and/or departments of the company and third-party customer companies and to model the information needed to manage the work and information flows among the relevant stakeholders.

In this industrial case, the APS model design was built based on the model-based systems engineering methodology defined within the context of the project Virtual Spacecraft Design (Rey 2013), which is described in Chapter "Extending the System Model". The model focuses on identifying the structure of any relevant information that the system has to store and manage to provide the needed functionalities. It was produced through a functional analysis based on the requirements and use cases shown in the previous subsection. After several revisions, the model shown in Fig. 3 was reached.

The model consists of two elements: the product, which involves the power plant turbine, and the service, which involves the inspection of the turbine for maintenance purposes. Actors can also be classified into two categories: (1) those who approach the problem from the point of view of the product and (2) those who approach the problem from the point of view of the service. The first category of

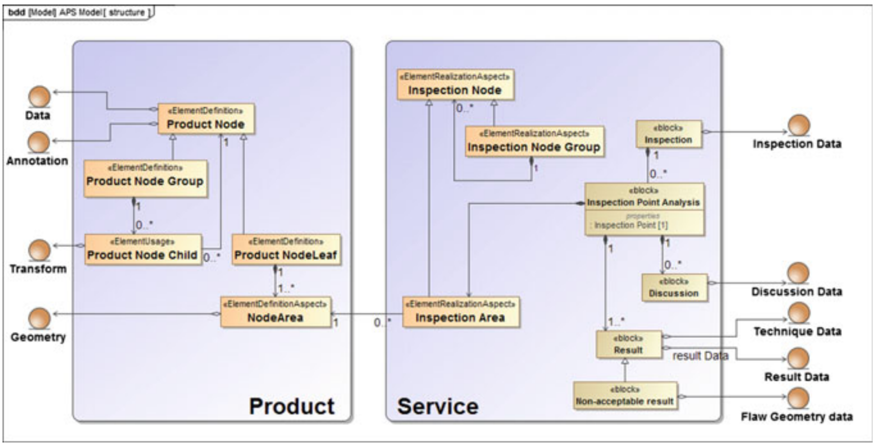


Fig. 3 Actor-product-service model diagram

actors consists of technicians and workers from the power plant who are interested in the product and its operation as a whole. The second category consists of technicians from the maintenance company who are interested in the planning, execution and analysis of the inspection results and who will be entering these data into the model.

The APS diagram presented in Fig. 3, based on SysML modelling languages (Friedenthal et al. 2014), represents both the product and service. These two models are organised in hierarchical trees and are connected to each other by their leaf nodes. After several attempts, this structure arose as the best way to organise the information.

In the product model, each node represents a component of the turbine in such a way that every component consists of the assembly of its children. The product model represents how the whole product is formed or assembled by the sub-systems, which in turn are formed by more basic sub-systems and so on, until the basic components are reached. The leaves of the product model tree are formed by the basic parts of the product, which does not mean they are small or simple; rather, they are simply pieces that are not formed by others. These blocks are shown in Fig. 3 as *NodeLeafs*.

Hanging from the leaves are areas that are not part of the product itself but are areas of interest within the *NodeLeaf* components. These areas are an important concept because different areas of a component have different physical requirements and are not subject to the same conditions. Therefore, the model specifies each of these areas (called *NodeArea* in Fig. 3).

The service model is formed by the inspection tree and the results. Whereas the product tree was intended to show the hierarchical structure of the product, the service tree has been created to express the way in which inspections are performed. Thus, the nodes of this tree represent not the physical parts of the product but parts or layers of the inspection. In this way, the model represents the structure and organisation of the whole turbine inspection. Just as the product structure is stable, so too is the service model structure throughout the turbine life-cycle.

The leaf nodes of the inspection tree are the *Inspection Areas*, which are the points that are going to be inspected. The service model represents turbine sections that are inspected at the same time (inspection areas), regardless of whether they are part of the same physical component of the product. It is important to keep together parts that are physically close or under the same operation/environmental conditions. As shown in Fig. 3, the two models are related by the areas formed by one or more products.

The model presents a block called *Inspection Point Analysis* that is associated with each inspection area. This is where new results and the associated data are stored after every inspection. In addition, the model allows for discussions related to each inspection point. This feature allows the technicians to analyse the results in a collaborative way. In addition, by keeping the entire history of decisions over the product stored together with its model, the risk of information fragmentation is avoided. In the service model, the discussion block hangs from either the Inspection

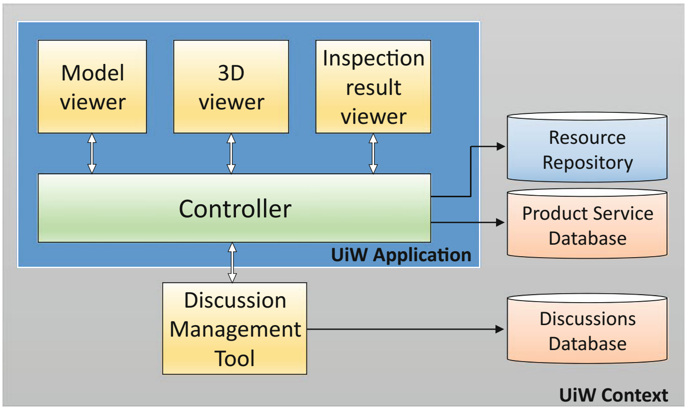


Fig. 4 Block architecture of the system

Point Analysis or from each result. However, discussions for decision-making are often based on several results, which is why this discussion block is associated with the Inspection Point Analysis block.

All the hierarchical information regarding products and services is stored in a database called *Product Service database* (Fig. 4). This database also contains all the data regarding the service (inspections, techniques, results and flaw geometry) and the product (technical specifications, annotations and geometrical transformations). However, the 3D models files, inspections result pictures, technical documents and other additional information are stored in a repository called *Resources repository*. All the information regarding discussion management is stored in its own database.

2.3 Implementation Approach

To meet the industrial case requirements, a system architecture composed of four main modules was designed (described in more detail in Sect. 3):

- *Model viewer*. This module is an interactive viewer in which the user can navigate the different elements of the product and service models using a hierarchical tree (presented in the previous subsection).
- *3D viewer*. This module consists of an interactive viewer that shows the three-dimensional geometry model of the product (the power plant turbine) and presents information about the service (inspection results) linked to the 3D product model.
- *Interactive Inspection result viewer*. This third module is a viewer that shows the inspection tasks and results stored in the database (*Product Service database*) and in the repository (*Resources repository*).

- *Discussion management tool*. This module is an external application that allows users to discuss the inspection results, make proposals, make comparisons with other results, etc. The purpose of these discussions is to achieve a final decision about how to proceed after carrying out inspections. This module is a customisation of an existing opensource tool called Redmine (Redmine 2006).

Figure 4 shows a simplified representation of the system architecture, in which the four modules are connected and managed by a controller that is also in charge of the communication with the Product Service database and the Resource repository. The database contains information regarding the product and service models, following the structure of the APS model. Currently, the company database contains only some of the product information and is organised following a model based solely on the service. One of the contributions of this industrial case is to extend the company database to the APS model so that it is organised according to a model that takes into account both products and services.

The repository stores different resources, such as the 3D model files, inspection result pictures, technical documents and additional information. The discussion management tool does not use the controller to access the discussion database but rather has direct access.

The physical architecture of the system is shown in Fig. 5. This architecture also presents the decisions adopted regarding the platforms and tools used to develop the system. The implemented system has been designed as a web-based client-server distributed architecture that allows the user to access the system through a web browser. The 3D viewer runs on Web Graphics Library (WebGL 2001).

The 3D viewer module has been developed using the Unity (Unity 2005) platform and integrated in the ASP project using WebGL. Originally, the 3D viewer module was built and integrated using the Unity plugin for web navigators (Unity 2015), whose operation was based on the Netscape Plug-in API (NPAPI). However, the majority of web browsers have now disabled support from this API (Google Chrome did so in its version 42, April 2015) because, according to web browser companies, it has become a leading cause of hangs, crashes, security incidents, and code complexity (Chromium Blog 2013).

The modules *inspection result viewer and model viewer* were implemented using ASP.NET (ASP 2002). The server side also contains a set of databases and repositories that form the Product Service database and Resources repository. These repositories store all the information and data that the application needs. Finally, the discussion management module is based on an existing tool named Redmine, an opensource project management web application written using Ruby on Rails (Ruby 2005). This module has its own database.

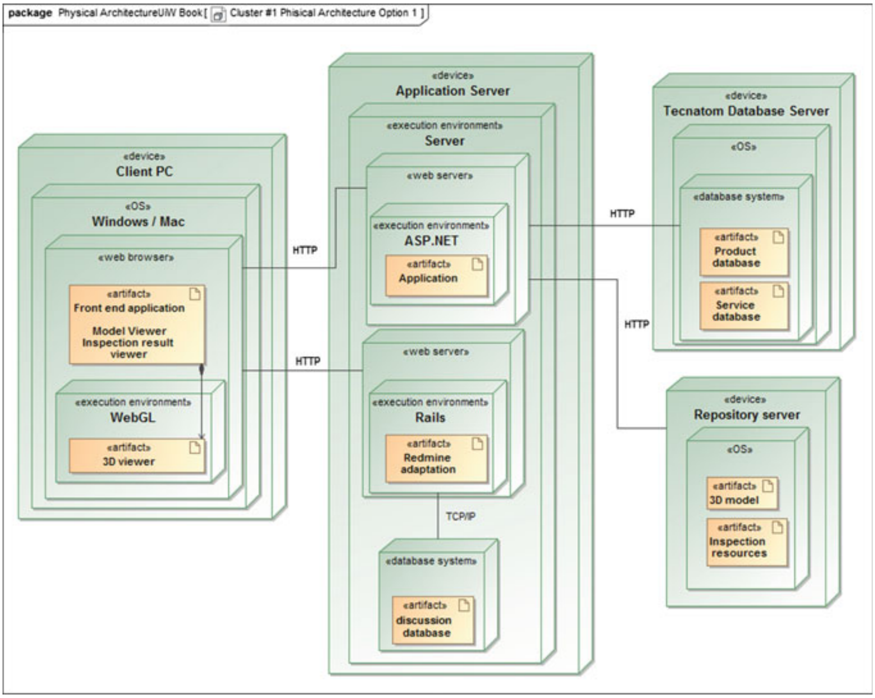


Fig. 5 Physical system architecture diagram

3 Contributions and Implementation, Virtual Reality in a Web Context

A layout of the implemented application, which is divided into four modules presented in the architecture (*model viewer, 3D viewer, interactive inspection result viewer and discussion management*), is shown in Figs. 6 and 7. Figure 6 presents the interactive views and Fig. 7 presents the discussion management tools, which will be describe hereafter. The implementation was carried out taking into account the company needs, the system requirements and the use cases. More details about the system can be found in Gonzalez-Toledo et al. (2015).

3.1 Model Viewer Module

In this industrial case, the product consists of a power plant turbine, whereas the service consists of the instructions for planning the inspections and the inspections carried out in the turbine. The model viewer allows actors to gain access to all the information stored in the system in an efficient and collaborative way.

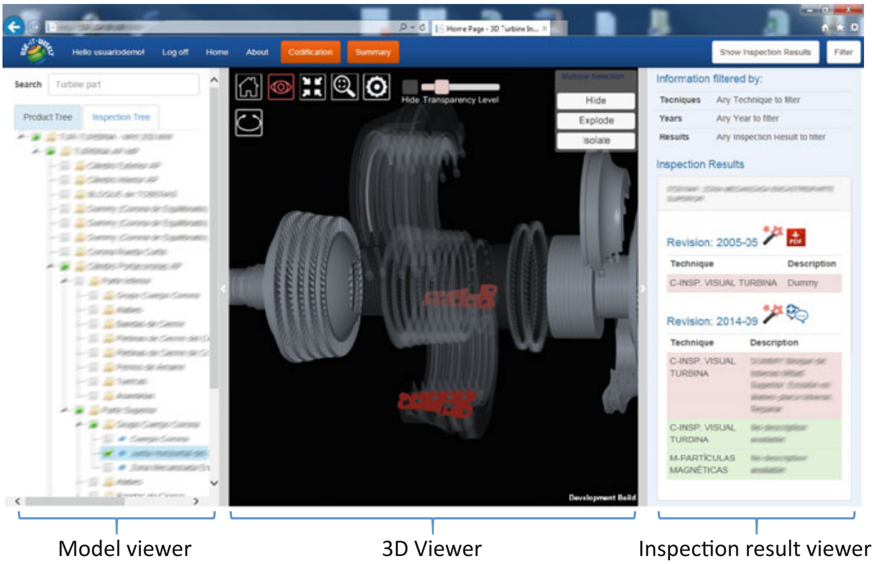


Fig. 6 Application user interface. *From left to right* model viewer, 3D viewer and inspection result viewer

Fig. 7 Discussion management tool

The system has two types of potential users: the staff of the inspection and maintenance company and the staff of the power plant owner company. The first group might be more interested in navigating through the inspection tree model to conduct the inspection, whereas the latter might be more interested in navigating through the information from the point of view of the product.

When using the model viewer, users can choose which of the two navigation trees they want to use and can easily change between them by clicking on the corresponding tab. This allows the users to navigate through the product or inspection model interchangeably. The system is in charge of keeping the displayed information consistent and allows different users to use the application and collaborate so that they can analyse the product (turbine) state and make decisions together.

Once the user reaches the node of interest and selects the appropriate options in the tree, the system will show the requested information with the support of the other viewers.

3.2 3D and Inspection Result Interactive Viewer Modules

Both the 3D and inspection result viewers (Fig. 6) work together to show information about the product and the service. The 3D model of the turbine allows users to visualise and interact with the product model and understand information about the service, whereas the inspection result viewer allows users to investigate the inspection results in depth.

The module 3D viewer graphically represents the 3D geometry of the turbine model. In addition, the application allows users to interact with the product by navigating around the turbine 3D model. To help the user with the visualisation of hidden parts, mechanisms have been implemented, such as an advanced navigation system, identification and selection of different parts and occlusion management:

- *Navigation around the 3D model*. The user can navigate around the turbine model using the mouse and the keyboard to visualise the turbine from different points of view (Fig. 8). The user can select each part of the turbine with the mouse and access detailed information on the selected part.
- *Occlusion Management*. Because there are turbine parts that are occluded by others, the system provides mechanisms to make them visible. When the user is interested in a selected part, the viewer is able to provide a complete view of the part without losing its spatial relationship between the other parts of the turbine. Several mechanisms have been studied and classified in Elmqvist and Tsigas (2008) and Tominski et al. (2014) that could be employed to allow for this function, such as the cutaway views (Burns et al. 2008), 3D Magic Lens (Ropinski et al. 2004), transparency techniques (Burns 2011) and exploded views (Li et al. 2008). The last two techniques are both implemented within this system.

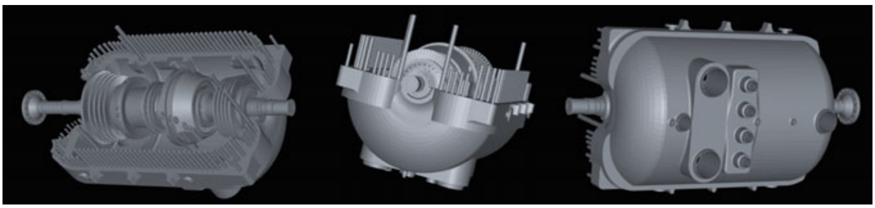


Fig. 8 The user navigates around the turbine, obtaining different points of view

The *adaptive transparency* mechanism makes each part that occludes the selected part transparent. In addition, when the user navigates around the turbine, the transparent objects change according to the user's point of view, as shown in Fig. 9.

The exploded view allows the user to discover and access the internal parts of the turbine (Fig. 10). The explosion refers to the simultaneous separation of parts in an explosive way and takes into account the assembly information stored in the product model.

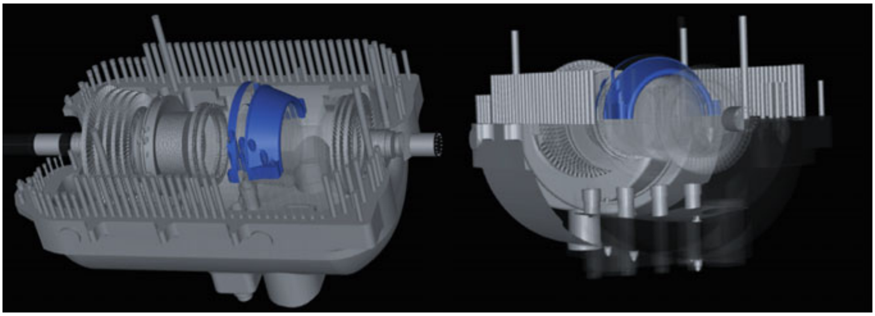
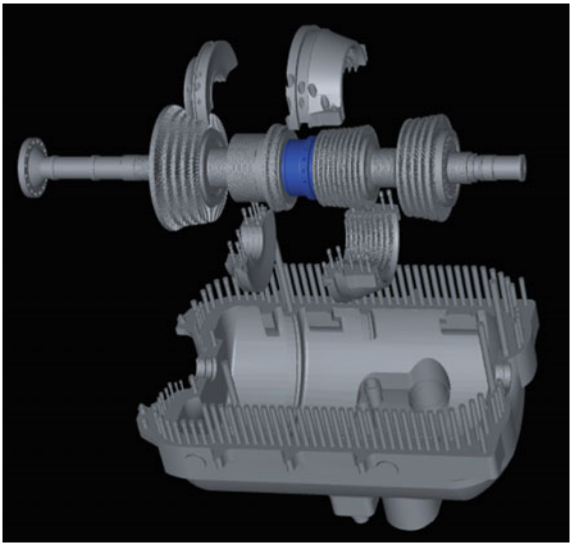


Fig. 9 Adaptive transparency view

Fig. 10 Exploded view



Regarding to the module inspection result viewer module, the inspection data can be shown in two ways:

- Together with the 3D model. Different mechanisms have been implemented to present the inspection result information in the 3D viewer. One of the mechanisms consists of overlaying the turbine graphical model with symbols and colours and relevant information regarding inspections, flaws and repairs. To achieve this, the application uses different symbols and colours that correspond to specific information, for example, whether the inspection result is acceptable (the turbine part does not need to be repaired) or not (the turbine part must be repaired). Another mechanism consists of pointing and tagging inspections results in a specific location of the turbine (over the 3D turbine geometry).
- Within the *Inspection Result Information panel*. The inspection results can also be presented in the Inspection Result Information Panel. This panel shows a summary of the inspection results carried out on a specific turbine part, for example, the technique used in the inspection, the sum of all flaws found at a selected part or their description. The shown information can be selected and filtered by the user. This panel also provides a set of links through the discussion management tool that connects the inspection results with the associated discussion.

3.3 Discussion Management Tool

The discussion management tool allows for analyse of the inspection results in a collaborative way by allowing the different users (power plant operators, inspection service engineers, power plants manager, etc.) to be involved in the final decision-making process, such as re-scheduling future inspections or scheduling maintenance activities to repair or replace an affected turbine part. This tool increases the amount of communication among actors, makes documentation easily accessible and enables the sharing of past experiences. Discussions that are associated to specific inspection results are accessible from the *Inspection Result Information panel*. Once the user has selected a discussion, the tool is opened (Fig. 7).

The discussion can be at two different states: open and close. If the discussion is open, the tool provides a set of controls for registering new contributions (text or attached files) and setting connections between different discussions. Different users will have access to different topics of discussion depending on their role. Once the users have a make a decision and conclude their discussion, it is closed and the system provides a report of the discussion and the decision.

4 Conclusions

The main aim of this chapter was to report on the development of a UIW-collaborative tool that assists in the collaborative management of inspection results. By decreasing the decision-making time and the amount of time taken for repair and maintenance procedures, the tool optimises the activities and increases the productivity of the power plants.

The UIW-methodology has made it possible to identify challenges that must be addressed in an effective way. The problem was modelled by use cases, requirements and a system architecture. In addition, an APS model was used to identify the structure of the relevant information that the system stores and manages to provide the needed functionalities.

As result of the work developed and the experience accumulated in this industrial case, it seems appropriate that the information systems of a company that has a problem such as the two hierarchical trees should be consistent with the APS presented. The APS model has been presented as an important output of this project; using a system that follows this structure would yield important benefits for the company.

Finally, this chapter demonstrates the implementation of a tool that offers a web-based application for the visualisation of the product and the data regarding inspection results, such as inspection data, techniques used and information about flaws found in a specific part of the turbine. This information is shown in two ways: (1) through a classic web app, that is, with hypertext, using plain text, tables, lists, photographs, 2D planes, etc. and (2) through a 3D module. The latter allows users to see information in a three-dimensional model of the turbine geometry and to navigate through the different parts of the turbine. The tool also includes a collaborative decision-making application to manage all stakeholders' proposals, annotations and discussions to assist in the decision-making process.

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Rock Crusher Upgrade Business from a PLM Perspective

Simo-Pekka Leino, Susanna Aromaa and Kaj Helin

Abstract Global trends of ecology and sustainable development, safety awareness, changing legislation, and urbanization, together with the economic situation, force industry to find solutions for extending product lifecycles, while maintaining and improving machine system performance and other properties during the lifecycles. Together with these societal issues, firms are struggling with competitiveness. This chapter introduces the new Use-it-Wisely (UIW) approach to upgrading rock crushers at customer sites. The higher level problem needing to be solved concerned making upgrade delivery projects profitable and more desirable for customers, manufacturing OEMs and suppliers. The main recognized and treated bottlenecks were related to knowing the actual status of the upgrade target, communication and collaboration with stakeholders, verification and validation of upgrade specifications and an efficient information flow between the stakeholders. Augmented reality (AR), Virtual environments (VE), camera based 3D scanning, and cloud based solutions are the selected pieces of technology for solving the bottlenecks. They enable better communication, collaboration and involvement of all stakeholders, including customers, internal stakeholders, suppliers and partners. They also better enable the planning and discussing of service quality activities. Product life-cycle management (PLM) is the framework for developing and managing product related information, processes and collaboration expanding towards product middle-of-life, end-of-life, and service lifecycle management. This study is a proof-of-concept that demonstrates the potential of contributions to business model innovations and game changes for upgrading business.

S.-P. Leino (✉) · S. Aromaa · K. Helin
VTT Technical Research Centre of Finland Ltd., Espoo, Finland
e-mail: simo-pekka.leino@vtt.fi

S. Aromaa
e-mail: susanna.aromaa@vtt.fi

K. Helin
e-mail: kaj.helin@vtt.fi

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Keywords Technological support of collaboration · Upgrading of assets · Business model innovation · Product life cycle management · Mining and construction

1 Introduction

This chapter introduces how novel digital technology may enable an innovative new business model for upgrading old machines, in the mining and construction industry. Global trends of ecology and sustainable development, safety awareness, changing legislation, and urbanization, together with the economic situation, are forcing development of solutions for extending product lifecycles, while maintaining and improving machine system performance and other properties during the lifecycles. Together with these societal issues, firms are struggling with competitiveness. Often, they optimize short-term financial performance, while missing the most important customer needs and ignoring the broader influences that determine their long-term success (Porter and Kramer 2011). A true understanding of customer and user needs, and the needs of society, in general, is often missing. Simultaneously, core competences and key assets, such as knowledge and skills of employees and partners are underrated.

However, the most enlightened manufacturing firms are seeking new business and revenues from services and maintenance, such as the upgrading of older machine individuals. However, service design raises new challenges, compared to traditional product design engineering. Compared to physical products, services are generally under-designed and inefficiently developed (Cavalieri and Pezzotta 2012). This problem is the focus of Product-Service System (PSS) research. On the other hand, Product Lifecycle Management (PLM) is a strategic approach, where business is seen from a product perspective covering product related information, processes and collaboration. Thus, PLM should be a framework, where PSS and service products are developed and managed. However, conventional views of PLM tend to stress the design, engineering and production phases, while the use and end of life phases are, typically, not very well covered (Wuest 2015). This is the challenge of the case company, as well. It faces the problems of maximizing customer value and societal satisfaction, while increasing their own profitability. The principle of "shared value" (Porter and Kramer 2011) is proposed as a solution for creating economic value in a way that also creates value for society, by addressing its needs and challenges.

1.1 The Industrial Case

The industrial case relates to equipment manufacturing and services for the mining and construction sectors. Two companies, an original equipment manufacturer

(OEM) and a research and development (R&D) partner in upgrade services, were involved in the case study. The OEM case company, a manufacturer of rock crushers wants to serve their customers by providing machine upgrade solutions that support machine utilization and the customers' capability for crushing rocks, for instance, near urban areas, by decreasing the noise and dust levels of the machines. This is challenging, because every partially configurable machine individual is different when it leaves the factory and it is often modified by the customer or a third party during its lifecycle. The lifecycle may exceed ten years and, during that time, machine deformations typically occur, due to harsh conditions. Therefore, it is difficult to know the status of the machines at the customer sites, around the world. Thus, machine upgrade projects are, generally, not very attractive or profitable. The major high level business questions are:

- How to make upgrade business profitable
- How to establish a successful business model for rock crushing machine upgrades
- How to effectively manage upgrade service projects?

1.2 Product Life Perspective and Product Life-Cycle Approach

Having a long tradition (Wuest 2015) in both engineering and management science, Product Life-cycle Management (PLM) proposes to help with the challenges of maintaining the performance of existing products and developing new competitive products for changing and turbulent business environments. Fast reactions to these changing markets and customer requirements, as well as the involvement of stakeholders, requires a sound information basis, which, in manufacturing, could be provided by PLM (Wiesner et al. 2015). Besides product and process related data, PLM also takes into account the interdependencies of information and communication between all of the stakeholders involved in the product lifecycle (Wuest 2015).

PLM originates from Product Data Management (PDM) with its original focus on design engineering data for Computer Aided Design and Computer Aided Engineering (CAD/CAE) (Wiesner et al. 2015); however, PLM increasingly focuses on the whole product lifecycle (both the product types and product individuals) and promises to manage all involved data and information (Wuest 2015). While the initial objectives of PDM were to improve product quality and reduce costs, additional objectives also became important (Wiesner et al. 2015): time reduction, streamlining of processes, increased value for the customer and innovation. Thus, newer PLM approaches are aligned to changes in market conditions and technical opportunities (Wiesner et al. 2015).

In PLM, life phases of products can roughly be divided (Wiesner et al. 2015) into the Beginning of Life (BoL), the Middle of Life (MoL), and the End of Life (EoL). This view is different from marketing, where a product life is divided into five phases: introduction, growth, maturity, saturation and degeneration (Wuest 2015). To elaborate, the three phases of product life in PLM are (Wiesner et al. 2015):

- **BoL**: The product is imagined as an idea in the minds of the designers, which are then converted into a detailed product specification, in the definition stage. During the realization phase, the product is manufactured and delivered to the customer.
- **MoL**: The product is in the possession of the customer, who uses it for their applications. The product is also supported by the manufacturer, in order to maintain its functionalities.
- **EoL**: The product loses its usefulness for its intended purpose. It is retired or upgraded by the manufacturer or disposed of by the customer for eventual reuse or recycling.

By definition, PLM takes a holistic view to product life, taking into account both the lifecycles of product types and families, as well as product individuals. However, as previously stated, the focus of PLM has been more on the beginning of life than on the middle or end of life phases. Newer proposed approaches such as "*Closed-loop PLM*" (Jun et al. 2007), take an even greater holistic view upon of the entire product lifecycle, which, ideally, also includes the end of one lifecycle merging into the beginning of the next (Wuest 2015). The concept of a closed loop PLM provides the opportunity to maximize the benefits of the lifecycle operations. This raises the importance of knowing what the whole product lifecycle activities consist of, how its information is created, used, and modified during the product lifecycle, and which lifecycle information affects the product lifecycle operation (Jun et al. 2007). The aim of a closed-loop PLM is to close the information gaps between the different phases and processes of the product lifecycle of individual products, both backwards and forwards (Wuest 2015). Recent PLM approaches also consider product related service in the lifecycle of products (Wiesner et al. 2015). However, closed-loop PLM and service requires dealing with products as item-level individuals, which is still a common challenge (Wuest 2015). In other words, manufacturing companies that want to develop and offer service products, e.g. product upgrades, often do not know the exact status of product individuals at their customer sites. The common question is how product individual level upgrades and service products can be supported in PLM?

1.3 Tool Selection

The main industrial problem treated in this chapter concerns making upgrade services profitable and establishing a business model to support that goal. This chapter covers the biggest bottlenecks. These are:

- Knowing the actual status of the upgrade target, thus getting initial data and information for an upgrade delivery project
- Global communication with customers in the field, to form a true understanding of their needs and possible limitations
- Validation of customer requirements, to ensure that the needs are understood and correctly specified
- Management of upgrade service products and offerings
- Support of engineering design of upgrades, taking into account the limitations
- Collaboration and communication between the upgrade stakeholders
- Validation of the proposed upgrade solution with the customer
- Efficient information flow during delivery of the upgrade project.

As previously stated, PLM, for the case company, is the framework of developing and managing product related information, processes and collaboration. On the other hand, PLM as a theoretical concept as well as from an industrial implementation viewpoint, is just expanding to cover a product's middle-of-life, end-of-life, and service lifecycle management. The above listed bottlenecks are, at the same time, common PLM research targets and problems related to the case companies' upgrade service business. PLM is about creating, using, modifying, and managing product and service related information, for all stakeholders. In this case, information related problems are more specifically related to issues in Table 1.

The preliminary and principle selection of the proposed tools and solutions for the above described bottlenecks and the PLM information related problems are partly based on previous experiences with certain tools and techniques, and partly on a collaboration with other Clusters and partners, in the Use-it-Wisely (UIW) EU-project. The proposed main solutions to the problems and expected advantages are listed in Table 1.

Table 1 PLM related challenges of rock crusher upgrading and proposed solutions

PLM related challenge	Proposed solution	Expected advantage
Creating digital data and information about the target machine, including 3D geometry	3D scanning (3D data capture)	Fast and cost-efficient way to get the actual status and geometry
Visualization of upgrade service offerings and proposed solutions for customers	Augmented Reality (AR) Virtual Environments (VE)	Mobile and cheap solution for operations in field Possibility to test non-existing solutions and environments
Visualization of the target machine status and boundary conditions for engineering designers	Virtual Environments (VE)	Possibility to test non-existing solutions and environments Effective way to share information and knowledge
Keeping digital data and information up-to-date and sharing it in an appropriate format, for all required stakeholders	Cloud-based PLM module	Possibility to automate information management and dynamically involve different stakeholders

Two major principles in proposing and selecting tools and solutions for the described problems are: (1) To utilize "COTS" Commercial Off-The-Shelf solutions and (2) the possibility to integrate them into company processes and information management systems, so that they benefit business. Different versions of the selected technologies are tested and developed from the perspective of functionality, user acceptance and business process benefit.

Finally, data processing and information flow between the applications that support the upgrade sales-delivery process is established, based on cloud technology and a product lifecycle management system. Modular and configurable upgrade solutions enable information re-use and an effective engineering design phase of the project.

Utilization of techniques and methodologies, such as VE and AR in this case context, can be put under the umbrella of "virtual prototyping", which is defined by (Wang, 2002) as follows: "*Virtual prototype, or digital mock-up, is a computer simulation of a physical product that can be presented, analyzed, and tested from concerned product life-cycle aspects such as design/engineering, manufacturing, service, and recycling as if on a real physical model. The construction and testing of a virtual prototype is called virtual prototyping (VP)*". When virtual prototyping is considered from an engineering design and product development viewpoint, taking into account product information management and the whole product lifecycle, it should be connected with PLM development. In (Leino 2015) the theory and practice of virtual environments, based on virtual prototyping in product development and product lifecycle management, is discussed. Furthermore, (Ovtcharova 2010) provides a practical outline of the process definition and IT-system environment of "virtual engineering", and (Bordegoni et al. 2009) introduces a mixed prototyping approach and framework for product assessment. They see it as a practice for effective and rapid design reviews and validation of new products from an ergonomic and usability perspective. Engineering design reviews (see e.g. Huet et al. 2007) are one of the most important application areas of virtual prototyping. However, the majority of the published virtual prototyping examples are related to new product development, which is not really the case, in this research. The important question is: how to mix the virtual and physical worlds of existing and to-be-defined objects?

1.4 State-of-the-Art of the Proposed Technical Solutions

Augmented (**Mixed**) **Reality** (**AR**) was proposed as a means of improving the customer interface, including visualization of upgrade offerings, as well as validation of upgrade solutions. It was also intended to assist service and maintenance workers in the field, for instance, in assembling the upgrade solution on top of an old machine. Augmented (Mixed) Reality involves the superposition of computer graphics over real objects or scenes (Shen et al. 2010). Compared with VR, AR is a semi-immersive design environment in which the users can see the real world, while performing feature modelling, on a virtual product. Recent industrial applications of AR include, for instance, collaborative product design and development (Shen et al. 2010), design reviews (Verlinden et al. 2009), development and planning of complex production processes and systems (Dangelmaier et al. 2005) and architectural and Construction Site Visualization (Woodward and Hakkarainen 2011). AR helps the understanding of project documentation (Meža et al. 2015) and enables graphical highlighting of an interesting phenomenon already in the design phase, thus, determining problems and risks, sooner (Tuma et al. 2014).

Virtual Environments (**VE**) were recognized as a medium for collaborative engineering design and as a communication medium between the upgrade service stakeholders, including the customers and partners in the supply network. Virtual Environments can be defined as "*interactive, virtual image displays enhanced by special processing and by nonvisual display modalities, such as auditory and haptic, to convince users that they are immersed in a synthetic space*." (Ellis 1994). However, VE have presented challenges to human-computer interaction (Wilson and D'Cruz 2006). Research with VE started in the 1960s, with NASA being one of the pioneer institutes. However, after several decades, the technical and methodological development of VE is now becoming mature enough for real and serious utilization in industry. VE is currently reliving a renaissance.

VE for virtual prototyping of assembly and maintenance verifications has already been introduced by Gomes de Sá and Zachmann (1998). They saw it as a very promising technology, but they also state that it would not become a wide-spread tool before being integrated with IT infrastructure. One of the recent studies related to the design review of complex industrial assemblies was introduced by Di Gironimo et al. (2014). They have already solved many of the product information management challenges specifically related to VE and PDM interfaces. Other manual assembly and maintenance related VE research were reported, for example, by Chryssolouris et al. (2000) and Gomes de Sá and Zachmann (1999).

3D scanning was proposed as a piece of technology that enables efficient initial data gathering (i.e. 3D geometry) at the customer site. 3D scanning is a technology that analyses real-world objects and environments in order to gather data on shape and appearance. From the data, three dimensional models of reality can be constructed. In principle, there exist two commercially available methods on the market: (1) active (e.g. laser, sonar) and (2) passive (e.g. photogrammetric scanning using mobile digital cameras). There are many recent examples of the use of different 3D scanning technologies in industry and civil engineering. The approach of Erdos et al. (2014) on retrofitting complex engineering objects, such as factories and utilization computer aided design, is similar to ours; however, their paper is more focused on the technical development of 3D scanning devices. Bosche and Haas (2008) report technical 3D scanning advancements in the architectural and construction sectors as do (Bi and Wang 2010) in manufacturing. Many of the recent technical developments are related to 3D scanning with portable devices, such as smartphones, tablets and PDAs. Examples of such research are reported, e.g. by Ancona et al. (2015), Kolev et al. (2014), Tanskanen et al. (2013).

3D laser scanning and point cloud based applications are used, for instance, in the renewal of electrical substations, when the original CAD models are outdated (Gonzalez-Aguilera et al. 2012), which is also similar to our approach. Kumar et al. (2012) have utilized point clouds in reverse-engineering and they introduced a detailed methodology of scanning and applications. Berglund et al. (2014) have reported how 3D laser scanning enables the capturing of spatial digitized data, quickly, in order to support discrete event simulations of production systems. This integration of point cloud data, with simulations, is supposed to enable better decision-making (Berglund et al. 2013). It is also based on the created realistic visualization and better common understanding of the redesigned production systems (Lindskog et al. 2014). Based on the experiences of (Weidlich et al. 2009), 3D laser scanning can enhance the creation of virtual test scenarios related to optimization and extension of existing environments.

1.5 Outline of This Chapter

The rest of this chapter is organized as follows: The next section introduces more detail on how the technical solutions were applied, what they are, and how they were tested and evaluated. Furthermore, the next section describes the conceptual definition of the new product upgrade service model. First, the as-is situation and requirements analysis are explained.

After that, in the Discussion section, the benefits and limitations of selected and developed technical solutions are reported and discussed compared to the requirements and situation before the projects, as well as compared to other published research. Also discussed are what implications can be drawn from this research for PLM development and implementation. Finally, concluding remarks are made on benefits and further challenges.

2 Tool Applications and Solution to the Company Challenges

The major business problems are:

- How to make upgrade business profitable
- How to establish a successful business model for rock crushing machine upgrades
- How to manage upgrade service projects efficiently.

These questions were approached by modelling the as-is situation in the case companies, discussing it with the product stakeholders and recognizing the most remarkable bottlenecks of the machine upgrade projects. These included communication channels on the customer interface, validation of the problem definition with the customer, getting the initial data for the project, effectively designing an upgrade solution, verification of the solution and validation with the customer and end user. The business cases were created with the requirement of cheap and easy to use technology that can be integrated with business solutions.

Figure 1 illustrates the complex network of internal and external product upgrade stakeholders, and their concerns. The rich picture shows how society and authorities put into place regulations and ethical demands for the end-customers of the OEM manufacturing company concerning, for instance, noise and dust levels near urban areas. These demands originate with the end-customer and end-users and go to the OEM. For example, if end-users need to decrease the noise levels of their rock crushing machines, they may ask the OEM to upgrade the machine to fulfil the noise level requirements of the authorities. The OEM wants to serve the end-customer as well as possible, while simultaneously trying to keep their business profitable. They need to effectively manage the end-customer interface as well as their internal and external upgrade delivery processes. Previously, these processes have not been optimal, causing productivity challenges.

As was described in the Introduction section, AR, VE and 3D scanning were proposed as technical tools in order to meet the business goals of upgrading old rock crushing machines at customer sites. Cloud solutions and PLM system configurations were adopted to support the required information management processes. The following section introduces evaluation of the proposed technical applications.

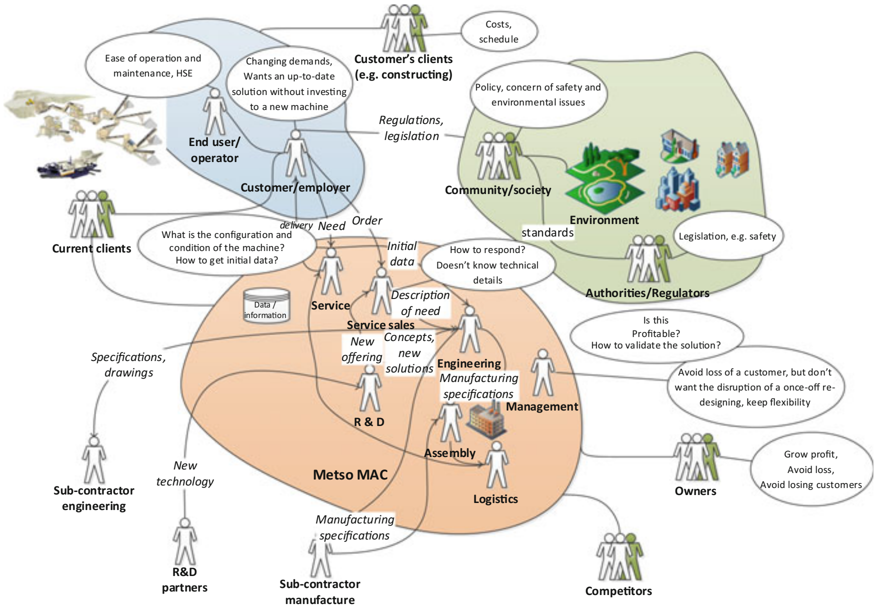

Fig. 1 Rich Picture model describing the complexity of an as-is situation between stakeholders

2.1 Trials and Demonstrations

The tools and solutions to enable an innovative new business model for upgrading old machines were tested and developed during three trials and a demonstration period. This section introduces a summary of the goals, methods and results of the trials and demonstrations.

