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# A DECISION SUPPORT APPROACH FOR MODELING SUSTAINABILITY CONSEQUENCES IN AN AEROSPACE VALUE CHAIN

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## ABSTRACT

Next generation jet engine technologies are typically driven by performance, value and environmental challenges, and appropriate technologies are developed in international research programs. One on-going engine component technology project at an aerospace component manufacturer aims to develop an engine with less fuel consumption. A likely consequence is higher pressure in the core engine, which leads to higher temperature. One way to handle the higher temperature is using a more advanced Ti-alloy for the product component, which will render a different sustainability profile. One weakness in current decision situations is the inability to clarify and understand the "value" and "sustainability" implications compared to e.g. performance features of concepts. Both "value" and "sustainability" include a rich set of features important for successful introduction of new products and product-service solutions to the market. The purpose with this research is to provide decision support for companies in early development phases for assessment of value and sustainability consequences over product-service system lifecycles.

A workshop was held with the aerospace component manufacturer and a value chain partner focusing on material handling, to: i) get a better understanding of activities, flows and ownership related to the studied materials at the two companies, ii) to understand the companies' perspective at new suggested scenarios with regard to these materials, and iii) define relevant scenarios to look into more in depth from a sustainability and value perspective. Three different scenarios were developed with differences in ownership, responsibilities and value streams. It is therefore essential to be able to quickly assess and optimize consequences of such alternative scenarios.

Based on the workshop experiences and scenarios, a modeling and simulation approach to assess sustainability and value consequences for the scenarios is proposed. The sustainability consequences are based on a sustainability life cycle assessment and a risk assessment. Key features of the proposed tool include: consideration of the time dimension, societal sustainability consequences, risk assessment, company value assessment, and cost/revenue perspectives.

## INTRODUCTION

Highlighting two of the perhaps most influential trends in aerospace and aerospace manufacturing would be the challenges related to what is referred to as the un-sustainable society, and the shift to a globally competitive marketplace. The first challenge raises the importance to understand and act upon global conditions that fundamentally changes the conditions for our living in general and flight operations in this case. The second challenge further increases the need to find innovative ways to compete and truly understand the value proposition of the solutions being offered.

Common to both these observations is that decision support in product development is difficult due to either the in-completeness of information or the difficulty to quantify consequences of what these trends actually mean in practice.

### Sustainability Aspects in the Aviation Industry

Sustainability is a significant driver and will influence current and future solutions within the aeronautic industry. This is evident as the Advisory Council for Aeronautics Research in Europe (ACARE) has developed a Strategic Research Agenda (SRA) for aeronautics in Europe, with the means to guide and coordinate research initiatives. In the Strategic Research Agenda (SRA)-report [1] it is stated that there is a need to reduce the environmental impact of aircraft and associating systems during their lifecycle; from operation, maintaining, manufacturing to the disposal phase. Also in the SRA2-report [2] some targets have been even more emphasized and the "Ultra green air transport system" is one of the high level targets.

At the component manufacturer, which develops, produces and maintains aero engine products, efforts to reach the strategies of ACARE have turned into concrete targets on product functionality such as lighter weight, noise reduction, emission reduction and high reliability. New fuels, new design to reduce fuel burn, and new flight routes are also important aspects to consider for reduction of the environmental impact from airplanes in operation [3]. When full life-cycle responsibility is added, not only from an environmental but also from a social perspective, and from material extraction, via production and use, to component scrapping, the complexity increases even more. There is a challenge in being able to optimize these aspects and at the same time be competitive on the market, possibly also in finding new ways to be competitive using sustainability as a driver.

Fuel saving or alternative fuels are the focus of many research studies to improve the sustainability parameters for aviation. Different technologies, for example air-to-air refueling [4], design solutions such as open-rotor [5,6] and environmentally friendly propulsion systems [7] as well as flight routes [8] are proposed as a route towards sustainability.

### New Innovative and Improved Product Technologies

One way to address the sustainability challenges is to introduce new technologies that are more efficient and have lower environmental impact for a certain performance than existing products. Next generation jet engine technologies are typically driven by performance, value and environmental challenges, and appropriate technologies are developed in international research programs. One on-going engine component technology project at an aerospace component manufacturer aims to develop a more fuel-efficient engine. A likely consequence is higher pressure in the core engine, which leads to higher temperature. One way to handle the higher temperature is using a more advanced Titanium (Ti) alloy for the product component, which will render a different sustainability profile due to the potential availability problem of some metallic elements in the future.

