TOWARDS ASSESSING THE VALUE OF AEROSPACE COMPONENTS: A CONCEPTUAL SCENARIO

Marco Bertoni[1], Christian Johansson[1] and Alessandro Bertoni[1]
(1) Luleå University of Technology, SE

ABSTRACT
The development of complex products, characterized by long lifecycles and deep supply chains, requires enhanced capabilities to assess, in an early design stage, the value of a solution not merely from a requirements fulfilment perspective. The paper proposes a conceptual scenario, described in terms of activities, inputs, outputs, actors and mechanisms, which details how aircraft components can be developed and assessed with a focus on their value contribution at system level. Moreover, the paper proposes an approach to communicate the lifecycle value contribution of design solutions across a heterogeneous set of value dimensions, drivers and criteria, directly through 3D CAD models. The scenario, together with the methodological and technological tools enabling value assessment, has been created and preliminary validated together with major European aerospace manufacturers.

Keywords: Value driven design, Decision making, Knowledge maturity, Value visualization

1 INTRODUCTION
All designs are created for a purpose. When dealing with “tame” problems [1] only, such purpose is well mirrored by the product requirements, which often provide a good enough basis to identify the *best* of the available design alternatives. However, when paying increasing attention to “wicked” problems [1], the capability of a solution to add value to customers and stakeholders is more difficult to be assessed without explicitly linking the product features to the initial needs and expectations. In this context, measuring requirements satisfaction is no longer sufficient to assess the “goodness” of a design, therefore the technical product performances need to be complemented by more qualitative criteria to better understand the value of a solution from a system and lifecycle point of view.
When collaborating with several partners for the development of new products/services, the initial purpose is often lost when the requirements are cascaded down to suppliers and sub-contractors. Hence, the sub-system manufacturers tend to target local optimal designs minimizing the costs, rather than to comprehend how a radical innovative technology might add value to the overall system and to the different customer levels.
This issue is particularly evident in the commercial aerospace business. Comfort, timeliness, entertainment and environmental consciousness are emerging driving forces in new aircraft development programs [2][3]. On a more technical level, this demands for altered functions in the engines to improve the efficiency in energy use [4], which turns into new requirements for the engine sub-systems and components.
At component level, a good understanding of the intended use of the forthcoming solutions (i.e., of the purpose of the system) is crucial to realize the relative importance of derived requirements and, eventually, to make the right decisions on the technologies to be developed. Not communicating such purpose to the designers increases the possibility of generating sub-optimized solutions adding un-necessary risk and costs to the entire system. The development of value-assessment capabilities can support the sub-system manufacturers in better satisfying the “needs that matter”, avoiding large, expensive, and ultimately unsuccessful redesign cycles at all levels of development.

2 MOTIVATIONS AND OBJECTIVES
Nowadays, raising the designers’ awareness on the overall value delivered by radical innovative design solutions at component level is a major challenge for the aerospace sub-system manufacturers. The concept of value is far more difficult to manage and communicate than technical- and cost –related information, and the knowledge used for calculating the value contribution of a solution is less intuitive to formalize, access, validate and share than other product properties [5].

This calls for a methodological and technological approach to simulate and communicate, in an objective and transparent way, the value contribution of alternative design options and technologies early in the product development process. The objective of the paper is to propose a conceptual scenario, described in terms of activities, inputs, outputs, actors and mechanisms, which details how design concepts at component level can be developed and assessed with a focus on their value contribution at system level. The scenario is mapped against the Stage-Gate® process developed by Cooper [6], and highlights how the design activity needs to be complemented when introducing value as main measurement criterion in an early stage. Furthermore, the paper describes an approach to communicate the lifecycle value contribution of design solutions directly through 3D CAD models, as a means to enable more value-driven, lifecycle-oriented, decisions during conceptual development.

3 METHODOLOGY

The research can be methodologically likened to action research, which is commonly described as a set of iterative activities performed jointly by practitioners and researchers [7]. The value assessment approach proposed has been developed within an European Commission's Seventh Framework (FP7) Programme project, which has provided access to several aerospace companies (i.e., major aircrafts, engines and sub-systems manufacturers and other companies with experience in aerospace development projects).

Action research follows a particular diagnosis, invention and reflective learning cycles [8], which is aligned with how the authors have performed the research in the project. Empirical and qualitative data have been collected through the authors' active participation in physical and virtual work-meetings with the industrial partners. The discussions with the aerospace companies in the diagnosis stage have contributed to the clarification of the problem domain, to the definition and validation of the scenario and to the development of the visualization approach. Reflective learning has been aided by the continuous participation in debriefing activities, held by the research team in relation to the work-meetings. The findings have been iteratively discussed and validated with the project partners, which have actively participated with their knowledge and expertise to the development of a preliminary mock-up for value assessment and visualization.

4 EMERGING DECISION-MAKING ASPECTS IN PRELIMINARY DESIGN

Stage-Gate® [6] is a common process in aerospace to guide the development projects from idea generation to product launch. The key components of the Stage-Gate® are the *Stages*, where information-gathering activities (summarized by deliverables) take place, and the *Gates*, where information is assessed and decisions are made.