2.1.1 Trial 1: Evaluation of the Proposed Business Model

Goal: The objective in Trial 1 was to discuss and evaluate a new proposed business model and preliminary ideas concerning new upgrade delivery processes and tools. The new business model should provide the possibility to design, configure and customize upgrades for the customers, machines, based on a catalogue of upgrades, with the support of advanced tools and solutions, which would help to reduce cost and delivery time. The aim was to improve profitability and systematize work.

Material and method: A process diagram ("Swim-Lane") was made from the proposed business model. It described a hypothetical sales-delivery process within the new business model in which organizational functions and/or networked companies are involved. The process diagram was evaluated by using a walk-through method in a focus group session.

Results: The new proposed business model received common acceptance from the focus group. However, the main discussion continued to be on current business challenges. Therefore, the summarized main challenges in the current upgrade process, were as follows:

1. Presently there is no clear upgrade process
2. Sometimes it is difficult to prepare a reliable and fast offer for a client after specific requests are made for an upgrade
3. Documentation needs to be improved for better information sharing
4. An easier and faster process for collecting initial data for upgrade projects is needed.

2.1.2 Trial 2: Evaluation of 3D Capture Technology

Goal: The objective in Trial 2 was to test and evaluate different 3D scanning systems and the usefulness of produced 3D data, for upgrade design in Virtual Environments and in engineering/design application such as CAD/CAE.

Materials and method: During the test, data was collected and three different 3D scanning systems were compared. These systems included one laser scanning and two different systems for 3D reconstruction from multiple camera images. There were three different cases:

1. A mobile rock crushing unit of the OEM
2. A commercial component—gear box
3. Production line—jaw crusher assembly line.

Two different 3D scanning techniques were tested: (1) laser (active) and (2) photogrammetric (passive) mobile digital camera (still and video) based. Figures 2 and 3 are from the first tests of camera based scanning.

Results: 3D scanning seemed to be a very useful technology. However, based on these tests, the data pipeline from the scanned raw data to CAD/CAE or VE software was only working properly in the photogrammetrically generated 3D models. This scanning accuracy is not always suitable for detailed design, but can be applied to concept design and discussing the boundary conditions for the design. The accuracy of laser scanning is probably also suitable for detailed design, however, the data import to the CAD and VR software did not yet work properly, with the given pieces of technology. Table 2 explains the evaluated advantages and disadvantages of the two 3D scanning methods.

For instance, (Golparvar-Fard et al. 2011) have also compared two 3D scanning methods, camera based and 3D laser scanning, in modelling the as-built status of a construction site. They concluded that camera based methods are less accurate, but that both methods are capable of producing 3D representations for visualizing the environment, from different viewpoints.

Fig. 2 In the Trial 2 Camera based photogrammetric 3D capture was applied in scanning a gear box at the OEM factory

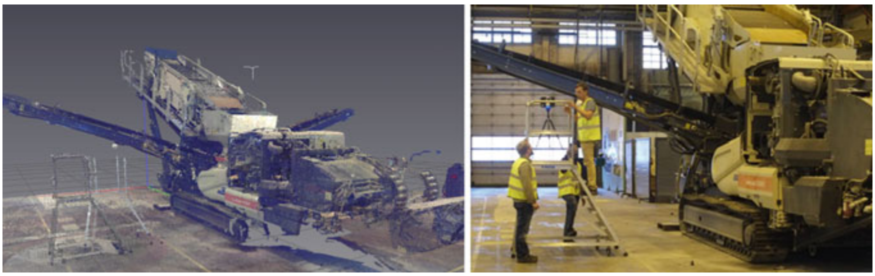

Fig. 3 Laser scanning and generated point cloud representation

2.1.3 Trial 3: Evaluation of Digital Visualization Technology

Goal: The goal of Trial 3 was to evaluate two different 3D visualization systems, during an upgrade design. AR and VE systems were tested to support design reviews.

Materials and methods: The design object, reviewed in the test, was a machine maintenance platform attached to a mobile rock crushing machine. This was an upgrade module for an existing machine. The purpose of the maintenance platform was to provide a safe, ergonomic and efficient workspace for maintenance workers. In the AR test, the system included a virtual model of the upgrade module (the maintenance platform), the real rock crushing machine, a virtual frame and a cover, a real environment, three different postures of a digital human model (DHM) and a human participant. In the VE test system, the model included a virtual model of the product (the maintenance platform), a virtual model of the rock crushing machine, a virtual environment, three different postures of a DHM, a human participant and 3D models of hands and shoes. Nine people from the OEM company participated in the AR test and ten people from the company participated in the VE test. Questionnaires and interviews were used as data collection methods. Figure 4

Table 2 Advantages and disadvantages of 3D laser scanning and camera based 3D capture

Method	Advantages	Disadvantages
3D laser scanning	Accuracy Speed	Not portable Requires special training Limited and/or laborious possibility to generate 3D models for VE and CAD/CAE
Camera based	Can be used with a normal smartphone Easy-to-use Relatively inexpensive	Limited accuracy Model quality depends on user skills Sensitive to light conditions

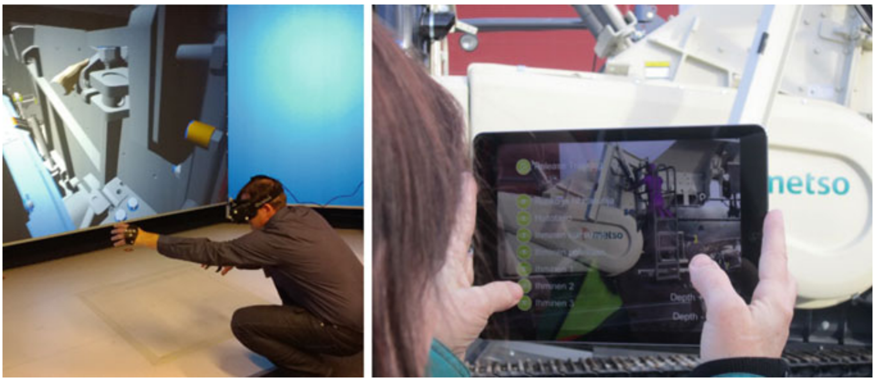

Fig. 4 Upgrade design review in a VE (*left*) and upgrade validation with an AR application (*right*)

shows the testing of the VE with the upgrade design engineer (left), and the testing of the upgrade visualization AR application, with an end user.

Results indicate that both of the AR and VE prototypes were suitable for assessment of certain human factor/ergonomic (HFE) related issues (Aromaa and Väänänen 2016). AR-systems could be particularly valuable for illustrating upgrade solutions to the upgrade stakeholders (marketing, customers and assembly workers) in the field. The VE prototype was more comprehensive and immersive for the designers, when reviewing the HFE issues of the upgrade machine.

In addition, data sharing was tested. Data sharing was tested by means of the RD Cloud™ platform. It allowed the 3D scanned data (point clouds, polygon models and design models related to photos and video) to be stored in the cloud, as well as the data collected from the AR-system. The users were able to understand and appreciate the potential of the tool, but it needs greater customization, according to the users' needs (i.e. show photos preview, allow CAD data conversion in other formats, enhance the uploading feature, etc.).

The demonstration phase was aimed at proving the technical maturity, usability and usefulness from the viewpoints of end users, customers and other stakeholders, as well as to demonstrate the big picture (capability from upgrade delivery process and data management viewpoints) and business impact potential. The three demonstration cases, and their evaluation criteria, are listed in Table 3.

Figure 5 shows how the new pieces of technology should contribute to the upgrade delivery projects. Previously, there were no process or method definitions

Table 3 Demonstration cases and their evaluation criteria

#	Demonstration case	Evaluation criteria
1	Smartphone, video based, 3D-scanning and automatic 3D model creation. Data collection for upgrades with collaboration with engineering service provider	Anyone should be able to use a smartphone for scanning (no restrictive requirements on how to record the video) The quality of the pictures, the transfer speed and the quality of the created 3D model Also the usability and the overall workload and time of this scanning method
2	Noise encapsulation demonstration for a customer (or sales personnel) with AR and VR. Review a large scale machine upgrade with a customer, verify key customer requirements, such as maintainability, transportability etc.	User experience, interviews and monitoring (end-customer, serviceman, designer)
3	Dust suppression or safety upgrade installation (combination of Cases #1 and #2). Review a minor/mid-size machine upgrade with engineering and customer	Get initial data from existing products (3D scanning with video) Check the upgrade installation in 3D CAD, with a scanned model Also check with a virtual model and AR Data pipeline Interview test users (assembly workers, designers, servicemen, sales, customer)

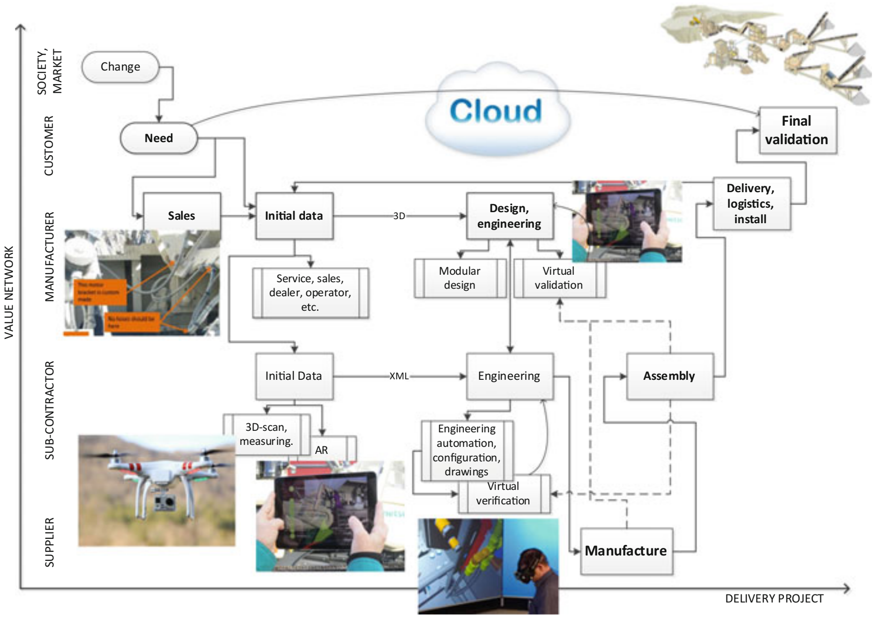

Fig. 5 The new innovative rock crusher upgrade delivery process that exploits 3D capture, AR/VE and Cloud

for old machine upgrade projects. It has been more of an ad hoc activity, as described in Fig. 1. Product processes of the OEM company have been optimized for configuring and producing new machine variants, and the upgrade projects have been disturbing this day-to-day business. Moreover, it has had a narrow perspective without taking into consideration the roles of partners, suppliers and customers. Firstly, the UIW-approach made these processes and roles explicit, taking into account the whole chain, from customer needs to upgrade deliveries. Secondly, in the UIW-approach, the aforementioned pieces of technology enable the retrieval of information on the initial situation at a customer site, collaborative design and verification and validation of the upgrade solutions (Fig. 5). Cloud solutions enable information flow and processing.

3 Discussion

The main high level industrial problems touched in this chapter was about making upgrade services profitable and establishing a business model to support that goal. However, this chapter does not describe a business model; neither does it show quantitative evidence about increased profitability. Nevertheless, this chapter does discuss how future novel pieces of technology may change upgrade project processes and remove current major process bottlenecks that hinder profitability. There is no quantitative data supporting the claimed productivity increase. Instead, productivity is claimed to be increased by better effectivity, more value adding work and less waste in the upgrade processes. This was preliminary assessed by using as-is and to-be process models and simulation games. The main bottlenecks of upgrade service profitability are related to knowing the actual status of the upgrade target, communication and collaboration with stakeholders such as customers, engineers, service personnel and supply networks, as well as effective tool, method and information management, during an upgrade delivery project. Thus, optimal support for the design process requires integrated 3D digitalization and a multidisciplinary approach in order to solve the complex problems (Weidlich et al. 2009).

The new approach is based on clever engineering design solutions for the upgrade products, as well as on the digitalization of information flows of the upgrade projects. Clever engineering design solutions mean modularized upgrade products and services that can be configured, at least partially, for a specific customer need. Thus, less engineering work from scratch is needed. Digitalization of information flows means, of course, that information is in digital format, but also that it flows through an upgrade service project smoothly. It means that the data and information are correct, up-to-date and available for all stakeholders, when needed. This is the task of PLM. PLM should support (Jun et al. 2007): Management of lifecycle objects, collaboration between customers, partners and suppliers, and the firm's ability to analyse challenges and make decisions on them. In most cases, it is necessary to share product information with several suppliers and partners.

Digitalization saves a lot of calendar time and unproductive work, but it also makes information content richer. When, for instance, a realistic digital 3D model of the upgrade target is instantly available to designers, they can begin the definition upgrade solution immediately, with more reliable initial data. Furthermore, additional information about the upgrade target status can be attached to the model. This means making information content rich, which is also the task of PLM. Productivity increases by decreasing unproductive work during an upgrade delivery project. When information is correct and available, there is less need for searching and rework due to wrong status information and corrections. The status information can be discussed among all stakeholders and decisions can be made based on better quality information. For instance, 3D laser scanned models can increase understanding and bridge the gap between different areas of expertise (Lindskog et al. 2013).

Requirement specifications of the upgrade can be validated with the customer and the proposed upgrade solutions can be verified against the requirements and validated with the customer, based on virtual models. Virtual design reviews allow multiple designers and other stakeholder to highlight possible design flaws and make choices in real time (Di Gironimo et al. 2014). When design flaws are recognized earlier, with a virtual prototype model, and engineering changes are made based on them, there is a potential for decreasing changes with manufactured physical products.

Furthermore, AR- and VE-based visualization enables better understanding of information, and thus, better communication and involvement of the stakeholders. People with different backgrounds and prior knowledge can create similar mental models, which enables better discussion and decision making (Lindskog et al. 2013; Leino 2015). Virtual models enable stakeholders that are unexperienced with CAD to work with virtual prototypes (Gomes de Sá and Zachmann 1999). Additionally, the stakeholders can virtually test and train the use of the products, before they exist, which can lead to improved usability and ergonomics (Ottosson 2002).

Therefore, more knowledge is involved in the process, which decreases uncertainty and improves the quality of decision making. The changing market situation and customer needs can be responded to with better knowledge management, leading to new product-service innovations. VE based virtual prototyping does have the potential to improve overall product quality, especially for those business processes where humans play an important role (Gomes de Sá and Zachmann 1999). Therefore, the potential business impact of VE is also manifested though a more holistic view of the PSS, rather than just a component or product centric view (Ovtcharova 2010).

3.1 Product Lifecycle Management Perspective

There is an industrial need to have easy access to product use phase (MoL) information, in order to better provide a value adding combination of products and services for customers (Lejon and Jeppsson 2015). On the other hand, manufacturing companies still have a traditional engineering approach to the tangible part of engineering and leave the intangible service element to intuitive processes and methods (Cavalieri and Pezzotta 2012). The shift from traditional product centric product development to PSS development is an opportunity to create radical innovations (McAloone and Andreasen 2004), but it requires an increased awareness of complex lifecycle issues, including variance of stakeholders and societal issues. Cavalieri and Pezzotta have discussed using virtual environments for interaction between service providers and clients and visualizing new service concepts. A similar approach is part of our UIW-concept, as well. Virtual environments and virtual prototyping enables extending the virtual phase of the product lifecycle towards service planning and management, thus integrating traditional PLM and SLM (Service Lifecycle Management).

However, from a PLM perspective, a sound methodology to combine product lifecycle and service lifecycle does not exist. Therefore, challenges remain for closing feedback loops from, for example, the service delivery to the BoL phase of products (Wiesner et al. 2015). The closed-loop PLM approach intends to close these loops and emerging new technologies enable the gathering and analysing of product lifecycle information and decision making, without spatial and temporal constraints (Jun et al. 2007). In recent papers, e.g. (Lejon and Jeppsson 2015) feedback loops are closed using advanced sensor technology that records the events and status of the technical product, itself. Thus, our UIW-approach contributes to the closed-loop PLM and service lifecycle management by providing an approach that utilizes AR, VE and 3D scanning for gathering and analysing product lifecycle information.

The main phases of product life are the beginning of life (BoL), the middle of life (MoL), and the end of life (EoL). In the closed-loop PLM, designers and production engineers receive feedback information from distributors, maintenance/ service, customers, re-manufacturers, etc. This information, from the MoL and the EoL, can also be indirectly used for the design and production of the next generation products (Jun et al. 2007). Traditionally, this kind of product individual status information is lacking in product design and development, but the closed-loop PLM aims to enable it in successful business operations. Thus, our UIW-approach contributes to closing two information loops in product life:

1. Upgrading a product individual at a customer site
2. Bringing the product MoL and EoL knowledge to a new product and service design and development.

The Closed-loop PLM can have direct and indirect loops of information flows over an extended product lifecycle, meaning that a lot of product lifecycle information can be accumulated and used, not only in the current lifecycle, but also with the next (Jun et al. 2007). Our UIW-approach enables the gathering of the digital status data and information, such as a 3D model of an item-level product individual and information about its use and circumstances, at the customer site. This approach can contribute to the concept of Product Avatars (Wiesner et al. 2015), where the idea is to create virtual, item-level, product individual models, where product lifecycle information is linked. It encompasses philosophical ideas similar to that of the German “Industry4.0” concept (see e.g. Brettel et al. 2014), where production systems and product individuals should have virtual twins. Our 3D approach enables both the effective design and development of an upgrade delivery PSS through the virtualization of the product and the related work tasks. Furthermore, it enables the taking of product MoL and EoL information into account, when designing and developing new generation products and services (Fig. 6).

3.2 Tool Use Limitations

Relatively new pieces of technology have been developed and tested as part of the UIW-product-service upgrade approach. They have not really been implemented into business processes; this study has been more of a proof-of-concept. The technology maturity, usability and benefits have been evaluated against business cases in order to assess the realistic potential in creating new value and innovative upgrade business. Here, it is important to understand that value cannot be purely measured quantitatively in money, but rather that value is created in more fluent

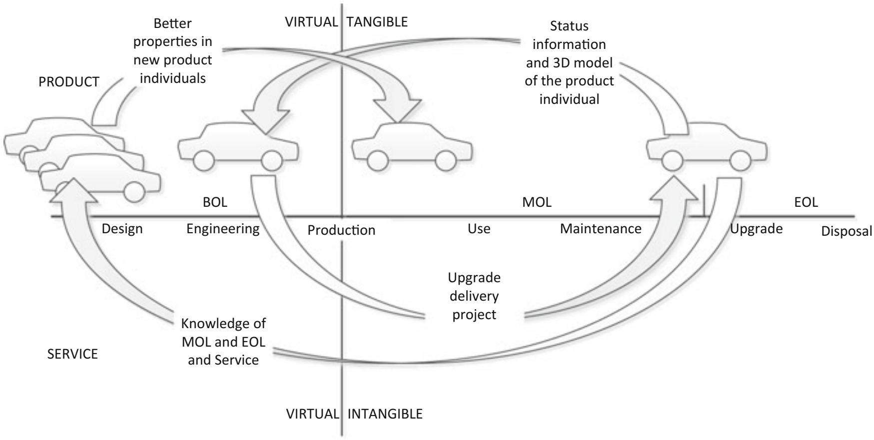

Fig. 6 Closing knowledge loops of product lifecycle by virtualisation product representations

processes, such as customer satisfaction and quality. On the other hand, if we consider the impacts on productivity (Tangen 2005), we need to distinguish between efficiency (doing things right), effectivity (doing the right things) and usability. Previously, it was claimed, that our UIW-approach increases productivity by decreasing the amount of waste, such as searching for information and unnecessary rework. This can only be evaluated by looking at the impact at the business success level. The difference between evaluating the usability and efficiency of a certain tool, such as an AR device, and the effectivity on a business process level, can be described with the distal/proximal evaluation model (Blessing and Chakrabarti 2009). What clearly increases productivity, where the total upgrade process is concerned, is the use of digital models created in VE as instruction material in AR (Damgrave et al. 2014).

The limitations of the present VE system result in an inability to test all aspects of design, which often leads to only emphasizing the testable aspects (Damgrave et al. 2014). Virtual prototyping, which is also VE and AR based, has been commonly claimed to shorten product development lead times and increase flexibility. However, the above mentioned problem, of the possibility to simulate all aspects of design, may lead to a situation of "*pseudoflexibility*" (Damgrave et al. 2014).

So far, in the UIW-project, it has not been possible to see the actual distal impacts, i.e. business benefits. However, the tested tools and methodology seem very promising. Considering the rapid technological progress, it is safe to say that it may be a potential game changer in upgrading business.

However, there is a "*Virtual prototyping paradox*" (Leino 2015) involving the difference between the claimed benefits and the expectations related to VE and virtual prototyping, and the actual industrial implementations and evidence for business advantages. On the one hand, this may be caused by the ambiguous definition of virtual prototyping. It seems to be useful for practically everything, but this broad applicability can also be a source of difficulty (Ellis 1994). Thus, the barriers of implementing VE and other such technology are not only caused by costs of equipment, but also by the knowledge of how to work with it (Ottosson 2002). Without seamless integration with a firm's processes, information management and way of working, this technology will not create the potential value. In all likelihood, both the new tool and existing processes, as well as the fundamental way of thinking, will require adjustment in order to create the maximum value (Damgrave et al. 2014). Without making clear connections with the input and output of other process and project phases, there is a risk that VE will just be handled as a tool, separate from the product processes.

From the technology perspective, the described UIW-approach includes AR, VE, camera based 3D scanning, as well as cloud and PLM solutions. They were tested and proven to have great potential for making product-service upgrade business more profitable. Affordable technology, such as mobile phones can already be used for 3D scanning and AR-applications. Some researchers (Meža et al. 2015) also see the potential of, such things as AR applications, but they are sceptical as to the possibility of replacing the conventional product information presentation techniques. Concerning virtual assembly simulations, (Chryssolouris et al. 2000) state that despite the time technical level and realism of VE, its feasibility and usefulness was demonstrated, especially when taking into account human involvement, in the process.

However, there are still some limitations (Table 4) related to technical maturity and user friendliness of AR/VE and 3D-scanning. The human factors of these technologies are also critical and they are dealt with, e.g., in the paper of (Wilson and D'Cruz 2006). Most of the current VE applications still require a high level of craftsmanship to achieve the potential advantages, and the applications are often built for a dedicated process or project (Damgrave et al. 2014). According to

Table 4 Limitations and anticipated near future improvements of the used technology

Piece of technology	Current limitations	Near future improvements
Augmented Reality (AR)	Data pipeline Integration with PLM Often requires tailoring Technical problems, such as stability of images	Standardization of data formats and information models Growing market will foster SW and HW development of COTS
Virtual Environments (VE)	Needs an expert operator Integration with PLM	VE will be integrated with PLM and CAE Standardization of data formats and information models
3D scanning	Accuracy Usability	Growing market will foster SW and HW development of mobile devices
Product Lifecycle Management (PLM) and Cloud	Integration Information models	New PLM models including MoL, EoL and service Standardization of data formats and information models

Damgrave et al., one reason for this is a lack of standardization, but so is the ignorance of technology developers in regard to available possibilities and real user needs. However, technology is progressing fast and this is the right time for establishing prerequisites for digitalization of machine upgrade processes.

4 Conclusion

This chapter has introduced the UIW-approach to upgrading rock crushers at customer sites. The high level business problem to be solved concerned making upgrade delivery projects profitable and more desirable for customers, manufacturing OEMs and suppliers. The main recognized and treated bottlenecks were related to knowing the actual status of the upgrade target, communication and collaboration with stakeholders, verification and validation of upgrade specifications, and an efficient information flow between the stakeholders.

AR, VE, camera based 3D scanning, and cloud based solutions were selected in order to solve the bottlenecks. One principle in the selection was to use commercial off-the-shelf (COTS) tools, as much as possible. Laser based 3D scanning (active) was also tested and compared with camera based photogrammetric scanning (passive). The accuracy of laser scanning was better, but camera based was chosen because of its mobility and ease of use. Nowadays, almost everyone carries a smartphone, which makes camera-based 3D scanning attractive. 3D scanning enables fast and cost efficient acquisition of the actual 3D model of the product individuals, at customer sites. VE is a means to visualize scan based 3D models, as well as CAD based 3D models, so that all stakeholders can better understand them. This enables better communication, collaboration and involvement of all stakeholders, including customers, internal stakeholders, suppliers and partners. With the use of VE and AR, it is possible to illustrate upgrade offerings for customers and to test proposed solutions, virtually. They also enable the planning and discussing of service activities. The proposed solutions can be verified and validated, before building physical products. VE/AR and PLM based solutions enable more fluent information flows and sharing, which improves overall productivity. Cloud based PLM enables automation of data operations and flows dynamically between the stakeholders.

Technology maturity, usability and usefulness were evaluated from a business benefit viewpoint. It can be concluded that maturity and usability are not yet quite good enough, but taking into account the current speed of development of such devices, they probably will be good enough, in the near future. However, this study was more of a proof-of-concept, which demonstrated the potential of contributing to business model innovation and game change, in an upgrade business. The tools and methods were not actually integrated with business processes and information management systems in production. Questions still remain as to what level of integration is needed between the tools and the IT systems for cost efficiency, and what kind of PLM information model development is needed. However, these aspects were kept in mind and carefully considered. In principle, there are no major technical obstacles for implementation and integration of the whole architecture. However, in addition to the technical issues, new processes and work methods may require an even greater effort.

This study has practical implications in industry and implications in PLM and engineering design research. This paper shows how novel technology can be utilized in industry and how it might enable business model innovations related to individual product upgrade services. However, this also requires a holistic and humanistic approach, taking into account processes, organizations, networks, leadership and ways of working. This paper contributes to research by discussing the closed-loop PLM concept, involving virtualization of PSS development and upgrading product individuals in MoL and EoL lifecycle phases. Connection to Product Avatars and the Industry4.0 concept was also discussed, from the perspective of the virtualization of product individuals and the enrichment of the digital 3D model, with knowledge from the middle and end of life phases. How VE and AR contribute to PLM was also discussed, in this context.

In a more philosophical way, the value of the UIW-approach can be explained with the notion of "*Bounded Rationality*" (Simon 1995). It means that human rationality is bounded by the very narrow focus of human attention. Because design is a process of searching, discovering the right goals, and finding information about constraints and available alternatives, it is highly valuable if we can extend the focus of designers and help then to see the right goals and choose the right alternatives. In the PLM and product development context, it must be understood that all stakeholders are also designers who not only contribute to the technical solution, but also to each other's success and well-being. This can also be understood with the shared value approach (Porter and Kramer 2011), which emphasizes a firm's opportunity to better utilize skills, resources, and management capabilities in order to better understand customers and mechanisms that influence productivity and success, both from economic growth and social progress perspectives.

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Space Systems Development

Mauro Pasquinelli, Valter Basso, Stefano T. Chiadò, Carlo Vizzi and Michele Cencetti

Abstract This chapter describes the Space cluster use case using the innovative Space Tug project as an example. It provides an overview of the objectives (customer in the loop, quicker technical response) and related methods to support foreseen improvements through a dedicated toolchain. The IT infrastructure used for the demonstration is used as an enabling and demonstrative system with a focus on modelling and collaboration aspects, as outlined in Chapter "Extending the System Model", on the flow of information, and on tool infrastructure and project costs. Descriptions of the developed tools are as follows:

- A web-based toolchain that includes functional analysis, discipline analysis, 3D modelling and virtual reality for project team collaboration.
- A workflow manager for collaboration between different companies.
- Small devices called 'probes' to ensure security and data protection in inter-company collaboration.
- A configurable customer front-end to ensure that the customer remains informed.

M. Pasquinelli (✉) · V. Basso
Domain Exploration and Science Italy—Engineering,
Thales Alenia Space, Turin, Italy
e-mail: mauro.pasquinelli@thalesaleniaspace.com

V. Basso
e-mail: valter.basso@thalesaleniaspace.com

S.T. Chiadò
Vastalla, Turin, Italy
e-mail: stefano.chiado@vastalla.com

C. Vizzi
Technology Research Advanced Projects & Studies, ALTEC, Turin, Italy
e-mail: carlo.vizzi@altecspace.it

M. Cencetti
Mission Operations and Training, ALTEC, Turin, Italy
e-mail: michele.cencetti@altecspace.it

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1 Introduction

1.1 Competition and Challenges in the Space Industry

The space era started during the Cold War, and tight competition between USA and USSR accelerated technological achievements, enabling the launch of an artificial satellite in 1957, the survival of a human orbiting the Earth in 1961 and landing on the Moon in 1969. This challenge led to a dramatic change, bringing a legacy of technologies that are evident to any person using a map, navigating using a GPS or using one of the many technologies that emerged from space research.

Currently, there are more than one thousand active artificial satellites, most of which are telecommunication and Earth observation satellites that monitor the environment, support disaster management, provide data to the scientific community, and support civil protection and military operations. There is also an outpost with a permanent crew of six people orbiting the Earth. There are also spacecraft exploring our solar system; observing or landing on planets, comets and asteroids; and telescopes observing the farthest zones of our universe.

Sixty years after the first artificial satellite, new challenges that are very different from those of the 20th century have arisen and may lead to improvements and progress for humanity. Examples of current challenges can be found in the roadmaps of the International Space Exploration Coordination Group (ISECG 2016), regarding a return to the Moon, paving the way for a human landing on Mars, and the current attempts to enhance satellite coverage to enable high-speed internet access using satellites.

What has changed in recent years? The current trends highlighted in the OECD (Organisation for Economic Co-operation and Development) report (OECD 2014) on the space economy reveal that:

- *Competition is increasing*. “Major challenges lie ahead both for the incumbents and for the new entrants into the space economy. In a globalised world, few sectors are sheltered from competition as the rapidly evolving global value chains in the space sector demonstrate. In addition, a new industrial revolution is looming on the horizon which holds out the prospect of deep-seated change in the traditional space industry” (OECD 2014).
- *Industrial complexity is increasing*. “private industry supply chains are getting more complex, influenced by the multinational nature of major space companies” (OECD 2014).

- *Exploration Missions are becoming more complex* and require international collaboration (ISECG 2016).
- *An additional commercial market is growing*. "The key drivers for more globalisation will include sustained institutional support from new sources worldwide, double sourcing guaranteed on the market offering new commercial opportunities, and a wider global addressable market size for all actors" (OECD 2014).
- *National space budgets are not increasing*. The space budget as a share of the GDP in European countries varies from 0.05 to 0.10% (OECD 2014).

Economy-driven and economy-driving challenges are expected in the future. The space industry is experienced and has technological capabilities. New improvements are needed to manage the prospective constraints that future scenarios involve. Among the many possible improvements (e.g., in product policies or technological R&D), this section analyses and proposes a solution for preparation of complex solutions by complex technical teams with continuous customer involvement.

1.2 Speeding up the Interdisciplinary Approach for a Quicker Response to the Customer

Adaptation to customer demand, continuous upgrades of provided services and products, and a quicker response to the customer are needed to manage the future space economy. These objectives of the Use-it-Wisely (UIW) project were analysed by the space cluster regarding the improvement of capabilities and efficiency of technical work.

The space industry handles complex products in a complex industrial organization that typically includes the customer; the customer participates in the design, verification and operations loops with engineering, scientific and high-tech capabilities. Customers may make decisions based on many key factors, such as political constraints (e.g., geographical return for member states in the case of the European Space Agency), the soundness of the solution, costs, schedule, and risks. For a commercial customer, the ability to quickly respond with an appropriate solution with the highest possible confidence that it meets the related needs is essential. The more complex the proposed solution is, the more of the following issues may appear:

- Understanding of real needs and constraints: the expressed needs and constraints may be incomplete or provided without a clear rationale (for instance, providing costly constraints that can be drastically reduced using alternative concepts).
- Feedback capture: customer feedback is essential to providing an alternative solution or to improving future products/services quickly.

- Traceability: the customer and user needs should be traced to the technical solution, changes should be clearly identified and their impact traced in the technical solution and retained for future evolution of the product.

The needs that arise from a customer-supplier relationship can be further broken down into technical team-level requirements:

- Responding to customer (or potential customer) requests or changes quickly, while managing complex technical issues in a distributed team, managing a large amount of technical data in a distributed team, and maintaining the required levels of quality and risks.
- Clearly presenting the technical solution to a potential customer, showing the advantages with regards to competitors by providing information at different levels of detail, clearly supporting any proposal for change by describing the advantages to the customer, and using clear, complete and visual means to show the solution and related operations (e.g., using simulation and 3D graphics).

1.3 The Proposed Solution

The proposed solution is based on analysis of an operational scenario, simplified but without loss of generality, comprising the following entities:

- The (potential) customer technical team: in charge of providing the needs and technically evaluating the solution or proposed changes.
- The solution provider technical team: manages the solution for the entire industrial team and acting as the main interface with the customer.
- The supplier technical team: a supplier of the solution provider, maintained in the loop to elaborate the solution.

As described in Chapter "Extending the System Model", modelling methodologies are expected to provide advantages for technical (and project) data management. Moreover, the current trends in industry show extensive usage of MBSE (model-based systems engineering) methodologies, the quality and benefits of which should grow in the upcoming decades.

The solution is a federated environment in which each of the actors from the aforementioned operational entities can work in a distributed model-based environment that fits their organization and their needs. Such a federated environment is based on the following assumptions:

- **Each environment is web-based,** meaning that the models can be accessed through dedicated services available on the company network (with security restrictions). This is already the case for some commercial or custom tools and the current trend is to move towards web-based solutions.

- **Any technical discipline can profit from such a system-level environment** to retrieve required information from the other disciplines and to provide the system-level information required to the other entities.
- The web-based environment shall be **semantically unique**, i.e., the data can be retrieved, inserted and processed univocally by a human operator or an automated routine programmed by an operator independent of the data originator/owner. This is explained in detail in Chapter "Extending the System Model". ECSS-E-TM-10-23A technical memorandum (ECSS 2016) describes the current effort in the European space domain to proceed towards an interoperable space systems data repository.

Based on the experience we have gained with model-based environments in recent years, difficulties arise in handling the interoperability of environments and security requirement compliance. These include four main issues, with related solutions:

- Data compatibility: solved using data semantics and well-defined and generic interfaces.
- Workflow realization: solved using the concept of services-based exchange between different entities and dedicated task definition and realization managers.
- Data security: solved using semantics and dedicated processes that allow a filtered exchange of information, clearly identifying what data exit the company network perimeter.
- Cost and maintainability of the IT infrastructure: solved using integration between tools that is based not on tool versions or custom formats but on mapping to common semantic data models or custom data structures defined at the user level (not at the tool vendor level).

The evaluation of a solution that follows such assumptions and constraints is performed for a demonstrative case. It is based on the future provision of an unconventional space-to-space re-utilizable product: a type of taxi service in space to move spacecraft from one position (orbit) to another that provides other servicing options. This concept is typically called Space Tug[1] and is assumed to be proposed as service to a commercial customer who decides to use this service or not based on their requirements.

This case was used because it includes a high level of complexity and can be briefly described and divided by entity:

[1]This case is freely derived from a national Italian project to have a clear idea of the consistency of the approach with a real study involving Thales Alenia Space and ALTEC (and other partners) but with no direct connection to the project. The data and ideas described in this chapter are not connected to the project and the data and concepts proposed are demonstrative.

- *Customer:*
  - Commercial customer: not constrained by political decisions or national budget allocation, intense worldwide competition.
  - Needs are (1) to determine if the proposed solution is effective, valid and advantageous, (2) to be supported during its design phase to eventually de-risk the interface with the Space Tug system, and (3) to be supported during operations.
- *Solution Provider:*
  - Provides the Space Tug, which will provide In-space Services: the Tug interfaces with the customer system or a dedicated interface, and related operations are coordinated.
  - Services provided are (1) engineering/project services provided to a potential customer during the preliminary design phase: to decide if the in-space service is suitable for its needs. (2) Engineering/Project Services provided to a customer during the design phase: to support any evaluation or potential changes and upgrades. (3) Engineering/Project Services provided to a customer during the operations: to support the operations and potential anomaly investigations or upgrade requested services.
- *Supplier:*
  - Provides the Ground Segment and the Ground Operations teams and manages operations.
  - Services provided are (1) engineering/Project Services provided to the solution provider to complement the space segment solution with ground-related operations, and (2) engineering/Project Services provided to the customer to support operations.

The following chapters show how the space cluster of the UIW project analysed a potential solution to support such actors and process. The space cluster is composed of Thales Alenia Space, ALTEC and Vastalla.

Thales Alenia Space has designed, integrated, tested, operated and delivered innovative space systems for 40 years. The UIW-project relied on the experience of the Collaborative System Engineering (COSE) Centre (at the TAS Turin site) on virtual reality, model-based interdisciplinary data exchange and systems engineering, and the design of exploration and science spacecraft.

The Aerospace Logistics Technology Engineering Company (ALTEC) is an Italian centre of excellence for the provision of engineering and logistics services to support International Space Station operations and utilization and the development and implementation of planetary exploration missions. The experience related to engineering and operations and competence in virtual reality and model-based design possessed by ALTEC were used in the project.

Vastalla is an IT company that offers consulting services, software development and IT system activities with an emphasis on IT security. Its experience was used for the collaboration portion of the overall solution and for the customer front-end.

1.4 Chapter Outline

Section 2 provides an overview of the application of the proposed solution. Section 3 provides a description of the demonstration and its outcomes. Section 4 provides conclusions and describes possible future applications.

2 Detailed Application of the Solution to Overcome the Challenges

2.1 The Users-Tools Functional Chain

The issues and considerations in Sect. 1 are translated into a modelling and collaboration methodology, a reference logical architecture and a tool chain to provide a demonstrative case to validate the approach.

Figure 1 shows the functional architecture of this tool chain, with the related tools or responsibilities implemented in the UIW-demonstration. The architecture is defined using a model-based approach with the ARCADIA methodology and Capella tool notation (Polarsys 2016)

For simplicity, the MBSE interdisciplinary and distributed environment is depicted only for the solution provider side and includes:

- *System Models, Simulation Models and Services Process manager:* this functional block is needed to support the interdisciplinary work between people and discipline-specific tools through dedicated adapters. This functional block also includes the definition of Engineering or Project Services to be provided to a customer.
- *System Simulation and Visualization:* this functional block is needed to support the visualization of the product, activities and simulation results.
- *Simulation Execution:* this functional block is needed to provide system level simulation, integrate discipline-level simulations, or provide early system-level simulation.
- *Extranet Interface:* this functional block is the gatekeeper that assures a safe flow of data.

