Overview of Value Driven Design Research: Methods, Applications and Relevance for Conceptual Design

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The overall cost of a new aircraft development program throughout the development life cycle is usually in the order of several billion dollars. In such vastly complex endeavours, Systems Engineering (SE) approaches are essential to transform complexity into smaller and manageable elements. Within the realm of SE, significant efforts were made to strengthen methods and technologies and to support collaboration and teamwork for concurrent product design, especially in the area of models and simulations management and integration.

Although SE has been practiced for decades, many have observed that the conceptual design stage of a complex system does not typically involve a broad, systematic exploration of design alternatives. In practice, the intuition of experienced designers is usually consulted in the pursuit of feasible solutions, i.e. designs within the acceptability range of stakeholder cost and benefit. This approach is susceptible to identifying locally optimised designs, which provide only a vague picture of the complexity of the broad space of possible designs.

A way to cope with this problem is to introduce optimisation techniques. Nowadays, most of the complex system optimisation processes involve product models (e.g. aircraft), component models (e.g. engine, airframe, landing gear, etc.), and sub-component models (e.g. fans, compressors, turbines, etc.), which are all linked via relevant high level attributes. Optimisation calculations are run over these model attributes, but still these techniques are mainly used today in the detailed design phase, leading to a focus on local optimal design at a sub-system or component level. Early in the conceptual design phase little attention is paid towards establishing the necessary links between the high-level system attributes and the overall 'value' of the system. Value provision objectives often are of less tangible nature than the technical system performance objectives and this generates major difficulty in retaining a value focus throughout the systematic decomposition of the system at hand.

Collopy and Hollingsworth [1] are among the pioneers to propose Value Driven Design (VDD) as an improved design process that utilises value models to perform early-stage design optimisation. The methodology introduces high-level value-based models, to be run on top of existing hierarchical aircraft models. A value model accepts a vector of product attributes as its argument to produce a scalar metric to rank a design. This metric often takes the form of Surplus Value (SV) or Net Present Value (NPV), which are surrogate objects for long-term profitability [1][2][3]. These objects are chosen because profit is the most intuitive dimension to assess the value of a system, and because it often represents an unbiased metric of the 'goodness' of the final product [4]. VDD methodologies are also emerging as enablers for fostering co-creation activities across the supply chain [5]. Thanks to VDD, engineers are able to make more informed short-term and long-term design decisions by focusing on those dimensions that add value from a system-level perspective [6][7], rather than the nearest customer needs and targeting local optimal solutions.

The VDD research conducted by the authors, mainly in the frame of the CRESCENDO project [8], have identified three main orthogonal axes along which design teams shall move to fully implement and gain benefits from VDD. These axes are the following: 1) Value model definition; 2) Product description; and 3) Model Based Systems Engineering (MBSE) Integration. These axes along with their respective components are presented in Figure 1.

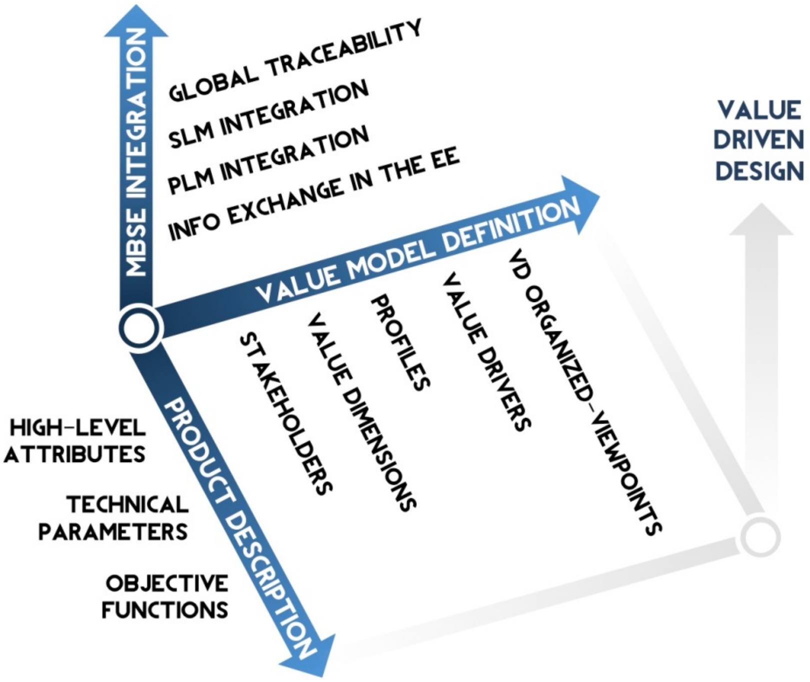

Figure 1: Value Driven Design main axes.