The potential risk of limited availability of alloy elements is one sustainability consequence that is of concern for the aviation industry. An example is described in a case at GE Aviation, where challenges of using rare metallic element, i.e. rhenium, became evident and demanded a new approach for material development [9]. The aircraft company Boeing has also presented a proactive approach with the mission to create a closed-loop Ti cycle within their value chain [10]. To get an overview of which alloys that are of concern for the technology programs, an availability assessment of the alloy elements can be conducted by using so called 'future contamination factors' [11] and checklists of supply risks [12]. To do an even deeper assessment the element's abundance, i.e. abundance of different elements in the lithosphere provides an indication of the scarcity of different elements on a global scale, and life cycle data of the elements need to be investigated.

### Business Model Responses to These Challenges

New innovative solutions can open up from understanding the material flows in combination with the value flows of how products are developed, manufactured, operated, maintained and re-cycled. The legislative aspects are also driving in this direction e.g. "Extended Producer Responsibility" (EPR) and "Registration, Evaluation, Authorization and Restriction of Chemical substances" (REACH). Businesses are responding to this by exploring ways to shift responsibility within the value chain and more refined controlling of aspects contributing to un-sustainable solutions. The incentive for companies to avoid costs and find new business opportunities based on new or emerging conditions is attractive. A simple example is the expected scarcity in physical resources of not only fossil fuels but also raw materials (e.g. for aircraft engines). Re-cycling, re-manufacturing and more efficient materials handling are likely to increase in importance [13]. So, keeping rare materials in closed loops within value chains will likely be attractive from both sustainability and value perspective. In aerospace closed material loops might help provide access to high value materials that otherwise are at risk for becoming degraded or spent when traded on the general metals market. So, what are the business model consequences of these new perspectives?

Product-service systems (PSS) have been proposed as a solution to both of the sustainability and the innovation challenge [14-15]. Initially, the concept of PSS stressed linking hard and soft elements, e.g., technology and sociology, products and services to target environmental problems [15]. This transition from goods-dominant logic to service-dominant logic involves a radical change both in how products are offered [16] and in the way they are designed and developed [17,18]. The focus of the design activity shifts from the definition of new products to the re-organization of existing elements based on new needs and values [19]. This leads to a growing need to include service activity in the design space [20]. This implies that developing a PSS is more than simply choosing the best technical solution; it instead requires identifying the preferred combination of products and services that enable maximization of value for customers and stakeholders, which may also include more thoughtful consideration of property rights than is common in industrial practice currently [21]. With the expanded life cycle commitment that PSS-focused development promotes, there is a need for more robust decision support that gives a common view of sustainability and value aspects over the value chain.

### Sustainability Decision Support

Many approaches and support tools for sustainability aspects in product development have been developed over the recent decades. Generally, existing approaches for sustainability focus on certain aspects of societal sustainability challenges, e.g. Environmental Management Systems (EMSs) [22], Cleaner Production [23], Factor 10 [24], Eco-design or Design for Environment [25-28], Life-Cycle Assessment (LCA) [29-31], a Framework for Strategic Sustainable Development (FSSD) [27,31-33], a Method for Sustainable Product Development (MSPD) [34], Templates for Sustainable Product Development (TSPD) [35], and a Sustainability Life Cycle Assessment (SLCA) Matrix ( [31,36], also called Strategic Life Cycle Management (SLCM) in previous research.

Recently, the SLCA matrix has been adapted for PSS development [37]. That study indicates that rightly adopted the new approach is capable of strengthening the strategic sustainability focus of PSS development in industrial practice. This is also supported by a case study where the long life light tubes producer Auralight International [38] successfully used the SLCA Matrix to map the ecological and social sustainability aspects when a PSS approach was explored for long-life products. Could this new SLCA approach then be a basis also for a new computer based decision support needed to visualize sustainability and value consequences over value chains?