On the customer side, we need to be able to respond to requests based on the services provided. Moreover, some services must be provided globally (e.g., workflow management) and could be allocated to a third-party such as an IT services provider, namely:

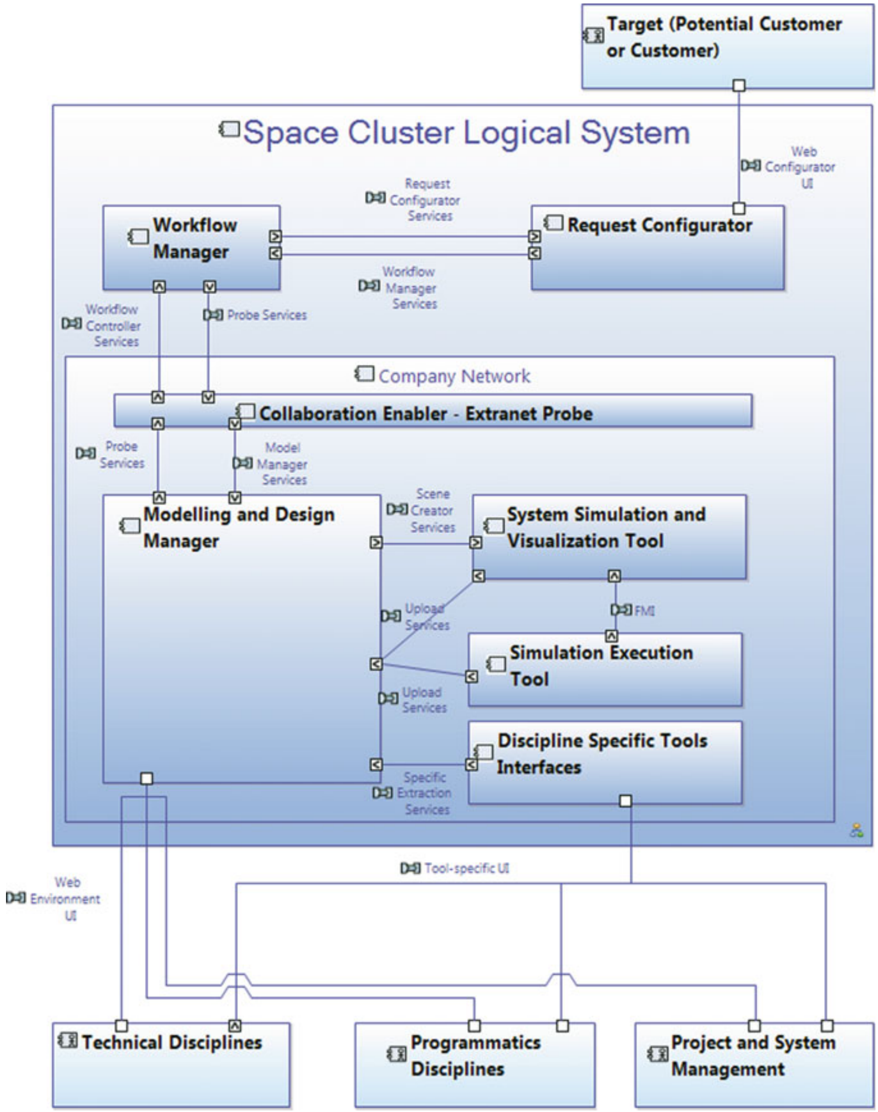

Fig. 1 Logical architecture of the solution

- *Workflow Control:* this functional block orchestrates the flow of information between actors.
- *Communication Tools:* this functional block allows for controlled communications that are external to the typical communication means.
- *Repository:* this functional block allows for a controlled repository of shared data.

On the supplier side, the MBSE environment is not explicit and is called Mission Control, based on the related function in the demonstration.

This functional architecture is then translated into a physical architecture, i.e., actual tools and applications, used in the UIW-project to provide an answer to the project challenges addressed in the first chapters of this book.

Maintaining customer involvement from the beginning is very important to guarantee the success of complex projects that manage extensive structured data, many companies working together, and many actors in the supply chain. In these business cases, supplier-generated feasibility and cost estimates take several days, so it is of paramount importance to keep the customer in the loop from the first day. Tools that maintain an appropriate flow of information to the customer can be easily deployed.

Customers can access a web application that acts as a bridge between them and the suppliers. This web application is called the **Request Configurator**, developed by Vastalla. Using this web application, customers can login, request new quotations for an array of commercial Space services, review past requests, or order a commercial Space service.

This web application is closely connected to other software modules that form the backbone of the IT infrastructure and allow for a smooth relationship with the customers.

Customers are in the loop. This mean that they are informed in real time about the current state of their requests. Furthermore, they can exchange relevant information that allows the suppliers to correctly quote the requested service.

All requests, past and present, are managed by the **Workflow Manager** developed by Vastalla. This software component traces the status of requests along workflows. These workflows differ one from another depending on the commercial Space service being requested. The Workflow manager is an API-based software that is automatically configured (on-the-fly dynamic configuration) by the Web Environment. The Workflow Manager is designed as an open software that easily integrates with other software components through pre-defined APIs.

The Web Environment is the software component that generates the commercial Space services workflows. The dialogue between the Workflow Manager and the Web Environment is mediated by the **probes**, small devices that act as gatekeepers of the communication flow between the Intranet portion of the global infrastructure architecture and the common Workflow Manager.

The probes are very small devices (approximately the size of a cigarette pack) that use Raspberry Pi technology (Rapsberry 2016) and have the capability to filter the IP traffic going through them to allow only legitimate traffic to pass to the Workflow Manager. The probes act as gatekeepers and can be implemented as separate devices depending on company decisions. For demonstrative purposes, Raspberry PI® devices have been deployed (Fig. 2).

The Web Environment is part of the TAS DEVICE (Distributed Environment for Virtual Integrated Collaborative Engineering) Architecture (Pasquinelli et al. 2014), which also comprises the **Virtual Environment** (VERITAS) and the adapter to the discipline-specific tools. For this demonstration, a CAD adapter called RAP

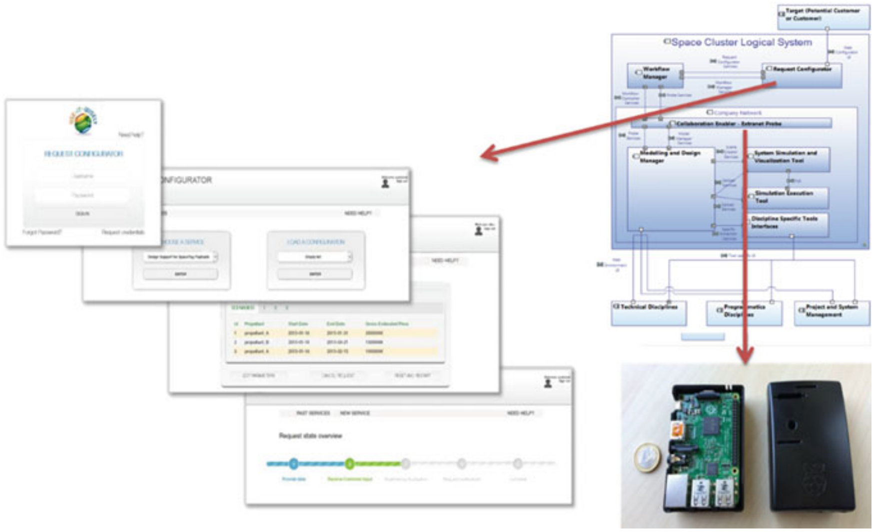

Fig. 2 Request configurator user interface and physical implementation of a probe (Raspberry Pi®)

(Retrieve cAd Parameters, internal TAS development) is used. **Modelica** (Modelica Association 2016) is used as the language for the low-fidelity system-level simulation using OpenModelica (OpenModelica 2016) or Dymola (Dassault Systemes 2016) to execute the code.

The **Web Environment** is a model-based and web-based operational prototype developed by TAS that is inspired by the current European space domain efforts (e.g., ECSS-E-TM-10-23A (ESA 2016) and ECSS-E-TM-10-25A (ECSS 2016) technical memoranda), OMG efforts (OMG 2016) and THALES corporate-level (see Capella (Polarsys 2016)) initiatives but with a clear objective of enabling a social-technical network of people and tools to collaborate on technical solutions.

It is worth noting that the solution described in this section is a demonstrative research case to demonstrate and validate the architecture and methodology and that these prototype tools have not been deployed in the TAS or ALTEC networks.

The application of MBSE methodology is helpful not only during the design phases but also during the operational scenario of a Space system (Cencetti 2014). A model-based approach allows for better organization of the information that characterizes the execution of a space mission. The definition of a structured data pattern can help manage the information and ensure a more straightforward connection with the product baseline.

Elaboration of the information that emerges from a complex system is often not easy to manage during an operational scenario. For example, manned spacecraft and other classes of space systems are often characterized by a broad set of parameters, subsystems and data that must be properly understood and monitored to avoid incorrect interpretation of actual scenarios. Troubleshooting activities often require the retrieval and analysis of system documentation, which are generally difficult to perform when the information is not collected in a structured manner. These issues also arise during the design phases of a complex system when different domains are involved and many people with different backgrounds and skills collaborate on the same project. All the information generated during the design process is generally used during the operational phase in management of the space system. Space Operations are currently investigating and developing innovative solutions for exploiting system data. The increasing complexity of aerospace products leads to increasingly difficult management of available resources and telemetry data. From the literature, it is possible to see how different research initiatives address the definition and assessment of more effective approaches than the traditional ones. For example, web-based frameworks and MBSE methodologies are some of the research topics that are starting to spread across different phases of the spacecraft lifecycle, from design activities to dismissal processes. In the last few years, the development of MBSE design and analysis methodologies has gained increasing interest in the industry. The implementation of design solutions that ensure more effective management of system information allows for significant time and cost reductions.

Examples in academic literature show how the application of MBSE starting from the preliminary design phases can ensure more straightforward information management during operational activities.

A model-based approach can generally be used to support two main aspects of the product lifecycle: operational design process and space mission execution.

The main objective of the operational design process is to focus on organization of all the activities that will characterize the actual space mission. This process mainly addresses the design of the features of the operational phase. The same concepts can also be used during the execution of the real mission, ensuring a better connection between the data generated during the design process and the available information, e.g., telemetry. Examples of elements that characterize the design and organization of the operational phases are:

- Launcher constraints
- Ground station characteristics
- Spacecraft constraints
- Mission-specific constraints
- Payload constraints
- Launch window prediction
- Spacecraft and launch vehicle separation sequence
- Positioning and manoeuvring strategy
- Tracking schedule
- Scheduling operational events
- Ground station coverage
- Impact of the space environment on operations
- Payload operations strategy
- Data circulation scheme

- Feasibility of the mission
- Operational feasibility of the mission
- Mission operations concepts
- Ground segment internal and external interfaces
- Format and method of data exchange
- Data processing tools
- Mission operations team organization (preparation and execution phases)
- Testing strategies, methods and scenarios

These functions and processes represent some of the key elements that characterize the ground system and operations domain (ECSS 2008).

The information collected during design activities can be used to support preliminary analyses of a space mission with dedicated simulators of system performance. These data allow for more effective generation of simulation scenarios than in traditional approaches. A model-based philosophy ensures a seamless connection and consistency with the available baseline data. Analyses such as mission feasibility or ground station coverage can be performed within the same environment.

The design parameters of a system or equipment can be mapped with data such as telemetry to allow a direct connection with the product baseline. Thus, it is potentially easier to recover information for troubleshooting or anomaly characterization. The monitoring of a specific variable can be better supported if the operational range and other information are linked to reduce issues that can arise, as in the error-prone process of data retrieval from documentation.

The use of a model-based approach from the preliminary design activities to production can also benefit the operational phases. The information collected in a common system model can be used to properly support operational scenarios because the data can be navigated and tracked more consistently.

2.2 Development Innovation

When new methodologies are introduced in a company, there is some natural resistance due to the cost of the introduction and maintenance of a prospective new or updated tool chain, as well as the need for users to adapt their comfort zones. This has been experienced by the authors of this chapter in many fields.

Currently, the actual evolution of a concept into improved ways of working should be evaluated from a technical innovation perspective and also from business innovation and IT perspectives. The latter two are not trivial, especially the IT perspective. Many medium-large companies rely on complex software infrastructure, and even if their processes are acceptable and independent from the IT tools, daily work and related infrastructure costs are highly impacted. Therefore, the Space cluster scenario considered two main issues: (1) Tool interoperability and the maintenance cost of the interfaces, and (2) security and collaboration between different networks.

The first issue is easy to identify in any tool chain. Any tool has input/output capabilities and typically has custom interfaces or standard interfaces (e.g., using reference formats common for that type of application). For models, the model data interchange format is quite difficult to exchange because even if it is based on standard languages or semantics, the user typically enhances it for their own purposes to create a new "dialect" of the language or can base their interfaces on custom object libraries.

Moreover, format updates, tool updates and even technological updates can add to the high maintenance cost of the original tool interfaces.

The second issue is very critical, considering that company network security is a very sensitive topic, especially in companies that handle confidential data (e.g., working on protected innovation or with governments or military entities). Security is a continuous issue that limits the effectiveness of the daily work of those collaborating with an entity external to its network. The solutions studied by the space cluster in the UIW-project were:

(1) Use of semantic models to define the product, activities, services, actors, requirements and needs.
(2) Use of probes as interfaces between networks, profiting from the semantics of the I/O data.
(3) Simplification of interfaces and user-oriented management of the models and related formats.

There are many initiatives related to the enhancement of semantics in data generation, management and exchange. In our case, we used a simplified approach based on:

- Class diagrams to represent semantic classes, attributes and relationships; these class diagrams can be transformed into classes in an object-oriented language or simply mapped or transformed to data exchange formats using specific rules.
- Libraries of objects, specific to the domain or the project, to provide an additional level of semantics for the technical toolchain or to enhance the user experience.

Figure 3 shows an example of how the use of such class diagrams improved tool interoperability. The definition of services, as in the Web Environment, is read by the Request Configurator and used to create the customer form. The two tools were developed by two different people using different languages. To adapt the interfaces, a meeting on the semantics and a meeting on the integration tests were sufficient to produce a working prototype.

The Web Environment tool is based on a complex data model with more than one hundred classes (and related relationships) but the most important level of semantics is the possibility for the user to generate libraries of categories, properties and other types of knowledge based on their experience and specific expertise.

The Probes are compact devices that, from a hardware point of view, are Raspberry Pi devices: they have enough computational power and overall features

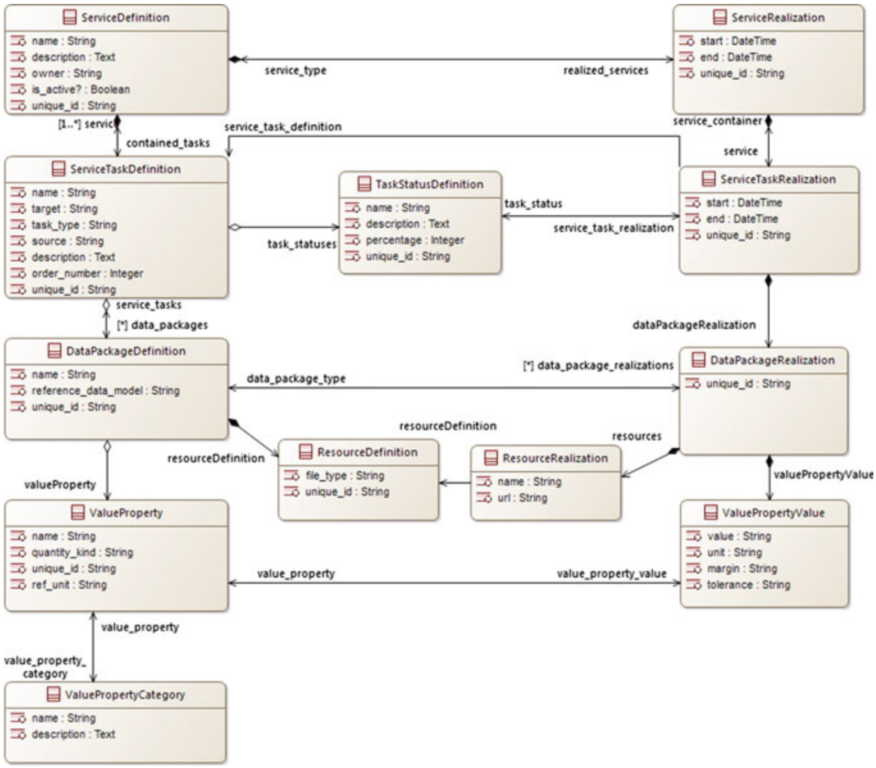

Fig. 3 Example class diagram representing the data model of a service (partial view)

to perform their task in the architecture. The Probes host business logic together with the necessary tools for managing the traffic and requests that goes through them. Disclosure properties are tagged within the data so the Probes can communicate to the Workflow Manager how to treat different data flows depending on the tag.

The software on the Probes consists of an open source framework (nodejs 2016) that is based on a Linux distribution tailored for Raspberry Pi devices [Raspbian (Rapsberry 2016)]. The Probes primarily exchange JSON files with the upper and lower parts of the architecture.

The innovative standpoint is that some tasks that were once delegated to complex and expensive ad hoc-designed appliances can now be largely replaced by very simple devices that have enough computing power and features to filter TCP/IP traffic efficiently and offer programmers a flexible platform to easily develop programs.

The Request Configurator and the Workflow Manager are software components that can be programmed dynamically using an API-based paradigm.

In our case, the Request Configurator and the Workflow Manager are programmed in real time from the Web Environment. This means these systems are not rigid or static from a design point of view.

Thus, the Web Environment can leverage these capabilities, and engineers who work on the Web Environment can change workflows on their side and these changes are automatically mirrored in other parts of the architecture without the need to reprogram the source code.

This is a clear advantage because it summarizes the advantages of decoupling systems and seamless integration using publicly available APIs.

Information tagging helps to preserve data privacy. Some data needs to be disclosed to the customer whereas other data might not. Some data needs to be disclosed to other parts of the supply chain/toolchain and so the Probes handle this part along with the Workflow Manager.

2.3 Results

Space Cluster's objective was to build a Model-Based Collaborative Environment for collaboration through the entire lifecycle and technical activities that involves potential customers and the industrial consortium.

The approach used by the Cluster to achieve this objective is described in the architecture below (Fig. 4).

The components of this architecture show the processes and tools developed by the Space Cluster within the UIW-project. They have been upgraded and improved during each iteration until obtaining tool interoperability at the end of Trial 3. The main achievements of these upgrade process are summarized below:

- It was possible to show how the logical architecture was implemented in the physical architecture and interoperability of the tools.
- The web-based Engineering Environment can define and expose services.
- The service requested by the user can be composed of several tasks defined in the Web Environment. A task is used to manage the flow of information or provide the customer feedback on the current status because it is possible to associate data and potential statuses with each task.
- Tasks can be visualized in a tree map to manage and understand the service more easily.
- The connection between the Request Web Configurator (RC) and the probe was successfully defined and tested and the Workflow Manager enabled management of the flow of data and information between the probe and the RC.
- All the actors involved in the process were successfully involved. ALTEC Mission Control was implemented and defined in the Web Environment.
- The tools that are part of the prototype were rapidly integrated.

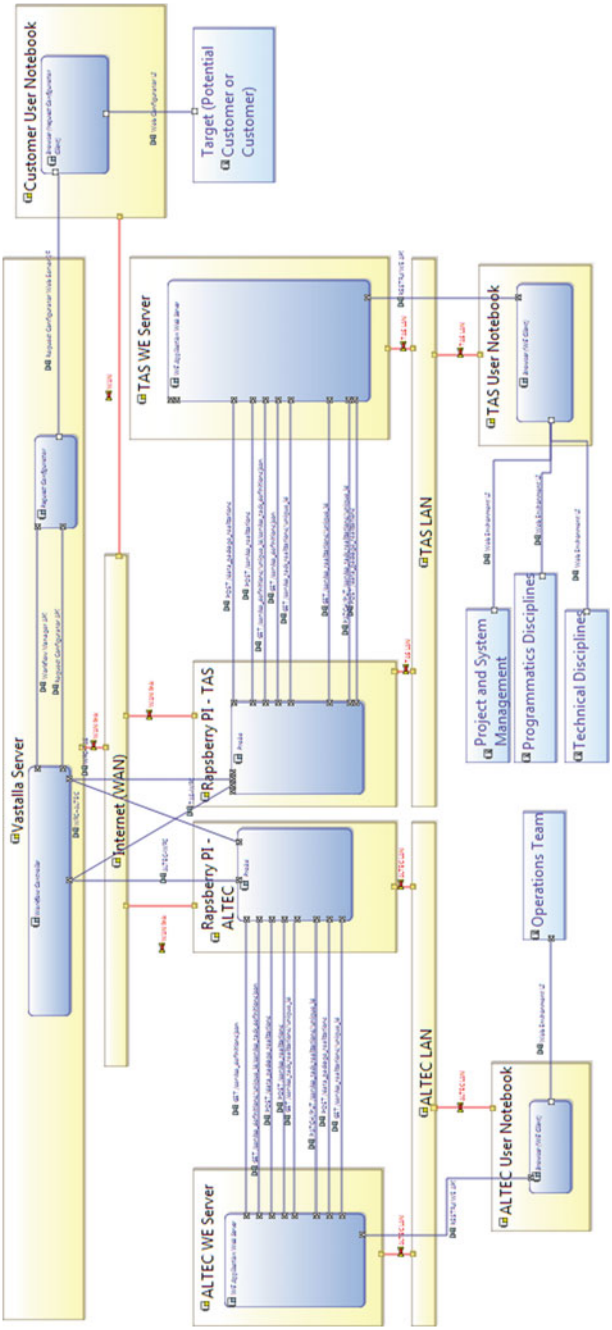

Fig. 4 Physical architecture of the overall demonstrative environment

The purpose of the demonstration phase is to create an end-to-end process to validate the tools and the related methodologies and acquire feedback from end users and process stakeholders.

3 Outcomes from the Application

3.1 Benefits of the Methodology and Related Tools

There are three main aspects in which benefits were demonstrated: (1) Support software development and maintenance, (2) user experience, and (3) potential impacts on the project. Regarding software aspects, the methodology chosen for the Request Configurator, Workflow Manager and Probes allows for easy integration of different components using APIs. Furthermore, maintenance of the software components is easier, leveraging on existing and widespread programming frameworks (Fig. 5).

Using APIs enables easily extending the features of the software components, provided they are designed with APIs in mind.

The methodology used to develop the Engineering distributed architecture, i.e., web-based tools for collaboration, visual supports (VR and in-browser 3D/2D visualization), web APIs for model-to-tools interfaces and use of data models and libraries for semantics, enabled the development, modification and integration of a complex environment using a rapid prototyping approach and rapid evaluation of outcomes (Fig. 6).

Regarding user experience, at first glance, the user is typically afraid of new tools and methodologies. The feedback gained from a preliminary dry run of the demonstration (a complete demonstration is planned a month after the conclusion of this chapter) showed interest from the participants, the user interface and process felt comfortable and were seen as potentially improving efficiency in daily work. The main aspects that were appreciated were:

- The availability of all the information in an easily accessible format, saving time searching for data or verifying that the data is the latest. In late phases of the project, this is typically well established with current processes that strictly control the baselines and changes but these processes are typically too expensive in early phases and for quick upgrades. A methodology similar to the one presented is expected to bring a new perspective in this sense.
- The presentation of information for any type of user (visual 3D/2D data and tables available in the browser) allows for a clear understanding by the entire team at a glance.
- The possibility for more controlled communication with external entities is considered a great improvement that has become particularly critical recently (due to security limitations).

Fig. 5 Sample images from the request configurator

Fig. 6 Web modelling environment and virtual reality data accessible using simple but effective technologies

- The possibility of a direct and controlled link with many customers is considered as potentially improving the relationships during the upgrade or order process and to store experience and retain customer feedback for future reference.

Visualization capabilities can also be used to support data exploitation and graphical elements can be generated based on data available from the system model. Thus, information can be exchanged in a more straightforward manner. An example of an orbital representation is provided in Fig. 7. Both the analytical solution (conics) and the numerical solution can be represented using the same interface.

Regarding potential programme improvements, the use of an MBSE methodology within the context of operational scenarios leads to several advantages over traditional approaches. The definition of a structured system model that includes all the elements pertaining to the actual space mission positively affects the management of a space system. This approach reduces the time and resources needed during the design phase because data are managed in a structured manner. For example, the documentation can be generated in a straightforward manner to reduce the time spent on version control, consistency verification and updates. In the same manner, a model-based approach can also be used to support the management activities for a space system during a mission. Possible data that can be supported in

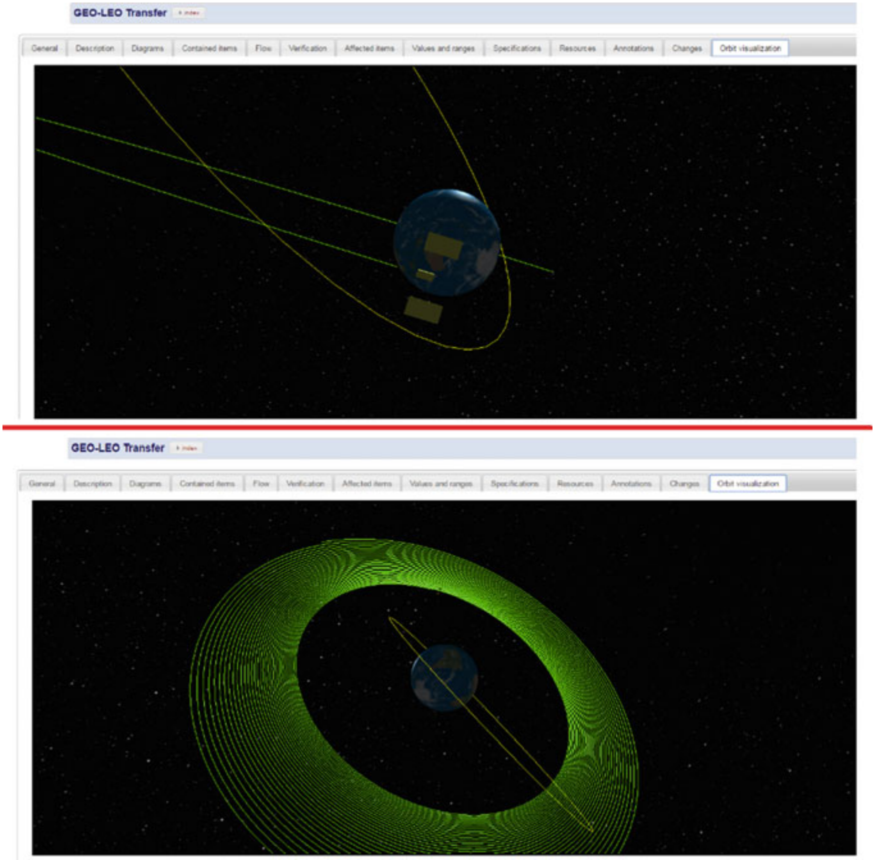

Fig. 7 Orbit visualization capabilities

this manner include: anomaly reports, stowage notes, mission action requests, electronic flight notes, international procedures, and generic ground-rules, requirements and constraints.

These products can be collected and mapped in a more effective manner and linked to the system baseline. This connection improves the capability to manage issues and non-conformances that can arise during the mission.

The planning of operational activities can be widely enhanced through a model-based methodology. Activities such as procedure scheduling can be performed in a more straightforward manner, reducing the time spent on activities such as document versioning or updates. For example, procedure generation can be performed using the information collected within the system model. In this manner, the changes to the current baseline of the operational activities can be tracked with fewer problems.

The operational scenarios can be designed during system development using the same model-based approach that characterizes all the other engineering domains. The use of a model-based methodology also ensures better exploitation of the data available from the system design. The information generated during the design phase can be exploited during the actual operational scenario, reducing the gaps that often occur during real missions. This information can be used to properly manage troubleshooting activities, telemetry elaboration and historical data retrieval. A formal data structure can reduce the time spent on data inconsistencies or baseline updates. This is also reflected in the data exchange process that can be performed with less effort than the traditional approach.

4 Conclusions and Future Work

The technologies that we use have proven to be very promising and show potential to address many more issues and challenges that we experience in our everyday working life.

The Request Configurator, Workflow Manager and Probes will be improved further to add additional features and expand their capabilities.

The Web Environment and its connection with Visualization, Simulation and Discipline tools demonstrated good maturity, and their use is currently planned in parallel with a project, to continue the validation approach in a more complex environment. The outcome of the UIW-project provided the team with very good feedback regarding potential benefits and areas for improvement of identified limitations. Such feedback will be used internally to the companies and with the relevant partners in order to improve the way we are transitioning to model-based engineering environments.

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Adaptation of High-Variant Automotive Production System Using a Collaborative Approach

Jonatan Berglund, Liang Gong, Hanna Sundström and Björn Johansson

Abstract Automotive manufacturing systems are high investment assets in need of continuous upgrades and changes to remain relevant and effective. The complexity of such a system is reflected in the difficulty of making holistically informed decisions regarding the upgrades and changes. To reach holistic and sound decisions it is important to collaborate between departments, experts, and operational actors during the planning and development of upgrades and changes. Such collaboration should be supported by tools, models, and methods that facilitate understanding and enable the users to express their input and feedback in a clear and understandable manner. This chapter describes the development and evaluation of one set of tools. The developed tools combine 3D imaging and virtual reality technologies to facilitate the creation of decision support models that are accurate, realistic, and intuitive to understand. The developed tools are evaluated by industrial engineers in the area of manufacturing R&D.

Keywords 3D-imaging · Collaboration · Cross-functional teams · Manufacturing · Virtual reality · Simulation and modelling · Layout planning

1 Introduction

This chapter describes the Use-it-Wisely (UIW) approach being implemented in the industrial production of automotive products in the heavy and medium sized truck segment. The high investment product-service referred to in this part of the project is

J. Berglund (✉) · L. Gong · H. Sundström · B. Johansson
Product and Production Development, Chalmers University of Technology, Gothenburg, Sweden
e-mail: jonatan.berglund@chalmers.se

L. Gong
e-mail: liang.gong@chalmers.se

H. Sundström
e-mail: suhanna@student.chalmers.se

B. Johansson
e-mail: bjorn.johansson@chalmers.se

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thus the production system put in place to physically realise the trucks developed and sold by Volvo Group. The act of establishing a production system, the truck factory, is indeed related to a high investment and a long term commitment. The truck manufacturing industry is characterised by high product variability (Johansson et al. 2016). This means that customers are able to customise their purchases by selecting various features to a high degree. While this is a competitive advantage in the market place, it can be both costly and technically challenging to realise on the manufacturing side. In short, for a production line to reach optimal efficiency it needs to be perfectly balanced, meaning that the work carried out in each step takes an equal amount of time to perform. It is theoretically possible to design such a production line, given that each product is identical, from an assembly process perspective, to the previous/next one. In the case of products as component rich and complex as trucks this is never the case, and instead, manufacturing companies resort to managing the variation in their products. In the end, it comes to a trade-off between flexibility and cost.

A manufacturing system is a complex entity consisting of several subsystems such as building infrastructure, material handling, equipment, electrical wiring, maintenance and support, and so forth. These subsystems are different in nature. For example, the building infrastructure is physical and rather stationary; walls can be torn down or put up and the roof can be lifted but for the most part the building exists as it is. The material handling subsystem is necessary for the operation of the plant. It consists of, for example, physical assets like storage structures, forklifts that move products and components, software that handles the manufacturing execution information, and the personnel in the logistics department. All these subsystems share the same physical space where they need to co-exist and, ideally, function in harmony to achieve the overall goal of the manufacturing system.

As the product, the truck, develops and changes over time, to follow market trends, regulations, and technical innovations, so must the factory that produces it. This again emphasis the continuous need for upgrades and improvements on the existing manufacturing system over time. However, the upgrade and improvement process of a factory is a complex task, as indicated by the many subsystems and actors that exist in it. The actors, or functions if you will that are responsible for doing so are often not directly involved with the operational activities and day to day workings of the factory itself. As a result, there is a largely underutilised body of tacit knowledge and experience represented in the operational part of the organisation. If this knowledge and experience can be utilized in upgrade and improvement projects, the information input of these projects would be expanded. It is important to capture the viewpoint and perspective of all involved actors in order to make informed and holistically beneficial decisions. The work behind this chapter has put a lot of focus on reaching and harnessing this knowledge and experience in areas where it was previously overlooked. The hypothesis is that by involving relevant actors and stakeholders in the upgrade process there is a reduction of the risk of errors and a higher frequency of first time right in the process of upgrading the manufacturing system.

This chapter presents the development and evaluation of methods and tools that support the production engineering organisation to carry out the planning and design of upgrades of the production system. The approach combines 3D-imaging technology and the latest in virtual reality to make the design and planning process more inclusive and to draw upon the tacit and empirical knowledge of the operative actors in the production organisation.

This chapter is structured as follows: Sect. 2 provides an introduction to the automotive production system at hand. Then, Sect. 3 presents the application of the collaborative tool, previously described in Chapter "Operator-Oriented Product and Production Process Design for Manufacturing, Maintenance and Upgrading", in the production system context. Finally, Sect. 4 gives a summary of the findings based on surveys and interviews with pilot users of the developed tools.

2 The Industrial Case

This section provides an overview of the production system at Volvo Trucks, which has been the specific subject of this work. The purpose is for the reader to get a feeling for the environment and context which has shaped the development of tools and which is the basis for evaluation of the implementation of the tool.

2.1 Describing the Problem

The Volvo Trucks manufacturing organization is represented on every continent, totalling over 20 factories worldwide taking part in producing the various models and brands of Volvo Groups Truck Operations (Volvo Group Financial Report 2014). As a manufacturer of automotive products Volvo is bound by regulations and strict rules for conformance to these regulations. This means that a much of the product is subject to testing with regards to function, safety, and quality. But how does such a large company ensure that their products are produced in the same way and with the same result in all of their various locations? Often times, work conditions and workplace safety regulations differ between countries, not to mention between continents. And the manufacturing equipment and machinery which is available for purchase in Kaluga, Russia, may not be available to the plants in the US or Brazilian markets. Transporting equipment across borders is costly and would result in dependency on a supplier that is situated half a planet away.

To combat this, and related issues, Volvo uses something called Master Processes. These are guidelines that govern any business process within the company, including manufacturing. It sets the basic requirements of the process, and gives guidelines to how it should be designed. Take for example the assembly of the firewall component. The firewall is a barrier situated in front of the driver in the cab, it separates the driver environment from the engine. If the assembly of the firewall is performed according to the same specification in the various plants there is a greater probability that the resulting trucks are equal. Another benefit with this

Table 1 Targeted impacts and means of attacking them for the collaborative approach of managing upgrades

Targeted impact area	Means of impact	Variable name
Production and delivery of personalised final products	Rapid reconfiguration of production system based on point-cloud scanned facility models	Market agility and flexibility
Cost and time in product/process development	Proactive system testing and pre-validated performance	Ramp-up time
Time reduction for new processes and plant designs	Virtual assessment of manufacturability based on hybrid digital models (3D scan + CAD). Proactive development and operator training efforts	Production set up time
Environmental footprint and the resources consumption during the production and use phase	Reduction of error rates, scrap and waste generated by the production system	Environmental footprint

strategy is that improvements to the processes that are found in one location of the globe are possible to implement in all other locations. This strategy can found in other sectors, for example in heavily standardised fast-food restaurant chains. These tend to be constructed in a very similar way regardless of their location, especially the production system, e.g. kitchen and ordering section. Thereby allowing companies to collect data from several locations and aggregate them to draw more robust conclusions in a limited amount of time. Furthermore, it makes it possible to implement operational improvements invented and validated in one location across the entire organization.

As can be inferred by the above section, there are many challenges facing a production company in this sector. At the outset of the UIW-project, a number of areas were targeted to bring improvement to the change and upgrade processes, see Table 1.

2.2 *Actors and Their Tasks in the Production Organisation*

The production system is a cyber physical system in the sense that it consists of technical equipment and machinery that is, to a large extent, operated by humans following a set of rules and methods. Therefore, to make any attempt to change and impact the operations of the production system it is important to understand its users, from here on out referred to as actors, and their relation to each other and the technical system. To understand who the actors in the production organization are and what work tasks they perform, a mapping effort was carried out. The mapping was supported by data from three sources within the company:

– **Available documentation**: All work positions are described in documentation in the Human Relations (HR) department. The information is used for hiring new personnel and the content is the responsibility of the technical manager of the relevant area. These documents provide a technical and objective view of the different actors involved.
– **Discussions with researchers**: Through open dialogue with researchers that participate in the UIW-project a rich picture was created. The rich picture maps both internal and external actors on a more abstract level, to model their needs and motivations and how they relate to each other.
– **Structured interviews with managers in the production organisation**: There were three departments in the production organisation responsible for change work. Managers from each department were interviewed about the practical implementation of the change process. Some of the practices differ from the documentation, and in some instances the output from these interviews helped clarify and interpret the formal information.

The following actors along with their work tasks were identified during the process:

– **Line Builders**: This actor represents the external suppliers of machines, tools and equipment for installation and integration into the Volvo production system.

  Responsibilities:

  • Delivery and installation of equipment.
  • Service of equipment according to service level agreements.
  • Support in training of maintenance personnel.
  • Support in improvement, re-furbishing and new investment of equipment.

– **Managers**: This actor represents the management of Volvo production facilities.

  Responsibilities:

  • Lead and control the operations.
  • Manage personnel, follow legal instructions on work environment.
  • Development of processes and personnel.
  • Take decisions on improvements and investments.
  • Implement changes in the production system when needed.
  • Follow-up on operative KPIs.
  • Drive strategy work.

– **Maintenance planner**: This actor represents the role of maintenance planning in the factory.

  Responsibilities:

  • Planning and preparation of work-orders and planned maintenance by ordering the needed material and services.
  • Provide work-instructions when needed.

- Daily/weekly planning, weekly reports.
- Analysis and follow-up of work-orders with the maintenance personnel.
- Ordering of spare parts, materials and services.
- Work cross-functional and participate in needed forums.
- Educate personnel in maintenance planning system.
- Track and follow-up on maintenance KPI's.
- Contacts with suppliers of equipment and machines (service, purchasing, ordering).
- Equipment and machine management and handling of unit exchanges.

– **Manufacturing Engineers**: This actor represents technicians of Volvo in charge of the design and implement of any update or change into the production system.

  Responsibilities:

  - Follow-up, analyse and improve the process within the delegated area of work regarding quality, OEE and productivity.
  - Propose and implement improvements.
  - Perform studies on methods and update description on methods within the delegated area of work.
  - Preparation and planning of manning, operations, work instructions.
  - Participate in work environment meetings.

– **Simulation and layout technicians/engineers**:

  Responsibilities:

  - Performs simulation assignments on product and process, off-line simulations.
  - Strategies on off-line robots for production, introduction of new solutions.
  - Understanding of visualization, simulation, off-line programming in production.
  - Investigations on process and product regarding flows, stations and fixtures.
  - Ensure that changes are implemented according to strategies and VPS directives.
  - Develop and present suggestions for improvements.
  - Coordinate changes in process layouts (2D and 3D).
  - Participation in Volvo Virtual Manufacturing network.

– **Operators**: This actor represents shop floor operators of Volvo that performs the daily work in assembling the product.