The first axis (*Value Model Definition*) is concerned with the characterisation of a value model that is common to the stakeholders in the value chain. This can help diverse SE processes that are of relevance for the Conceptual Design, including the analysis of the stakeholder needs, the definition of business strategies, the establishment of the system requirements and/or the justification of the decision criteria that are used during trade-off studies. This axis is itself decomposed to address several issues.

a) Conceptual modelling of the relevant criteria and measures for the trade space exploration. One approach consists in identifying all relevant stakeholders in the value chain (i.e. airlines, airports, society, etc.) and their value dimensions. A reference resource is built to describe the value dimensions of each such stakeholder, including some 'soft' dimensions such as 'image' or 'reputation'. Additionally, stakeholder profiles can be modelled by means of characteristics such as various airlines' business models, fleet composition or practiced routes. Then high-level value drivers that are sufficiently generic and shared within the domain are identified. These are the possible drivers at business or operational levels that are recognised as actual means to improve the perceived 'value' along a specific dimension [9]. Examples are operational drivers such as the turnaround time, or economical drivers such as Maintenance, Repair and Operation (MRO) costs. These domain dependent drivers are identified, defined and organized according appropriate viewpoints. Based on these resources, it becomes possible in the context of a given project or program to identify and to isolate different value creation strategies, defined as consistent sets of value drivers that improve the value along specific value dimensions as perceived by key stakeholders [10].

b) Methods that make 'value' commensurable. A mathematical value model needs to be defined expressing the stakeholders' value perceptions and their interactions into a single measure that can be used to evaluate the available concept alternatives. In this respect, looking at monetary value is the most common method. Value is usually estimated economically. However, despite their attractiveness, economic based models are inherently limited and potentially misleading. There is a need to introduce and maintain a 'value oriented focus' and thus derive conceptual design and modelling methods that guide development teams to retain a coordinated 'intent'. In practice, conceptual design modelling methods may include the introduction of 'Design Merit values' for concept evaluation [11].

The second axis (Product Description) is concerned with the description and comparison of the design alternatives. Again, this axis can be decomposed into:

a) Methods to elicit technical solution parameters that are relevant for assessing the proposed solutions. These parameters are variable characteristics or features of architectures or of design solutions than can be related to the higher-level attributes used as drivers or selection criteria.
b) Definitions of a mathematical value model to express or assess the contribution of a given solution to the 'value' of a design solution. Models must be created for the components that produce performance attribute values, operations or costs; to understand the trade-off factors and the interactions between various design parameters. Consistent objective functions must be formulated for each component.

Eventually, the third axis (MBSE Integration) in Figure 1 is concerned with the integration of the VDD methods within an operational MBSE environment. The main endeavour is to connect or integrate the value engineering models and data with the other system engineering artefacts and processes, including requirements establishment and concepts evaluation activities and models. General SE processes, standards and information systems are considered. This axis is connected to current Product Life Cycle management (PLM), Application Lifecycle Management (ALM) activities and standards, to support the management and the exchange of the information within the Extended Enterprise (EE) or among partners, as well as global traceability of relevant data. Sharing information about the 'intent' of a design solution very early in the system development process amongst the risk-sharing partners can help suppliers anticipate underlying needs, support major trade-offs and achieve desired technology readiness levels in time. Controls are needed to allow this to be done in accordance with enterprises' strategies and governance. This axis can be decomposed into:

a) Process modelling: a generic process is defined and a portfolio of techniques and tools considered. The aim is to articulate a generic process, making use of 'value' representation and 'value' cascading as an upfront complement to the 'traditional' requirements cascading in the context of the EE [10].
b) Information system and platform to support the management and exchange of value related information. This mainly involves semantic web technologies to apply a linked data approach to the VDD application domain.

The main reason for exploring the VDD domain is the realisation that requirements alone have shown to provide insufficient insight into the original intent and context of a design, increasing the risk of delay, rework and sub-optimal solutions. Hence, VDD methodologies are emerging as enablers for fostering co-creation activities across the supply chain, avoiding falling in the trap of focusing only on the nearest customer and targeting local optimal solutions, rather than on those dimensions that add value from a more system-level perspective. The proposed framework aims to provide a guidance to design teams aiming to adopt VDD in their everyday working activities. Its objective is to enable the definition of more robust methodologies to capture, consolidate and prioritise needs and expectations, to condense them into value dimensions and drivers, and to use the latter in conjunction with requirements to guide design trade-offs dealing with multiple levels of customers and stakeholders in the conceptual design stages.

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