As identified in previous research [9], the deliverables brought to the *Gate* meetings include summary documents, criteria documents, design rationale documents, technical reports, analysis results, and test reports, as well as the tacit knowledge of the people performing the work. Yet, the empirical study shows that value-related information is not reported at the gate in a clear, transparent manner, thus value-oriented decisions are difficult, because lacking of adequate supporting documentation.

4.1 Value Assessment

Considering that every system exists to deliver value to stakeholders [10], at the time of making a decision the analysts need to establish a link between the technical parameters and the customer value, in order to identify the *best* alternatives. As pointed out by one of our contacts in the aircraft engine manufacturing business, today the advantage of a solution is mainly expressed by technical performance figures and cost: "*Nowadays you can easily tell why a solution is the optimal one in terms of performances, however it is not straightforward to see if it is optimal also from a value perspective. Hence, we have to look at people, tools, processes for developing the optimal solution both from a business as well as customer viewpoint*".

In spite of the centrality of the value concept, in literature there is a wide diversity of opinions and many speculative assertions on the real meaning of value, and on how decision makers should assess and trade-off design concepts against value-related criteria.

Value Driven Design (VDD) [11], for instance, aims to enhance existing systems engineering methods by "*introducing economics in the decision making process and enabling optimum solution strategies to be instantiated during the conceptual and preliminary design stages of a product*".

VDD can be seen as an overall scoring system, feeding a vector of attributes (*Extensive attributes*) into a function (*Value model*) with the purpose of producing a scalar number (*Surplus value*) to rank a design. Surplus value is a surrogate object for profit, which may take the form of Net Present Value (NPV) when the product generates revenues over long periods. Extensive attributes are attributes of the system being designed, or of its components, such as all performance attributes, reliability, maintainability, safety, cost, schedule and technical risk.

For a system characterized by high costs, a long lifecycle, complex interdependencies between its components and dynamic operational contexts, value is also determined by the capability to maintain or improve the function in presence of change [12]. Tradespace exploration [13] considers customer value embedded in the customer process context and utilizes various "ilities" [14] (i.e., *Survivability*, *Adaptability*, *Flexibility*, *Scalability*, *Versatility*, *Modifiability*) as criteria to evaluate the system robustness under changing operational conditions. The "Epoch" framework proposed by Ross et al. [12] allows the systematic creation of trade-space models to quantify these "ilities". Other valuation methodologies do exist (e.g., *Real options for flexibility* [15] [16]) but only for a few of these criteria.

Furthermore, value is often intangible [17], perceived by the customer as an individual rather than objectively defined by a provider [18]. Goods and services can be arrayed on a continuum of relative tangibility, with goods being more tangible and services more intangible [19]. Intangibles are often associated with knowledge, emotions and experiences, dimensions that cannot be experienced by the customer before using the product. Steiner and Harmor [20] have proposed an extended model of customer value, which includes intangible criteria (such as epistemic emotional or image value) to be used for assessing the overall value of a system in the beginning of a product development project.

4.2 Knowledge Maturity

Making a decision is often about dealing with trade-offs among conflicting parameters. Trade-offs are more difficult to handle as uncertainties in the problem definition and in the knowledge base increase. Relevant value knowledge is typically dispersed across many different functions in the organizations, it is often poorly formalized and agreed, rarely readily available, and difficult to communicate in a similar way as technical- or business-related product characteristics [5]. Moreover, value knowledge is mostly tacit, poorly validated and difficult to readily associate with the product in question. This means that the decision makers need to know, when analysing a trade-off, if the figures provided in relation to a given value criteria are reliable, or are based on flawed or missing information [21] (e.g., placeholder values [22]), as well as on assumptions lacking of completeness, trustworthiness, or accuracy [23].

Raising the awareness of what such flaws entail is a first step towards increasing decision makers confidence in the trade-offs they need to make. From a value perspective, it is necessary to critically evaluate the status of the knowledge on which the value model is built. Some of the questions regarding how to assess the readiness of information or how actionable the value-related knowledge are: How much trust can be put in the output of the value assessment activity? What is the level of completeness of the information used for the value calculation? Are there any uncertainties? What assumptions have been made? Is there any information missing? Are there needs for further developments of knowledge assets to contribute more clearly to the objective? Is there tacit knowledge to complement (or perhaps challenge) the formal documentation and how well is it aligned?

In these situations, there is a degree of uncertainty that needs to be handled, perhaps not by directly focusing on reducing the uncertainty, but rather by assisting the decision makers in achieving a better understanding of what those uncertainties, ambiguities, and assumptions actually involve [24]. The concept of knowledge maturity [9] is therefore crucial as a practical decision support for value assessment. The objective is to support decision makers in the process of challenging value-related assumptions, of evaluating cause-and-effect relationships and of assessing the accuracy, quality, stability, completeness, and relevance of value-related knowledge at hand. Knowledge maturity can increase decision makers' awareness of the knowledge base on which the value assessment is based and support cross-boundary discussions on the perceived maturity of available knowledge.