  Responsibilities:

  - Follow work instructions.
  - Perform assembly and material handling.
  - Quality assurance of product assembly.
  - Report issues on product or process/methods to manufacturing engineers.

– **Material Handlers/logistics engineers**: This actor represents technicians of Volvo working with internal material handling and logistics.

  Responsibilities:

  - Support internal Material Handling organisation with Logistics.
  - Engineering work (manning/balancing, material façade, routing etc.) in selected areas.
  - Support Global Sourcing logistics representatives in the sourcing process.
  - Prepare selected new parts and suppliers for being taken care of, and implemented in a quality assured way.
  - Parameter settings needed in local material systems for selected parts and suppliers.
  - Continuously monitoring of, and act on, compliance to or any need of changes in-present logistics set up due to changes in e.g. volumes.
  - Follow up globally agreed, or other relevant, (K)PIs.
  - Participate in the continuous improvement work in the daily work.
  - Participate in local/regional a/o global networks to contribute to the process development.

– **Introduction Engineers**: This actor represents Engineers of Volvo working with introduction of product changes into the production systems.

  Responsibilities:

  - Keeping the global master processes updated and compatible with the new products.
  - Work on a local, regional and global level to adjust and align manufacturing processes.
  - Coordinate the testing and verification of new products into the production system.
  - Assess and abridge consequences and product- and production requirements between construction and product development departments.
  - Coordinate the introduction of new product change orders.
  - Assess and abridge product- and production requirements between manufacturing engineering/product development and local site technicians.
  - Coordinate product and process issues with local site technicians.

A holistic system understanding is of great importance when working with complex systems (Checkland 2000). To place the identified actors and their work tasks in context, a rich picture (or context map) was created during a workshop. The picture links the actors and their motivations and needs with each other and the core entities of the company, Fig. 1.

The rich picture takes on the perspective of the manufacturing organisation and centres on a factory. At the core are things that the manufacturing organization can control to some extent. Such as the production line, the work instructions and the maintenance. Further out from the centre are entities that exist in the environment

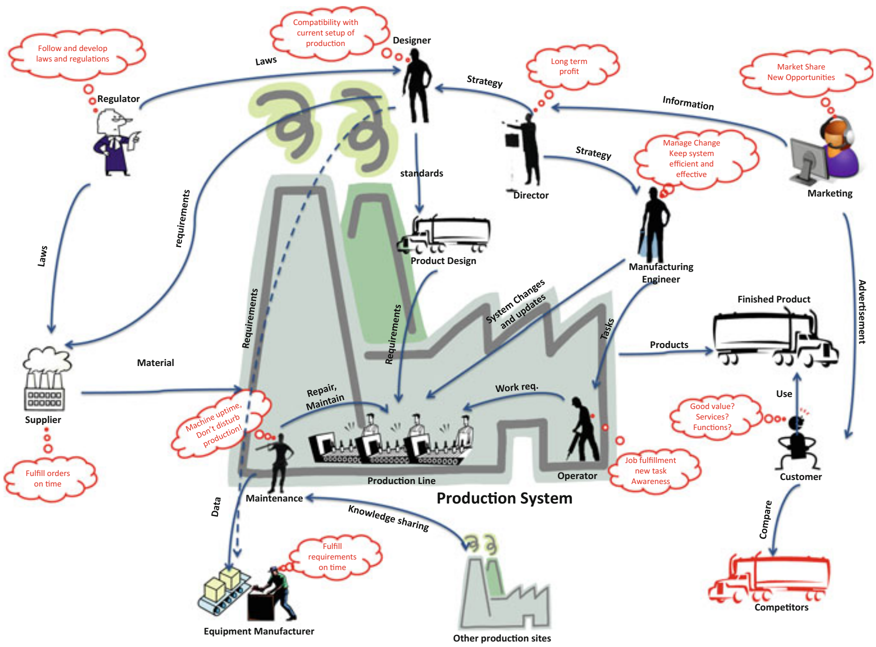


Fig. 1 Rich picture illustration of the different actors, their motivations and relationships to the manufacturing system

around the factory. These can be internal to the overall organisation, such as product designers, marketing department, and other production sites. They can also be external to the overall organisation, such as the customers, legislators, and suppliers. Together this network of actors creates a very complex canvas on which the manufacturing of trucks must exist and perform over time.

2.3 *Adaptation of Production Systems: Changes and Upgrades*

As stated in the introduction to this chapter, the truck manufacturing industry is a high variant product sector, and as such it is prone to changes (Johansson et al. 2016). Changes in the production systems of Volvo are driven by needs coming from either the product or the production process itself. Product driven change occurs when the product changes, or when new products are introduced. Process driven changes are motivated by cost savings, technology upgrades, or quality issues. Also business related motives such as moving parts of production in-between production sites can be said to belong in the process driven change category. Through interviews with company employees at management level and

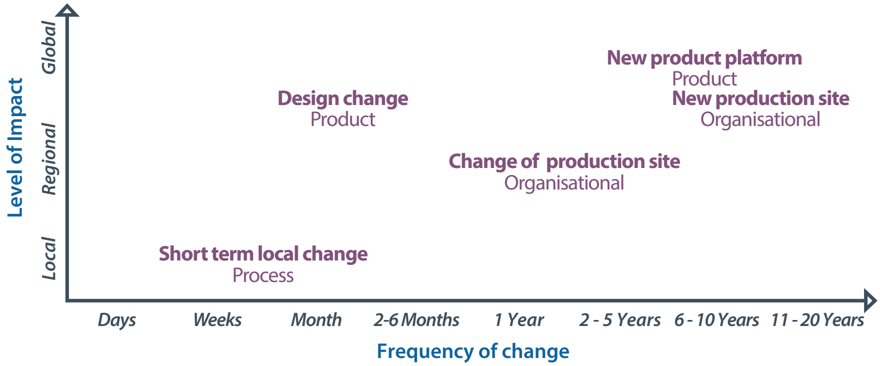


Fig. 2 On production system change at Volvo Trucks; their frequency and level of impact on the organisation

documentation in production project process guidelines, a number of change types were identified. These types along with their frequency and level of impact are visualised in Fig. 2.

As mentioned earlier, there are guidelines and steering documents that govern the change and upgrade process. Depending on the impact and size of the change process, different sets of guidelines and steering documents are applicable. To gather these guidelines and support engineers that work with changes, Volvo has developed a project steering model. It covers all project stages chronologically starting from the investigation stage, which covers the needs and drivers for change, through to the ramping up of production in the new system and a follow-up on the results. While this project steering model is used by the engineer managing the change process, many of the actors described earlier are involved through their stated work descriptions.

Anytime a change or upgrade is to be implemented in the factory, it has to be planned for and modelled in advance as to not disturb the ongoing operations more than necessary. This is due to the fact that a production system is a high cost investment that relies on continuous use, e.g. the manufacturing of products, to bear its investment cost. For these models to be valuable and valid as decision support they need to accurately reflect the current conditions of the system (Berglund et al. 2016). Figure 3 shows an example of a model from the robotic laboratory at Chalmers, incorporating the 3D imaging technologies described in Chapter "Operator-Oriented Product and Production Process Design for Manufacturing, Maintenance and Upgrading.

There are oftentimes CAD models of the production system available that were created during the installation of the system, or at the latest change or upgrade to it. However due to the natural entropy of such complex systems, such models are seldom up to date with the current conditions. Using out of date models can lead to unforeseen issues such as new equipment not fitting into the allotted space, or that developed solutions are not feasible in reality. By using a modelling tool which can

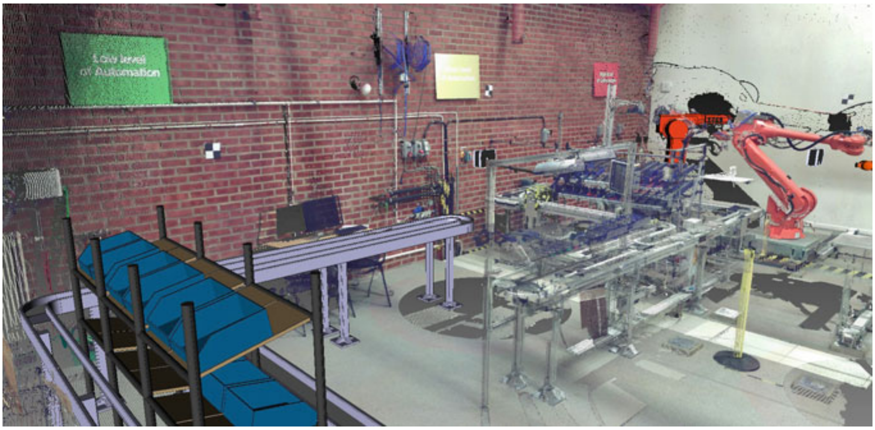


Fig. 3 A hybrid point-cloud and CAD planning environment to position a conveyor in the existing factory layout

include spatially captured properties of the existing environment, e.g. 3D-imaging data, companies can reduce the risk of bad decision due to outdated or incorrect information, while saving time and money in the planning phase of new development projects (Lindskog 2014).

As previously mentioned, a holistic approach and view of the system is necessary to avoid sub-optimization and to leverage resources in an effective way. One way of achieving this is cross functional actor involvement, and letting the end users of the system have a say in the planning process. In the case discussed here, end users are represented by e.g. assembly operators, material handlers, or maintenance engineers. One benefit of involving end users is the possibility to tap the empirical knowledge and practical knowhow that system design engineers might be lacking. The research carried out in this project looks to harness that empirical knowledge and make use of it in the planning process to improve the end result while decreasing the risk of making costly and time consuming mistakes.

2.4 The Volvo Trucks Production System as a Product-Service System

In addition to the actor and task mapping conducted in the previous sections, a third model was generated to better understand the setting and current state. It explicitly divides the production organisation of Volvo into Actor, Product, and Service categories. The Product Service System (PSS) is a concept developed for supporting sustainable consumption where the producer retains responsibility of the product throughout the use phase by selling its function as a service rather than the physical product itself (Mont 2002). This model fits well with how a production system is thought within an industrial company. It is an investment bought and sold

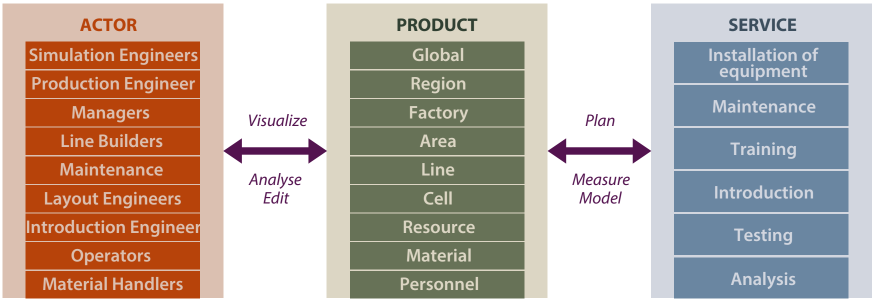


Fig. 4 Actor PSS model of the production system at Volvo

within the company and both the seller and buyer are equally adamant of keeping the system functional, providing the service of producing vehicles. Thus, the product in the view adopted by the project, are the components of the production system. The APS model was used to infer how a 3D visualisation tool could be linked to the system. The mapping of the Actor PSS that was defined for a general production system for trucks can be seen in Fig. 4.

The actor part includes all the identified actors from Sect. 2.2. The product part concerns the production organisation broken down hierarchically from the global organisational level down to the actual resources on the factory shop-floor. The service part holds a list of the main activities which are carried out by those resources.

3 Development and Evaluation of Collaborative Tool

This chapter describes the development of the tool for the industrial case. It exemplifies use cases within the manufacturing development process at an automotive company where a need for this technology has been identified. A demonstrator that was developed is described and finally the results from testing the demonstrator with end users within an industrial company.

3.1 Development of the Technical Solutions

As mentioned in the previous section, the solution should support planning of upgrades and changes to the existing system by providing an accurate current state model and a realistic and intuitive visualization environment to elicit domain expert feedback. The improved current state representation reduces risk of taking decisions based on faulty data. The realistic visualization lowers the threshold to understanding the model so as to make the involvement of stakeholders from different areas of expertise easier. The solution was developed in an iterative fashion, starting in a laboratory environment at Chalmers University of Technology. That stage of development was then implemented using Volvo factory equipment and production system environment. Based on the response the solution was refined and improved further before finally being applied to several factory units at Volvo.

The demonstrator case used for the development of this tool was looking at the early design phase and the involvement of cross functional actors. Figure 5 below depicts the focus of this project, in the context of a simplified version of the production project methodology used at Volvo Trucks.

The demonstrator case chosen was looking at the early design phase and the involvement of cross functional actors.

The demonstrator consists of a virtual model of a Volvo factory in United States. The virtual model is a hybrid using both measurements captured using 3D imaging technology and CAD data. The demonstrator is accessed using a VR kit from HTC. The architecture of the demonstrator is set up according to Fig. 6.

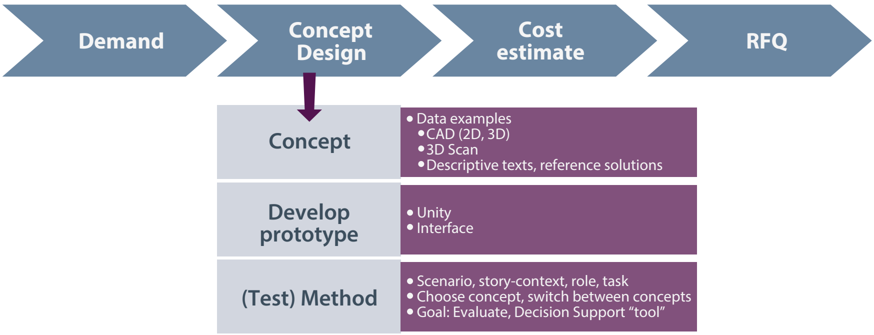


Fig. 5 Process targeted by the demonstrator, put in context of a simplified version of the production project methodology in use at Volvo

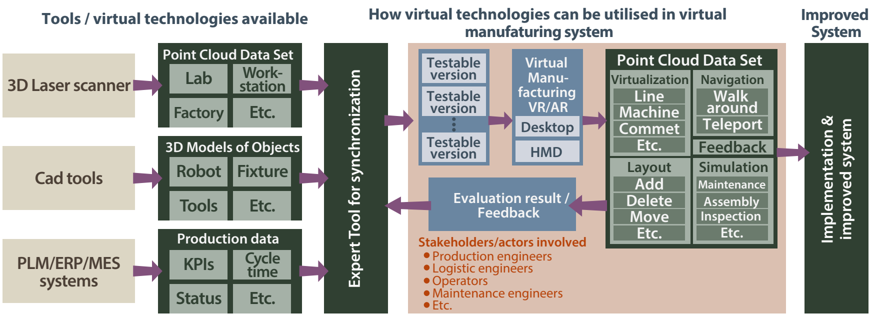


Fig. 6 Architecture of the collaborative VR tool

Table 2 3D imaging data summary

	Firewall cell	All data collected
No. scans	5	82
Area coverage	390 m^2	6600 m^2
Size of raw data (.fls[a])	843 MB	13,840 MB
Size of processed data (.off[b])	714 MB	n/a
	Firewall cell	All data collected

[a]Native scan data format of FARO laser scanners (www.faro.com)
[b]Object file format a geometric data format that was used to import 3D imaging data into unity 3D

The 3D imaging data was captured by Volvo employees and assembled by researchers from Chalmers University of Technology. The data was then combined with CAD data to form the virtual model in Unity 3D environment. The user goes through a short training scenario and is then presented with the factory model. During the demonstration the user is able to modify the layout and store the changes. He or she can load stored layouts from other users and review them by leaving feedback on selected features in the layout.

The data collection was conducted by Volvo employees on site at a Volvo run plant in the United States. The data collection was conducted during two days and resulted in a total of 82 individual scans, covering a large portion of the main assembly line. The section of the factory that was used for the demonstrator, the firewall subassembly consists of only five scans, but data from surrounding areas were also included to give context to the cell which is a part of the whole. Table 2 gives more details on the data collected in the US factory.

3.2 Implementing the Demonstrator Solution

The focus of the demonstrator was the design stage for upgrades of existing production system infrastructure. In this process there is an overarching goal of adhering to global manufacturing guide lines, i.e. the Master Process, as well as aligning the different production sites to a more homogeneous manufacturing solution. This can potentially increase consistency in quality and improve the possibility to spread improvements and kaizen work throughout the organization. (e.g. an improvement found in One factory can immediately be introduced also in other factories). This ties back to reaching actors in different location with the concepts. An actor working with the fire wall process in factory A can look at and assess the corresponding fire wall process in factory B, and thereby learn from other company sites.

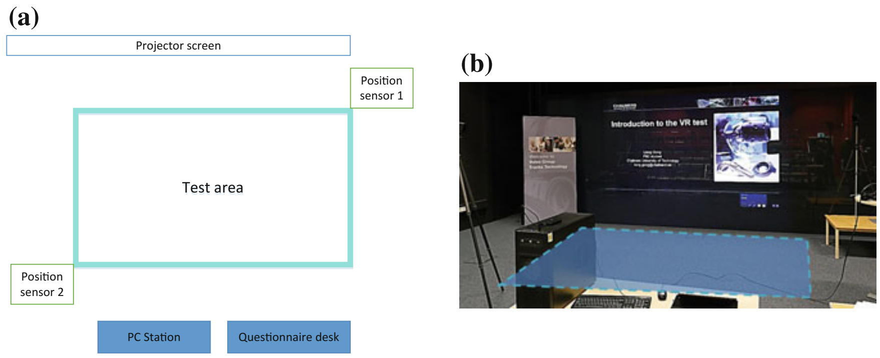


Fig. 7 Demonstrator setup: (**a**, *left*) schematic illustration, (**b**, *right*) photograph, the outlined rectangle indicates the test area

The demonstrator was set up in Volvo facilities, in an auditorium with a stage area and a back projected screen. The setup consisted of:

- A PC station with demonstrator software
- Positioning sensors on tripods to track the VR space[1]
- Head mounted display (HMD)[2]
- Two hand held controllers for interacting with the VR environment[3]
- Presentation screen used to give instructions before the test and to duplicate the VR user's view for onlookers and researchers during the test

A schematic overview and a photo of the test facility can be seen in.

To the left and rightmost sides of Fig. 7b are tripods holding sensors that continuously tracks the location of the HMD and the two controllers. Near the front of the picture is the PC that runs the software and in the background the back-projected screen is visible. Data extracts from the demonstrator depicting the current conditions of the Fire wall production cell as captured using a 3D laser scanner is shown in Fig. 8.

In total, participating in the demonstrator evaluation were nine persons from different actor groups within Volvo and one senior researcher in the field of virtual production from the research team at Chalmers. The participants where all involved in the engineering side of the organization, working with R&D related to manufacturing. The average age of the group was 38.8 years.

[1]Part of the HTC Vive kit.

[2]Part of the HTC Vive kit.

[3]Part of the HTC Vive kit.

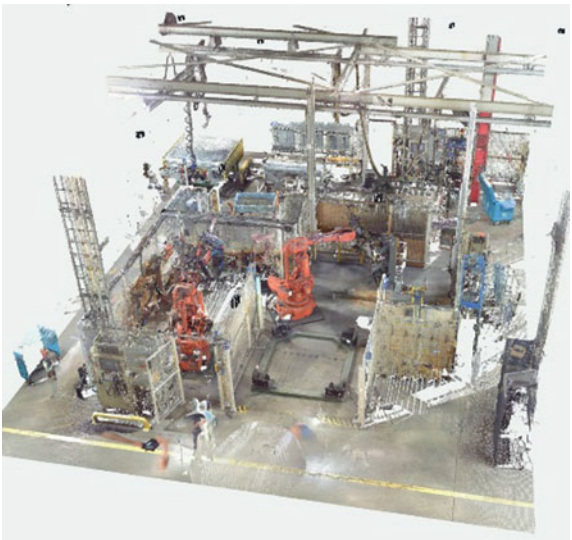


Fig. 8 3D laser scan data of the production cell used for the demonstrator

3.3 Conducting the Evaluation

The demonstrator evaluation was initiated by the researchers introducing the UIW-project, along with its aim and scope. Then a presentation detailing the test procedure was given collectively to the test subjects (the subjects were brought in groups of 1–4 persons). The procedure of the demonstrator was as follows:

In group:

- Overview of the VR application structure—Description of the system and motivation behind it
- Getting started—Theoretical introduction to the VR system and how to interact with the system

Individually:

- Testing the equipment—The participant familiarizes with the interface in a test environment
- System demonstration—The participant conducts a series of tasks in the demonstrator system
- Questionnaire feedback—The participants document their experience by answering a questionnaire

During the individual portion of the evaluation, each of the participants in turn wore the VR gear and conducted a series of tasks in the modelled environment. The tasks consisted of an initial training scenario where the participant is given basic instructions to familiarize with the VR equipment. These tasks include navigating through the environment, interacting with objects by grabbing and moving them, leaving feedback by pointing at objects, and using the menu system to store and load configurations of the environment. This training and introduction was carried out in a model of the Chalmers production system lab, screenshots from the training module of the demonstrator can be seen in Fig. 9.

Once the participant was familiar with the navigation and controls they were asked to proceed to the next step of the demonstration. In the second step the participant is shown a scaled down version of the 3D imaging data of the US factory, positioned on a table. The participant can walk over the model and inspect the layout of the plant. The participant is then asked to locate the highlight area, which is the fire wall cell. By using the hand controller to touch and click the volume of the fire wall cell area the participant is moved into a full sized model of the cell. In this environment the participant was given some time to explore freely, using the navigation controls, before being given a set of tasks. The tasks were a

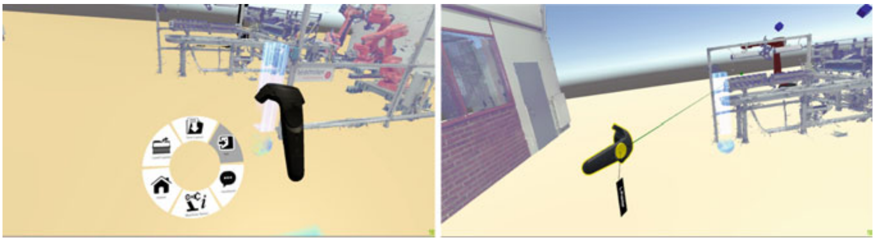


Fig. 9 Screenshots from the training environment depicting the menu and pointing activities

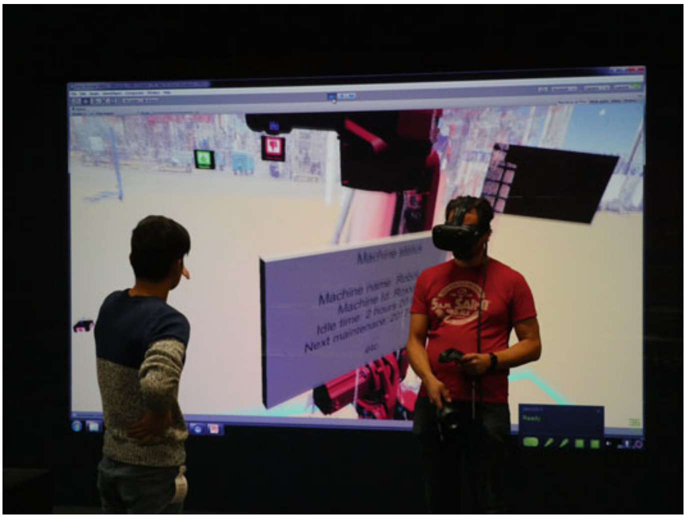


Fig. 10 Participant (on the *right*) being guided by a facilitator (on the *left*) during the demonstrator evaluation

repetition of the training tasks, but where given in a non-explicit manner, such as move objects to the positions you see fit or leave comments indicating if you like or dislike some feature of the model. The fire wall cell model also included virtual information plates with equipment data. A picture showing one of the participants while interacting in the real sized virtual factory environment is seen in Fig. 10.

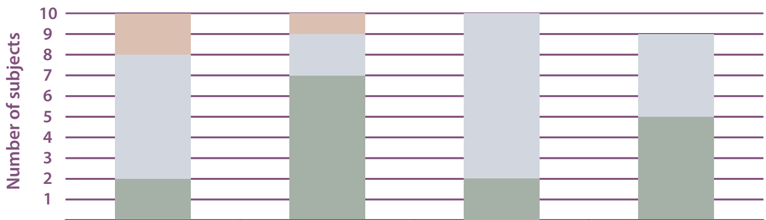
After completing the tasks in the demonstrator scenario, each of the participants were given a questionnaire to fill out. The results from the questionnaire are presented in subsequent sections.

3.4 Result from the Evaluation

The questionnaire had two parts, one qualitative which leaves room for the respondents to express in words their experience, and to motivate their choices in the quantitative part which ask the respondents to rank different aspects of the demonstration and the value of the proposed system to different stakeholders. Figures 11 and 12 below summarises the quantitative responses that were given by the test persons.

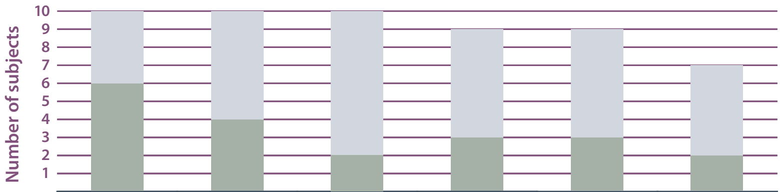
From the responses it is clear that a majority of the test persons saw benefits from the system, for the various stakeholders. Most benefit was recognized to the user, in other words the engineers and the factory personnel who would use it to develop better upgrades. While no one disagreed strongly about the benefits of the system, one users was not sure about there being clear benefits to Volvo from using it. However, that same user agreed to the overall benefits to different stakeholders in the second table, Fig. 12.

Table 3 shows the qualitative questionnaire responses from the demonstrator subjects. In the comment sections some reoccurring themes were positive benefits such as easy to use, visually representative of the real factory, accurate and “near” life like experience. Some obstacles that were detected was dizziness when using the HMD (one user), disorientation (one user), and that the tool as such/interfaces took some time to get used to (two users).



	Easy to use	Clear benefits	Useful	Recommend
Strongly Disagree	0	0	0	0
Disagree	2	1	0	0
Agree	6	2	6	4
Strongly Agree	2	7	2	5

Fig. 11 User feedback on the collaborative VR tool design concept evaluation



	to user	to company	to customers	to network	to EU	to society
Strongly Disagree	0	0	0	0	0	0
Disagree	0	0	0	0	0	0
Agree	4	6	8	6	6	5
Strongly Agree	6	4	2	3	3	2

Fig. 12 User feedback on the benefits/value of the collaborative VR tool to different stakeholders

Table 3 Benefits/value at different levels of impact based on questionnaire and interviews

	Benefits, value
End user	The virtual model is easy to understand. Easier than previously experienced models. It is easier to navigate the model in this way. More functions could be implemented dealing with trial and error
Company	The system supports giving users the same view of the production system. It gives better understanding. Of course the system could provide value. One user was not sure about the value on a company level, and another stressed the importance of that it should be easy to prepare the input, preferably through integration with the existing PLM platform
Customer	The system can provide value to the customers on a long term basis. And that the work and communication with them can work quicker
Value network	Respondents stated that this system can make interactions easier. And also that it would be nice with many users sharing the same environment simultaneously
EU	On an EU level the respondents felt that the system can lead to better understanding, more interaction, and therefore better decisions. One respondent said: “Will push EU as an enabler of new technology” Generally a lot of focus was placed on faster and easier decision making and communication quality. Ultimately leading to better products delivered
Community/society	On the societal level some users saw direct benefits through shifting some processes to the digital world and thus requiring less travel needed and reduction of material used for prototyping. At the same time some of the respondents were not sure about the benefits at this moment

When asked about other uses and advantages of the system, respondents expressed that they either liked or wanted: Point clouds are good for quickly viewing actual station layout, system can be used to showcase new products/tools with its uses, and manufacturing simulation in VR.

The respondents were also asked in what areas within the manufacturing system that they saw uses for the collaborative VR tool. “In which areas of manufacturing do you think this system can be beneficial for the improvement of current work practice?”. The categories that were presented to them are based on the work of Nee

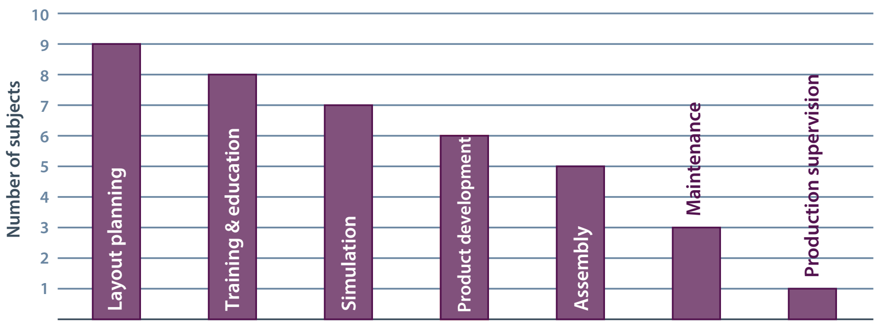


Fig. 13 Areas of application as selected by the respondents

et al. (2012). The most promising application areas was seen to be layout planning, training and education, and simulation. Figure 13 lists the aggregated results from this part of the questionnaire.

The things that users liked about the experience and system for virtually accessing the factory ranged from smart/easy interaction to novelty and state of the art. In general, the spatial understanding, realism, and the holistic visualisation of the production system was repeatedly stated as valuable. When asked about drawbacks the test subjects lifted that the point density in the Point cloud data was too low, this is a performance issue with the system where points have to be reduced to maintain an acceptable frame rate. For five of the ten respondents this was their first experience using VR systems. Towards the end of the questionnaire the respondents were asked:

"*What challenges do you anticipate if your company is going to implement this VR systems?*"

The answers given can be categorised into three different challenges: *data compatibility*, *organisational attitudes*, and *cost*. The first category is probably most central to the possible implementation at Volvo or any company. Data of the various aspects of the production system resides in many internal systems and in different formats. Accessing all of it seamlessly is a challenge, one that is addressed also in other research projects carried out within the Volvo Corporation. In addition, there would need to be an infrastructure in place to handle the 3D imaging data and making sure it is recent enough for it to be used. The second challenge relates to acceptance within the organisation. This requires education and training of users as well as incorporation into existing work methods. Finally, some of the respondents raised the issue of cost, where should the "burden" be placed on a system that does not exactly fall under any of the traditional department structures?

4 Discussion

As with any new tool or technology there exists both benefits and limitations and these will be discussed in the following chapters.

4.1 Identified Benefits

3D-imaging provides visually realistic and geometrically accurate snapshots of the physical properties of the real world. The snapshots are stored in a format often called point clouds and can be used for modelling and analysis in virtual planning software. The point cloud data can be overlaid with other models and/or information regarding the various subsystems, separately or in parallel to find, discuss, and analyse issues and changes. Through the natural ease of understanding these models provide, they allow the various actors and experts that are using the system to express their different needs and requirements (Lindskog 2014). In this manner they can provide a valuable discussion ground and act as decision support for a manager, allowing him or her to make informed decisions with an expanded understanding of the consequences. Furthermore, it gives him or her a tool with which to visualize and communicate the decisions in a way that is approachable by all different actors regardless of technical background. By being able to include a broader range of actors and end users there is potential to gather a broader range of inputs and design comments to feed into the decision process.

Simplifying and speeding up the workflow to produce models enables iterative and frequent use of the models throughout the development process. It also means that a higher number of concepts and ideas can be tested and explored. The collaborative virtual reality models allow actors to experience the models in a 1:1 scale. Participants in the evaluation described that this gave them a better sense of the proposed solutions. Furthermore, the ability to share these realistic models with users in other departments or countries within the organisation was stated as a benefit.

Volvo has been working actively with virtual reality in a research capacity for several decades. However, it is only with the recent development and the introduction of VR on the consumer market that the usability and cost has created the conditions for making use of it in large scale, across the organisation. Previously, this technology work was limited to large test facilities and costly fixed installations. The ability to set up and implement solutions at a low cost means that investments in development of technical solutions and work methods can be shared and benefited from on a greater scale than before.

4.2 Identified Limitations

3D imaging is still an expert tool. And to introduce another expertize to the existing roles in the manufacturing organisation can prove costly. Furthermore, 3D imaging data capture is still a manual operation which requires users to access the production system at rest. This is costly, either through shutting production down or through accessing the system at night/weekend or vacation time. These requirements can limit the ability to collect new data on the fly or just-in-time as it is needed. At the same time, collecting data at opportune times, might mean that it is incorrect or outdated when it is needed in the decision making process.

Another important aspect is that the 3D imaging models do not replace CAD representation in every aspect. 3D imaging data is a surface representations of the geometries present in the real world. As such they are missing design aspects and construction information that is key for some simulation and analysis activities. So while 3D imaging data is good for some activities there might still be need for high fidelity and detailed CAD representations for other tasks.

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Supporting the Small-to-Medium Vessel Industry

Nikos Frangakis, Stefan N. Grösser, Stefan Katz, Vassilis Stratis, Eric C.B. Cauchi and Vangelis Papakonstantinou

Abstract The aim of this chapter is to present a methodology for supporting the collaboration between the involved parties and for augmenting the final product with an always up to date digital file. The methodology is based on three support tools, which focus on the life cycle of small craft passenger vessels made of composite materials. The chapter concentrates on FRP (Fibreglass Reinforced Plastics) made vessels with length overall up to 30 m and total capacity up to 150 passengers, for the purposes of cruise ship liners disembarkation, scheduled routes or transportation of professional personnel to offshore sites. The collection of proposed tools consists of the "Vessel Meta-File", a user-friendly, web-based, information rich, technical meta-file that acts as the main knowledge-base between the ship-yard, which is the constructor of the vessel, the classification society, which is the controlling body imposing the restrictions of the vessel and the end-user. The Vessel Meta-File enables the storage of information regarding all

N. Frangakis (✉)
I-SENSE Research Group, Institute of Communication and Computer Systems, Zografou, Greece
e-mail: nikos.frangakis@iccs.gr

S.N. Grösser · S. Katz
Institute for Corporate Development, Bern University of Applied Sciences, Bern, Switzerland
e-mail: stefan.groesser@bfh.ch

S. Katz
e-mail: stefan.katz@bfh.ch

V. Stratis
OCEAN Boatyard Company OE, Attica, Greece
e-mail: vstrat@ocean.gr

E.C.B. Cauchi
SEAbility Ltd., Athens, Greece
e-mail: sea@seability.eu

V. Papakonstantinou
International Naval Survey Bureau, Piraeus, Greece
e-mail: vagelispapakon@gmail.com

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aspects of a vessel's life cycle; from initial customer requirements, to drawings, material and equipment data, sea-trial reports to post-delivery survey and inspection reports. The Vessel Meta-File provides a collaborative platform for sharing such data among all involved actors across the vessel's life-cycle, reducing costs involved in the design, production and maintenance phases. The proposed methodology introduces the use of two additional tools which can be used in conjunction to the Vessel Meta-File. First, a Dynamic Causal Context Model that describes the mechanisms and variable interactions between the Yard, the Classification Society and the end-user, and enables the three different parties to forecast trends in the behaviour of the small craft passenger vessels market and allow predictive actions and decisions such as the upgrade of a vessel to support and extend its life-cycle. Second, a "Vessel Configurator" system is also proposed to assist the transformation of the business and operational requirements derived from the Dynamic Causal Context Model to technical specifications that comply with current national flag or international regulations for the specific type of vessels.

Keywords Naval sector · Small vessels · Business models · System dynamics · Communications · Computational simulation

1 Introduction

1.1 Introduction of the Cluster Case and the Respective Cluster/Company Challenges

The aim of this chapter is to present a methodology, based on three support tools, which focus on the life cycle of small craft passenger vessels made of composite materials. The chapter concentrates on FRP made vessels with Length Overall up to 30 m and total capacity up to 150 passengers, for the purposes of cruise ship liners disembarkation, scheduled routes or transportation of professional personnel to offshore sites.

The collection of proposed tools consists of the "Vessel Meta-File", a user-friendly, web-based, information rich, technical meta-file that acts as the main knowledge-base between the yard, the classification society and the end-user. The Vessel Meta-File enables the storage of information regarding all aspects of a vessel's life cycle; from initial customer requirements, to drawings, material and equipment data, sea-trial reports to post-delivery survey and inspection reports. The Vessel Meta-File provides a collaborative platform for sharing such data among all involved actors across the vessel's life-cycle, reducing costs involved in the design, production and maintenance phases.

The proposed methodology introduces the use of two additional tools which can be used in conjunction to the Vessel Meta-File; a System Dynamics Model (Groesser 2012a) that describes the mechanisms and variable interactions between the Yard, the Classification Society and the end-user, and enables the three different parties to forecast trends in the behaviour of the small craft passenger vessels market and allow predictive actions and decisions such as the upgrade of a vessel to support and extend its life-cycle. A "Vessel Configurator" system is also proposed to assist the transformation of the business and operational requirements derived from the Dynamic Causal Context Model (see Groesser, Chapter "Complexity Management and System Dynamics Thinking") to technical specifications that comply with current national flag or international regulations for the specific type of vessels.

The Cluster's main actors include (a) the ship yard: OCEAN, (b) the classification society: INSB and (c) the end user representative: SEAbility. Below each actor is described in more detail framing its activities around the Vessel information rich-Meta file.

OCEAN is essentially a boat manufacturing company which specializes in building work boats and passenger vessels made of composite materials. The company is based in Greece, a country with numerous islands and economic activity related to tourism. As with other Greek boat manufacturing companies, OCEAN has its roots in production of coastal fishing boats for professional use. Although production of professional fishing boats is still a major boat market sector for countries like Greece, focusing on product-markets related to tourism and efficient sea-water transportation is essential in times where local economies and demand are hit by global recession. Using its past reputation for tough, over-engineered professional boats, over the past years OCEAN has invested efforts in specializing in passenger vessels for all purposes but mainly tourist transportation. As any other manufacturing process involving complex products, boat manufacturing involves marine specific materials, parts, conformity to marine specific regulations, design patterns, etc. For this purpose, OCEAN is working within a network of marine professionals and marine related companies: Equipment vendors representing foreign manufacturers, local equipment manufacturers, material manufacturers, technical consultants and certification bodies (Shipping Registers or Classification Societies). Each of these companies brings its expertise, experience and innovation into the final product. The boatyard's task is summarised as the effort to use and concentrate the best options offered by this "network of companies" in order to satisfy customer-specific requirements.

INSB is a non-governmental ship classification society active in the international maritime industry. It promotes ship safety standards by providing customers with reliable technical services for their ships and marine installations, while cost leadership and quality compliance (Certified by ISO 9001: 2008) are embedded in every aspect of its operations. INSB provides proper certification to vessel, according to national and international laws and regulations. Through a sound organisational structure and technically competent human resources, it enjoys worldwide confidence on the part of all major maritime stakeholders. INSB operates internationally via a well-structured expanding network in 50 countries with 6 regional offices, 60 field stations, 200 ship surveyors and auditors supported by professional staff, able to respond timely and effectively in Europe, Asia, Africa and the Americas—wherever ships are being built, repaired or operated. INSB Class aims to be a preferred global technical provider of risk management solutions, enhance its customers' quality orientation and environmental and business performance. Safety for life and property at sea, quality, sustainability and immense responsibility for environmental protection are the bedrock of INSB's corporate mission. INSB business deliverables and technical services satisfy internationally-recognised safety and quality standards, IMO Conventions, national requirements and general EU criteria.