### Decision Support for Value Chain Collaboration Around PSS Development

The mechanical engineer's toolbox for working with the engineering design is typically a set of CAE (Computer Aided Engineering) tools. The evolution of computational software for performance analysis (Computational Fluid Dynamics, Multibody Dynamics, etc.) has had great attention to the development of algorithms, mathematical formulations, and in general, functionality required to model different physical mechanisms. This evolution, irrespective of field of application (mechanical engineering, construction, etc.), is still important, but there is also a need for a broader view on how simulations are used in a business perspective to support new product development. That means utilizing simulation to guide what to develop rather than focusing on if the developed product does not fail regarding performance, hence the interest in simulation driven design for PSS. So, challenges are now more on validating the methods used for virtual verification, realizing multidisciplinary simulation, and taking into account the complete product life cycle including disassembly and remanufacturing [39].

In the case of PSS an interest has increased when it comes to model and simulate the functions and processes related to systems where the products are designed. Where it comes to providing functions, this means modeling and simulation of the integrated design and development of hardware, software and services.

### Simulation Support

The advancement in the simulation software area has now reached a stage where, for example, Finite Element Analysis (FEA) can be used by designers in regular design work. Simulation software supports the design engineers' to achieve their goal, which is to develop a product. Adams and Askenazi argue that there is a gap between the area of engineering design and traditional computational engineering. The advancements in simulation software make it possible to fill that gap with a new professional role, a design analyst; who is neither a designer nor an analysis specialist, but something in between [40].

For manufacturing process parameters, the preparation lead-time is still a bottleneck for early phase design. Prasad [41] addressed a challenge to "Consider manufacturing constraints up-front e.g., during a conceptual stage of a product development process". This challenge today is due to the time to generate advanced analysis models, each requiring several weeks to build. To predict product properties engineers build different models. FE models are one type of model. Depending on what kind of FE model the time to generate them can span from hours to weeks. Important product properties needed early are quite often dependent on models that are time consuming to generate, creating problems during the earlier phases when the time pressure is greater.

Here, knowledge based approaches; Rule-based simulations, e.g., Knowledge Based Engineering (KBE) [42], have been used in industry to reduce time spent on design by automating routine tasks. KBE tools that have been developed within industry are used as internal company specific design support tools that almost never reach outside company walls. KBE tools are also closely coupled to the specific knowledge for solving engineering specific problems and, by tradition, bound to geometry modeling. By looking outside the computational side of design and bringing in engineering design methodologies and knowledge rich strategies, knowledge enabled engineering [43] can be reached. The aim is to capture both the formal design knowledge and the tacit, unspoken knowledge to aid the design process, allowing for both products, services as well as process components to be captured, modeled and used.

 

Once representing the PSS as a model, it can be designed, defined, modeled, simulated and evaluated. It is possible to 'engineer' the PSS, and an interesting method for increased customer involvement during the complete development process is suggested by Campbell et al. [44]. The challenge is how to represent the properties of services since we may no longer mean dimensions and tolerances of physical artefacts. A systematic approach that incorporates customer operations, based on quality management, is suggested by Schmitt and Hatfield [45], much in line with Grönroos [46] and Fransson [47], pointing out how the provider can take advantage of learning from customer use by for example making invisible services visible. Tools for PSS can be based on combinations of product models and service model, such as the product-service hybrid pyramid presented in Fritz et al. [48]. The need to model and simulate different value-adding activities arises.

## RESEARCH METHODOLOGY

The objective of this paper is to answer the following question: Is it possible to generate relevant scenarios of activities, flows and ownership in the value-chain with the objective to keep valuable materials in a closed-loop system. The purpose of this work is also to give an introductory approach to a decision support tool for companies in the early development phases to be able to model and simulate life cycle activities for valuable materials in the value-chain.

A case is described with two actors in a part of the value-chain of the aviation industry to define relevant scenarios of activities, flows and ownership with the purpose to find the most optimal scenario of keeping valuable materials in closed loops. In this case, a new Ti-alloy, Ti-834, was being considered for use in future jet engine components to meet the higher temperature requirements. To clarify and build different material-loop scenarios is interesting as it might be of economical value to the jet engine manufacturer, dependent on the potential availability risks of the alloy elements.