5 SCENARIO DEFINITION: VALUE ASSESSMENT OF AN IMC COMPONENT

In the future, aircraft engines are expected to become larger in diameter to increase the bypass flow, thus reducing fuel consumption and obtaining other desirable effects. Engines are also expected to support a More Electrical Engine concept [4], an innovative architecture that aims to replace electric,

hydraulic and pneumatic systems with one single, globally-optimised, electrical system, enabling the proper integration of propulsion and secondary power into the airframe.
In the light of these trends, it becomes less intuitive for an engine sub-system manufacturer to understand which component/technology might offer the highest value contribution in 10, 20 or 50 years. Considering, for instance, the development of an innovative engine intermediate case technology (IMC - Figure 1), engineers and designers must be aware, early on, of the impact of their design choices in a lifecycle perspective.

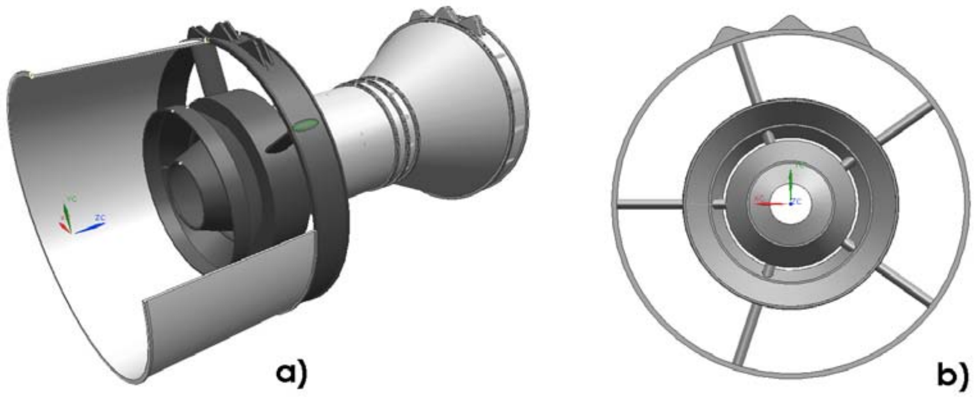

Figure 1: a) IMC (dark grey) position in the engine and b) IMC in a front view.

In the aerospace industry today, preliminary design decisions are strongly driven by requirements fulfilment. High/low cycle fatigue, limit/ultimate load capability, hale ingestion, strength and stiffness, corrosion, oxidation and creeps are the main criteria used for the evaluation of IMC concepts at the gate [25], complemented by cost/benefit analysis and feasibility/manufacturability studies. Targeting lifecycle commitments, these “traditional” dimensions need to be further complemented by criteria able to assess the “goodness” [26] of a design alternative from a system (i.e., assessing the impact on the overall engine/aircraft system) and lifecycle point of view (i.e., assessing the impact on the way the product is operated, maintained, serviced, dismissed, upgraded or recycled).
Moving from these needs, and using as a reference the IMC, the authors have developed a conceptual scenario aiming to support the design teams in making more value-conscious decisions in preliminary design. Figure 2 shows the set of activities, the actors and the related documentation that characterize the scenario, mapping it on the Stage-Gate® process adapted from Cooper [6].

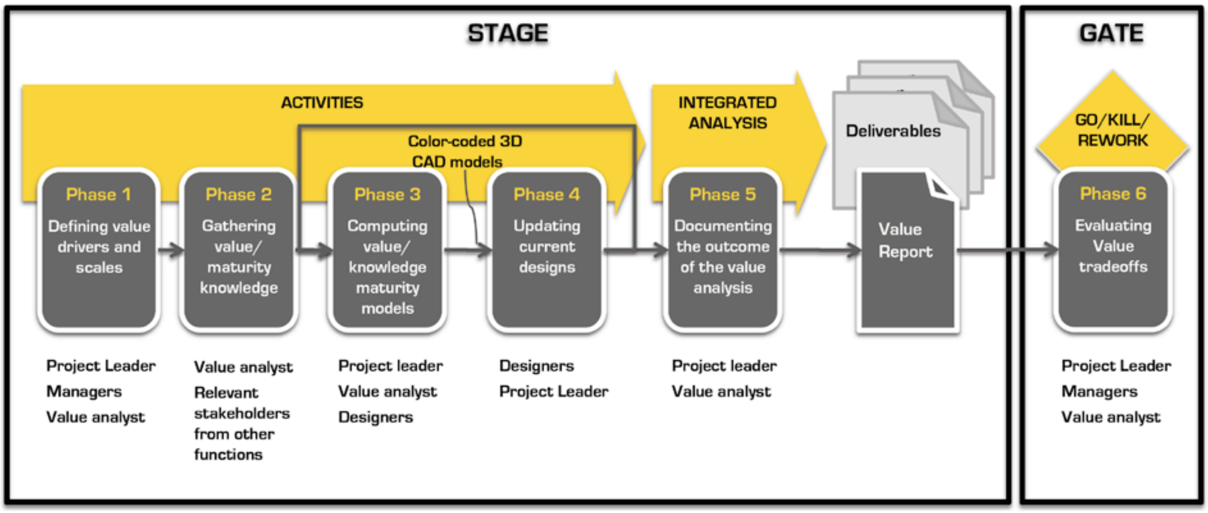

Figure 2: Scenario phases mapped into the Stage-Gate® [6] process model.