SEAbility is a private Greek SME, specialising in representing shipping lines, performing vessel port operations as well as consulting to Shipping and Transport Lines. SEAbility is proficient in all aspects of Containerised as well as of RoRo (Roll-On/Roll-Off, as in e.g. ferries, where loading and discharging of wheeled vehicles takes place horizontally) and conventional shipping. It is especially strong in vessel port operations, Logistics and Cost Management, ship operations and efficient handling. Its activities include managing sea transportation services and adding value to them through well-trained and motivated team members interacting with an advanced IT environment. At the same time, it is a consultant to Shipping Lines on issues regarding their introduction to new markets, the handling of their fleet and of their services. These issues comprise operational, scheduling, financial, environmental and marketing aspects and optimisation whilst also taking into account and evaluating possible synergies with existing services loops (of the same shipping line or other lines), aiming at economies resulting from scale and also from scope.

1.2 Connection to the UIW-Challenge in Part I

Via the development of a single rich-metadata file the consolidation of the shipbuilding process, better management of costs and improved maintenance planning, Use-it-Wisely (UIW) will be able to offer extended lifecycle and improved post construction survey and certification processes, hence costs reduction in EUR and environmental costs.

Improving certification of existing and new passenger ships is achieved through the reduced consideration time and approval in accordance with national regulations and any amendments thereto. The digitisation of the relevant law is combined with the initial configuration request of the owner of the vessel and allows the owner to take more informed decisions on the type of the vessel needed and allowed. Two steps will provide the improvement: (1) Standardisation of requests and (2) Combination of the consideration and the rules in conjunction with their amendments and application in the standard requests.

Moreover, unification of standardisation will aid increasing productivity. Decreasing review times and approvals, the time of final certification is reduced, so the society becomes more efficient in handling requests by the owners and the ship owning companies of passenger vessels up to 30 m in length overall and passenger capacity of up to 200 passengers. Improved response times, minimise decision time for shipbuilding and rebuilding by the owners therefore produce more efficient passenger ships "decreasing the operational cost" (lighter ships = decrease in fuel consumption), or possible increase in capacity or a combination thereof. To elaborate more on how each actor benefits from the overall achievements of the UIW-challenges:

Customers will be able to:

– View the final outcome as a whole from day one
– Make decisions based on visualised scenarios which will include information such as physical properties and cost
– View and visualize any change or update
– Track changes during any stage of production or use of product.

The boatyard will be able to:

– Offer and quote to customers with virtual models of the final product
– Make proposals, estimate costs regarding material and parts
– Conform with specifications, rules, guidelines
– Optimize designs
– Validate manufacturing procedures and processes
– Validate changes of design, materials and parts
– Track changes and updates
– Communicate the project and its properties to vendors and subcontractors.

The Classification Society will be able to:

– Offer to the customers an automated consultation tool
– Keep track of the legislation and its changes
– Follow the modifications to the vessel and their conformity with legislation
– Have an overview of previous approved solutions to offer to customer.

1.3 Reasons to Select the Tools

The tools (vessel meta-file application and vessel web configurator) selected to facilitate the communication between the actors are mostly web-based, so as to enable the modern cloud-based approach of software and also to enable various approaches of exploiting their usage, namely software-as-a-service (Dubey 2007). Moreover, business modelling for analysis and prediction has been used for informed decision making and thus it was logical to use such tools for long-lived products, such as vessels.

2 Tools and Solutions

2.1 Development Process

The objective of the Cluster 5 model is to link business activities to the objectives of individual market actors and show their impact on the UIW-objectives. To achieve that, individual models for SEAbility, OCEAN, and INSB have been built. Each

	2015											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seability	LS	LS	LS	HS	HS	HS	HS	HS	HS	LS	LS	LS
OCEAN	HS	HS	HS	HS	HS	HS	LS	LS	LS	HS	HS	HS
INSB AR	LS	LS	LS	HS	HS	HS	HS	LS	LS	LS	LS	LS
INSB NR	HS	HS	HS	HS	HS	HS	LS	LS	LS	LS	LS	LS

Fig. 1 High season (HS) and low season (LS) for each actor (AR = annual requests, NR = new requests)

model was extensively validated on the level of system structure and behaviour (Groesser et al. 2012). The individual models were subsequently linked together to form the Cluster 5 industry-model. The industry model is driven by the demand from the tourism market which is strongly seasonal. The operators buy boats and try to optimize the purchase so that the boats are ready for service at the beginning of the high season (SNAAM 1985). This is reflected in the model with yearly oscillation patterns for all market actors in customer demand; i.e. tourists for SEAbility, boat orders for OCEAN and INSB respectively. The yearly high season and low season periods for the market actors are shown in Fig. 1.

The touristic high season for operators in Greece typically spans from April to September inclusive, of each year. This means that prior to the period when cruise ships with tourists start their schedules to Greece, the boats have to be operational and to achieve this the boats are built between October and June of each year, a period which represents the high season for the boatyard OCEAN. It is important to note that in the model operators tend to target April for boat delivery times and rather restrictive towards early and late boat deliveries, meaning that they postpone the purchase to the next year, resulting in strong peaks in the purchasing behaviour in the simulation results. Annual requests for INSB are occur between February and July so as to ensure that the boats are ready for that year's operation, while new requests for boats run parallel to the construction of boats and result in a high number of new requests for INSB between January and June.

3 Results

3.1 System Dynamics Model

3.1.1 Overview of the Integrated Industry Model

The elements of the integrated industry model.

The industry model consists of the three individual models for the market actors which are complemented by a market model simulating the market behaviour of

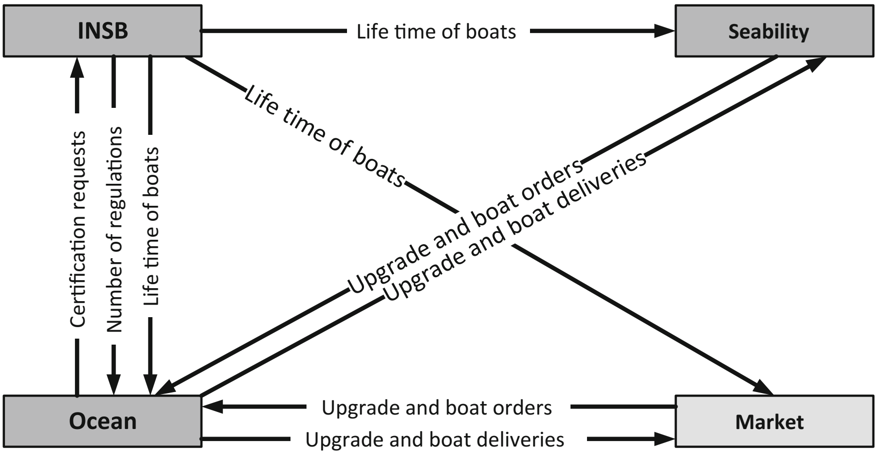

Fig. 2 Sector diagram for the integrated industry model

SEAbility's competitors. Figure 2 shows the major information flows of the industry model. Due to the size of the model and the number of connections between the individual models, only the most relevant information flows are displayed (for a further example of this approach see (Groesser 2012b). INSB's impact is mostly through the setting of boundaries and constraints such as boat lifetime, i.e. the time that a boat is allowed to operate, which will be evaluated in the policy analysis. Furthermore, INSB identifies the number of changed regulations and that information is passed on to OCEAN. OCEAN sends the certification requests which INSB then handles. In addition, OCEAN receives the boat-building and/or upgrade orders from SEAbility and the market, which in turn lead to construction of boats which are then delivered to the respective operators. The relevant market is divided in two parts (Fig. 3), "*All other markets*", representing the overall tourism-related shipping demand with the exception of Santorini, which is modelled separately as Santorini is the area of operation for SEAbility.

All operators for the market have a decision making structure similar to that of SEAbility, but base their decisions uniquely on the high season, whereas SEAbility also includes low season factors in its decision-making process. Furthermore it is assumed operators always have the financial means to buy boats when it is necessary.

The market in Santorini is depicted to grow as shown in Fig. 3, while the other market are assumed to be constant at 1.8 million passengers per month. The individual models for the three market actors INSB, OCEAN, and SEAbility are described in more detail below.

INSB is the certification society in charge of managing the changing regulations and certifying both boats in operation as well as new buildings. For the purpose of the model, the impact of INSB on the entire model is rather small. The certification

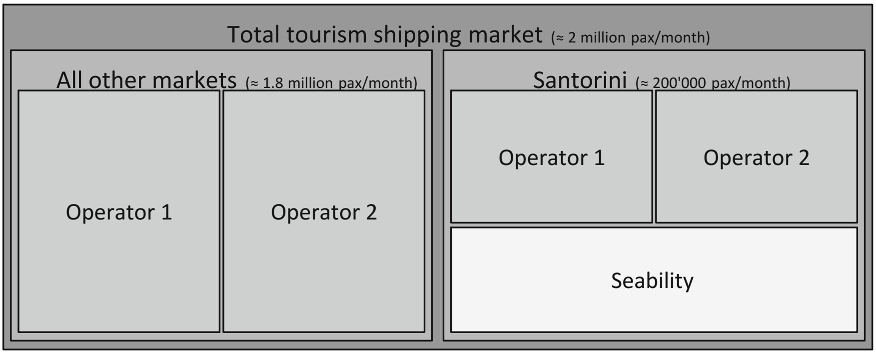

Fig. 3 Elements of the market, SEAbility competes for customers in the Santorini market, pax/month means passengers/month

society adds a delay when it comes to the construction of the boats through the checking of the boat's design. INSB's importance in the model is in setting the framework for boat operation such as the total time a boat can be used, which we will evaluate in the policy section. One of the most important features of a classification society is to ensure that boats are kept in order and designs for boats are safe. However, for the purpose of this model, individual boat designs have not been modelled and thus this role has no impact in the model. It is assumed in this model that all boat designs are approved. The certification role of INSB is limited to certifying each new construction and the annual certification of each boat. This delays the construction of the boat and removes the boat from use in the low season, which is only applicable to SEAbility.

The structure in Fig. 4 shows the different steps that have to be taken before a new request is complete and is certified. The first two steps "*guidance*" and "*survey*" are done during the construction of a boat while the latter two "*consideration*" and "*certification*" are done upon completion of the construction of a boat, thus extending the boat construction time.

Figure 5 shows the behaviour of handling time for new requests (left) and allocated capacity for new requests (right). INSB's business consists of two separate elements: The annual requests (AR) and the new requests (NR). The annual requests happen during the entire low season when boat operators do not operate their boats (with the exception of SEAbility) while new requests peak towards the end of the low season when boat operators want to put their newly purchased boats to service. This leads to peaks in handling time as seen on the left and peaks in allocated capacity as seen on the right. The boat construction business is cyclical and there are periods without boat construction. However, INSB cannot anticipate that and still provides capacity that then is then underutilised.

OCEAN is the boatyard in this cluster. The company is an important player in the industry, having a market share of 80% in passenger boats. While OCEAN's

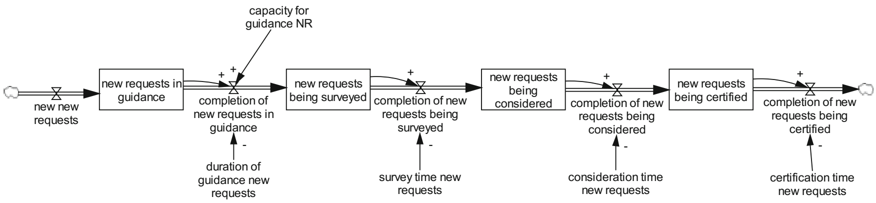

Fig. 4 Essential structure of the INSB model: handling of new request

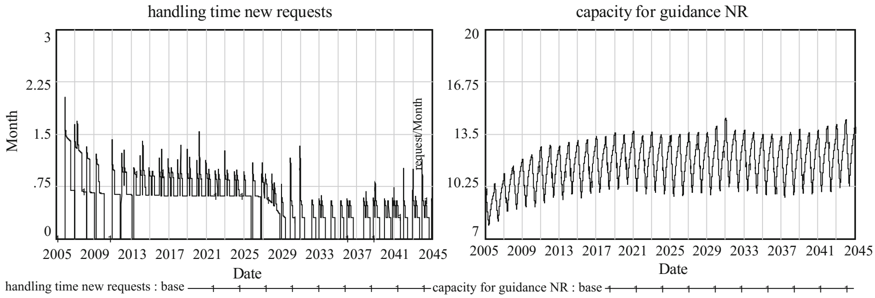

Fig. 5 Essential behaviour of the INSB model about new requests

portfolio features a multitude of boat designs of various lengths, for the purpose of the model this portfolio was simplified to comprise two categories, viz. small (<10 m) and large (>10 m) boats. To keep the model as simple as possible, newly constructed small boats are used for a single purpose, as utility boats and all small passenger boats have to be converted from utility boats. The resulting difference in the construction of small boats between reality (where only a few small boats are designed as passenger boats) and the model is only marginal and has no impact on the validity of the model results.

OCEAN and its competitors perform three types of boat related services: (1) construction of new boats, (2) conversion of the type of boat, and (3) upgrading of boats. The construction of new boats is the process where a new boat is built from scratch. In the model, this is done for small utility boats and large passenger boats. The construction of a new boat triggers a new request for certification with INSB. The conversion of the type of boat is done by taking the hull of a utility boat and changing the set up to make it usable as a passenger boat. The conversion of a utility boat to a small passenger boat is shorter than the construction of a new boat, but the boat also has a shorter lifetime due to its past use as a utility boat. The conversion of a boat also triggers a new request for certification with INSB. The upgrading of boats does not change their general set up. However, it updates the technical set up of the boat (e.g., efficiency, emissions, attractiveness).

Upgrading is the shortest of the three services, and does not trigger a new request with INSB as the technical set up of the boat essentially remains the same.

The causal structure shown in Fig. 6 shows OCEAN's building process of large boats. The orders come in from the operators (MARKET and SEAbility) and the construction is prepared. Then, the boat is constructed and released to the market. OCEAN experiences the same purchasing behaviour with strong peaks as INSB since the operators try to optimize their purchasing behaviour by having the boats delivered and operational just before the start of the high season.

The construction time for boats are varies and depends on their size (Fig. 7). For small boats the construction time starts at around 4.75 months and decreases slightly to around 4.25 months. This decrease is due to the implementation of the UIW tool (shown in the following chapters) and a reduction of changes in regulations. For large boats, the building time increases from 5.25 to nearly 8 months. This is due to the fact that the average size of large boats is assumed to increase steadily, hence longer construction times. However, the increase is softened by the implementation of the UIW tool for improved communication between the boatyard and the certification society, with the time savings shown in Fig. 19. In Fig. 7, the dotted line is the planned construction time while the solid line shows the actual construction time. The graph shows how the implementation of the UIW tool in 2015 significantly reduces the delays from changes and regulations (from about 0.5 months to a few days) by comparing the planned construction time (dotted line) to the actual construction time (solid line). The purchasing behaviour of the operators of the boats results in large oscillations in the utilisation of OCEAN's

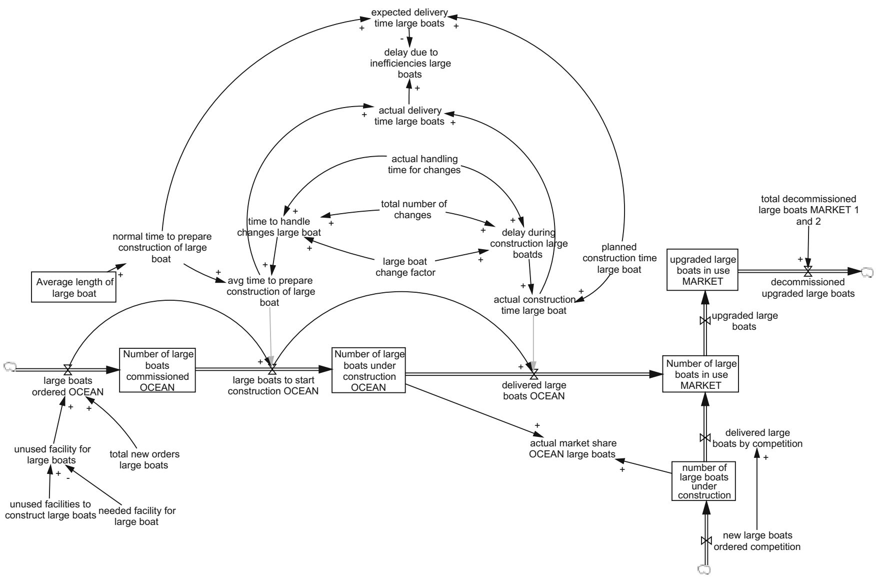

Fig. 6 Structure for building large boats

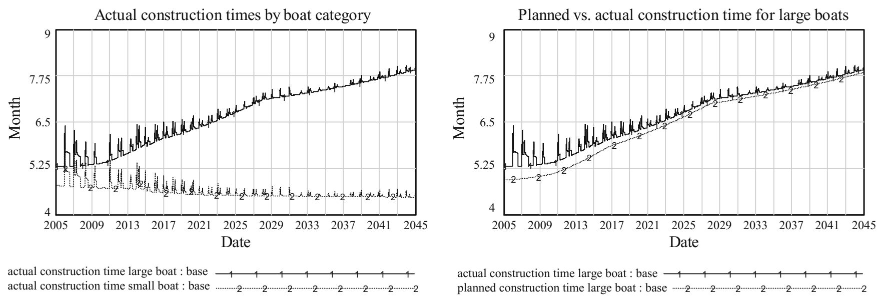

Fig. 7 Essential behaviour of important indicators for OCEAN

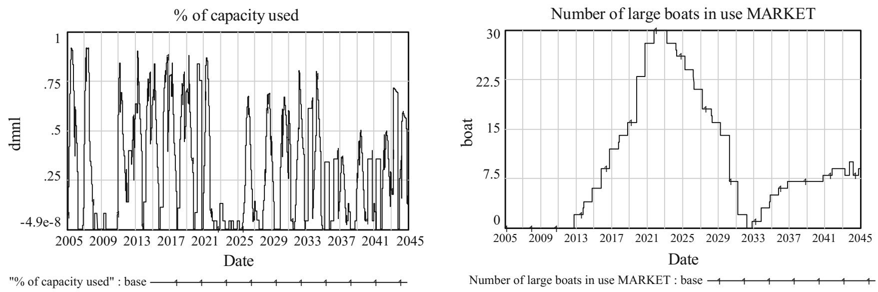

Fig. 8 Short term cycles in large boat construction (*left*) and long term business cycles for OCEAN (*right*)

capacity. In addition to short term oscillations, OCEAN also experiences long term oscillations in the construction of large boats (Fig. 8, right side). The solid line shows the number of large non-upgraded boats in use in the entire industry. The first period of construction of large boats is from 2013 to 2021, during which 30 large boats are built. Between 2021 and 2032 all of these boats are upgraded (and thus are not counted in this variable anymore), whilst new large boats are built after 2033.

SEAbility represents the operator side in the industry model. Passenger boat operators in Greece mainly operate in the tourism high season and has as a main market the carriage of tourists from cruise ships anchoring at sea near the island harbours to the islands' disembarkation ports and back. SEAbility operates in the market of Santorini, but the essential market and operator dynamics are assumed to be the same for all operators. Other elements of the business model for operators can be additional local boat tours for the tourists that are in the islands (having arrived at the islands both by cruise ships and otherwise) as well as low-season services (e.g., ambulance, longer transport routes, postal), however, only SEAbility has included these services in its model. Operators use a variety of boats for their services. Some boats are converted sail or fishing boats and some are newly-constructed boats. With their demand for boat construction, the operators fuel the business of the other actors. To model this more in-depth, the model features an extensive decision-making structure based on demand and current market share for all operators. There is a bias for large boats in the market as the purchasing decision for large boats has to be made prior to the purchasing decision for small boats as the larger boats take longer to be constructed, if the boats are to be operational at the start of the high season.

The business objective for boat operators is to have sufficient boats profitably to cover the demand. Operators have the choice to build small or large boats (Fig. 9). The newly-built boats subsequently age and become less attractive to tourists and more costly to operate. Eventually and after operating for their entire allowed usage time, the boats are decommissioned, leading to replacement purchases if demand warrants this. For the large boats, the operators have the opportunity to upgrade the boat thus leading to an increase in attractiveness and decrease in operating costs.

In the model, SEAbility starts operation in 2015 in the Santorini market, which is expected to decline in customer demand until 2020, followed by recovery. This development is mirrored in Fig. 10 (left) where the demand is sufficient to trigger the purchase a boat in 2015 and 2026 and a second boat in 2037. Interestingly, the boat purchased in 2015 is decommissioned in 2025, leaving SEAbility with no boat for about a year as the decision making by SEAbility is rather conservative and does not allow for the purchase of a boat to replace the existing boat because the demand is insufficient. Utilisation (Fig. 10, right) is below 100% until 2025, indicating that there are overcapacities in the market that linger until 2026, when demand has picked up sufficiently and capacity is adjusted.

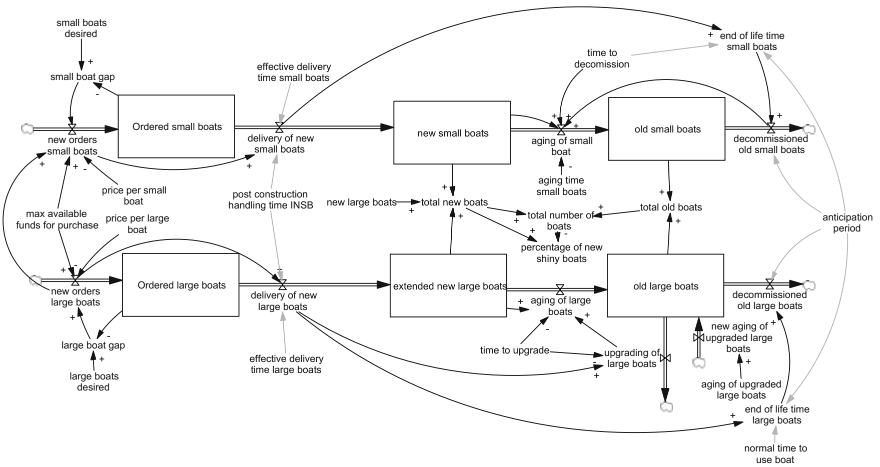

Fig. 9 Fleet composition for operators (using SEAbility as example)

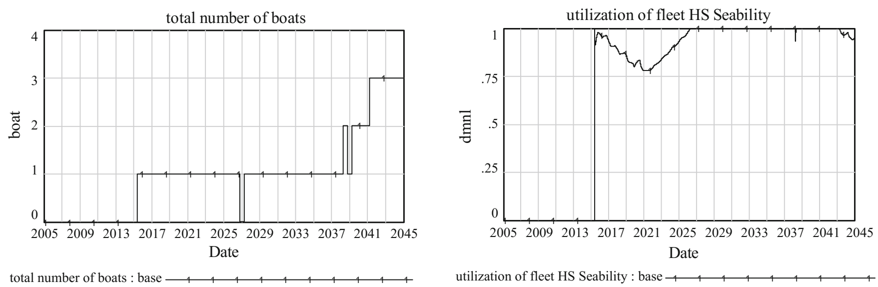

Fig. 10 Essential behaviour for SEAbility, showing the entire fleet for SEAbility (small and large boats)

	240 months (base)		120 months (base)
Large boats	Normal boat life time		Extended life time
Small boats	Time utility boats	Time to use small boats	

Fig. 11 The different lifetimes in the model

3.1.2 Policy Analysis with the Integrated Simulation Model

Policy description and results.

The evaluated policy is one set by INSB for the entire industry in terms of the lifetime of the boat. INSB regulates the normal boat lifetime and it is assumed that the extended boat lifetime is always 50% of the normal boat lifetime (Fig. 11). The extended boat lifetime can be achieved by upgrading large boats. As small boats cannot be upgraded, their life span is entirely defined by the normal boat lifetime. The operational lifetime of small boats is further decreased by the fact that in the model all small boats are converted utility boats and can only be used for the remaining lifetime of the boat. To capture the effects of the boat lifetimes, the time horizon for the simulation has been set to 480 months (forty years) with ten years simulating past behaviour and thirty years simulation time into the future (measured from the base year of 2015).

For the policy analysis of the boat lifetime there are two policies simulated in addition to the base case shown in Fig. 11. The policy "boat lifetime 204" (LT204) simulates the effects of 204 months normal lifetime and 102 months extended and "boat lifetime 276" (LT276) with the values of 276 months normal lifetime and 138 months for extended. The simulated policies show the effects, if INSB chooses to reduce or extend the permissible use time for boats by three years.

As can be seen in Fig. 12, OCEAN profits from a reduced boat lifetime. LT204 (dotted line) performs better nearly throughout the entire simulated period. This can be expected because with a reduced boat lifetime operators need to replace their boats sooner and this leads to more boat orders. Interestingly however the runs only start differing in 2023. The available facilities (i.e., production capacity) stay roughly the same for all scenario until 2033, so the improved financial result after 2023 is mainly due to a better utilisation of the available facilities. The comparison between LT276 (dashed line) and the base case (solid line) is also interesting because over large parts of the simulation period, the LT276 run performs better than the base run. This is counterintuitive since a longer boat lifetime result in fewer boat orders. The cause for LT276 to perform better lies in a better distribution of orders during the multi-year cycle. The difference only changes in around 2037 when many of the large boats need to be replaced and since the lifetime of large boats is more sensitive to any reduction or extension of the normal boat lifetime, the effects can be observed more sharply after 2037. Also, in that time there is a strong clustering of orders in the LT276 run prompting OCEAN to expand its capacity sharply. The fact that both policies fare better over most of the simulated period suggests there are local optima for setting the boat lifetime where OCEAN does not lose revenues but the operators have the possibility to maximize their revenues through longer use of their boats. This does not occur in the current base case where the normal boat lifetime is 20 years.

For the operators, however, the effects are mostly opposite. Naturally, the operators would like to maximize their revenue and use the boat as long as possible. The effects of increasing and decreasing the boat lifetime results in a difference of about 1 million euro of cash flow in the case of SEAbility and a larger increase in spending for "Market 1", one operator in the market representing half of the transport capacity of all the other markets (Fig. 13). "Market 1" is used for illustrative purposes, all other operators experience the same effects. The case of SEAbility is interesting because the cash flow for both policies performs better between 2035 and 2045 although the base run eventually catches up. For "Market 1", however, the spending on boats is higher for both policies, which should only be expected for the LT204 run. SEAbility profits disproportionately from more frequent replacement of their boats because of the small size of their fleet, which explains the better performance of LT204 and saves more money in the case of LT276. In the case of "Market 1", both policies are more expensive because in LT204 boats have to be purchased more frequently and in LT276 the boats are more evenly distributed allowing the operators to purchase more large boats.

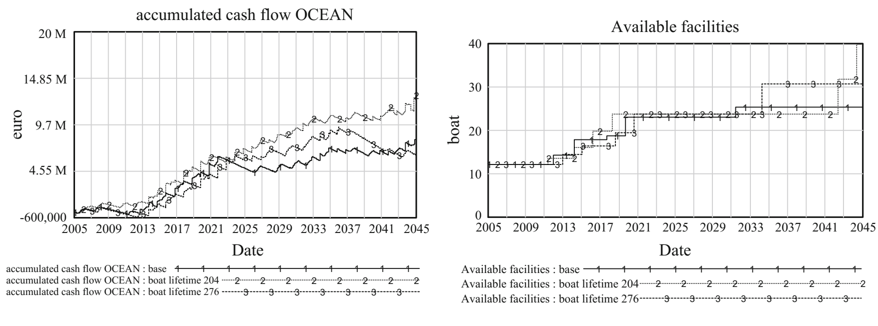

Fig. 12 Effects on OCEAN for the different policies

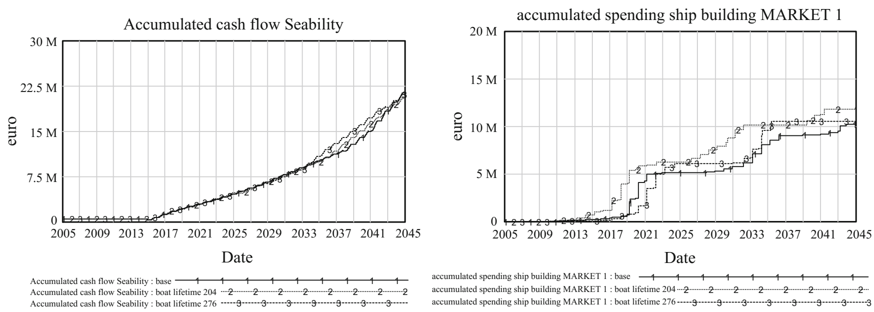

Fig. 13 Effects of the policy on the operators SEAbility (*left*) and Market 1 (*right*)

Interestingly enough, one could expect that large boats with their longer lifetime would be subject to greater demand, yet this is not the case; this is mostly because the decision-making does not, for planning purposes, take into account the entire boat lifetime but rather a shorter planning period of five years for strategic decisions. Irrespective of the boat lifetimes, the total demand for the entire market (except Santorini) increases steadily and tops of at 40 large boats for the base run. For both LT204 and LT276 however, the number of large boats increases to around 50 as the boatyard's capacity is more evenly distributed over the years, leading to more purchases of large boats as more capacity is available because boat orders are less clustered.

3.2 Information Technology Support Tools

The shipping cluster is using two distinct information technology support tools. A Redmine based communication hub (Redmine 2006), called the vessel meta-file application (Fig. 14).

And a vessel web-configurator, which includes the relevant legislation (MoMM 1979a, b, 1988, 1996, 2011) (Fig. 15).

In the vessel meta-file application, each actor has assigned a specific workflow, which enables the correct transition of the different procedures from one state to another state.

Currently five different workflows exist:

1. Workflow for the conduction of a survey
2. Workflow for the completion of a technical work
3. Workflow for a document request
4. Workflow for an initial configuration of a vessel
5. Workflow for the initial price quotation for a vessel.

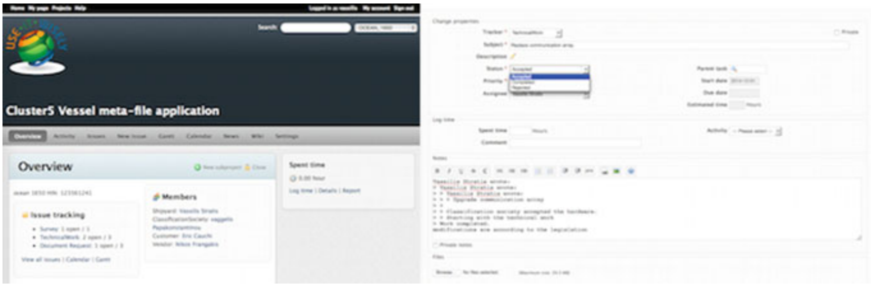

Fig. 14 Vessel metafile application

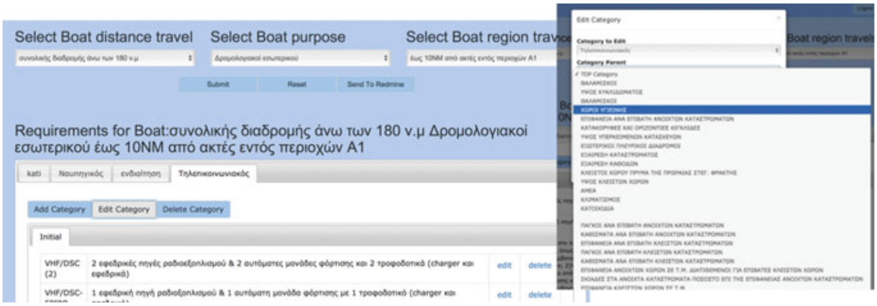

Fig. 15 Vessel web-configurator

Each actor (Shipyard, Classification Society, Customer, Technical Consultant, National Supervisor and Vendor) is assigned a specific workflow to facilitate the verified procedure.

The states of the workflow include:

1. New: the workflow has just started
2. In Progress: currently some actors are actively working on a task
3. On Hold: the task is on hold for some reason
4. Accepted: the task has been accepted by the appropriate actor
5. Declined: the task assignment has been declined by an appropriate actor
6. Completed: the task has been competed
7. Rejected: the task completion has been rejected by an appropriate actor.

For example, the shipyard is able to start a new task "Technical work" and is able to change its status to in progress, on hold, completed or rejected. For the same task, after the shipyard has marked the task as completed, the classification society should check the outcome and mark the task accepted or rejected based on the results of the survey. Moreover, the customer is able to decline this task if the results are not satisfactory (Fig. 16).

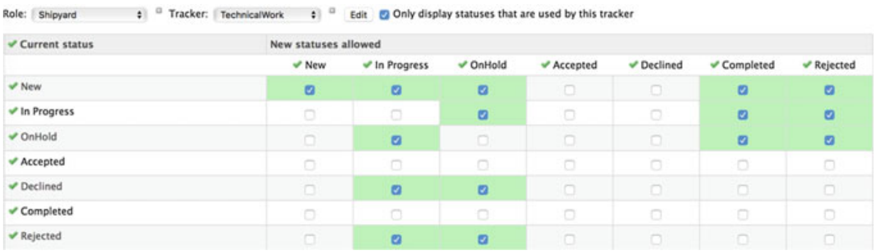

Fig. 16 Vessel metafile application workflow configuration

Similar workflows exist for all the procedures, ensuring transparency to the activities and collaboration of the actors.

The vessel web-configurator enables a future customer to enter the initial requirements into a web system, which then displays a rough overview of the applied legislation (SECP 2000; SoNaME 1990). This enables the future customer to finetune the initial requirements. The legislation is updated by the classification society and covers all the aspects of the vessel.

4 Discussion

4.1 Benefits of Using the Tools

4.1.1 Impact of the System Dynamics Scenario on Cluster Objectives

The objectives for the UIW Cluster 5 scorecard have been set as part of the UIW-project. The objectives have then been subsequently added to the model and the simulated results are compared to the set objectives. As part of the UIW-project, Cluster 5 has also developed a tool to facilitate the communication between the boatyard (OCEAN) and the classification society (INSB) in terms of regulations and amendments of regulations. The tool is only applicable to large boats and only those results are reported. For the simulation, the tool and its effects have been modelled and two runs (one with UIW tool, one without) have been executed. The objective of the UIW tool is a shorter construction time through improved communication which means that its impact is negligible in terms of technological progress (objectives 4a and 4b) and therefore only the run with the tool active is reported for these objectives (Figs. 17, 18, 19, 20 and 21; Tables 1, 2, 3, 4 and 5).

A system which will integrate past project experience, boatyard's infrastructure and technical ability, vendor solutions and classification society rules into one system which will produce the best possible solution for one customer's business requirements as a dynamic meta-file with possible visualisation of attributes and specifications. Project attributes will be based on future platform's output which could be dynamically changed according to each actor input. Initial requirements will be pre-validated by the future platform. Pre-validation will be based on data passed by the Classification society. Selection of specific materials and parts will be based on data passed by vendors and suppliers. Any aspect of initial design or change on initial design will be optimised and checked for compatibility with all

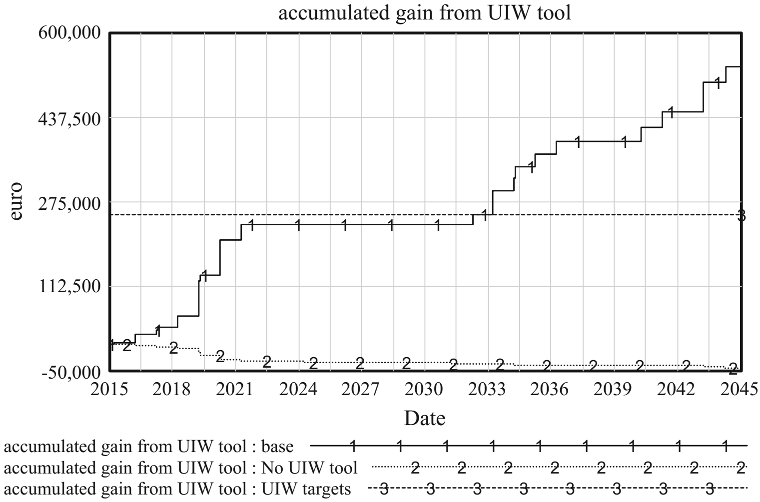

Fig. 17 Graph for gain from UIW tool

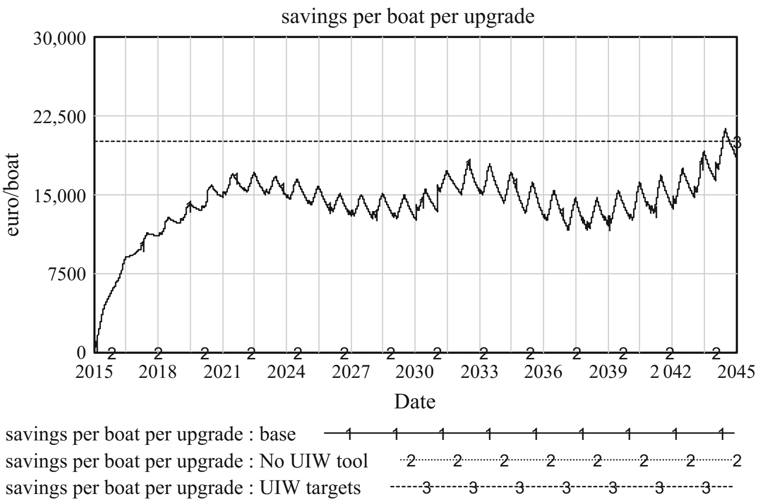

Fig. 18 Graph for savings per upgrade

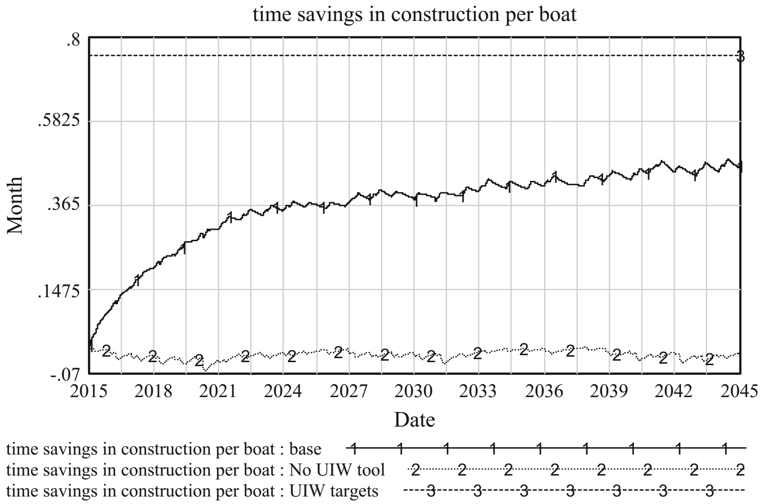

Fig. 19 Graph for time savings

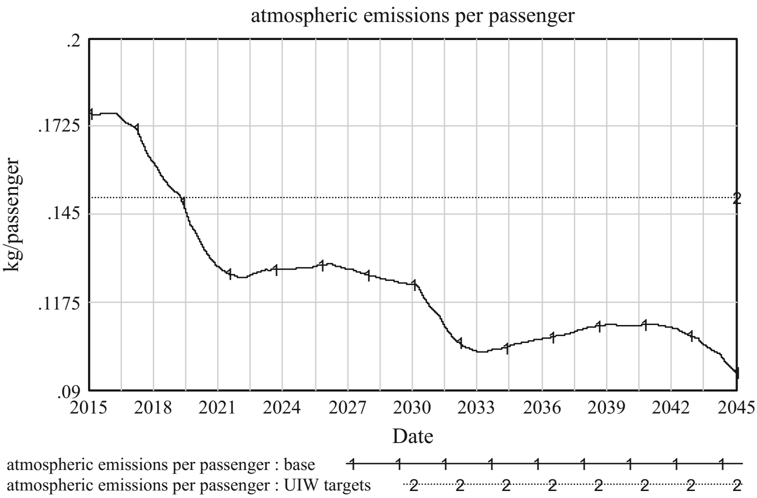

Fig. 20 Graph for atmospheric emissions

actor's specifications. A system acting as a pool of information for all parties would solve the problem of information flow. A system which would integrate properties such as technical specifications, rules, physical attributes, cost, etc. in a virtualised model would solve the problem of optimizing design to dynamic updates and changes. The final result would be a new process of manufacturing where final outcome is based more on initial design than on continuous design cycles.