An availability assessment of the Ti-834 alloy element was therefore conducted using the future contamination factor index [11] and the supply risks checklist [12]. Also the element's abundance was investigated. This assessment was described and used as a background and incentive to build possible closed-loops systems for the material alloy.

Individual interview meetings with the project leader, the purchaser and the material engineer at the manufacturer were conducted, in addition to two workshops with the companies. At the workshops it was a mixture of different roles in the workshop groups: environmental engineer, procurer, project leader, product development specialist, material specialist, product developer, business developer, chemicals expert, manager. The objectives with these meetings were to: i) get a better understanding of activities and ownership regarding materials at both companies, ii) understand the companies' perspective of some suggested scenarios of activities and ownership regarding materials, iii) identify some relevant scenarios to look into more in depth from a sustainability perspective, and, iv) identify some features of a new decision support tool for assessment of value and sustainability consequences over product-service systems.

## RESULTS

### Alloy Availability Assessment and Scenario Creation

Based on the availability assessment it was found that the Ti-alloy 834 contained Molybdenum (MO), Niobium (Nb) and Tin (Sn) that are scarce in nature, and have a high risk to contribute to contamination in nature. It was also shown that because of their scarcity and location, there is a future supply risk for some of the elements, e.g. Mo and Nb, that might influence the cost for purchasing and managing these alloys. When this information was given there were incentives to find solutions for: i) material efficiencies, i.e. reduced scrap production and optimal scrap management (which directly could give reduced costs); and ii) material availability, i.e. make sure there is enough (or affordable) amount of the alloy in the future for the product during the total manufacturing period. In this case, it means a period of 30-40 years. The focus of this case study was to investigate possible solutions around material availability and several aspects were discussed such as *how to secure material flows, how to build reliable cooperation with suppliers and customers*, and *decide of optimal owner solutions of activities, products and services*. From these discussions scenarios of activities and ownership regarding materials were created.

### Scenarios of Activities and Ownership Regarding Materials

The research team gave five scenarios regarding possible future value chain configurations. These were suggesting: i) changing roles of value chain actors; ii) extent to which the value chain maintains materials in a closed loop; and, iii) the implications of that for necessary roles within the value chain. The scenarios were illustrated and summarized in a diagram (Fig. 1) with the axis:

x - actors owning material over product life cycle
y - level of involvement of one of the actors

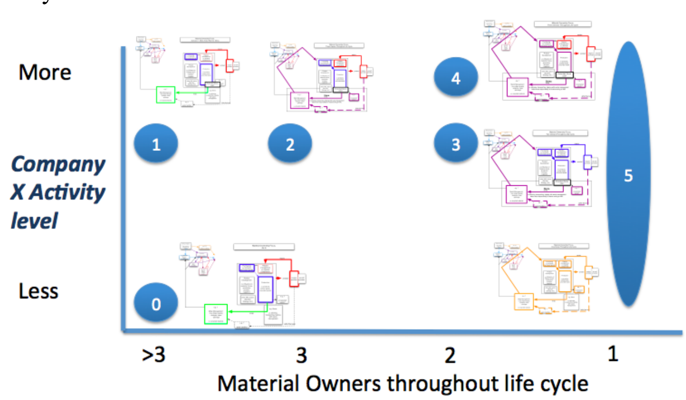

**Figure 1. Possible scenarios depending upon material handling company's level of activity and the number of material owners throughout the product's life cycle.**

The result from discussions at the workshops was to select for additional consideration three of the five scenarios with differences in ownership, responsibilities and value streams (Fig. 2). These were selected as these were considered to be most realistic for the two companies.

The first scenario suggests that the materials handling company has more responsibility in helping out in sorting and optimize the recycling process at the manufacturer, but the ownerships aspects remain as today. The companies argued for this scenario as they could see a short-term economic incentive to reduce material losses and become more efficient in how they manage the material.

The second scenario reduce the owners to three, which means that in addition to that the materials handling company takes a larger responsibility of the material sorting process they or someone of the material suppliers take the ownership of the material throughout the recycling process of the material. This scenario could be of interest if there is a clear incentive to keep the valuable material in closed-loop within the industry. Otherwise they sell to the market where they get the best price.