5.1 Phase 1: Defining value drivers and scales

The first activity in the scenario concerns the development and negotiation of the value drivers and scales, which includes the definition of a baseline (minimum acceptance level) and a target (ideal situation) for benchmarking the design concepts from a value perspective.

The project leader, together with the members of the management team, kick-off the development activity by detailing the project context and its metric, on the basis both of the requirements list received from the engine manufacturer and of the specific company's strategy and objectives. Once the high-level objectives are set, they are cascaded down to component-specific value drivers with the help of a value analyst. The value analyst is a key player in the scenario. While managers and designers are often too deep inside their own working field to have a complete understanding of the implications of a given technical solution, the value analyst possesses wide knowledge and a deep understanding of the dynamics of the product within the overall system and along its lifecycle.
Value drivers are defined from six generic lifecycle-oriented value dimensions, intended as generic value parameters applicable to products of different kinds. These criteria have been identified and developed together with the industrial partners to capture the main value aspects to be addressed by aerospace projects. They are: *Performance attributes*, *Risk*, *Profitability*, *Operational Performances*, *Ilities* and *Intangibles* [27].
The project leader and the managers, supported by the value analyst, specify each driver into criteria, which are more product-specific and directly related to the component under development. Given a value dimension *such as Profitability*, the team might define *machine commonality* as a relevant driver, which might be further cascaded down to criteria such as: *% of reuse of existing turning machines*. Similarly, the value contribution in terms of *Operational Performances* of two IMC concepts, such as Concept A and Concept B, might be evaluated, using *availability* as a driver and *Mean Time Between Maintenance, Mean Time Between Failure, etc.*, as criteria. Radar plots can be used to visualize and compare, using a scale from 1 to 9 and (baseline=3, target =7), the value contribution of different IMC concepts (Figure 3).

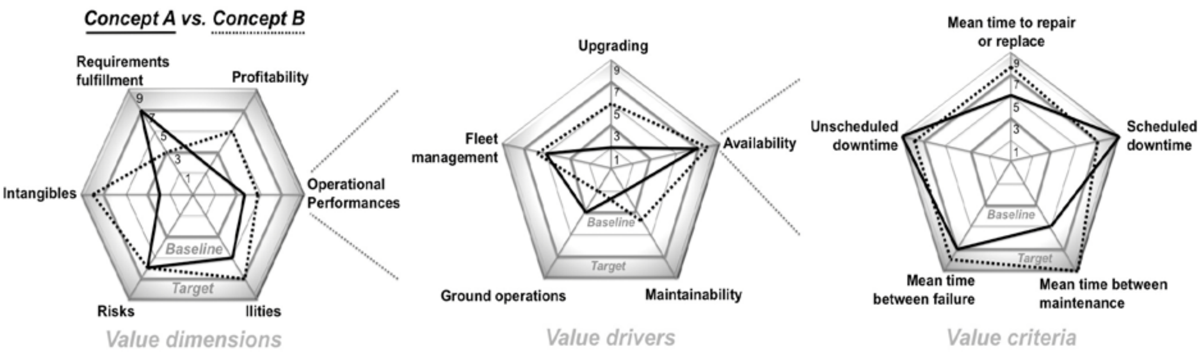

Figure 3: Comparison of two IMC concepts against value dimensions, drivers and criteria.

Some aspects of the product lifecycle may be more important then others, so the team has to assign weights to each dimension, driver and criterion, as well as a baseline and a target for each parameter, growing from the previous experience with the product in question. Weights, baselines, targets and the final value scales are reviewed by the stakeholders and accepted by the management, which sets the expectations for the next gate meeting. After the work is initiated, the Project leader communicates expectations (scales definitions and acceptance criteria) to the project team. If necessary, the project leader assigns resources, such as, additional expertise or additional manpower, to meet the acceptance criteria as closely as possible.

5.2 Phase 2: Gathering value/maturity knowledge from the later lifecycle steps

Once the value drivers, their weights and the acceptance criteria are set, the value analysts prepares the ground for the value assessment task, by establishing links with stakeholders and sources that might possess value-relevant knowledge to compute the value contribution of the sub-system.
The value assessment activity cannot be based merely on the geometrical, cost and sales information available within the company, but requires an additional set of models, owned by the customers, to be properly executed. In the IMC example, the value analyst needs to evaluate the IMC integration with the engine, assessing the impact of an IMC concept according to attributes such as payload, range, fuel burn, weight, reliability, maintenance cost, manufacturing cost. Furthermore, he needs to evaluate the impact of a solution at aircraft level, such as on the fuselage, wings, avionics, landing gears, etc. From an operational perspective, it is essential to provide a sound estimation of the expected airline

profitability, gathering knowledge about fleet size, turnaround time, overhauls, etc., and assess how a design alternative can contribute to leverage these parameters. Eventually, when possible, the value analyst might assess the impact of an IMC alternative in terms of intangibles, i.e., in terms of how a component can, mostly indirectly, impact on the passenger satisfaction, feeling and emotions.