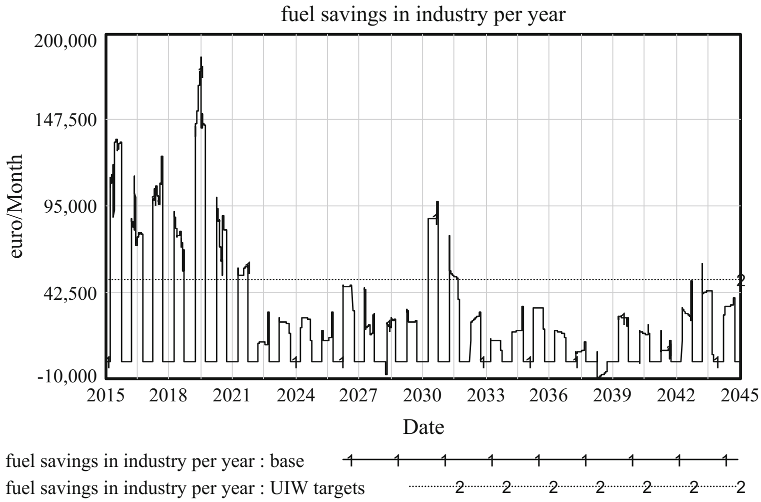

Fig. 21 Graph for fuel savings

The process of deciding on the construction details can be summarised on the following steps:

1. Boatyard decides on materials, based on project requirements (for example cost and weight) and availability from vendors. Material specifications and data sheets are already embedded into the system. Hence, selection is optimised using initial requirements.
2. Calculations regarding material aspects, structural elements and other construction design elements are made by the system, using predefined Classification Rules.
3. A pre-validated construction plan and engineering analysis is produced.
4. Any change or update during the duration of the project dynamically change attributes of the construction plan.

4.2 *Limitations of Using the Tools*

The decision-making of operators is highly individual. Factors such as how aggressively is growth pursued and the timing of the boat purchase depend greatly on how individual operators perceive the market. For the purpose of this model, only one decision-making process is modelled, leading to a reduced amount of richness. This decision-making process can be adjusted for parameters of

Table 1 Objective 1 of the UIW Cluster 5 scorecard

Objective	Behaviour
Name of the objective: Economic gain from UIW tool	Figure 17
Objective definition: Increased ability to rapidly follow the market dynamics by means of fast production and delivery of personalised final products	
Cluster-specific objective: Quick reaction to varying service demand, regulation change, alterations requests from the customer through value chain integration (€250–300k for the entire industry)	
Explanation: The graph above shows the target as a dashed line and the simulated result as 1 and 2. The time horizon reported here is from 2015 to 2045 as the tool is not implemented prior to 2015. There are two large boat purchasing cycles. The first one starts in 2015 and lasts until 2020 and the second one starts in 2030. In both periods, a large amount of the operator's transport capacity is replaced with large boats. The economic gain of the UIW tool consists of two parts: (1) The construction of the boat occupies capacity for a shorter period of time as the exchange of technical information between the certification society (INSB) and the boatyard (OCEAN) is improved. Thus, the boatyard can construct more boats during the same building period. (2) The operators (SEAbility) need to commit fewer financial resources with shorter lead times when purchasing a boat and can therefore react better to market trends. The improvement is due mainly to a reduced time to react to changes in the design of boats as well as improvements in handling times for new requests. The target is reached around 2032. Between 2015 and 2030 there are no large boats built and thus no gains from the UIW tool are obtained. The benefit in this objective is measured for the whole industry and accumulated over time The dotted line shows the comparison run in the case that the tool is not implemented. The reference year is again the year 2015 and the effects are accumulated. The "No UIW tool" run shows an accumulated loss for the industry of about 50,000 Euro. This makes sense given that the tool shortens construction times for large boats. This leads to the operators having to make decisions with larger uncertainties about the utilisation of their fleet. This in turn leads to overcapacity in the market. This can be confirmed as the Market 1 as a sample operator uses two more large boats and has a marginally lower utilisation rate over the simulation period in the run without the UIW tool. Therefore, the benefit derived from the improved information exchange and resulting shortening of construction and order times, not only has financial benefits for all actors but also supports an improved use of resources available, e.g., boat materials that are not used for construction	

aggressiveness and other factors to more optimally manage an operator's fleet, but it will remain only a guideline on how actual decisions are implemented. Therefore, the market structures are kept as simple as possible. There are just two operators in each market, with the exception of SEAbility being a third, each representing a collection of small operators. The behaviour for many small operators is unlikely to be much different as the model assumes the same decision making process for each operator. Inefficiencies in the purchasing behaviour are, such as an undersupply of available boats, are due to a lack of capacity of OCEAN and of competitors.

Similarly, the topic of upgrading is simplified. For each operator, the upgrading policy can be set individually, but stays uniform for the entire fleet. The operator has no opportunity to change its operating policy from one boat to another. This is obviously a simplification to achieve a manageable model. However, the current

Table 2 Objective 2 of the UIW Cluster 5 scorecard

Name of the objective: savings per boat	Figure 18
Objective definition: Cost reduction of around 30% by decreasing lead times in product/process development	
Cluster-specific objective: Reducing time and costs by 30% due to the availability of the vessel technical information (from €50–60k to €40k)	
Explanation: This objective shows a different aspect of the implementation of the UIW tool. The graph shows the target from the UIW-objective as a dashed line and the result of the simulation as a solid line. The solid line shows the 12 month average for savings in upgrading. While objective 1 concerns the construction of new boats, the implementation of the UIW tool also facilitates and improves the upgrading of existing boats. Upgrading is in general a shorter process than complete construction, as the hull and other elements of the boats remain intact. Regardless, the savings are in the same range as for building on a per case basis. Thus, the tool has a larger impact for the upgrading as it has for building. The objective of €20K is achieved towards the end of the simulation period, when the database in the tool includes nearly 90% of all relevant regulations and amendments. The simulated results oscillate due to the fact that the improved communication between the certification society and the boatyard also depends on the number of amendments. Amendments to existing regulation happen mostly when there are new constructions which in turn take place mostly when fleets are renewed. The renewal of fleets is a cyclical process and causes the oscillating behaviour shown in the graph above The dotted line shows the run simulating without implementing the UIW tool. In the case of upgrading, no capacity issues are expected to matter and therefore there is no loss to be reported. Thus, the run shows a constant 0	

Table 3 Objective 3 of the UIW Cluster 5 scorecard

Name of the objective: time savings in boat building	Figure 19
Objective definition: Set-up and ramp-up time reduction for new processes and plant designs (30%)	
Cluster-specific objective: Decreased lead time in product modifications by at least 20% (from ca. 90 to 70 days) due to better information about the modifications costs needed to meet new business demands	
Explanation: Time savings from the implementation of the UIW tool are shown in the objective above. The target (dashed line) is never reached by the simulation result (solid). This is due to the fact that the initial goal was set for larger boats. Larger boats have longer lead times and changes in the design take longer to be amended. In the case of large boats in the simulation, its result shows a reduction of lead times of nearly half a month. The improvement after the implementation of the UIW tool is initially steep as more and more new requests comply with the system and flattens out after around 2021 when the smaller improvements are due to a decrease in amendments necessary in the regulations. The dotted line shows the “No UIW tool” run and shows a small negative time saving of around three days. This is due to the increased construction of boats and the creation of occasional bottle necks for new requests at INSB. The bottlenecks are corrected rather fast and therefore the run is always very close to 0	

Table 4 Objective 4a of the UIW Cluster 5 scorecard

Name of the objective: emissions per passenger (part a of the 4th objective)	Figure 20
Objective definition: Reduction of around 40% in the environmental footprint and resource consumption during the production and use phases of the meta products, together with an increased use of more environment-friendly materials	
Cluster-specific objective: Ability to consider environment-friendly materials that could expand the life cycle of the product while decreasing the environmental footprint due to better forecast and planning (reduce atmospheric emissions to less than 0.15 kg per passenger per voyage)	
Explanation: This objective describes the decrease in emissions due to the use of new materials and technologies. The graph shows the emissions per passenger transported. This is calculated under the assumption of a homogeneous set of high season transport routes. A constant load factor for the market is also assumed to be at 80%, meaning that on average for each voyage 80% of capacity is filled. Depending on the load factor, the overall level of emissions per passenger increases or decreases but the general behaviour stays the same. The behaviour is due to two factors of fleet management: (1) There is an overall trend to lower emissions per passenger due to improvements in technology and (2) there are periodical increases of emissions caused by boat aging. It is assumed that due to wear and tear of the engine and other related boat characteristics the older boats operate at a lower efficiency and produce more emissions per passenger. The decreases in emissions comes from the increased building periods we have seen in objective 1. There is no run without the implementation of the UIW tool shown as the differences in the emissions per passenger are only marginal	

Table 5 Objective 4b of the UIW Cluster 5 scorecard

Name of the objective: Fuel saving (part b of the 4th objective)	Figure 21
Objective definition: Reduction of around 40% in the environmental footprint and resource consumption during the production and use phases of the meta products, together with an increased use of more environment-friendly materials	
Cluster-specific objective: Ability to consider environment-friendly materials that could expand the life cycle of the product while decreasing the environmental footprint due to better forecast and planning (decrease of fuel consumption at approx. €50–80k/year)	
Explanation: This objective addresses fuel savings due to improvements in material usage, technology and designs. The graph shows the UIW-target as a dashed line and the simulated result as a solid line. The simulation results show the comparison of the savings in any month compared to the same month a year ago. The savings are adjusted for market coverage, i.e., show the comparison if all passengers are served. There are some periods where operators do not have enough boats available to serve all passengers (between 2016 and 2021). This is also the period during which the largest yearly savings in fuel are realised. During this period a large number of boats are replaced with boats with a higher fuel efficiency and thus lead to fuel savings while also maxing out on the available capacity for boat construction and a backlog that causes the market to be underserved	

setting of the model allows among other things to compare the effectiveness of upgrading strategies.

Regarding the Information Technologies (IT) support tools, the main limitations lay in the complexity of the tools (Snabe et al. 2006; Grossler 2004).

5 Conclusion and Future Work

Building an industry model generated an important amount of information for strategic thinking and decision making to the cluster members. On one hand, it provided a clear link between the cluster activities, e.g., the development of the UIW tool and the UIW-objectives. On the other hand, it explicated the link between the individual and partially conflicting business objectives of the different market actors. One example is the boat lifetime which can be regulated by INSB. INSB's main concern for regulating the boat lifetime is safety, but at the same time it is a strong tool to manage the industry as a whole. SEAbility and OCEAN, however, have potentially conflicting objectives regarding the lifetime of boats. SEAbility requires the lifetime to be as long as possible as the initial purchase of the boat represents a significant investment. In particular, when it comes to converted small boats, the boat lifetime needs to be above twenty years to allow the effective and remunerative use of the small boats. On the other hand, OCEAN has an interest in shortening the lifetime of boats to increase replacement purchases although local optima exist where this causal relationship is reversed.

Overall, the model depicts the general dynamics of the ship-borne tourism industry in Greece and has been validated by market actors at the level of model structure and model behaviour. However, the lack of available data does not allow for a more in-depth calibration than the expert opinion of the cluster members. The difficulty in getting a clear set of data is that classifications, for example, include many other types of boats besides passenger boats, and thus during the model development it could not be identified which of the built boats are relevant for the model. In the end limited data sets for customer demand in Santorini were available as well as boat construction numbers for OCEAN. While the lack of data did not allow for modelling the actual development in the industry, the model provides value nonetheless by explicating the causal relationships between the different actors and markets and their respective dynamics. This allows users of the model to test possible outcomes of business decisions under any current circumstances.

The trade-off between the different market actors requires more research. In particular, the search for optima and their implications for operational safety will bring important insights for the management of the entire industry. Since this model has a strong focus on allocating the available resources of the boatyard and classification society equally between the different operators, it would be of interest to define more individual building and upgrading patterns for operators to allow for more detailed testing of the individual operator's strategies. Finally, the aspect of sustainability of boat replacements has not been addressed and could potentially alter the attractiveness of policies that shorten the boat lifetime.

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Sustainable Furniture that Grows with End-Users

Tim Bosch, Karin Verploegen, Stefan N. Grösser and Gu van Rhijn

Abstract Economically and environmentally it might be more responsible or even feasible to combine products and services to elongate product lifetime. Gispen, a major office furniture producer in the Netherlands, has embraced circular economic principles to create new business, extend product life time and improve the adaptability of their products. In the Use-it-Wisely (UIW) project two applications were developed. To estimate possible business impacts of adapting a circular economy concept for a company, a dynamic business model simulation has been created by using the system dynamics methodology. And second, Gispen has developed a new Circular Economy Design Framework to support circular product design development. A combination of basic principles to design, upgrade, and reuse products according to circular economy principles are included in the framework as well as a circular life cycle assessment methodology. The development process, non-confidential company results of the tool application and directions for future research are described in this chapter.

Keywords Circular economy · Business models · Life Cycle Analysis · System dynamics

T. Bosch (✉) · G. van Rhijn
Department Sustainable Productivity & Employability, TNO, Leiden, Netherlands
e-mail: tim.bosch@tno.nl

G. van Rhijn
e-mail: gu.vanrhijn@tno.nl

K. Verploegen
Gispen, Culemborg, Netherlands
e-mail: karin.verploegen@gispen.nl

S.N. Grösser
Institute for Corporate Development, Bern University of Applied Sciences, Bern, Switzerland
e-mail: stefan.groesser@bfh.ch

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1 Introduction to the Company Challenge

The market for office interior design is changing. In the last decade, costs, efficiency, quality, and design were the main drivers for office manufacturers. Nowadays, new market demands and government legislations have an impact on business. Customers have become more environmentally conscious, and the global market for environmental friendly goods and services is estimated at €4.2 trillion (Department for Business, Innovations and Skills 2012). By that, manufacturers of office furniture have to show and prove the circularity of design and manufacturing (e.g., end of life options, sources of material, and sustainability of suppliers). Furthermore, future government legislations require European manufacturers in many industries to assume responsibility for their products after use either for disposal or for reuse, and encourage them to incorporate as many recyclable materials as possible in their products to reduce waste (Communication from the Commission to the European Parliament 2015).

Besides the increased awareness on environmental issues, the market demand is fluctuating and has become more unpredictable, and strongly declined in recent years due to its sensitivity to the economic conjuncture. After a peak in 2007, total industry production has decreased by more than 14% and total sector employment decreased by 20% between 2007 and 2011 (CEPS 2014). Moreover, the market for office interior and furniture has moved closer towards a commodity market with the consequence to strongly compete on prices. Prices and margins have dropped significantly over the past decade. Office furniture has become a substitution good, i.e., multiple goods satisfy the same consumer need and therefore can be replaced by one another and tend to be influenced by cross-elasticity of demand, even though the acquisition value of furniture is still fairly high. Nowadays, employees of most companies work at all sorts of locations and new technological developments effect the way of working dramatically (e.g., virtual meetings, tablets). Moreover, new flexible, customized, and innovative office concepts are required to support the new generation of employees in the best possible way (Vos and Van der Voordt 2002; Vink et al. 2012). Office furniture should be more adaptable to future customer demands, i.e., the furniture should be able to handle better the changes in requirements for functionality, look and feel and numbers, but still guarantee a high level of quality and at a reasonable price. Proved sustainability, flexibility, and upgrades will become crucial elements to office furniture companies to guarantee long-term success. This leads to shorter lifecycles of office furniture due to changing demands on functionality.

Gispen, a major office furniture producer in the Netherlands, is aware of these changes and wants to overcome highly competitive dynamics in the current Dutch furniture market, in a lesser degree in the European market, by developing new product-service combinations (see company profile). Innovative product-service combinations prolong the life cycle time of an asset and thereby avoiding a new purchase incentive. Gispen especially focusses on the innovation of products and services based on circular economy principles (Ellen MacArthur Foundation 2013). Currently, most products in the field of office interior are designed, produced, and sold to the end-user. In case of malfunction, out of fashion, or changing requirements of the end-user, a new product is designed, produced, and sold again. The circular economy concept aims to keep products, components, and materials at their highest utility and value at all times (Ellen MacArthur Foundation 2013; McKinsey 2011). In contrast to a traditional linear economy, i.e., “take-make-dispose”, the circular economy emphasizes reusability of products and raw materials as a starting point and minimize waste in the entire industrial and ecological system. Careful consideration of product design and materialisation may result in longer use of materials. Designing new adaptable and upgradable products is crucial in realizing this circular economy-based new business model.

To implement new product service combinations, aimed at implementing innovations and therefore elongating a products life, a sound business model should be developed. Currently, a strong interaction between Gispen and the customer during the sales and implementation stage (i.e., <1 year) takes place. However, office furniture will commonly be used for more than 10 years and hardly any interaction with customers occurs. Hence, it is currently almost impossible to directly perceive change in customer requirements, and thus benefits of upgrades or lifespan expansion cannot be reaped. In a new, alternative business model, Gispen wants to strengthen the relationship with the customer by more frequent interactions. Only then, Gispen could directly perceive changes in customer needs and consequently adapt or upgrade the products to meet these needs.

Next to product design and an appropriate business model, other crucial elements are, among others, organizing new closed-loop processes such as reverse logistics (Savaskan et al. 2004) or remanufacturing (Allwood et al. 2011). Remanufacturing will be one of the processes to close the loop and restore worn-out products to new-like condition and sometimes superior in performance and expected lifetime to the original new product. The total value of sold remanufactured goods as a share of total sales of all products within the furniture sector was estimated 1.3% in the US (USITC 2012). The Dutch report ‘Remanufacturing HTSM’ indicated that the market size of remanufacturing in the furniture industry in the Netherlands could be estimated at 50 million Euro (Innovatie Zuid 2013).

This chapter describes the developments at Gispen to close the gap: changing from a linear into a circular concept with a special focus on circular economy oriented alternative business models and circular product design. We have selected two methods from the Use-it-Wisely (UIW) platform. First, to estimate possible business impacts of adapting a circular economy concept for a company, a dynamic business model simulation is developed. We use the system dynamics methodology (Groesser, Chapter “Complexity Management and System Dynamics Thinking” of this book) to develop this analysis. The development process, as well as non-confidential company results, are described in Sect. 2.1. And second, Gispen has developed a new design Circular Economy Design Framework to support circular product development. Basic principles to design, upgrade, and reuse products according to circular economy principles are included in the framework (Van Rhijn, Chapter “Fostering a Community of Practice for Industrial Processes” and Pajula, Chapter “Virtual Reality and 3D Imaging to Support Collaborative

Decision Making for Adaptation of Long-Life Assets" in this book). Section 2.2 explains this design framework. Section 3 concludes this chapter and provides avenues for future work.

Company Profile Gispen The Gispen Group BV is the second largest office furnisher and designer in The Benelux. Gispen was awarded the greenest company in the Netherlands in 2011 and has a long tradition of working environment friendly, i.e., from 2008 the EMAS certificate (verified environmental management). Gispens' mission statement—Be at your best—is put to practice by Gispens' core values: Sustainability, Innovation, Inspiration, and Design. Gispen as a designer, manufacturer and supplier creates ideal environments that have a positive impact on people. This combination provides all the ingredients needed for a sustainable approach through design, manufacturing principles and taking responsibility for a closed-loop system. Hence, the core value sustainability is increasingly important. In everything Gispen designs and produces they wish to make a positive contribution to the environment in which people live and work. In 2014, 21,000 products collected for repurpose and almost 1800 products have been refurbished, upgraded and brought back into use (sold) by Gispen. Having tools to make sustainable choices and to provide detailed, well-founded information to the end user assuring the necessary accountability has been the motivation to develop the models and tools described in this chapter (Fig. 1).

Fig. 1 Collecting, disassembly, remanufacturing and reassembling of office furniture at Gispens manufacturing site in Culemborg, The Netherlands

2 Detailed Application of the Tools and Solutions to the Company Challenges

To tackle the company challenges as detailed in the introduction, various tools and methods are needed. In the UIW-project the following applications were developed to achieve the goals of Gispen:

- *A System Dynamic (SD) simulation model*. The SD model provides detailed insights into the dynamics of the changing business model. The business model will change from a single transaction model (sale/buy) to a (circular) product-service model. Hence, we develop a multiple transaction model with split payments.
- *A Circular Economy Design Framework*. In order to create awareness among customers and engineers and be able to rank product designs, a Design Framework, including a checklist has been developed. A circular Life Cycle Assessment (LCA) methodology is also part of this framework.

The process of developing these tools is a valuable undertaking by itself. This development requires attention, involvement of key personnel, and disciplines as well as intensive discussions amongst various company disciplines. Awareness and gaining acceptance for and a deeper understanding of choices made out of routine are part of this surplus.

2.1 Towards a Circular Economy Business Model

A business model aimed at sustainability by means of re-use, remanufacturing and recycling depends on products that are returned either to a manufacturer or specialized third parties. The business model needs to have ownership by the manufacturer as a starting point to close material loops. Ultimately, customers will not buy new furniture, but they only pay for use, i.e., changing from ownership to performance-based payment models (e.g., Stahel 2010; Webster 2015; Lovins and Braungart 2013). To investigate a new circular business approach and simulate different circular based service scenarios for different customers and type of products, a dynamic modelling approach has been adopted (Groesser, Chapter "Complexity Management and System Dynamics Thinking" this book). The SD model supports enhancement of the decision-making process by the Gispen management team to develop, implement, and grow a new business model based on a circular economy (i.e., what kind of business model scenario might be successful within the model boundaries and assumptions). We used the software Vensim© (Ventana Systems, Inc., Harvard, Massachusetts) for the development of the simulation software. Vensim is able to simulate dynamic behaviour of systems that are impossible to analyse without appropriate simulation software, because they are unpredictable due to many influences and feedback interrelations.

2.1.1 Development Process

An iterative approach has been used to quantitatively model Gispens' new business model. In the group model building sessions (Vennix 1996) the following steps were undertaken:

- Define the most important central KPI's, i.e., business objective variables, for Gispen. A shared definition of the business objective variables was determined to evaluate effects of different tested policies and scenarios. Hence, a common understanding of profit, total turnover, market share, etc. for current and future scenarios was formed.
- Define the relevant variables in the causal-context model (Groesser, Chapter "Complexity Management and System Dynamics Thinking" this book). A management science approach was used to structure discussions on input variables and important outcomes.
- Determine and quantify the relationships between central KPI's and variables in the model. Gispen management was frequently consulted to ensure that the model building proceeds in the right direction. Moreover, the Gispen management was involved in testing the model and evaluating the benefits for Gispen provided by the model. Gispen employees from sales and the financial department were involved to provide data on relevant business parameters which are used as initial values in the model. Macro-economic predictions at an EU level, existing GDP data, market trends for the office furniture market, standard values for cost and time to implement new business models structures and Gispen specific data such as annual reports and branch reports were incorporated (e.g., Cijfers and Trends Meubelindustrie 2013). Not all data required by the model (e.g., the quantitative relationship between product attractiveness and company profit) were known. Expert meetings were used to define best expert estimates for these assumptions in the model (Ford and Sterman 1997). Furthermore, several scenarios in terms of macro-economic conditions were taken into account (i.e., negative, neutral and positive trends) as well as a predefined bandwidth for variables with a high level of uncertainty. Furthermore, the scenario and policy variables with the highest impact on business performance as well as the bounds for the set-up of these variables were defined.
- The model was validated on the level of model structure and model behaviour (Groesser and Schwaninger 2012). The focus was on internal and external validity of the model, for instance, were all relationships correctly modelled and KPI's calculated in a correct manner, and concurrent validity, i.e., does the model give similar results for the model predictions and Gispen historical data.

A circular business scenario was modelled and evaluated. Within this business scenario, office furniture will be leased to an user (who will pay per month) and will get a financial incentive by Gispen after several years of use. In this model, Gispens' current, i.e. linear, as well as the new circular business model were both included (Fig. 2).

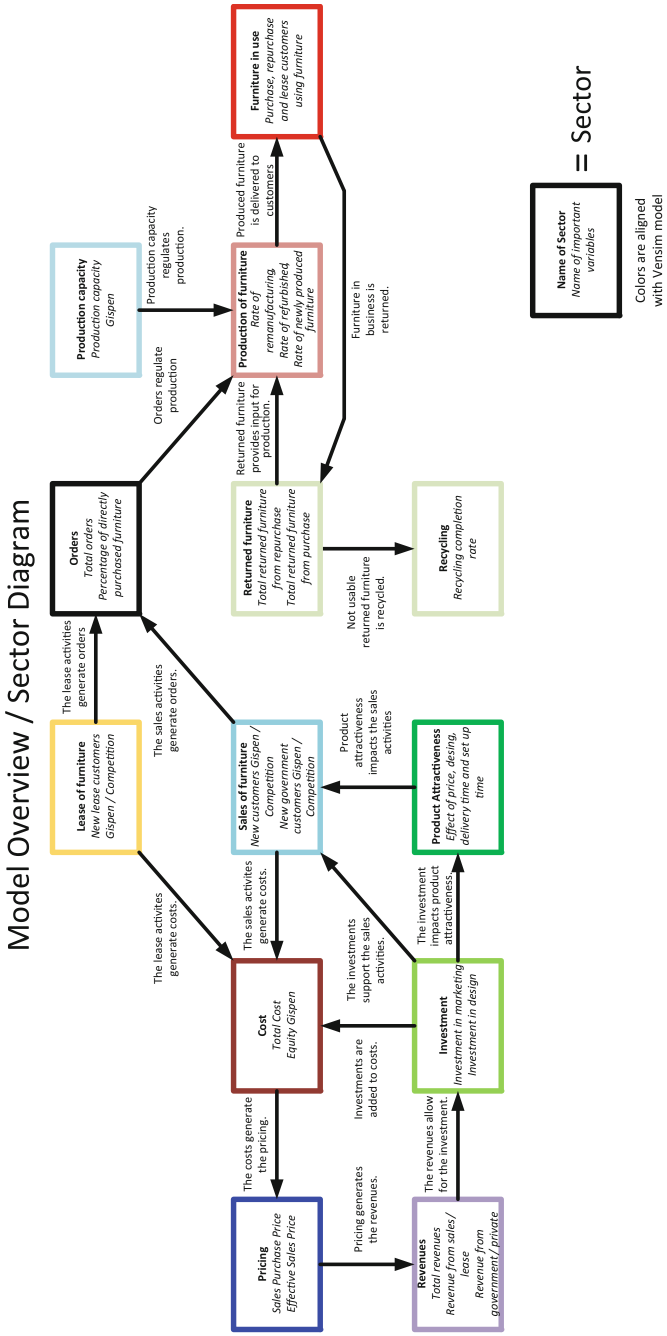

Fig. 2 A schematic simulation model overview of the first version of Gispen's circular business model

The main learnings from this model were summarized and included in a more simplified SD model to facilitate an easier understanding. Moreover, the simplified SD model has a narrower system boundary and focused only on the new business model (Fig. 3). Following the conclusions of the first model the new business model was treated as a separate business unit with no influence from running businesses, apart from some initial assumptions such as that Gispen already had a customer base. Different model development steps were undertaken to ensure a consistent model in which all relationships were modelled correctly and all KPI's were calculated in a correct manner. Moreover, the structure of the model has been discussed extensively in several workshops and the face validity of the behaviour of the model was evaluated (for validation see Chapter "Complexity Management and

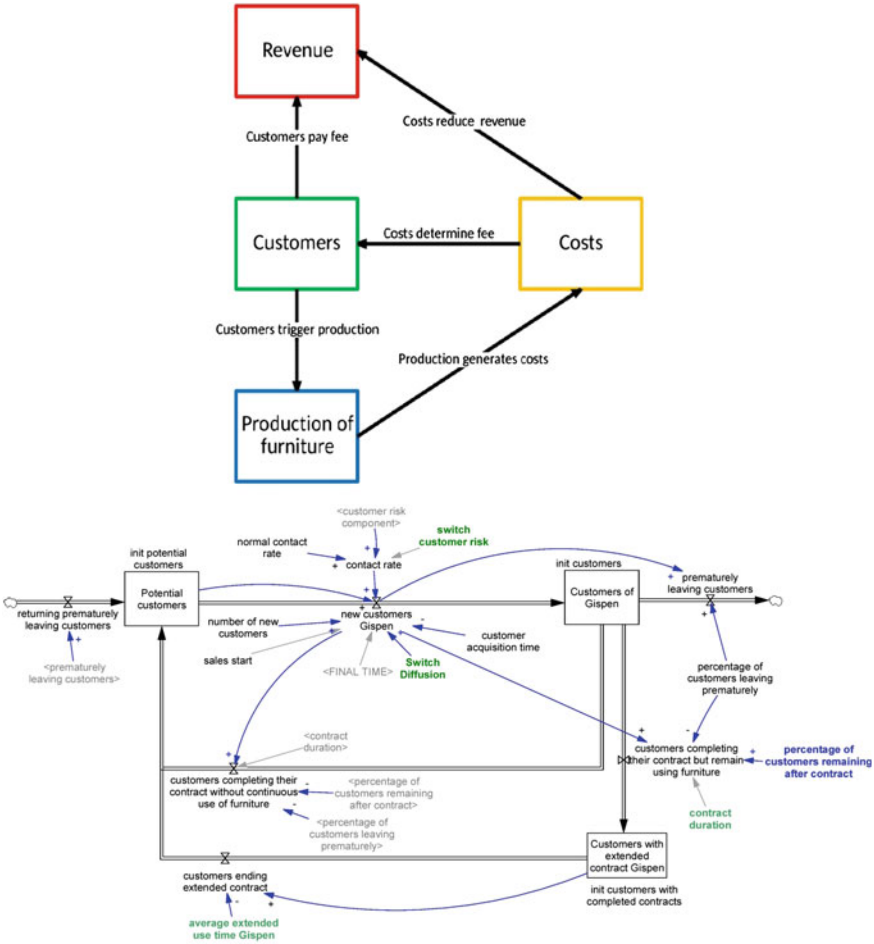

Fig. 3 High level overview of the final business simulation model (*top*) and a more detailed impression of a part of the SD model (*bottom*)

System Dynamics Thinking”). The initial settings of the models parameters were checked and different scenarios evaluated to see its effects on the most important KPI Gispen was interested in: the break-even point.

2.1.2 Results

In this section, the most important outcomes of the simplified model are described. In the final version of the model, historical data of the current business model were used where reasonable. This model included three major loops, the loop of cash, the loop of customers, and the loop of products, i.e., furniture. These three loops were modelled only considering circular economy furniture and not making a difference between refurbished and remanufactured furniture and different types of customers, i.e., new or existing customers in different market segments. Cost structures were implemented in simple terms.

From the simulation model the following conclusions were drawn:

- The implementation of circular economy of assets with a long usage cycles generates long delays with high negative initial cash flows in a pay per use scenario. This leads to the conclusion that lease models, as we currently know and apply, are less usable to drive more sustainable use of products. Integration of service components and solutions to get through the ‘first use’ period needs to be considered in more detail as this causes a highly negative cash flow (Fig. 4). A possible option, among others, is the intensification of the use of products, i.e., stimulate multiple or serial use (Webster 2015; Stahel 2010). Another option that might be viable is upgrading existing Gispen products, as a service, at the customer site (i.e., move from production to services).
- The business model made it possible to simulate not only Gispen’s internal processes, but also their interaction with market and competitors. This also allowed to focus on the adaptation of the market, competitors and own organization, pinpointing the uncertainty of the adaptation speed that is a critical point in the model. Figure 5 shows the accumulated profit for the base run and two alternative scenarios. The base run is simulated with an adoption fraction of 0.008, meaning that 8 contacts out of 1,000 between clients result in a successful client acquisition and an effectiveness of marketing of 0.00025, meaning that 25 out of 100,000 potential clients are attracted every month as new customers. To show the effects of different adaptation speeds the scenarios ‘comblow’ and ‘combhigh’ have been created with the settings of 0.004 for adoption fraction and 0.000125 for effectiveness of marketing in the ‘comblow’ run and 0.012 and 0.0005 for ‘combhigh’ respectively. ‘Comblow’ therefore simulates the effects, if the adoption is low in both marketing and word of mouth while ‘combhigh’ simulates when the new business model is embraced more quickly by the customers. In terms of effects the breakeven point for the business model in the scenarios are 109 (comblow), 147 (base) and 150 (combhigh). Low adoption rates have therefore a positive effect on the time to breakeven, mainly due to the

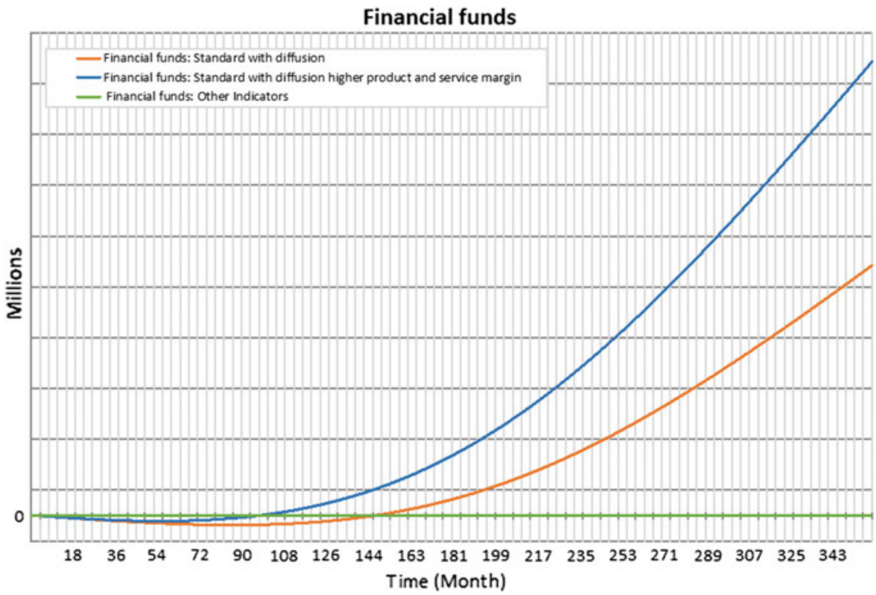

Fig. 4 Example of system dynamics simulation outcome: two scenarios of how financial funds develop over time given different assumptions for the product and service margins

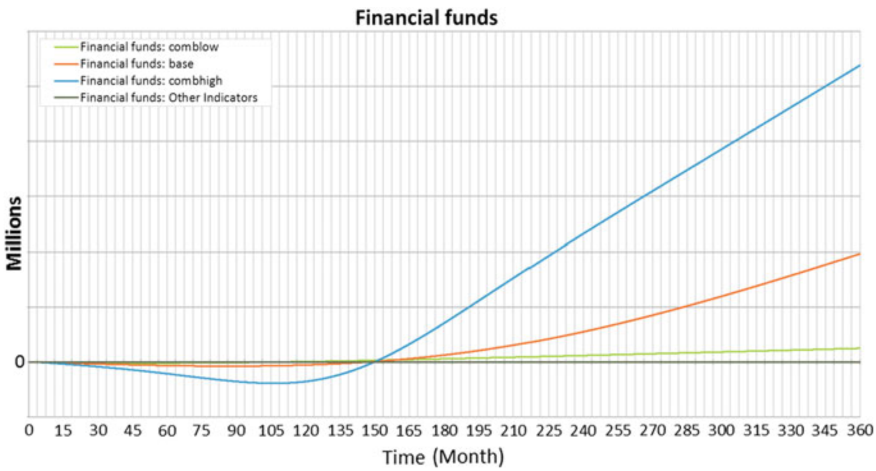

Fig. 5 Accumulated profit for Gispen for different adaptation rates

fact that investments are low. The challenge for the new business model is that the costs arise at the beginning of a customer contact (production costs), while the flow of revenues is distributed over the entire duration of the contract (breakeven of an individual contract is between 39 and 40 months on a 60 months contract). This is illustrated by the scenario 'combhigh' where many customers are attracted quickly. Once the new business model is implemented however, the higher rate of turnover of furniture (and thus input for refurbishment) also makes the financial funds grow the fastest.
- Main added value of dynamic modelling is the deeper understanding of the mechanisms simulated. The method forces the user to provide well-founded reasoning and data to make the model reliable.

2.1.3 Upgrade as a Service

In essence the goal is to waste as little resources as possible. To do so one option is to upgrade or remanufacture existing, client owned furniture. A service is provided by the manufacturer and resources remain at the highest utility value. In practise the process starts with an inventory of the furniture in use and an inventory of the desired requirements for this furniture. These two are matched and additional services are executed, if possible on the customer site to keep transport to a minimum. A proven concept so far is to reuse desks and remanufacture the pieces to 'as new' desks. Visually the remade desk cannot be set apart from newly produced, and warranties are applicable for the remade desk. Since there is no shift of ownership and most of the existing materials are reused, the remade desk is considered a service. Which in turn can be embedded in a pay per use model. Even though the costs are still incurred at one moment in time, whereas the service is payed over a period of time a combination of tools can prevent the extreme dip in cash flow as described above. If at initial delivery a service package, including maintenance and upgrades, is agreed a more stable cash flow can be realized

2.1.4 Benefits of System Dynamics Modelling

The current simulation model concentrates on the objectives of Gispen but could also be used as an illustration of added value of business or process modelling for other companies. The development process of a model itself forces participants to create a shared vision/idea of the new business concept. Moreover, it organizes thoughts, concepts and ideas and how these interrelate. To create commitment of management or stakeholders they should be involved in this development. Furthermore, this development process leads to a better understanding of all related aspects and their relationships. A first simulation of strategies ('trial and error') can be done in the model before implementation in the real world takes place. Thereby more successful and durable changes in any business model are supported.

2.1.5 Lessons Learned

The lessons learned of the application of system dynamics modelling in supporting the exploration of alternative business models are summarized below.