The third scenario is the same as scenario two in terms of the recycling flow of the material but this scenario also suggest a reduction of material owners to only two. Here the manufacturer is the owner of the material and takes back the product component after use, i.e. possibly by selling the function and do remanufacturing of certain parts. The incentive for this scenario is if the same alloy is used during the product's long market life (in this case 30-40 years). Some incentives for this scenario that need to be considered is for example, the likelihood for the company to shift from producing artifacts to delivering services, the likelihood that tougher legislation or requirements from customers will require closed material loops and reduce material degradation. However, there may also be disincentives for this scenario that need to be considered, for example the likelihood for new materials to be introduced and replacing the alloy.

Based on the workshop experiences and scenarios a need was identified to be able to quickly assess and optimize consequences of these alternative scenarios. A modeling and simulation approach to assess sustainability and value consequences of a given PSS scenario was suggested. The features of such a decision support tool was identified in the workshop groups to be able to provide support in:

- Identifying when in time the different scenarios may be most profitable to introduce
- Identifying potential sustainability consequences from the different scenarios
- Doing a risk assessment to estimate the potential costs for the sustainability consequences identified
- Doing a value assessment to estimate value aspects of different scenarios

These features will be used for simulation to explore the consequences of these scenarios.

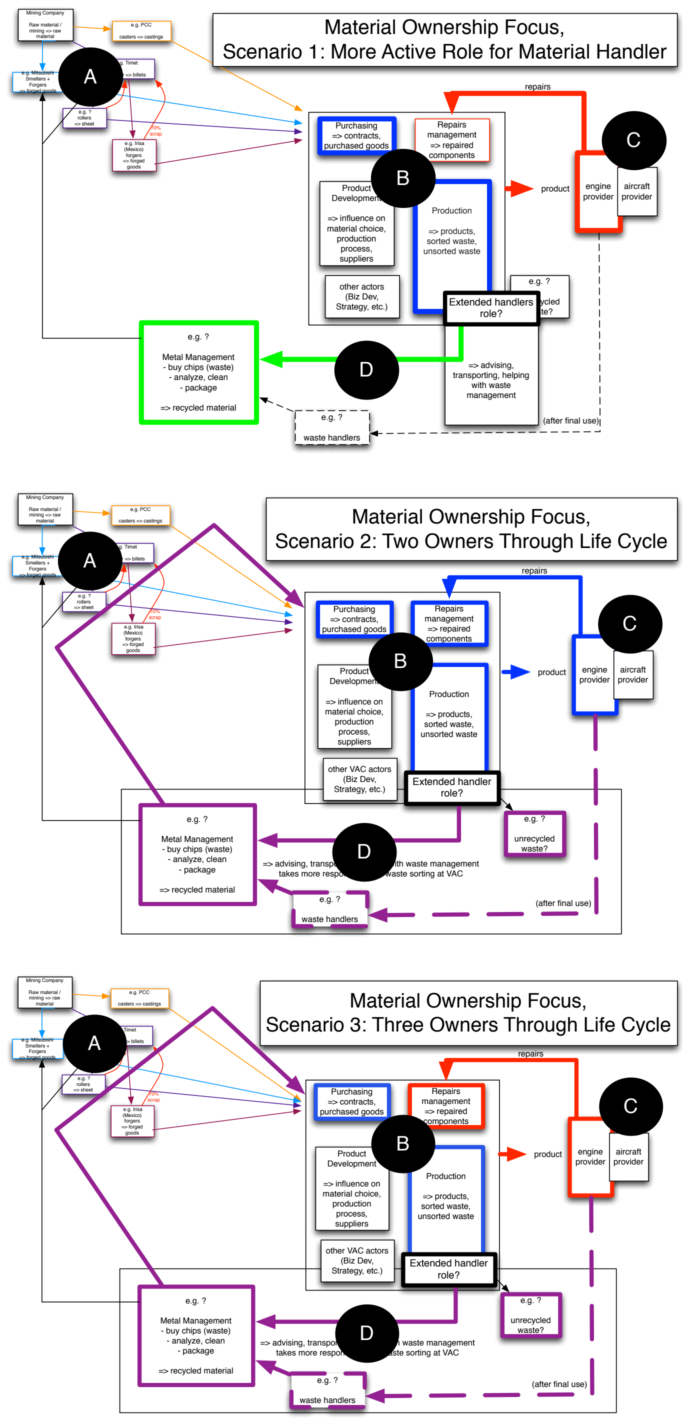


**Figure 2: Three scenarios showing alternative value chain configurations. (A: Raw material producers; B: Engine component manufacturer; C: Engine manufacturer; D: Material handler)**