Such models, when available, are typically dispersed within the extended enterprise. There are, therefore, severe challenges in identifying and sharing them in a satisfactory manner. Privacy, security, and interoperability issues are main inhibitors for an effective sharing, thus value assessment requires an enhanced degree of openness, trust and cooperation throughout the supply chain to facilitate the free exchange of information.

A feasible approach in this context is to treat the models as black boxes, i.e., sharing the location of a particular model and retrieving only the results of a particular calculation, without seeing how the model is configured. The concept of *black boxes* implies that an object is viewed only in terms of its inputs, outputs and transfer characteristics without any knowledge of its internal workings, that is, its implementation is "opaque". In this context, the concept of web services can offer a feasible solution by allowing the client (a company that is part of the virtual enterprise) to access a value model.

If value models do not exist, the value analyst needs to contact experts in the extended enterprise and, together with them, develop an ad-hoc model. In case the development of quantitative models is too labour-intensive (or based on immature knowledge), the value analyst might gather a multidisciplinary panel of experts that will be in charge of providing a qualitative feedback on the value contribution of a given design alternative.

5.3 Phase 3 & 4: Computing the value models and updating current designs

During the *Stage* the value analyst, together with the project leader and the designers, initiates the evaluation of the value contribution of the available design concepts. The information about the IMC alternatives developed up to this point is fed into the value models obtained in the previous step, to highlight negatively impacted areas and to establish the necessary corrective actions and to produce a ranking of the current designs.

During the empirical study many stakeholders have expressed a preference towards a single numerical metric for value, both to make easier the comparison between dimensions very different in nature and to mitigate the problem of deriving reliable absolute figures for all the criteria in a preliminary stage. In a nutshell, once a value study is performed for a given component, the outcome of the analysis is expressed in terms of a "delta" between the baseline (i.e., minimum requirement) and the target (i.e., expected outcome). In the spirit of stressing the value contribution of radical designs, the baseline for a new product/service is set on closely related development projects characterized by incremental improvements, while the target is defined on the basis of the customer needs and expectations as well as emerging from system-level long-term forecasts. The output of the value study is eventually expressed using scalars from 1 to 9, which represents the degree to which the design satisfies these two benchmarks. Scalars also work as common denominators that allow the analyst to compare the results of studies targeting heterogeneous value dimensions. All the information regarding the value contribution of such work-in-progress concepts is then fed back to the designers to suggest improvements or areas perceived as weak.

How to facilitate engineers and designers in linking the "value" dimension to the product components, so to enable more value-oriented decisions (and to reduce information overload), has been subject of discussion with the industrial partners. The "theory of cue summation" [28] has been seen as particularly interesting to enhance information processing and to address the problem of information overload. Colours have emerged as one of the key cues for value representation because of the several beneficial effects for decision-making that have been reported by Karayanidis [29] and McNab [30]. The processing of colour has been found to precede the processing of other attributes [29] and, at the same time, to be highly associative [30], creating a constant link between value information and the product model.

Colour-coded 3D CAD models have been proposed as a way to communicate value-related information to the designers. A preliminary mock-up has been realized with the intent to provide a discussion base for value and visualization. The LIVERy (LIghtweight ValuE visualizatoR) [31] conceptual mock-up is intended as a plug-in for a 3D CAD software that exhibits the value contribution of a component as an additional layer of the product structure. The value contribution is displayed across each value dimension and driver using a scale of colours, typically from green (i.e., high value contribution) to red (i.e., low value contribution). A conceptual representation of the LIVERY interface is shown in Figure 4.