- To simulate the relevant aspect of reality in detail, a quite comprehensive and thus complex model was developed. The quantification of the resulting relationships is time demanding and challenging, but results in a detailed understanding of the mechanisms involved. After the detailed understanding of relevant system, the extensive simulation model was simplified. The second simulation model focusses exclusively on the new circular economy business model of Gispen. By using this model with lower complexity and details, it was possible to provide relevant information to the management team enabling them to obtain the insights for their decision making. In other words, only after the detailed model was developed it was possible to focus on the relevant mechanisms in the simplified model which then provided better insights in the relevant developments of the business model with concrete results. It is often, not always, beneficial to develop a larger model first to be able to evaluate what aspects of a situation are actually necessary.
- It was possible to demonstrate the robustness of the model through many extreme condition tests and through the consistency of the units of measure. To have a more practical discussion on the feasibility of circular business model scenarios, it is useful to provide detailed information for decision making. A dashboard which shows the assumptions in the model and visualize the input and output could be a helpful means to enable even deeper discussions.
- In certain cases, to show to the management a certain trend, the timescale assumption was set to 2050. This was necessary since the delay times (use periods of the furniture products) in the modelled business system are relatively large and hence, changes in the underlying business model can only be seen, for instance, after several iterations of remanufacturing of furniture. A time horizon of 2050 is long, given that the time horizon for decision-making is regularly much shorter. After determining a trend by using the model with the long time horizon, it would be useful to then relate again to a timescale of 7–10 years. Disparities in business dynamics and decision dynamics are challenges which the SD model could demonstrate. But given the dominant paradigms for decision makers and the strong competition in the furniture industry, the SD model could not influence the decision making processes regarding the time expectations.
- The model is a means to evaluate the business potential. Such simulation models are used a few times during a year when the top management team reflects about its current corporate strategy.
- Group model building turned out to be successful in face-to-face meetings (Groesser, Chapter "Complexity Management and System Dynamics Thinking"). Misunderstandings or decisions taken were easier to understand in these meetings compared to virtual meetings or discussions.

- Involvement of different stakeholders, among others, management representatives during the development process and critical decisions on assumptions of the model will require time, but at least the major and important conclusions of every development step should be evaluated by management. Moreover, the assumptions taken during development process should be shortly described and presented to management.

2.2 *Creating a Design Framework for Circular Economy Office Furniture*

Gispen has a high level of customization (i.e., Engineer To Order projects). In the near future Gispen wants to keep this high level of customization in their products, but at the same time a modular product design should allow easy (dis)assembly and adaptability. In order to do so, design guidelines and circular requirements for product design, re-design and remanufacturing are necessary. These guidelines are part of a Circular Economy Design Framework (hereinafter Circular Framework, Fig. 6). The ultimate goals to achieve with support of the Circular Framework are (1) no waste or pollution during the entire life cycle (2) 100% re-use of products, modules and parts, (3) no use of energy from non-renewable resources for producing products or the use of products itself; (4) no use of virgin materials and (5) maintain the highest possible value of the product during the product lifetime and maximisation of product lifetime itself.

The Circular Framework provides an approach including a checklist to sustainable design and aims to support designers and R&D officers within Gispen to develop circular office furniture. Moreover, this approach will support Gispen to

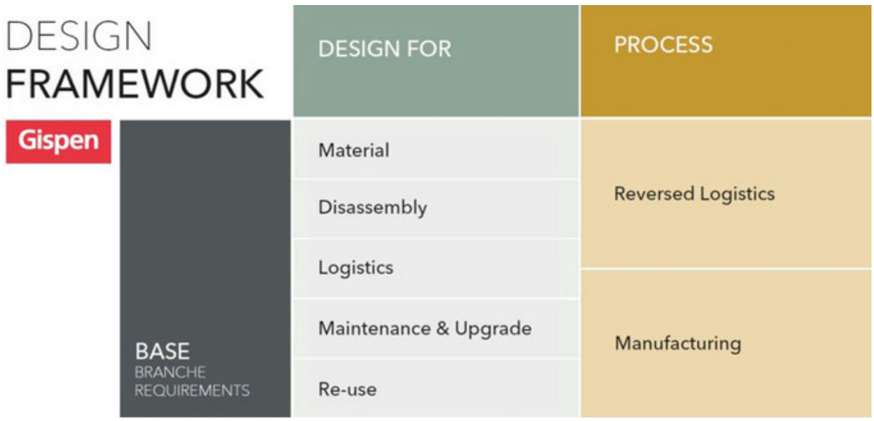

Fig. 6 The Gispen circular economy design framework

adapt, by upgrading or retrofitting the product at the customer site or remanufacturing at the factory floor, in order to prolong the lifespan of the product and to meet the changing end-user needs. The checklist is based on some of the design principles described elsewhere in this book (Van Rhijn, Chapter "Fostering a Community of Practice for Industrial Processes" this book). All due to improvement of product design, more sustainable actions can be taken in the future. In other words, the lifespan of products and modules can be more easily prolonged. The initial cost trade-off is not incorporated in the Framework which is purely aimed at product design.

Sustainable design choices need to be well-founded. Generally accepted are LCA tools to calculate environmental impact. However, traditionally these tools have a take-make-dispose scenario. Insights in reuse, remanufacturing and the impacts thereof is needed. So the traditional LCA tool needs to be upgraded including new closed-loop scenarios, according to the circular economy concept. Besides a checklist, a Circular Life Cycle Analysis tool (C-LCA) is part of the Circular Framework. The background of this methodology has extensively been described (Pajula, Chapter "Virtual Reality and 3D Imaging to Support Collaborative Decision Making for Adaptation of Long-Life Assets" in this book). This tool aims to support product development and is based on the quantitative LCA methodology (Fig. 9). Besides product development departments, sales representatives should be able to show the effects of a particular circular scenario (e.g., sell, repurchase, and lease back) on environmental impact for different kinds of furniture, materials, and processes. Moreover, the combination of qualitative design requirements and quantitative LCA calculations provide an in-depth product evaluation to support the transition to a more closed-loop system.

2.2.1 Development Process of the Circular Framework and C-LCA Methodology

An iterative and participatory design (e.g., Douglas and Namioka 1993) approach was used to create the Circular Framework Checklist and C-LCA methodology. All stakeholders (sales, marketing, and R&D employees) were actively involved in this process. The major steps for the framework and C-LCA development are described below:

- In a first stage, interviews were conducted to collect requirements from different company discipline perspectives.
- A conceptual design of both tools, based on existing methodologies and literature, end-user requirements and experts, has been created.
- This first concept of the tool has been presented to all stakeholders and validated. For example in the C-LCA, the information included in the database and its level of detail has intensively been discussed and finally a consensus has been reached. Furthermore, the degrees of freedom at the scenario definition stage were determined as well as the dashboard information shown to customers (by

sales and marketing representative) and R&D to support design decisions. For the framework major topics concerning product design were discussed as well as the level of detail of the framework.
- Several prototypes have iteratively been tested and evaluated by the company. Typical products were evaluated using several linear and circular life cycle scenarios. Feedback on user interfaces, level of detail and usability of the databases was collected by the development team to improve the final versions of the tools.
- A final version of the tool has been presented to all stakeholders.

The iterative, participatory development approach for these tools was particular useful for several reasons. Firstly, including stakeholders created a shared view on how the tools are going to be used and underline the benefits of the tools for this particular interest group. Secondly, participation required input from all stakeholders and thereby different perspectives. By providing input it becomes clear if and for what reason there is resistance regarding the new approach.

2.2.2 Results—Checklist

The Circular Framework contains a checklist for circular product design that results in a circularity score. Availability of design and process information, were the major requirements for the checklist. From a practical perspective, the time spend on the assessment of a product design with the checklist is crucial and should therefore be limited.

Office furniture is subject to various regulatory requirements aimed at health and safety of the products and the office environment (e.g., NEN-EN-1335-2 2009). These requirements remain 'intact'. Moreover, regulatory requirements are always fulfilled and are therefore not part of the final circularity score. The DESIGN block contains design rules and guidelines that are related to product design principles, clustered to main topics (e.g., re-use or maintenance). The PROCESS block contains all principles related to process a product. Each topic in both blocks contains various questions to provide an overall (single) score for a product. Questions in the checklist should simply be answered by clicking (1) = 'Yes' or (0) = 'No'. A clear definition for each aspect in the Circular Framework was determined and has been presented in Table 1.

To rank the different design and process aspects in the design checklist the 'in pairs equations' method (e.g., van Dieën and Hildebrandt 1991) has been applied. All predefined aspects were presented in pairs to experts inside and outside the company. They were asked to indicate which factor in each pair contributes most to a circular product design. Using these scores, frequency proportions and z-values (relative position with regard to the average) were calculated. The z-values were subsequently converted to calibration units, using a standard conversion table (Swanborn 1982) and finally to weight factors.

Table 1 Definition of framework aspects and typical questions included in the circular framework checklist

Framework aspect	Definition	Typical statement in the checklist
Design—re-use	Re-use of products, parts or components for any (other) purpose after a certain use period instead of breaking them down into raw materials. In a closed-loop system maximisation of reuse requires high quality and flexibility as supported by design criteria for product modularity	Each product module has more than one functionality and in case of reuse a secondary functionality is available
Design—maintenance and upgrade	Maintenance of products, by taking care of products through (un)scheduled maintenance activities on a regular basis, will extend the product lifetime and retain the product's value	Product modules or components could be replaced or exchanged by one person within 10 min without damaging other parts through the use of dismountable connections
	Upgrading a product, by adding or removing parts from the original product leads to a functional or aesthetic improvement of the product without replacing the product as a whole and thereby extends the product lifetime	
Design—logistics	By taking into account product packaging and product design itself, volume, weight, waste, etc. will be reduced and thereby environmental impact and product damage will decrease during the transportation of products	The product has been designed to allow flat packed or nested transportation without increasing the risk of product damage during transportation or (un)packing activities
Design—material	In order to create a closed-loop system material waste does not exist. Design choices of materials are based on the ability to re-use materials with minimal energy, use of renewable resources and use of non-toxic materials	If available, recycled materials have been used to produce a product
Design—disassembly	Products are designed for taking apart (disassembly) complex products into interchangeable modules, parts or components to keep materials at their highest utility and value. In a closed-loop system products should be designed for effective disassembly without losing value in materials, energy and labour	If necessary, every product module could be disassembled into individual reusable components

(continued)

Table 1 (continued)

Framework aspect	Definition	Typical statement in the checklist
Process—manufacturing	A closed-loop system should avoid any consumption during the manufacturing process. Manufacturing energy must come from renewable source	Residual material and waste during (re)manufacturing will be collected, separated and recycled
Process—(reversed) logistics	The environmental impact of the supply of materials and transportation of products has been minimized by optimizing modes of transportation, strong collaboration with suppliers, local sourcing of materials and local (re)manufacturing and recycling of products	Suppliers deliver parts, components or modules in reusable packages which are in proportion to the size of the packaging content

Design - (dis)assembly	
Instructions for (dis) assembly of the product are available and easy traceable	Yes
The product can easily be disassembled to logic modules without any damage (i.e. by mechanical connections)	Yes
Each module in the product can be dissembled to separate and reusable parts	Yes
Modules and parts are stable during (dis)assembly and transportation	Yes
If necessary the product or module is transportable during (dis) assembly	Yes
Each module can be reached separately for (dis) assembly purposes	Yes
No special tools are need for (dis) assembly and the number of different tools has been minimized	No

Fig. 7 Product of Gispen (*left*) and checklist scores for some of the (dis)assembly questions

As mentioned in the development approach, by means of several iterations the checklist was tested and adjusted. During this development process the checklist has been used to evaluate several product designs. An example of an assessment has been presented above for one of Gispen's typical office desks (Fig. 7). For this office desk, which was not specifically designed for circular use, about 40% of the questions were answered positive. Using the checklist stimulated a better understanding of design choices and their influence in the circular product life cycle, awareness of the circularity levels of Gispens current products and supported a push towards more creative solutions. A circular product design as shown in Fig. 8 about 65% of the questions were answered positive.

Fig. 8 Nomi, a highly modular seating system. Upgrades and visual changes are easy due to the flexible design and removable upholstery

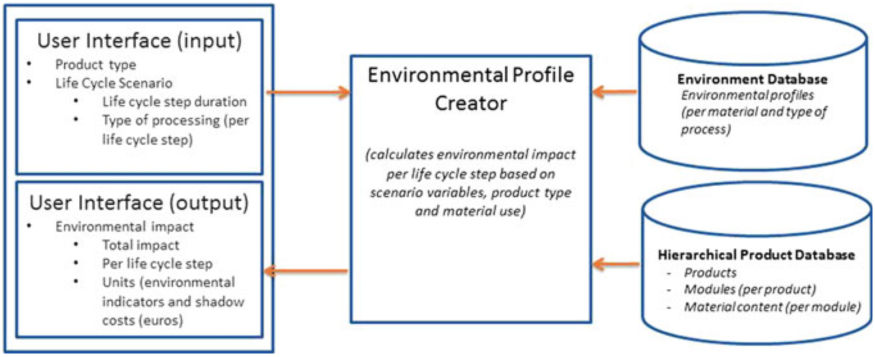

Fig. 9 A schematic representation of the CLCA methodology to calculate environmental impact of circular product life cycle scenarios

2.2.3 Results—C-LCA

The C-LCA tool is able to calculate environmental impact of an industrial product for the entire life cycle including closed-loop thinking (circular economy). A high level representation of the C-LCA methodology has been shown in Fig. 9.

The tool contains two databases:

1. A product definition database which contains relevant product characteristics. Product data are structured hierarchically; products are divided in modules, product modules contain information on material composition (type of material and the amount) and the required (re)manufacturing processes and transport for this product module.
2. An environmental profile database which contains the environmental impact (e.g. climate change) of materials (e.g. steel but also bio-based materials) and manufacturing (e.g., bending, final assembly), maintenance (e.g., cleaning) and transportation processes.

Based on the selected product type, the selected life cycle scenario (e.g. 'linear': Take—Make—Dispose or 'Circular Refurbishment': Take —Make—Use—Clean and repair—Reuse—Remake—Reuse—Dispose) and life cycle duration, the database information is used to calculate environmental profiles for the entire product life cycle. The total impact (expressed in, e.g., euros and kg CO_2) for a (circular) product life cycle scenario is calculated and presented to the user. Sales representatives are able to show the effects of different kinds of furniture and materials, and a particular use scenario (e.g. sell, re-purchase and lease back) on environmental impact. Engineers could easily compare the environmental impact of their design decisions and thereby optimise product design from a sustainability perspective.

The C-LCA tool has been used to describe various circular scenarios. For example, for a particular client of Gispen the estimated benefits of reuse were different based on the selected decision criteria. These decisions combined various factors (1) sustainability (2) aesthetic value of the office environment (interior design requirements) and (3) costs. By creating two scenarios where the aesthetic value was similar we were able to demonstrate that a higher percentage of reuse was the most efficient choice, i.e. sustainable wise as well as cost efficiently. Furthermore, by discussing the data it created the opportunity to collaborate on planning and disassembly issues in order to avoid unnecessary transport and thereby save additional costs. C-LCA calculations where performed for the product shown in Fig. 10. It is a normal desk with a table top made out of steel.

As can be seen in the results of the calculation (Fig. 11, right), opting for a refurbishment scenario saves 1.3 kg CO_2 emission per year during the total lifespan of the product, here set at 12 years. As is shown in the left graph in Fig. 11, reuse outweighs virgin production vastly. In the right graph of Fig. 11 benefits and additional contribution to the emission of CO_2 is presented. Except logistics, as

Fig. 10 Gispen TM Steel top

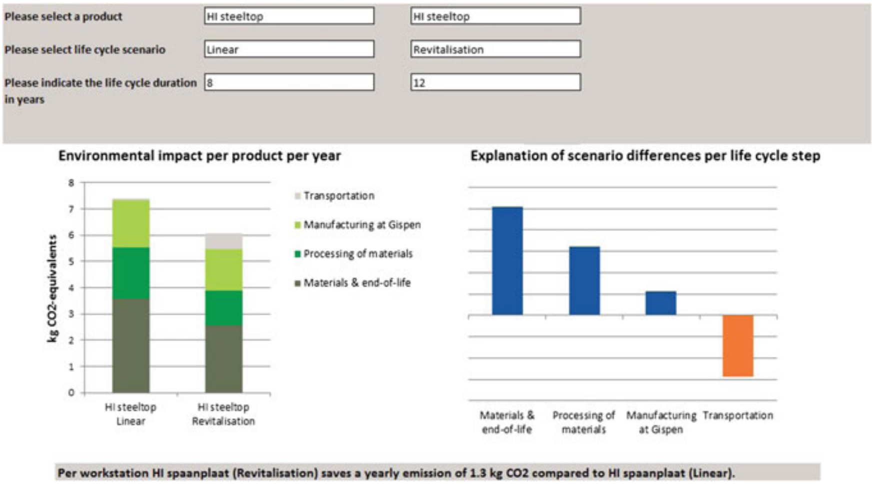

Fig. 11 Outcomes of the C-LCA calculations for a linear as well as revitalization scenario (*bottom*)

reversed logistics were part of this circular scenario, reuse reduces CO_2 emission compared to a linear scenario. Upgrading on site was the most optimal form of product-life expansion in this particular customer case.

2.2.4 Benefits of the Circular Framework and the C-LCA

By using the Circular Framework, Gispen could show customers the degree of circularity of their products and the effects of several product life cycle scenarios (i.e., linear vs. circular). A more quantified effect of, for example, design choices in material or packaging on the environmental impact could be visualized. Using the Circular Framework thereby supports a decision making of Gispen and their customers. Furthermore, the framework and C-LCA create awareness of choice of material and process impact amongst designers, R&D and sales employees. The mission and vision of Gispen are translated in realistic objectives and the framework has been aligned to these objectives. Thereby, it contributes to the development of a circular product portfolio.

The framework provides insight in the degree of adaptation to circular principles. By filling out the checklist for each product design, and thereby creating a total score for the product, it is possible to compare one product versus another. This circular product score provides information to monitor progress on circular design and adjust whenever necessary. The checklist is a first attempt to create a tool which is easy to use for designers and on the other hand is covering the broad topics of design for circularity.

2.2.5 Lessons Learned

- Involvement of different end-users during the development process requires time and effort but improves the understanding of the methodology and thereby creates the opportunity to deal with resistance against the new methodology. Moreover, user interfaces, are adapted to the different user needs and thereby usability has been improved. However, presenting the data in a way that is easily understood by the various user groups and has the right level of detail is still challenging.
- The Circular Framework checklist and C-LCA are just tools. If these tools are not adequately implemented in current design and sales processes within the company, the benefits of both tools will be marginal.
- Traditionally design for a particular discipline is built up on the creation of rules to be applied during product design in the product development department, or in concurrent engineering between departments within or outside the company. Designing for a closed-loop system is designing for future use, whilst use might change over time. Upgrading a product during its life time and usage will require the product development function to get directly involved in the customer interface. Product development engineers can no longer expect to be given readymade.
- It might be concluded that both tools can be applied in other sectors and companies but the success of the tools will be based on the willingness to embrace the principles and company culture of a closed-loop system.
- In general the C-LCA methodology is fairly technical and detailed product information on materials and processing is needed to make any calculation.
- Maintenance or updating the C-LCA tool with new products, modules, materials and processes can only be done by a few employees of Gispen. A LCA expert outside the company is needed in case alternative materials (e.g., bio-based materials like bamboo, engineered wood), which are not included in the current database, will be used in product designs.
- The C-LCA methodology provides outcome parameters (e.g. environmental costs in euros or CO_2 in kg) which could easily be understood by non-expert users.
- The checklist questions have been based on existing literature (e.g., Boothroyd 1980) and if needed, adjusted according to expert opinions. To ensure a similar understanding and interpretation of checklist questions different disciplines have been involved. Nevertheless, in depth knowledge of the aim of questions is sometimes required to get correct answers. A clarification has been added to support the user and avoid misinterpretation. Training of users will be considered in case this seems insufficient.
- The checklist is a qualitative assessment with a limit number of design and process aspects to ensure a limited time effort from engineering perspective and easy understanding from a customer perspective. The checklist has not yet been validated and is a first step to show circularity aspects in furniture to customers.

3 Conclusion and Future Work

Although the circular economy is a current issue, the industrial state-of-the-art is that still a limited number of manufactures have shown a shift towards a closed-loop business. Companies exploring these new strategies are primarily focused at servicing at their customers site and not on total efficient and cost effective reverse logistics, disassembly and remanufacturing strategies with their entire supply chain. Primary processes and supporting ICT systems are insufficient developed, neither is the use of alternative bio-based materials sufficiently developed to enable large scale exploitation. Gispen has successfully started working on circular economy projects. Simulated business model scenarios, among others, have been used to establish new business agreements with public and private companies in the Netherlands. To support awareness of designers and engineers the design methodologies will be implemented and updated in the near future. Furthermore, the circularity level of Gispen products can be transparently shown to potential customers by using the scores of the C-LCA and Circular Framework outcomes. By means of this data, customers can be informed by Gispen about the effect of their decisions and choices on product life cycle impact, business wise as well as from a sustainability perspective. A next step will be the transition from successful projects towards a closed-loop thinking company culture. Moreover, Gispen has identified additional needs and will continue the implementation of their circular economy strategy by the following developments in the near future:

- A furniture management system will be setup for monitoring product use and ageing at the customer site. Due to rapid technology developments, we now have access to a wide range of low-cost embedded microelectromechanical systems (e.g. accelerometers or gyroscopes). These sensor data could be useful to monitor product use (e.g., Cheng et al. 2013) and thereby support decision making to follow the best strategy for service and maintenance, disassembly, remanufacturing and recycling.
- To overcome the high labour costs caused by manual disassembly (Duflou et al. 2008), smart disassembly systems with operator ICT support for (manual) operations and semi-automated stations might be a direction for future developments. Moreover, the use of cognitive, vision-based robots for quality control of returned products (Vongbunyong et al. 2012) and for example the use of low-cost collaborative robots looks promising also for SME’s.
- A decision support system for remanufacturing strategy on a component level incorporating quality assessment of remanufactured components and products. This would involve new policies based on remanufacturing, reversed supply chains and revenue and cost management fit for these flows.
- Further business model exploration by the development of incentive based methods of contracting, including financial incentives for a closed-loop system possibly within a linear accounting system. Ultimately, Gispen creates sensible alternatives from a financial, fiscal, and legal point of view to ensure closed-loop

systems. This would need not only a pragmatic solution regarding incentives, but more general a systemic change.

- Development and use of new bio-based materials in office furniture. Finding materials that are fit for all the use requirements today, are renewable and of a stable supply. Nowadays, bio-based material is not of a fit quality and is unstable in supply which is devastating for high volume use.

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Comparing Industrial Cluster Cases to Define Upgrade Business Models for a Circular Economy

Magnus Simons

Abstract Upgrading is often seen as a means to strengthen customer loyalty between investments in new equipment, but there is more to it. It is a means to introduce innovation in small, but continuous steps keeping both OEMs and their customers at the innovative forefront of technical and business development. Upgrading also improves sustainability and it is a driver in the development of the circular economy. Basically upgrading means transformation of a used piece of capital-intensive equipment to meet the new conditions in the user's business environment, but in practice it can take on a variety of forms depending on what type of added value is provided to the customer. In this article, we define four generic types of upgrade business models based on the industrial cluster cases in the UIW-project. Using a modified business canvas approach, we define the four Upgrade business models and compare how they create value for the customers, how they organise their main activities and how they earn money. A central means of achieving profitable upgrade business is to develop efficient business processes through digitalisation and through the use of modern information technology. Here we identify four areas where technologies such as AR and VR help to create an efficient environment for information management and communication in the upgrade value network.

Keywords Upgrading · Business model · Digitalization · Information technology · Value proposition · Value network · Earnings logic · Business process · Circular economy

M. Simons (✉)
VTT Technical Research Centre of Finland Ltd., Espoo, Finland
e-mail: magnus.simons@vtt.fi

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1 Introduction

Upgrade is a life cycle service provided to an owner or user of capital-intensive equipment. As such it is one type of service product in a larger service portfolio provided during the life cycle of the equipment in order to enhance its performance. We define commercial upgrade service provided to a customer here as upgrade business. As a business model, the upgrade service differs in many aspects from services like spare part sales or maintenance. To put this new business model into context, we will first have a look at the concepts of circular economy and industrial service business.

Circular economy and industrial service business are slowly becoming common concepts in industry. They are, however, not new as concepts (Roos and Agarwal 2015), but as more and more efforts are put into this area, both by industry and academia, the terminology gets more vivid and the concepts get more comprehensive. In order to understand the role of upgrade business in industry, we start by identifying its context.

Circular economy and industrial service business are interrelated concepts (Roos and Agarwal 2015). However, they represent slightly different views on the same topic. While the concept of a circular economy starts at a system-level view on the industrial ecosystem (Stahel 2016) and material flows (Ellen MacArthur Foundation 2016), industrial service business takes the view of the company. The driver behind the circular economy is to achieve an ideal state resembling nature, where internal cycling of material is complete or nearly complete (Bocken et al. 2016).

Several authors have described business models for combining the drivers of the circular economy with the drivers of single companies (Allwood et al. 2011; Ellen MacArthur Foundation 2016; Bocken et al. 2016; Lacy and Rutqvist 2015). According to Bocken et al. (2016), two major strategies for building circular economy business models can be identified: (1) closing the resource loops, and (2) slowing the resource loops. The Ellen MacArthur Foundation (2016) has distinguished between finite stock and renewable material. They identify several strategies for prolonging these loops. From the Use-it-Wisely (UIW) point of view the finite material cycles are more relevant. Here the economic circles described by the Ellen MacArthur Foundation are to maintain/prolong, reuse/redistribute, share, refurbish/remanufacture and to recycle the finite materials.

Linton and Jayaraman (2005) have focused on different business models (modes) of product life extension for finite materials. The nine business models they have identified and their main focus or objective can be seen in Table 1. In this chapter, we will focus on upgrade, part reuse and remanufacturing which are closest to the cluster cases in the UIW-project.

Business models like recall, repair and maintenance strive to ensure that the delivered products provide the user with the physical and functional qualities they originally invested in as they bought the product. Through these business models the customer can expect to make continuous use of the product over its life time. But these models do not improve on the qualities of the product as technological

Table 1 Business models for product life extension (adopted from Linton and Jayaraman 2005, p. 1808)

Business models (modes) for product life extension	Focus
Recall	Safety and extend life
Repair	Life extension
Preventative maintenance	Continuous use
Predictive maintenance	Life extension
Upgrade	Reduce cost and extend life
Product reuse	Life extension
Remanufacture	Life extension
Part reuse	Reduction of materials and processing inputs
Recycle	Reduce material and energy inputs

development proceeds and, thus, they will not impact the competitive value of a product in comparison to other newer ones. This is the value added upgrade that business is focusing on and, hence, the way to differentiate from other service business models. Product reuse means transferring a product from one owner to another as it gets obsolete to the first one. Recycling is the re-use of materials in a product. This can be seen as the prevailing industrial practice for handling finite materials.

According to Linton and Jayaraman (2005), an upgrade improves the quality, value, effectiveness or performance of a product which has eroded over time as competitors bring new technologies to the market. "Very complex products may also contain components or subsystems with far shorter life-cycles than the product" (Linton and Jayaraman 2005, p. 1814). An upgrade may be conducted by the customer, manufacturer or a third-party vendor. Parts required for an upgrade are typically provided by the manufacturer or a third party. Upgrade involves moderate transformation of the unit. The information value is high, since the product life and/or capabilities are extended with only small amounts of material and labour.

Remanufacture is, by Linton and Jayaraman (2005) defined as the restoration of a used product to a condition close to that of a new one. The restored product "provides the performance characteristics and durability as least as good as the original product" (Linton and Jayaraman 2005, p. 1815). Remanufacture involves a major transformation of a unit, component or part. The value of added material is low, since few new parts are used, but the labour value added is high, since many parts may have to be tested and/or refurbished. Although much of the labour value-added is of a low skill level, low labour costs are an important element for the economic viability of this approach.

Part reuse is defined, by Linton and Jayaraman (2005), as "the use of a part in its same form for the same use without remanufacturing" (Linton and Jayaraman 2005, p. 1815). "The cost of collecting and testing the parts is much less than the cost of manufacturing new parts. Reuse of parts involves a major transformation of the product. It involves the extraction of the desired components from the product. The components may need to be tested and/or refurbished. The information value of this mode is medium, since knowledge of the product and the reuse requirements for the component is required. The material value added of the reuse of parts is high, since the component not only offers the correct material composition, but also the desired shape. The labour value is low, since like many of the other modes, it typically focuses on placement and extraction of the component" (Linton and Jayaraman 2005, p. 1816).

These business models for product life extension, described by Linton and Jayaraman (2005), focus on how to prolong the life span of the product and on what actions the extension will require. Other writers have also included other aspects in the business models. Lacy and Rutqvist (2015) also include the aspect of ownership of products, components and materials in their models. They describe five potential business models related to the circular economy. These business models are:

- Circular Supply-Chain—access to fully renewable, recyclable or biodegradable inputs
- The Product Life-Extension Business Model—making a product's useful life as long as possible and maximised profitability over the lifecycle
- Recovery and Recycling—every by-product and waste stream is optimised to maximise its revenue potential
- The Sharing Platform Business Model—provides a platform to connect product owners with individuals or organisations that would like to use them
- The Product as a Service Business Model—selling access to—and the performance of—an item on either a short or long-term basis.

In the UIW-project, we have focused on the upgrade of durable goods, which in traditional transaction based business models require big upfront investment. In this chapter, we will examine the experiences from the six industrial cluster cases in the UIW-project. Although most of them were at a very early phase of upgrade business development, each cluster had a shared vision of what kind of business activities they were aiming at. We will see from these cases how they consider closing the loops, prolonging the loops or how ownership of the durable goods could affect the business models for upgrading of them.

2 Upgrade Business Models

In this chapter we analyse the business models explored by the six cluster cases of the UIW-project in order to get a more detailed understanding of how these models work, what the drivers of these models are and what challenges related to these business models were identified during the research project. To compare the business models of the cluster cases, we used a simplified version of the business model canvas developed by Osterwalder and Pigneur (2010). We focus our analysis on the value proposition, the main resources and value network, the earnings logic of the business models used in the cluster cases and on the information management in main business processes. The analysis also raises the question of how the main actors in the value network have to transform their business model to create synergy between original equipment production and upgrading. In the next section we look at how upgrade processes can be made more efficient through the use of modern information technology.

The *value proposition* to the customer is a central part of the business model. It tells us what added value our service offering can provide to the customer. In the case of capital intensive equipment and machinery, the value of additional after-sales services is related to the use of this equipment. In an industrial business-to-business situation, a basic value for the customer is return on investment—invested capital should be used as profitably as possible over the span of the life cycle of the equipment. In practice, this can mean different things in different situations.

In the upgrade *value networks*, we can identify a set of basic roles occurring in slightly different ways in the different clusters. These are the user of the equipment, the main designer, the producer or provider of the equipment—here called the original equipment manufacturer (OEM), the upgrade service provider and provider of supporting services. The UIW-clusters are at an early stage of development of upgrade business and in most clusters, the final operational organisation has not yet been set up. Yet, from the organisation of the cluster cases we can see which actors the core companies in the clusters have identified as central partners and resources in their upgrade network.

Based on the cluster cases, we can say that the main *earnings logic* of the companies involved in upgrading is to improve their competitive situation and to earn more through improvement of added value for the customers. In most cases, upgrade business is focusing on and improving on already existing customer relationships. Upgrading can, however, also bring new customers through the added value of the upgrade service. To understand how the cluster cases aim to profit from the new upgrade services, we look at how this new service increases sales directly through sales of innovative upgrade services or indirectly through improved customer loyalty, and how costs are managed through the introduction of efficient service processes supported by new innovative digital information management solutions.

In the upgrade business, many business processes differ from processes used in original equipment manufacturing. There are also completely new processes like the reverse logistics process in remanufacturing. For many of these processes, a central feature is low volume and little repetition, customisation and a whole lot of information to be managed. In the UIW-project focus was on *information management* issues. We will in this chapter look in more detail at how this issue was met in the business models explored during the UIW-project.

Based on analysis of the cluster cases in the UIW-project, we can distinguish between four generic upgrade business models among the six clusters. We call these the ***Customized Upgrade***, the ***Modular Upgrade***, the ***Remanufacturing*** and the ***Service Upgrade*** business models. These models differ in the type of added value with which the customer is provided, but also in how this value is produced. Our study also shows that the different business models stress the need for development of digital means in different areas.

2.1 Customised Upgrade

The first business model is the Customized Upgrade. This model is based on the experiences from Clusters #3 and #5—the Italian and Greek the clusters (see Chapters "Space Systems Development" and "Supporting the Small-to-Medium Vessel Industry") in the UIW-project. Here the provider of a capital intensive physical product provides services aimed at upgrading the performance of the product, owned and used by an external customer, to meet new requirement from the customer or user of the equipment. In this business model, the service is initiated by the need of a specific customer and the service is customised to meet these needs. Central challenges in this business model are identification and management of customer needs in all phases of the service process, and to manage cost and time of the customised service performance.

2.1.1 Value Proposition for Customised Upgrade

In the Customised Upgrade business model, the proposition made to the customer is to adapt the original equipment to new needs of the customer. These needs may occur due to changes in the business environment of the customer, like new needs of the customer's customers or changes in equipment and services provided by competition.

Cluster #3 is looking at developing a new business model providing space services, using the Space Tug concept as an example in the project. A space tug is a type of spacecraft used to transfer payloads between orbits or to escape trajectory. Thales Alenia Space is studying this concept and related technological research in a parallel project (Pasquinelli et al. 2016). This was felt as the best disruptive example to study the UIW-methodology with respect to a new type of business. Moreover, it is a good example in the space domain where there is not a final customer who buys a spacecraft and related services, but there are multiple potential customers who can profit from a multi-mission spacecraft. This example is very complex, and the methodology may also be applied to conventional programs (institutional or commercial). In case of Cluster #5, customers are provided the opportunity to adapt the vessel from one type of shipping business into another as market demand shifts. Requirements for the new business activities are defined with the customers and they are implemented through technical or other changes to the vessel. Improved sustainability of the vessel is often an objective for the upgrade.

In Cluster #5, the aim is to upgrade the vessel according the needs of the owner. As market focus shifts from one segment to another, the vessel has to be adjusted to meet the requirements in the new market segment. This process also involves having the classification of the vessel checked and perhaps changed.

2.1.2 Roles in Customised Upgrade

In Customised Upgrade, the key players are the owner of the equipment and the OEM responsible for production of the original equipment. The customer initiates the upgrade process by presenting new needs and the OEM is responsible for providing the upgrade service. Due to the complexity of the customised upgrade process and the information management involved, the main roles like customer needs management, upgrade engineering and manufacturing are typically managed internally by the OEM. Supporting functions can be outsourced to expert organisations.

In both Clusters #3 and #5, the OEM is responsible for a majority of the roles involved. They are the provider of the solution, engineer, part or component manufacturer as well as coordinator of the final integration as part of the upgrade service. In Cluster #3, the responsibility for managing information related to the customer request is outsourced to Vastalla—a company offering IT consulting services, software development and IT systems activities emphasising especially on IT security. In Cluster #5, the boat manufacturing company OCEAN acts as both original equipment producer and as provider and producer of the upgrade service. Here the non-governmental ship classification society INSB, responsible for ship classification, survey and statutory certification and engineering approvals is a central actor in the value network. It plays an important role in the approval of the new, upgraded vessel construction, and it is involved as a partner in the early phase of the upgrade process.

Based on these two cluster cases, we suggest that in Customised Upgrade the control of the information flow requires the OEM to take a central role in the operative work. The mode of operation is vertically integrated, leaving only support functions and specialist functions to outside partners. Innovative development of core technology to support the upgrade business is done in a close network of partners (Fig. 1).

2.1.3 Earnings Logic in Customised Upgrade

Offering a customised upgrade requires unique input from the service provider and it is typically done at a high cost level. Due to this customised upgrades can only be offered if the price of the service is high enough or the costs can be returned otherwise. Then again, a high price requires high added value to the customer. This is typically achieved through the provision of unique service characteristics provided only to the customer in question. This can be seen in the case of Cluster #3,

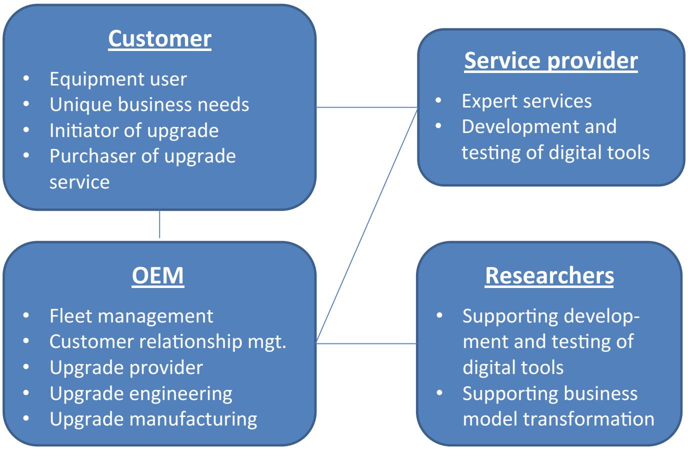

Fig. 1 Actors, roles and connections in the Customised Upgrade business model in the UIW-project

where the goal is to present a totally new, unique value adding service to the customer or user of the space equipment. Changing the use of a space unit in orbit was earlier done from a space shuttle, but today there is no infrastructure available for this task.

In Cluster #5, the upgrade service is aiming to transform the vessel from use in one business area to another. This can be profitable to both customer and service provider as long as the upgrade service is less expensive than options like buying a new vessel, but still the price is high enough to give the provider a good margin. Limited and less profitable customisations can be done, for instance, for the sake of customer loyalty.

Customised upgrade involves some extent of disassembly and reconfiguration of the existing equipment. In some cases this is done in the field, in other it is done at a factory. Since this involves activities not part of the original equipment manufacturing, it is likely to require some extent of dedicated resources, infrastructure and facilities. Since customised upgrade is based on initiatives from the customer, information management is crucial for cost management. Also management of critical skills and functions is likely to require in-house resources.

2.1.4 Information Management in Customized Upgrade

In Customised Upgrade, a major challenge in the actor network is the collection and management of customer-specific information. Customisation means deviations from standards and from previous activities, which again means that existing data and information is no longer up-to-date. Instead, customisation requires specification, documentation and management of new information. Since the generation of new data and information is a manual and often not a well-structured task, it is prone to mistakes and delays. Checking that all necessary information exists and is available is a major challenge in customisation. This is also true for the quality checking and the dissemination of correct and up-to-date data and information to all parties concerned. These challenges are reflected in the pilots made in Clusters #3 and #5.

Cluster #3 developed a system to enhance communication between stakeholders (including customers) in all communication-sensitive phases of the service lifecycle, from initial choice among design solutions, to choice among alternative configurations before service executions also supporting general decision-making processes during Space TUG operations. This cluster focused on developing a reference data model (meta-model) that can serve as standard for storing and interchanging industrial information. Cluster #3 is also developing a Web Configurator to enhance communication between stakeholders in the service lifecycle, modelling the application using the meta-model that makes use of software called the Web Environment.

Cluster #5 developed a system to support upgrades of small passenger boats. The upgrades can be driven by changes to regulation or variation in service demand, which have to be balanced with reductions in cost and lead-time of product modifications. Within UIW, Cluster #5 developed an information system to support upgrading activities in this context, through giving stakeholders access to an information-rich technical metafile for the vessel that includes all aspects of the vessel. The meta-file is accompanied by a vessel web configurator that is the customer's entry tool to the application suite of Cluster 5.