### A Decision Support Approach for Modeling Sustainability Consequences in an Aerospace Value Chain

The main parts of this model and simulation based decision support approach, illustrated in Fig. 3, have four areas (Risk, Timing, Value, and Sustainability) which need to be clarified to support decisions through quantitative measurements. For the users, e.g. product life cycle manager, procurer, service developer, project leader of product development team, there is a process of steps to go through.

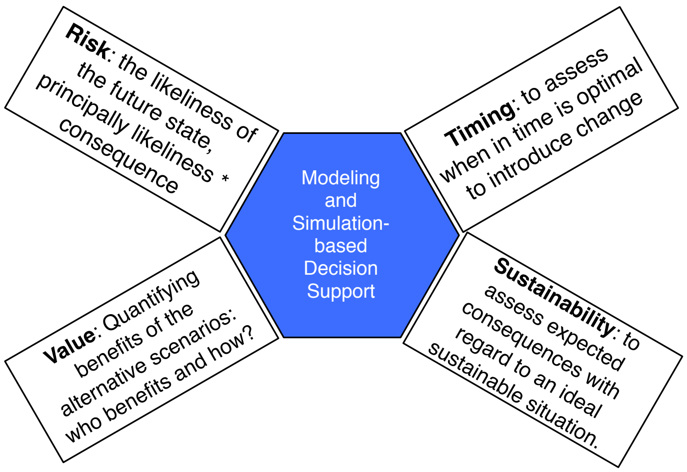


**Figure 3: The main parts: risk, timing, value and sustainability consequences need to be clarified to support decisions through quantitative measurements.**

Steps that need to happen in a process:

- **Stakeholder Analysis**: Identify who is going to participate.
- **Foresighting**: Identification of critical sustainability aspects with product concept. For material alloys an availability assessment need to be done to see if there is incentive to investigate further.
- **Definition**: Identifying flows, roles, and dependencies. In this step, the current situation together with potentially attractive scenarios are defined in more detail including the flow of materials, the roles of the value chain actors with regard to the handling of that material, and other aspects that the value chain depends upon (e.g. an actor may have knowledge regarding material handling that a direct material-handling actor is dependent upon, despite not handling the material directly). The focus of this step is providing scenarios that are defined sufficiently to move into detailed analysis.
- **Identification of business scenarios**: A discussion regarding possible future value chain configurations around changing roles of value chain actors and extent to which the value chain maintains materials in a closed loop and the implications of that for necessary roles within the value chain. The scenarios are plotted and visualized to get overview of scenarios.
- **Mapping out life cycle activities:** This step begins by mapping out in detail the life cycle activities (raw material production, production, use and maintenance, end of life) of the value chain in each scenario. Since the industry here (aerospace) has products with quite long timeframes, activities that recur periodically throughout the product life on the market will be listed as separate activities since the sustainability or value implications may change over time.
- **Classification of sustainability hotspots:** Use an SLCA Matrix (Fig. 4), mentioned in the introduction (Sustainability Decision Support) and in [37], to identify sustainability-related hotspots, the implications of which should be explored in more depth. The assessment ranking are considered from two perspectives: (1) relative (i.e. the sustainability aspects of a proposed scenario relative to the base case) to know if a scenario is better or worse than the current value chain configuration, and, (2) from a "full sustainability" perspective (i.e. the sustainability hotspots of a proposed scenario relative to first-order principles (requirements) for a sustainable society – see [31-32] for an explanation) to know the longer-term implications of the scenario in a sustainability context. The sustainability assessment needs to be repeated as various activities are updated during the product life on the market.