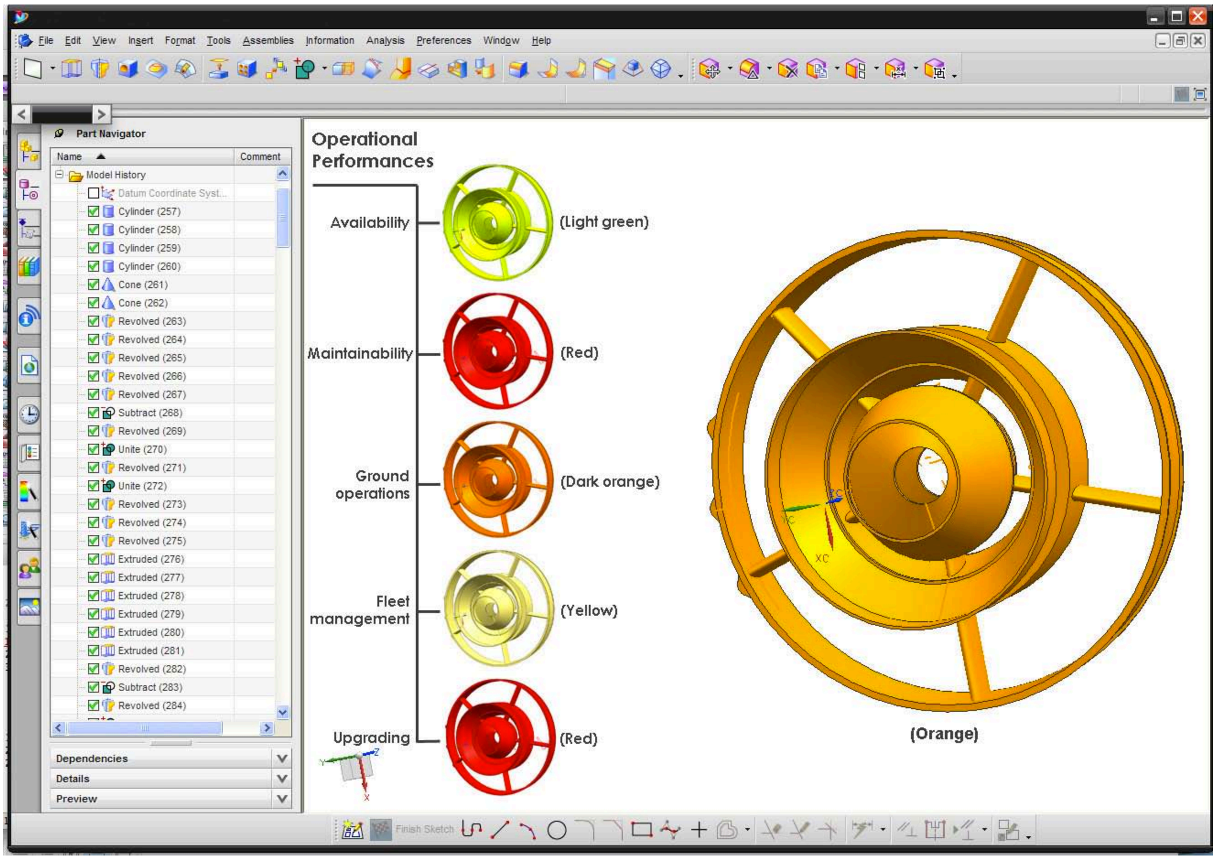

Figure 4: Conceptual mock-up of the LIVERY tool (based on Concept A).

Supported by this information, the engineers can review their design, and any necessary changes are considered. If some value dimensions are below the acceptance criteria, the designers can discuss with the project leader the necessary corrective actions, such as modifying of a geometry, introducing a new material or involving of external resources to support the development work.

5.4 Phase 5: Documenting value contribution for the Gate meeting

In the *Integrated Analysis* step, the team compiles all the material needed at the gate. The deliverables are prepared by the team members and forwarded to the project leader. The final value models are computed and included in a *Value report*, which provides feedback to the decision makers about the level of maturity/fidelity of the models used for the value computation.

The value analyst, assisted by the project leader, computes the state of readiness of the knowledge used to build, populate and compute the value models, using a narrative scale from 1 to 9 over three dimensions: input, method (tool), and expertise (experience) [9]. A rank as 5 indicates an *Excellent* knowledge maturity, meaning both that: 1) the content and rationale have been tested and proven, reflecting a known confidence; 2) the procedure to produce the content and rationale reflects an approach where tried out methods are used; 3) the workers continually reflect and improve and where lessons learned are recorded. Level 4 is defined as Good and level 3 as Acceptable. Knowledge maturity is Acceptable when: 1) the content and rationale are standardized; 2) there is a greater extent of detailing and definition; 3) the procedure to produce the content and rationale is stable (compared to previous levels) with an element of standardization and repeatability. Level 2 is ranked Dubious and level 1 as Inferior. A knowledge maturity level ranked 1 means that the content and rationale is characterized by instability (e.g. poor/no understanding of knowledge base) and the procedure to produce the content and rationale is dependant on individuals and formalized methods are non-existent (i.e., ad-hoc). The deliverables are finally sent to the management team, who will read the documentation and act as decision makers at the gate meeting. In conclusion, the material is ready and the gate meeting can be held.

5.5 Phase 6: Evaluating value trade-offs at the gate

At the gate meeting, the decision material is reviewed, a questions and answers session with the project leader is performed and a decision is made about the continuation of the project. The discussion between managers, project leader and value analyst aims to resolve the trade-offs between the alternative concepts, mainly focusing on value areas that are perceived as weak (i.e., being below the acceptance level - orange or red). Attention is also given to the areas that substantially differ in perception between the project leader's statement and the managers' understanding of what they have reviewed. This session focuses both on the numbers (i.e., value) and on the level of maturity/reliability of the knowledge behind the numbers (i.e., the knowledge maturity). Where needed, additional value analyses are requested to verify the correctness of the value statement and to decide among the trade-offs. Eventually, the gate is opened and expectations for the next gate are communicated to the project leader. To complete the phase the acceptance criteria for the next gate are decided and resources are allocated to the project leader.