2.2 Modular Upgrade

The second business model, used in the Finnish Cluster #2 (see Chapter "Rock Crusher Upgrade Business from a PLM Perspective"), we call Modular Upgrade. As in the previous business model also in this model, the OEM of a capital intensive physical product provides services aimed at upgrading the performance of the equipment, owned and used by an external customer. In this business model, the service is not defined by the needs of a single customer or end user. In this business model, the service provider defines the characteristics of the upgrade based on input from the market. In the Finnish case, the upgrades are changes to the physical machine predefined by the product development in the OEM. A modular structure of the machine enables the company to develop the features of the machines piece by piece. As the new modules are fitted to old machine constructions, they become upgrade options for the fleet of machines in use in the field.

2.2.1 Value Proposition for Modular Upgrade

In this business model, the upgrade service is predetermined by the service provider. Equipment owners or users are provided leading edge performance through predefined and productised modular upgrading of their equipment. Increased sustainability in use of original equipment can be part of added customer value. The added value depends on how the customer can utilise it in order to increase competitiveness or to move into new areas of business. In Cluster #2 crushers are, for instance, adapted for use in urban areas through additions of noise and dust-reducing modules. This gives the operator of the crusher improved opportunity to compete for sustainable urban crushing contracts.

2.2.2 Roles in Modular Upgrade

In Modular Upgrade the OEM plays a central role as the provider of the upgrade service to the owner or user of the original equipment. The OEM also takes the responsibility for the defining and engineering of the upgrade module. Modular upgrade sets the emphasis of efficiency of operative execution and thus requires specialised resources. A forward integrated role of the OEM creates a close relationship to the end users and customers, and through a thorough productisation of the upgrade service, operative functions like module production, customer interface design and production, and final assembly can be outsourced to a network of specialised actors.

In Cluster #2, Metso—the OEM—is concentrates on designing the modular upgrades based on thorough understanding of the technology and the market needs. The operative responsibilities for producing the upgrade service can be outsourced to a partner company. Since the modular upgrade, projects are limited in scope, they are not always suitable for the business processes of the OEM or for the organisations focusing on these processes. This is why Metso is considering outsourcing the production of the upgrade service to an external company such as RD Velho—a smaller and more agile partner organisation.

In the Cluster #2 case example, part of the operative information management is also outsourced to the network partner. In this case, RD Velho is responsible for collecting information on the machine as it is used in the field. This information is compared to the original geometry of the machine and to the geometry of the upgrade module to see how it can be fitted to the machine (Fig. 2).

2.2.3 Earnings Logic in Modular Upgrade

The Modular Upgrade business model strives to provide the customer with new, but not unique, functionality in order to improve customer competitiveness. Restricting the upgrade to single modules in the equipment limits both the effect on the performance improvement, but also the resources needed for performing the upgrade.

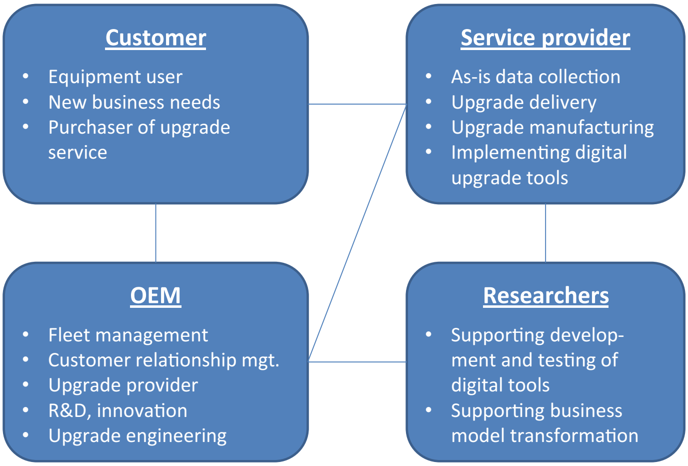

Fig. 2 Actors, roles and connections in the Modular Upgrade business model in the UIW-project

Basing the upgrade on design and plans from product development ensures that the efforts put on developing the module are re-used both in new products and in upgrades for other customers.

The modular design also means that the production of the physical module and its parts is repeated. This makes batch production possible and enables economies of scale in production of the modules. The experience from Cluster #2 shows however that the upgrade business is in many other areas quite different from the original equipment manufacturing and can benefit from separation between the two business models. For instance, the management of a modular upgrade project is much more limited than the management of an original equipment project. Also assembly of the module to a machine in the field differs significantly form new equipment production in the factory. Here, dedicated upgrade resources—in-house or external—can be necessary.

In the case of Cluster #2, an upgrading business already exists, but to improve profitability of this activity, a new mode of upgrade business is developed. In the new mode, the modular upgrade business model, Metso is to some extent reducing the customers' options from a completely customer needs-based mode to a modular, innovation-based mode. They are balancing added customer value with internal efficiency, cost, control and profitability.

2.2.4 Information Management in Modular Upgrade

In Modular Upgrade the challenges in information management are reduced significantly compared to the Customised Upgrade. Since it is a major part of development work and thus, also of information management, it is handled in-house in the OEM's product development organisation, the main information management challenges are related to what goes on outside this organisation. A major information challenge is to collect and keep up to date on what is happening to the fleet of equipment in use in the field. Machines change owners and they are transferred from one location to another. At the same time they are maintained, changed or upgraded by their owners or by third parties. Defining the interface between the upgrade modules and the equipment in the field can be considered a bottleneck of information management in this type of business model.

In Cluster #2, where Metso is already providing customised upgrades, the aim of the development process in the UIW-project was to improve profitability of this business. A central objective was to build and develop a dedicated business network to perform the upgrade activities. Presently, Metso designers and workshop personnel do upgrade activities in parallel with the development and production of new machines. Since the upgrades are generally small, unique projects, they are difficult to fit into the main activities. In the UIW-project, the role of the upgrade producer has been planned for RD Velho—today a subcontractor in engineering to Metso. This organisation can in the future be responsible for module interface design activities, and of the coordination of partial production and installation of upgrade modules. Through the support of an outside partner, Metso can free their own resources to focus on the main business.

Cluster #2 has in the UIW-project-tested 3D scanning technologies for creating digital data and information about the target machine including 3D geometry. This was used especially to document changes made to the machine during use. A central objective of creating new information about the machine is to enable fast design of the interface between the upgrade module designed by Metso and the machine in operation. Having complete information on the state of the machine during upgrade design, enables a fast upgrading process, especially when the upgrading is taking place in the field where the machine is used. Cluster #2 also tested VR- and AR-based review tools to envision upgrade solutions to engineers and customers. These tools were tested in design reviews with Metso engineers. The design object used in the test was a maintenance platform attached to a mobile rock crushing machine that was part of the upgrade for the already existing machine. The virtual reviews enable engineers to evaluate upgrade solutions before they are realised as physical elements of the upgrade module. This reduces the need for iterative behaviour in downstream functions like purchasing, component manufacturing, upgrade assembly and installation.

2.3 Remanufacturing

The third business model we call Remanufacturing. This business model has close resemblance to what Linton and Jayaraman (2005) call remanufacture, but it also has elements of the part reuse model. In this business model original equipment is disassembled into parts which are re-used in the production of new equipment. The new equipment can fulfil the same or similar functions as the original equipment, or it can have completely new functionality. A main objective of reusing parts is to create a sustainably produced piece of equipment through reduced use of material and energy resources in the production of the new equipment.

In the Dutch case, Cluster #6 (see Chapter "Sustainable Furniture that Grows with End-Users"), the core company is collecting furniture sold to external customers in order to re-introduce them as parts of new furniture. Collecting of furniture can either mean that the parts are bought back from customers willing to get rid of old furniture and selling upgraded furniture to new or repeat customers, or it can mean that the equipment is leased to the customer and parts of the old equipment are used as input for new equipment, thus reducing the cost of materials in the new delivery.

2.3.1 Value Proposition for Remanufacturing

Remanufacturing is typically driven by the values of the end user and by the OEM. The value proposition to the customer or end user of equipment is that sustainable and ecological values are endorsed in the production of the new equipment through prolonging of the life cycle of parts of the equipment. Hence, the material loops are secured through collaboration benefiting both the end user and the OEM.

In Cluster #6, the Dutch company Gispen is adding new customer value through sustainably remanufactured furniture. They provide the users new furniture, and at the same time they add new ecological value for the customer as they build the furniture from used parts, thus reducing the need for use of materials and energy in production.

2.3.2 Roles in Remanufacturing

In Remanufacturing, the OEM is typically in a central position. It manages the equipment design and business, and it has control of what parts have been used in what products and of the design and production information of these parts. In this position, it can be well positioned to also be a provider of remanufactured equipment. Forward integration for better control of the equipment fleet will for many OEMs become a necessity as they go into this area of business. Remanufacturing also involves other processes that are not needed in original equipment manufacturing. These are for instance, reverse logistics, disassembly of the original equipment and quality checking of reusable parts. These processes can be outsourced to dedicated expert organisations.

In Cluster #6, the OEM—Gispen—looked into the Remanufacturing model in order to gain insight in the effects and requirements for changing business. Close contact to the customers is crucial in order to tailor furniture to customer needs and in order to manage the fleet of furniture in use. This will also require management of a totally new operation like reverse logistics, the disassembly of old furniture and the quality control of used parts. Where the scale and duration is different between the OEM and the upgrade process, it is natural to look for new ways to organise the activities and sometimes this mean involving external partners to perform tasks and activities not suitable for own processes and organisation.

In the different scenarios explored in the UIW-project, Gispen is considering several alternatives for management of ownership of the furniture and components. One way is to buy back used furniture; another is to own the furniture and lease it to the user.

In Cluster #6, Gispen has chosen to cooperate mainly with the research organisation providing support in defining and analysing the new business model (Fig. 3).

2.3.3 Earnings Logic in Remanufacturing

The earnings logic of remanufacturing rests on the values of the customer. In remanufacturing, a product is produced through the reuse of parts, thus reducing the use of virgin materials and energy to form a new part. Often, but not always, this is lower than the price for new products. Since the reuse of parts involves reverse logistics, disassembly of the used product, and quality control, the production of the remanufactured part includes additional costs not included in the production of original parts. In Cluster #6 Gispen is providing the end user a new offering—sustainably produced furniture. This can be seen as an addition to their existing product portfolio.

As mentioned before, remanufacturing requires a whole range of new activities including management of the use base, logistics for the collection of used products, disassembly and so forth. This will require a dedicated workforce and infrastructure capable of performing at high productivity and low costs.

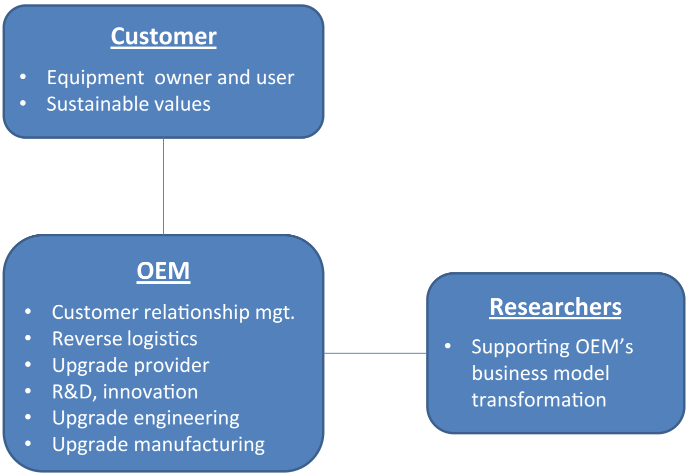

Fig. 3 Actors, roles and connections in the Remanufacturing business model in the UIW-project

A central challenge in remanufacturing is the management of the installed base. How can the service provider ensure that used parts are available as they are needed in the process of remanufacturing? One option for the service provider is to keep the possession of the goods and only rent or lease it to the user (see Lacy and Rutqvist 2015). This business model, however, also includes challenges. In Chapter Sustainable Furniture that Grows with End-Users, a scenario based on leasing of the furniture to the users, showed that a long usage cycles generates long delays with respect to cash flows for the provider and producer of the remanufactured product.

2.3.4 Information Management in Remanufacturing

As in most areas of the circular economy, a central idea of Remanufacturing is to ensure that efforts and materials included in an existing machine or equipment are used and reused as much as possible in order to reduce creation of waste and use of energy. This is a primary driver behind remanufacturing. Reusing components of equipment provides the customer with an ecologically more sustainable product, but productivity and profitability in this business requires strict control of both the flow of material and of information.

Cluster #6 focused on the development of a circular economy design strategy. To do this, the cluster developed tools and methods that speed up and improve the efficiency of the design information flow in the communication between customers, manufacturers and designers to design, upgrade and reuse products according to circular economy principles. In the UIW-project, Cluster 6 evaluated a Design Framework, a checklist approach to circular product design using a recently developed lifecycle analysis tool (LCA+) for circular economy scenarios. The aim of the task was to describe the development of a lifecycle analysis tool (LCA) and evaluate the usefulness of this tool.

2.4 Service Upgrade

The fourth business model is called Service Upgrade. Here new, innovative digital tools are introduced as part of a service in order to radically improve the added value provided for the customer. Using new, innovative digital solutions, the customer is offered an information service, which significantly improves critical business processes and the use of capital intensive equipment. This model offers unique business opportunities for service providers. This can, for instance, be a service supporting other upgrade activities either in-house or as a service to external customers. In the Swedish Cluster #4 (see Chapter "Adaptation of High-Variant Automotive Production System Using a Collaborative Approach"), the owner of the production equipment is planning and performing the upgrade of the equipment themselves. The original provider of the equipment can be involved in this process, but this varies from case to case. Services are also procured from outside service providers, but the main responsibility for the upgrade is with the owner. In the Spanish cluster—Cluster #1 (see Chapter "Collaborative Management of Inspection Results in Power Plant Turbines")—a service provider is improving its capabilities to provide a service to an external customer who owns the capital-intensive equipment. The information provided through the service can be used by the owner to maintain the equipment or as input for planning an upgrade to meet new needs.

2.4.1 Value Proposition for Service Upgrade

The value for the customer in the Service Upgrade business model is the improved efficiency of service provision and more valuable results.

Cluster #1 is striving to improve service performance in the turbine inspection process. Through the improved service, the customer gets better information on the condition of the equipment and can make better decisions on how to operate and maintain the equipment.

In Cluster #4 the production line for trucks is adapted to changed market needs. The changing demand for different types of trucks requires changes in technology and in layout in the production line. Another example of adopting to change market needs is when new legislation forces users of stone crushers to improve the safety of the operator to meet the new standards. The upgrade necessary to do this can be added as a module to the machine operating in the field.

2.4.2 Roles in Service Upgrade

In Service Upgrade, the focus is on the network actors providing services to the equipment owners.

In Cluster #1, the service providers are not providers of the original equipment, but specialise in providing high level, focused service for a specific market segment. The competitive edge for this company is based on managing the service task. In Cluster #4, where the customer is internal, the service provider is not the producer of the original equipment, but the service provider has been involved in designing and building the manufacturing system, and thus also has a thorough understanding of the system and its components. In both clusters outside research partners were involved in the development of new tools and technology for improving the service operation.

In the Service Upgrade the OEM of the equipment in use is not directly involved in the service, but the core actor in this value chain providing the service to the end user is the service provider. This actor is responsible for both planning and executing the service. External actors like research partners support the development of service technology (Fig. 4).

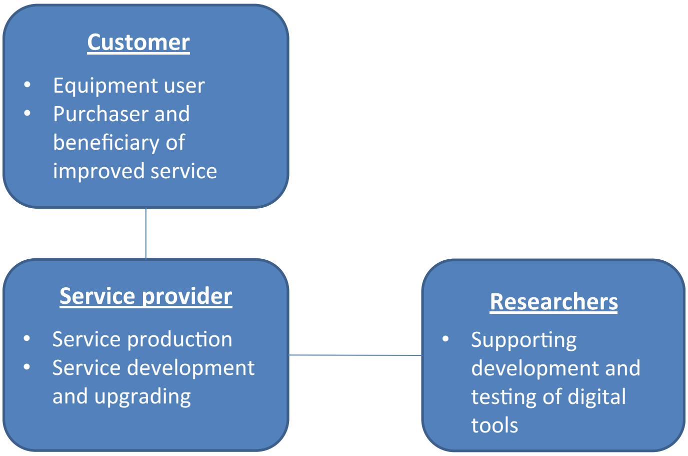

Fig. 4 Actors, roles and connections in the Service Upgrade business model in the UIW-project

2.4.3 Earnings Logic in Service Upgrade

In the Service Upgrade business model, the objective is to improve an existing service in order to improve customer value or to improve the efficiency of the service process. The first option will offer an opportunity to distinguish from competition and to charge a higher price for the service. The second option cuts cost for the service provider.

In Cluster #1, Tecnatom focuses on improving internal processes in order to meet the needs, not of a specific customer, but of the market as a whole. The new solution developed and piloted in the UIW-project enables Tecnatom to provide the customer more elaborate information on the condition of the power plant's equipment. This enables better and faster understanding for the customer of what has been done during maintenance and what still required.

In Cluster #4 information on the state of the Volvo production plant is collected through scanning. This enables efficient planning for upgrading the process to meet the new market needs.

2.4.4 Information Management in Service Upgrade

In Service Upgrade, a central objective is improving the value added provided by the service to the customer. This added value can be achieved through new digital means for creation of data or from new means to combine and bundle data to useful information, thus, making it easier for the customer to acquire and use the information. This can be seen in the pilots developed in Clusters #1 and #4.

Cluster #1 developed value-added turbine inspection services for the fossil power industries. The aim was to develop collaborative environments that make all available and relevant information accessible to all stakeholders taking part in the post-inspection decision-making processes. The ultimate goal was to reach faster decisions that minimise outage duration and better decisions that prolong the turbine service life by several years. Within the UIW-project, Cluster #1 developed a system that integrates 3D visualisation of the turbine with all inspection related data. From the upgrade process point of view, this tool is combining original design data with data from the equipment in use in order to enable efficient decision-making on what needs to be done to ensure continuous operation of the power plant.

Cluster #4 is focused on developing applications to store technical information of the production system and improving current work activities centred in a collaborative view. Through the system developed in the UIW-project, measurement data collected with a 3D laser scanner and CAD data of the production cell can be combined. The goal is to improve the communication between the actors from different departments in order to make technical decisions using this information. In the UIW-project Cluster #4 tested the system in an industrial setting supporting the decision-making of different actors in the manufacturing change/upgrade process. The test was based on a 3D laser scan of a part of the manufacturing which was due for an upgrade. The users were able to see the cell as-is in the first phase and then in the concept design phase they were able to visually compare alternative design solutions for the upcoming change.

3 Comparing the Business Models

In this chapter, we look at some common challenges related to the development and implementation of the four business models as well as some differences between these models.

3.1 Common Features and Challenge in Implementation of Business Models

All cluster cases in the UIW-project focused on developing existing customer relationships and the main focus of all OEMs in the clusters is on the customers owning original equipment produced by them. This forms the market basis for their upgrade business activities. Building a confidential relationship with a customer is an investment of time and effort, and it should be re-utilised as far as possible. This is true for all the business models. As the designer of the original machines, equipment or systems, the OEM possesses the information on how it was originally designed and built. This is also an asset for reuse. In practice, introducing a service business into an OEM organisation is not straightforward. There are challenges related to identification of the present owners of previously delivered products, understanding the upgrading needs of the customer, defining the state of the machine or system in operation, etc.

In general, we can say that the roles of the actors in the upgrade business are different from the roles these companies have in original equipment production. Upgrade projects are typically smaller in scope and shorter in duration than the original equipment production, and the original business processes are most likely not suitable for handling these new types of upgrading projects. Despite this difference to the original manufacturing process, the OEMs are in a central position in most of the upgrade business models presented in this chapter. Only in the Service Upgrade cases are the OEMs of the equipment not involved.

In all cluster cases in the UIW-project, the customer of the OEM is the owner and user of the equipment. In all but one case, this is an external party. Only in Cluster #4, the customer is internal—a separated department within the same company. In four of the cluster cases, the providers of the upgrade services are OEM companies responsible for designing and manufacturing the original equipment. They have a good understanding of the technology and how it works, and based on this they provide solutions to new customer needs emerged after the original piece of equipment was delivered. This is their competitive advantage as upgrade service providers. The service activities are also, in general, based on existing customer relationships.

A common challenge for most of the Cluster cases and to the business models relates to the role of the new service business as part of the company's overall business portfolio. To some of the companies in the UIW-project introducing an upgrade service meant adding a new service to the existing portfolio of services. To others it was more a question of improving on existing services. Although the objective of adding a new service is improved customer service and increased sales, the introduction of the new life cycle service is also connected with a sense of risk that it might endanger the success of existing business activities. The synergy (or sometimes the lack thereof) between the old and the new activities affects how the companies can benefit from introduction of new upgrade business activities.

For the customer or the user of the equipment, the introduction of an upgrade service offers a new alternative means of ensuring the continuity, quality and competitiveness of their activities and the use of the equipment in their possession. An alternative would be to buy completely new equipment specially built for or originally constructed more suitable for the new situation. For the OEM, finding a balance between original equipment production and upgrade life cycle services is a central challenge when considering entering the upgrade business. Defining the scope of the upgrades and the upgrade business, as well as, pricing of upgrades are important decisions in this phase. A sense of risk for cannibalising of existing business was discussed in several of the UIW-cluster. In this chapter, we have seen that prolonging the lifetime of a boat—a central goal of the circular economy business models described earlier in this chapter—is from an economic point of view not trivial for the companies. In the simulated scenario, OCEAN—the boat manufacturing company—generally benefits from a reduced boat lifetime, but this was not true for all situations. Additionally, the boat operator Seability seems to profit from a shorter life cycle, which can be considered counterintuitive.

Based on the analysis of the Cluster cases, we identified three areas of cost control through the creation of efficient business processes. These areas are:

(1) reuse of resources and components
   (a) original equipment as market base
   (b) materials and components
(2) developing dedicated resources and service infrastructure,
   (a) business network for upgrade production
   (b) service equipment as business platform
(3) streamlining processes through improvement in information management and communication

3.2 Main Differences Between Business Models

A primary distinguishing factor between the business models is the clear difference in the value proposition offered. While the Customised Upgrade focuses on uniqueness and customisation, the Modular Upgrade s owners of old equipment to reach leading edge performance level typically offered by new equipment through as a low-cost alternative. Remanufacturing offers sustainability as its main value proposition. Service Upgrade is as such not a novel business model, but an improvement on an existing life cycle service.

We can also see some differences between the roles of the OEMs in the different business models. While they are not heavily involved in the Service upgrade cases, they are at the centre of the three other business models. Here again there are some differences in what roles they manage in-house and what they can outsource. Based on the UIW-cluster cases, it seems that in the Customised Upgrade and Remanufacturing business models the OEM performs all major activities in-house and outsource only highly specialised tasks. In the Modular Upgrade network, partners can play a central role also in the realisation and delivery of the upgrade service.

In Table 2, we have summarised the main features of the four upgrade business models.

Table 2 Upgrade business models

Business model	Customized upgrade	Modular upgrade	Remanufacturing	Service upgrade
Value proposition	Enables equipment owners or users to capture unique, innovative business opportunities through an upgrade service tailored to their needs. Increased sustainability in use of original equipment can be part of added customer value	Provided equipment owners or users leading edge performance through predefined and productised modular upgrading of their used equipment. Increased sustainability in the use of original equipment can be part of added customer value	Providing sustainable equipment designs through reuse of component from used/existing equipment	Providing equipment owners unique, productised and digitally supported services to improve utilisation of capital-intensive equipment and to enhance end-customer service. Increased sustainability in the use of original equipment can be part of customer value
Market base and customers	Original equipment in use and its owners/users	Original equipment in use and its owners/users	Reusable components of original equipment in use	Original equipment in use and its owners/users
Upgrade task	Upgrading parts of the original equipment to meet new purposes of use	Adding upgrade module or replacing existing module with upgraded module	Reusing components of original equipment in new products	Information management to support upgrade and other service activities
Key actors and roles	**Customer**: equipment owner, initiator of upgrade process, purchaser of upgrade service **OEM**: fleet management, CRM, upgrade provider, engineering, manufacturing, development of upgrade business process **Service provider**: provider of outsourced expert services	**Customer**: equipment owner, purchaser of upgrade service, **OEM**: fleet management, CRM, upgrade provider, R&D, product development, productisation, development of upgrade business process **Service provider**: as-is data collection, upgrade delivery and installation,	**Customer**: equipment owner, purchaser of remanufactured equipment **OEM**: designer and producer of original equipment, designer and producer of remanufactured equipment, reverse logistics, **Researchers**: developing and testing of innovative digital technology,	**Customer**: equipment owner, purchaser of improved service **Service provider**: provider of improved service, service process development, testing and implementation of innovative digital tools **Researchers**: developing and testing of

(continued)

Table 2 (continued)

Business model	Customized upgrade	Modular upgrade	Remanufacturing	Service upgrade
	Technology provider: provider of digital tools, technology development and manufacturing **Researchers**: developing and testing of innovative digital technology, supporting business model transformation	management of upgrade process, testing and implementation of innovative digital tools **Researchers**: developing and testing of innovative digital technology, supporting business model transformation	supporting business model transformation	innovative digital technology, supporting business model transformation
Earnings logic	Improved sales through innovative capturing of customer needs and value Dedicated upgrade service infrastructure and resources Integrated information management in business network Value-based pricing	Improved customer loyalty, Added turnover per customer, Productised modular upgrade services Dedicated upgrade service network and resources Focusing in-house product development efforts on innovative modules and product features	Providing customer with sustainable equipment based on reused components Control of market base Reverse logistics process Remanufacturing process	Improved customer loyalty through improved service performance Improved productivity of service work Value-based pricing
Cluster cases in UIW-project	Cluster #3 Cluster #5	Cluster #2	Cluster #6	Cluster #1 Cluster #4

3.3 Similarities and Differences in Information Management

Since the focus of the UIW-project was on information management in the upgrade business, we will look more closely at the similarities and differences between the pilot solutions developed for the different business models in order to see if we can identify special information management challenges related to these business models. The pilots are listed in Table 3.

Table 3 Information management pilots in the UIW-project

Business model	Cluster case	Pilot	Abbreviation (see Fig. 5)
Customised upgrade	Cluster #3	Reference data model Request Web Configurator Web environment	CU1 CU2 CU3
	Cluster #5	Reference data model Vessel configuration tool	CU4 CU5
Modular upgrade	Cluster #2	Testing of 3D scanning technologies AR-based review tool	MU1 MU2
Remanufacturing	Cluster #6	Circular design framework	RM1
Service upgrade	Cluster #1	Webb app for managing inspection results using 3D environment.	SU1
	Cluster #4	Combination of measurement data collected with a 3D laser scanner and CAD data of the production cell	SU2

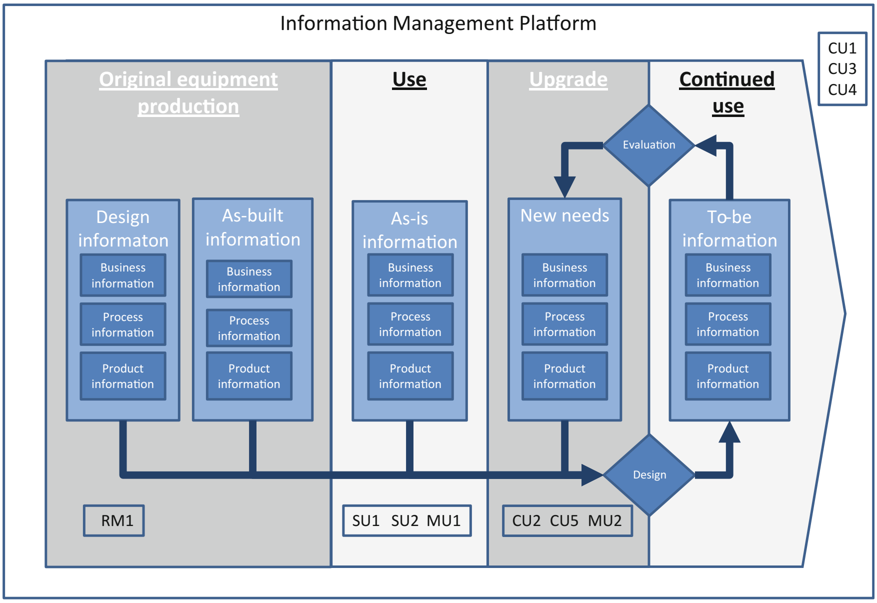

Fig. 5 Upgrade information management process

In Fig. 5, we have described a rough model for information management in the upgrade business. The starting point is the original equipment production and the design data created in this phase. In this model, we have divided the information in business-related data or information, process-related information and product information. While product data and information is stored in formal formats in CAD and PLM systems, process information and business information can take a variety of forms and the quality and completeness of stored data varies.

Designed information: reusing the original design information is a central factor in the business model of upgrading. This information is stored in the OEM's archives in different formats. Today, most of it is in electronic format, but for very old equipment or systems there may still be a need to look for this information on paper. Additionally, the electronic formats have changed over the year, so making use of old information might require updating the information to a newer format.

As-built information: in complex products like machinery and equipment there are often steps that are not documented fully during the design process. This so called as-built information is not always documented, but modern means like digital cameras have for some time been used to document this information.

Use-information: during the use of the equipment, changes are made for several reasons. Worn out or broken components are replaced, smaller or larger additions or upgrades are made, etc. Often these types of changes are not documented, or some of the information can be stored by the organisation responsible for the changes. In order to perform an upgrade, as-is information is often needed, and needs to be collected in one way or another. Formally stored information can be requested from the user or other actors, or information can be created from scratch.

Upgrade need information: the need for an upgrade can emerge from several root causes. It can be a change in the business environment of the user of the original equipment which triggers the need, or the user might have seen something similar somewhere else. Depending on how this need emerges, the initial idea can be more or less abstract and the solution might require more or less work. When the initial idea is abstract, several iterations between users, engineers and the production team can be needed before a solution acceptable for all parties is found.

To-be information: this is the data and information produced based on prior information, re-created information and new information. This information needs to be stored, maintained and managed for further use during the life cycle of the machine or equipment.

Twelve pilot demonstrations were made in UIW. Of these, ten are mapped on the upgrade process in Fig. 2. Two demonstrations focus on the business modelling in Cluster cases #5 and #6. These are not included in this analysis.

In Fig. 5, we see that the new tools and solutions developed in the UIW-project are focusing on four different areas in the upgrade process. First, we can see that two clusters have developed tools and methods for general information management in the upgrade process. Secondly, one group of tools developed by the clusters focuses on creating and evaluating information on new customer needs. Thirdly, three clusters have focused on as-is information; creating it through 3D-scanning, combining it with original design data and visualising it to support dialogue and decision-making among several actors involved in the process. Fourthly, one cluster focuses on the original equipment design process.

3.3.1 Pilots for Customised Upgrade

The tools and methods in the first area developed for general information management can be divided into two categories; one is the creation of a reference data model—a meta-file—for storing and managing all the life cycle information of the machine to be upgraded. The information stored concerns a specific piece of equipment, not a machine type or class. Without this system, the information is scattered around in the network of actors or even non-existing in formal sense. The second category of tools and methods in this group is the communication infrastructure between independent actors in the business network for the management of common meta-files. The meta-files and communication network tools were in the UIW-project developed especially by Cluster #3 and #5, and although similar tools can also be useful in other upgrade business models, the need for collecting and managing information on single customer needs and for transforming this information into new upgrade solutions makes a tool like this crucial in this business model.

The second area of tools development in the UIW-project focused on creating and evaluating information on the new needs of the single customer looking for an upgrade. This is crucial in the cases of customised upgrading. Understanding the needs of the customer, documenting it and evaluating it with different stakeholders is an essential part of the upgrading process. Mistakes in this phase of the process mean that everything done before the mistake is realised has to be reconsidered and possibly redone, and this costs both time and money. In both the Italian and the Greek cluster cases, the focus is both on documenting the customer's initial ideas for the upgrade, but also on evaluating and comparing different upgrade design solutions with the customer's needs and ideas.

3.3.2 Pilots for Modular Upgrade

In the Modular Upgrade business model, a great deal of information is dealt with internally by the OEM, and the special development needs were found in the customer interface in the management of as-is information. This represents the third area of tool development in the UIW-project. Comparing it with original design information and visualising the changes that have taken place in the equipment during use support dialogue and decision-making in a network of actors planning and designing the upgrade solution for the customer. Creating digital as-is information is essential in situations where this information does not exist or is not available to the actors performing the upgrade. In the Metso case, the machines have typically been in use for years and the user might have made changes to the machine without systematic documentation. 3D models of the used equipment were in Cluster #2 created using a set of 3D scanning techniques.

Also the evaluation of upgrade design solutions was considered important in Cluster #2. Here the focus was, however, more on visualisation for engineers and customers of how a predefined upgrade module would fit the customer's machine and to demonstrate how it would function with the new upgrade. To do this, virtual design reviews were held in a virtual reality environment that also made use of augmented reality solutions.

3.3.3 Pilots for Remanufacturing

The fourth area addressed in the development of the tools and methods in the UIW-project bring into focus the design of original equipment. As we saw earlier, Gispen focused on developing a circular economy Design Framework and demonstrated the use of a checklist for circular product design. This list was used for evaluating how well original equipment designs supported remanufacturing and circular design. In this case, the market base consists of re-usable components of furniture available and fit for recycling. The better the recycling already planned in the original design phase, the faster the market base of recyclable components will grow and the bigger the market base will become.

3.3.4 Pilots for Service Upgrade

The Service Upgrade pilots can be divided into two groups. First, one pilot focuses on creating the as-is information in an environment including several machines and equipment as well as infrastructure, in this case the building. The second pilot in this group documents and presents data on what has been done during maintenance of equipment.

In Cluster #4, as-is information of the Volvo factory is created through 3D scanning. In this case the object—the factory—consists of a wide range of equipment, the building, products, components, material, etc. Original information on the building or equipment can exist in a digital format, but most likely scanning the necessary information is faster than collecting original data from external sources.

In Cluster #1, a software tool is storing information on inspection and testing tasks, procedures and plans, information on results of inspections, as well as 2D drawings of the inspected equipment. A 3D model based on the 'as-is' turbine was created after 3D scanning the turbine. This 3D model is used to visualise the turbine and the inspection results in order to easily understand the overall situation and allow for the decision making of the stakeholders to take place in a collaborative manner and with all of the necessary information.

4 Conclusions

In this chapter, we have described four generic upgrade business models based on the six industrial Cluster cases in the UIW-project. These business models provide opportunities for producers of capital-intensive goods or equipment to strengthen the contact with their customers and to provide the customer valuable services aimed at improving their competitiveness under changing market conditions. The four business models all provide their own, specific added value for the customer. These business models can be added as part of the life cycle service portfolio in a company, but some of the business models can also have the potential to achieve more profound changes in how manufacturing companies operate in the future. For instance, remanufacturing has the potential to take manufacturing into a new cycle of material and energy flow, where existing physical parts become the raw material for the production of similar or even totally new products. Modular Upgrade can revolutionise how we see the connection between innovation and the product life cycle.

In the analysis of the business models, we realised that circular economy drivers were present in most of the cluster cases, but not necessarily in the way that they have been presented in academic work. Closing the material loop (Bocken et al. 2016) and thus, providing the customer more sustainably produced products was a driver mainly in the Remanufacturing case of Gispen in Cluster #6. Prolonging the loops (Bocken et al. 2016) was considered a challenge or even risk for the OEM companies in Clusters #2 and #5. Instead, these companies offered more sustainable operation of the original equipment as an added value for the customer. This can enable the customer to perform business activities in areas of high sustainability standards.

To the companies in the clusters, the upgrade business provides opportunity for added sales and turnover through the addition of new customer offerings, or through improvement in or replacement of existing services. To the OEMs providing upgrade services, it is also a means of improving the competitive edge in the original equipment market.

We also learned that, while providing existing customers with upgrade services can improve sales, profitable execution of this business requires efficient management of the business processes. While the circular economy business models focus on the reuse of finite or renewable materials, the business model used in the cluster cases are all centred on what could be called reuse of intangible resources. Development or strengthening of the long-term customer-supplier relationship was the main objective in most of the UIW-clusters. To the users of the equipment, prolonging of the economic life cycle of the equipment is a central objective, but to the OEM companies, this plays a secondary role. Among the companies in the six clusters, only Gispen was looking to directly close the material loop through remanufacturing.

The second means in creating efficient processes in the cluster cases was the use of dedicated resources. While the object of the upgrade activity is the same as in original equipment manufacturing, the process is not the same. Upgrading results in limited changes to the equipment and is thus a separate process. Depending on the case, the roles in the upgrade network can be managed in-house or by external partners. Dedicating special resources for upgrading activities gives a stronger focus to both the original equipment manufacturing and the upgrade activities.

Thirdly, the role of information management is emphasised in the upgrade value network since detailed information has to be collected from several sources using several different means. From the cluster cases, we identified four areas where modern information technology can improve information management in the upgrade business process. Firstly, it helps to create as-is information on equipment in use in, and in comparison to, this information with information from the original equipment design and production. Secondly, it can be helpful in creating, documenting and evaluating the upgrade needs of the customers or users. Being able to do virtual tests on new design solutions with the customer needs in a virtual environment is a central means for reducing iterations during design and implementation of the customer-specific upgrade.

Fourth, there is a need to consider upgrade business issues already in the original equipment design and manufacturing. This was demonstrated in the remanufacturing case of Gispen, but it will most likely also be of importance in cases of modular upgrading, where the feature of the product is upgraded by adding or changing specific modules.

Fifth and finally, upgrading is, by its nature, a process of information management in a networked environment. Joint information management and information sharing are crucial for the success of the upgrade business and, therefore, a common information management platform plays a central role in these activities. A central focus of the UIW-project was initially on technologies like VR and AR. These technologies are used for visualisation of electronically stored data. The work done in the UIW-project shows that there are several areas in the upgrade process where visualisation of information is needed. Visualisation of data and information can be a means to get a better understanding of three-dimensional models used for planning upgrades, and as such it can be a means for people of different backgrounds to communicate whit each other about the upgrade. These are central means in developing a dynamic upgrade process where data is collected from several sources and several actors have to understand and approve it.

A final conclusion of the findings from the UIW-project is that, although there are signs of the growing importance of environmental sustainability in the activities of companies in the durable goods area, in most cases the main objectives driving the companies to adopt upgrade business are still in line with more traditional service business objectives. Sustainability becomes a driver in business as a demand for sustainable products develops. This can be clearly seen in the crusher market in Cluster #2 and the boat market of Cluster #5. The different cycles in the circular economy will also compete with each other. Recycling of materials is already a huge business and for some raw materials like copper, a significant part of the material is already recycled (European Copper Institute 2016). Thus, upgrading is not only competing with virgin materials, but with recycled materials and from an environmental point of view, the benefit of using upgrades is the prolonging of the cycle. For the OEM companies the role of upgrading business alongside the original equipment manufacturing will change as margins from upgrading outperforms margins of original equipment manufacturing. In this situation, production of new equipment aims mainly at growing the market base for upgrading. In remanufacturing, the difference from recycling is the saving of energy as part are reused without heavy processing.

For OEM companies focusing on original equipment manufacturing changing to an upgrade business model based on ownership of the equipment, major changes in the capital structure are required. Building and owning the original equipment absorbs huge capital, while inbound cash flows will initially be low and gradually increase as business grows. In many companies, especially SMEs, these changes are likely to require renewal of the funding structure and possibly also the ownership of the company.

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