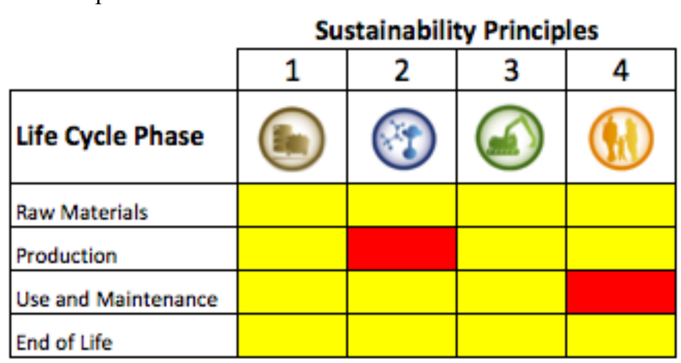


**Figure 4: A schematic example for the case of a Sustainability Life Cycle Assessment Matrix**

- **Classification of value dimensions:** This step identifies what needs to be considered in order to model and simulate the value aspects of the scenarios. The value assessments in this case are performed via availability and price of materials, and also value chain impacts of changes. This step could conclude when the sustainability and value dimensions are sufficient to initiate quantitative modeling activities. A value assessment matrix is used (see Fig. 5).
- **Classification of risks based on sustainability hotspots:** To be able to estimate when it will be economically beneficial for the company to change

from one scenario to another a risk assessment will be performed for each sustainability hotspot of the whole product market life. The Risk Assessment should be based on possible consequences, the likelihood of these to happen, and estimated costs if they happen. The reason for adding an assessment step is that it could enhance a comparison with other risks, and facilitate the communication of the result within the company and in the value-chain. The value assessment needs to be repeated as various activities are updated during the product life on the market.

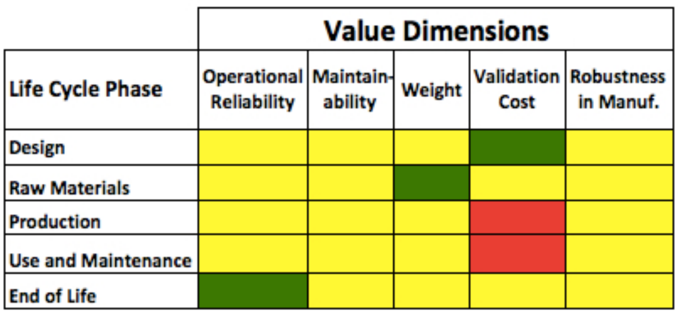


**Figure 5: Schematic example for the case of a Value Assessment Matrix**

- **Quantification and simulation of sustainability and value-driving activities**: This step is a simulation model and the expected outcome from using the tool will support the user from a communication point of view between collaborative partners in a value chain and as a means to assess the implications for each company's decision process. The exercise of making assumptions and restraints explicit and their consequences clear enabled collaborative innovation. This step includes:
  - o Prepare data for execution, e.g. data (quantities of material flow, value, sustainability impacts, risk, costs, etc.) is made available to the computer modeling environment.
  - o Define goals of simulation, e.g. decide what the intended outcome of the modeling exercise is, i.e. to [reduce/maximize/optimize] [value/energy/CO2 emissions].
  - o Select modeling / simulation method based on objectives and data available.
  - o Run simulations.
  - o Interpret and analyze model results with respect to defined goals, i.e. use model results to support decisions being taken.

## DISCUSSION

### The Modeling and Simulation Approach

The case presented here started out with a product component concept evaluation with the question, which Ti-alloy to use? Material choice questions are mainly decided upon the mechanical properties of the material together with known prices and availability prognoses. This essentially leads to product development questions being driven by responses to the questions: *Does the proposed solution provide the required function? Can the proposed solution be produced? Will the proposed solution be profitable?* However, when value estimates are made for proposed solutions, they are (often) primarily based upon current value chain configurations. A key aspect in this case of Ti-alloys is that one alloy that is not considered attractive in the future with the current value chain configuration may become more attractive if a different value chain configuration is considered. If, for example, an alternative value chain configuration allows for closed-loop management of a high-value alloy that would support maintaining purity of that alloy. Thus a material-based question that is frequently addressed through the modeling of a technical product system may benefit from an approach that includes modeling and simulating the value chain configuration.