6 CONCLUSIONS AND FUTURE WORK

It is a common practice for aerospace sub-system manufacturers to evaluate the "goodness" of a product/service mainly from a "requirements fulfilment" point of view, not taking the bigger picture in consideration. A main limitation of the current practices is that radical designs that would be preferred adopting a system view, tend to be rejected when merely evaluating their technical performances.

The aim of the paper has been to propose a conceptual scenario describing how design alternatives can be developed and assessed with a focus on their value contribution at system level. The scenario aims to improve decision-making in an early development phase, triggering decisions able to add value to customers and stakeholders along the entire product lifecycle. The work has shown that it is crucial to provide continuous feedback to the designers about how a given material/geometry/feature impact the way the product is operated/serviced/maintained/dismissed in order to drive value-oriented choices. In this spirit, an approach to visualize such contribution directly in a 3D CAD model (across a set of value criteria, dimensions and drivers) has been proposed and it is currently under development.

The scenario and the methodological/technological enablers proposed in the paper can be generalized in other product development contexts, especially in the ones dealing with complex products and featuring Stage-Gate® processes - such as in the naval and automotive industry. The development of an innovative brake-by-wire solution exemplifies well how the proposed approach can be adopted outside the aeronautical domain. Brake-by-wire represents the replacement of traditional brake components such as the pumps, hoses, fluids, belts and vacuum servos and master cylinders with electronic sensors and actuators. At sub-system level, this decision is not merely determined by the degree to which the solution address the list of requirements communicated by the car manufacturer, but needs to take into account a wider set of criteria encompassing how the different customer levels perceive the product from a value perspective. The steps in the scenario can guide the designers in evaluating the trade-offs at the gate, i.e. in defining, weighting and comparing drivers and criteria related to the different value dimensions of the product. The visualization approach can be used to communicate the system level impact of the solution, raising the designers' awareness on the worsening features (such as weight, part counts, etc.) as well as on the improving features (energy savings, reduced maintenance, etc.) of the solution compared with more traditional options.

Several issues still remain open to make the scenario successful in real life product development projects. Firstly, value assessment requires the sharing of a number of models, heterogeneous and dispersed across the extended enterprise, which requires enhanced enterprise collaboration capabilities to address security and trust issues. Moreover, together with the problem of defining relevant baselines and targets for the value drivers, value assessment suffers from the lack of quantitative data for the value calculation that makes difficult to evaluate trade-offs at the gate, Although the knowledge maturity approach discussed in the paper aims to cope with this issue, further work is needed to make the scenario more transparent and robust.

Despite a preliminary validation has been received through the interaction with several major industrial partners, especially for what concerns value visualization and knowledge maturity, the research is still in its infancy and needs to be followed by a piloting activity in a live product development context. The current efforts are oriented towards the development and refinement of the colour-coding visualization approach, together with the detailed definition of a black-box approach for sharing the value models.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 234344 (www.crescendo-fp7.eu/).

REFERENCES

[1] Webber M.M. and Rittel H. Dilemmas in a General Theory of Planning. *Policy Sciences*, 1973, 4, 155-169.

[2] Boeing. *Technology Redefines Joy of Flight*. http://www.boeingcapital.com/p2p/archive/06.2006/techredefinesjoy.htm, accessed 17th Dec. 2010.

[3] AIRBUS. *Setting new travel standards for all passengers*, http://www.airbus.com/en/aircraftfamilies/a380/passenger-comfort/, accessed 17th Dec. 2010.

[4] Provost M.J. The more electric aero- engine: A general overview from an engine manufacturer. In *International Conference on Power Electronics, Machines and Drives*, *PEMD´02,* April, 2002, pp.246-251.

[5] CRESCENDO. *D2.2.2 Benchmark of candidate approaches for value driven design*, EU FP7 CRESCENDO project public deliverable, 2010, available at: www.crescendo-fp7.eu.

[6] Cooper R.G. *Winning at new products: Accelerating the process from idea to launch (3rd ed.),* 2001 (Perseus Books, Reading)

[7] Stringer E.T. *Action Research, 2nd Edition,* 1999 (Sage Publications Inc., Thousand Oaks).

[8] Avison D., Lau F., Myers M. and Nielsen P.A. Action Research*. Communications of the ACM*, 1999, 42(1), 94–97.

[9] Johansson C., *Knowledge Maturity as Decision Support in Stage-Gate Product Development: A Case From the Aerospace Industry*, 2009, PhD Dissertation Luleå University of Technology.

[10] Richards M.G. *Multi-attribute tradespace exploration for survivability*, 2009, PhD Dissertation, Massachusetts Institute of Technology.

[11] Collopy P. and Hollingswort, P. Value Driven Design. In *Aviation Technology, Integration, and Operations Conference,* AIAA'09, September 2009.

[12] Ross A., Rhodes D. and Hastings D. Defining changeability: Reconciling flexibility, adaptability, scalability, modifiability, and robustness for maintaining system lifecycle value. *Journal of Systems Engineering*, 2008, 11(3), 246-262.