Despite the fact that both sustainability and value consequences are difficult to quantify in early phases, the authors argue that merely adopting a modeling and simulation approach drives the process of improving the decision base in a preferable way. Undergoing the proposed steps forces the actors to make explicit assumptions, restraints and statements rather than allowing them to remain implicitly inherent in high level statements. This approach does not explicitly specify the modeling approach to be used; rather, due to the complicated nature of the sustainability problem, a holistic approach enabled by sustainability principles is proposed. This is in contrast to many other modeling approaches that adopt a simulation approach more directly. Correctly implemented, the focus turns to the quality and completeness of data and assumptions made in the underlying model. In several cases, such data can be systematically improved, i.e. moving from opinions and intuitions to evidence-based statements.

A critique, and a natural risk, is that quantification of ill-defined concepts in early phases may give a false impression of more precision than actually exists. In the model and approach proposed this is acknowledged and the way to implement the decision support is initially via the risk analysis process, simply since risk analysis inherently deals with uncertainty. Once matured, the natural next step is to align the methodology with a robust design strategy, as statistical approaches are more suitable to handle uncertainty from a mathematical point of view.

### Risk-Value-Sustainability

Risks related to sustainability have been considered to have a significant impact on businesses according to WBCSD, 2004 [49]. Gaziulusoy et al. state that if the company understands how the actions of product development, on an operational level, are connected to company strategy and put that in a context of a vision for a sustainable society, a proactive behavior to address sustainability issues in companies can be encouraged. An awareness of sustainability risks for their business will function as an incentive to identify new technological and organizational innovation opportunities [50]. In parallel to risk estimation added value aspects and measurements of these can generate strong incentives for a change and support in a decision process.

### Value Driven Design for PSS

"Sustainable Value" (SV) is a concept put forth by Figge and Hahn [51] and used on the European scale [54] to arrive at a "return to cost ratio" that considers firm value relative to traditional environmental indicators as costs. The validity of this approach has been recently debated [53-55]. It is not yet clear how the approach proposed here might relate to this SV approach, which is targeted at the firm level. Aspects may be relevant or useful in the latter steps of the here proposed approach, despite this approach taking a perspective of a product and related value chain perspective, rather than a single firm perspective.

Shifting towards PSS, value is also becoming a more dominant driver and here Value Driven Design [56], VDD, is an interesting concept for PSS development. VDD is a system engineering strategy promoting the use of multidisciplinary optimization in design. VDD "is not a new method, process, or tool for design. Rather, it is a framework against which methods, processes, and tools can be assessed." VDD impacts the way in which designers deal with extensive attributes (i.e., in those attributes of a complex system whose value is a function of the values at the component level) [57]. In a VDD approach, objective functions need to be cascaded down to each component and the status of component attributes need to be monitored together with the status of system attributes to drive appropriate actions to maintain a balanced system. The VDD process is described by Collopy [56].

### Simulation Driven Design for PSS

Several recent examples exist on the developments of simulation driven design support for PSS recognizing value. Simulation supported service integration in engineering design environment for the purpose of PSS development have been displayed by Boart [58] and was further developed as decision support via a design automation approach [59]. Also including value assessments, and hence introducing the possibility to use other values than engineering values was introduced via the applications in aerospace sector [60-62]. The design automation approach opens up for value assessments of other values, e.g. ilities (flexibility, adaptability, etc.) and intangibles, since it visualizes the value contribution of the design alternatives against six main value dimensions: performance attributes, risk, profitability, operational performances, ilities and intangibles [63].

## CONCLUSION

This paper argues that a modeling and simulation approach can be adopted very early, from the initial exploration of alternative value chain configurations. In this case, two traditionally vague, yet important, areas (sustainability and value) are explored from a decision point of view. The key question is: *What alternative business models do we have and what can be said about these from the sustainability and value points of view?* Generally, the proposed decision support tool guides the user to follow the steps:

- Stakeholder analysis
- Identification of critical sustainability aspect with product concept
- Identifying flows, roles and dependencies
- Identification of business scenarios
- Mapping out life cycle activities
- Classification of sustainability hotspots
- Classification of value dimensions
- Classification of risks based on sustainability hotspots
- Quantification and simulation of sustainability and value-driving activities

The actual simulation of life cycle activities for valuable materials is on-going work.

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