[13] Ross A., Hastings D., Warmkessel J. and Diller N. Multi-Attribute Tradespace Exploration as front end for effective space system design. *Journal of Spacecraft and Rockets*, 2004, 41(1), 20-28.

[14] McManus H.M. Richards M.G, Ross A.M. and Hastings D.E. *A Framework for Incorporating "ilities" in Tradespace Studies,* In *American Institute of Aeronautics and Astronautics 2007 Space Conference and Exposition, AIAA'07*, September 2007.

[15] Saleh J.H., Lamassoure E.S. and Hastings D.E. Flexibility and the Value of On-Orbit Servicing: New Customer-Centric Perspective, *Journal of Spacecraft and Rockets*, 2003, 40(2), 279-291.

[16] Wang T. and de Neufville R. Using a Coupled-Design Structure Matrix Framework to Screen for Real Options "In" an Engineering System, In *INCOSE Symposium*, July 2006.

[17] Iacobucci D. An Empirical Examination of Some Basic Tenets of Services, In T.A. Swartz, D.E. Bowen and S.W. Brown Eds. *Advances in Services Marketing and Management*, 1992, pp.23-52.

[18] Kauppinen M., Savolainen J., Lethola L., Komssi M., Töhönnen H. and Davies A. From Features Development to Customer Value Creation, In *International Requirements Engineering Conference*, August–September 2009, pp.275-280.

[19] Vargo S.L. and Lusch R.F. The Four Service Marketing Myths: Remnants of a Goods-Based, Manufacturing Model, *Journal of Service Research*, 2004, 6, 324-335.

[20] Steiner F. and Harmor, R., The Impact of Intangible Value on the Design and Marketing of New Products and Services: An Exploratory Approach, In *Portland International Center for Management of engineering and Technology Conference, PICMET'09*, 2009, .

[21] Rosenzweig P. Misunderstanding the nature of company performance: The halo effect and other business delusions. *California Management Review*, 2007, 49(4), pp.6–20.

[22] Flanagan T., Eckert C. and Clarkson P.J. Externalizing tacit overview knowledge: A model-based approach to supporting design teams. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 2007, 21, 227–242.

[23] Darlington M.J., Culley S.J., Zhao Y., Austin S.A. and Tang L.C.M. Defining a framework for the evaluation of information. *International Journal of Information Quality*, 2009, 2(2).
[24] Stacey M. and Eckert C. Against ambiguity. *Computer Supported Cooperative Work, 2003, 12,* 153-183.
[25] Gustavsson R. Design Study of Advanced Metallic Structural Integrated Fan Outlet Guide Vanes in Civil Jet Engines, 2006, Master Dissertation, Luleå University of Technology.
[26] Cheung J., Scanlan J. and Wiseall S. Value Driven Design. An initial study applied to novel aerospace components in Rolls-Royce. *Advanced Concurrent Engineering,* 2008, Part 6, 241-248.
[27] Bertoni M., Eres H. and Isaksson O. Criteria for assessing the value of Product Service System design alternatives: an aerospace investigation. In *CIRP International Conference on Industrial Product Service Systems, CIRP IPS*^{2}*'11,* May 2011.
[28] Severin W. Another look at cue summation. *AV Communication Review*, 1967, 15(3), 233–245.
[29] Karayanidis F. and Michie P.T. Evidence of visual processing negativity with attention to orientation and color in central space. *Electroencephalography and Clinical Neurophysiology,* 1997, 103(2), 282-297.
[30] McNab A.L., Hess T.J. and Valacich J.S. Designing Interfaces for Faster Information Processing: Examination of the Effectiveness of Using Multiple Information Cues, In *Americans Conference on Information Systems, AMCIS'09*, 2009, August 2009, Paper 699.
[31] Bertoni A., Bertoni M. and Isaksson O. Communicating the value of PSS design alternatives using color-coded CAD models, In *CIRP International Conference on Industrial Product Service Systems, CIRP IPS*^{2}*'11,* May 2011.

Contact: Marco Bertoni
Luleå University of Technology
Functional Product Development
Division of Innovation and Design
Luleå, SE-97187
Sweden
Tel: +46 (0)920 492583
Email: marco.bertoni@ltu.se
URL: http://www.ltu.se/tfm/fpd/staff/faculty/berber?l=en

Marco Bertoni is Post Doc at the Division of Innovation and Design of the Luleå University of Technology. The focus of the ongoing research is on the conceptual phase of Product Service Systems, with the aim to understand how the lifecycle value of PSS design alternatives can be captured, visualized and communicated to the members of a cross-functional team during conceptual design.

Christian Johansson is a researcher in functional product development at the Division of Innovation and Design of the Luleå University of Technology. His main research interests include knowledge management, product development, and support for decision-making. The focus of the current research is related to use of knowledge management in stage-gate governed product development to support decision-making.

Alessandro Bertoni is a Ph.D. student at Division of Innovation and Design of the Luleå University of Technology. Alessandro´s research focuses on methodologies and tools for value driven design and for value assessment of PSS design alternatives in conceptual design.