SYSTEMATIC SEARCH OF OPTIMAL SPACE SYSTEM MISSIONS DESIGN USING SET-BASED CONCURRENT ENGINEERING BASED ON MODELS

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ABSTRACT

Traditionally, design teams (even those applying concurrent engineering) use point-based approaches: they try to identify the best option as soon as possible.
However, the probability that this initial point in the solution space is the best solution is almost zero. Designers will iterate around this single point and eventually converge on a solution that works, without being able to confirm that it is the best one. With this iterative point-based process, decisions are made too early and without sufficient knowledge, and are therefore invalidated later, resulting in rework and delays.

In contrast, Set-Based Design is a Lean engineering method where designers begin by proposing several options that potentially meet requirements and constraints. They thus delineate the region of the solution space where the best option can be found. The intensive exploration of this region allows the designers progressively reduce,its size by successively eliminating the weakest options or by reducing the intervals accessible to the design variables. At the end of this convergence process, the last remaining solution is the least bad, and therefore the best!
Set-Based Design thus contrasts with the more traditional Point-Based Design where a single point in the solution space is quickly elected rather than a set of points.

The following two figures show this difference in approach between Set-Based and Point-Based. On the Set-Based side, the superposition of several curves delimits the design space where options are feasible. On the Point-Based side, only the tests of each option allow concluding their relevance. Once a selected point has been identified as a feasible option, it becomes the solution with no guarantee that it is the best one.

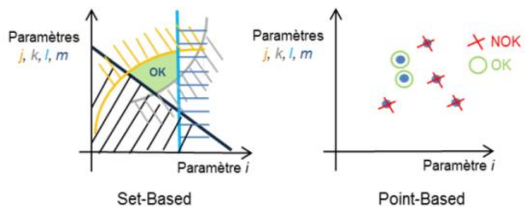


Figure - Set-Based versus Point-Based

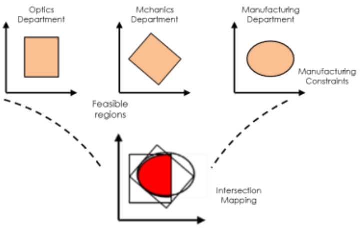
Set-Based Design has been successfully applied on Thales Alenia Space's missions. Starting from the *Voice of Customer*, all system stakeholders worked to identify the first key system-level decisions and associated knowledge gaps. As a first step, the teams had to characterize what level of satisfaction could be achieved for both customers and the company, based on the objectives, capabilities and resulting trade-offs. That means they had to delineate the region of interest as a set of intervals accessible to key performances while imposing a minimum of constraints. Throughout the design process, this approach helped guide the designers to the right choices. However, the manual exploration of large design regions and numerous trade-off curves limits the adaptation of this approach to larger, more complex systems..

To push these limits, we present in this paper an innovative a tooled-up model able to extend the application of Set-Based thinking to more complex systems.This is a new class of models, capable of stimulating the designer's reasoning rather than only modeling what this reasoning produces as proposed by most MBSE approaches.
We want to allow designers to create a general multidimensional model in which they can visualize which design variables influence which performances and thus characterize the design space. The objective is to facilitate and guide the exploration of this space.

Once the key decisions have been identified, their effects can be advantageously visualized by more traditional MBSE models (such as Arcadia/Capella).

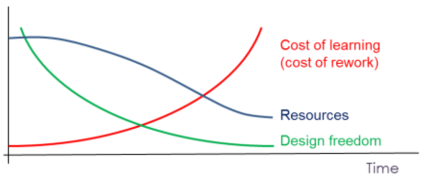
1. SET BASED CONCURRENT ENGINEERING INTRODUCTION

SBCE is the process at the heart of Lean in Engineering. This approach consists in establishing as early as possible the admissible design space by identifying the trade-offs and feasible intersections between variables, then developing the knowledge to narrow down this space by successive elimination of the worst regions towards the best solution.



Convergence by mapping the intersection of feasible regions

SBCE encourages the generation of knowledge as early as possible by exploring the design space to secure design decisions. Slightly provocatively, we talk about "deciding at the last moment". However, later does not mean too late. It is a balance between the cost of rework caused by making the wrong decision due to lack of knowledge and the cost of delay due to a late decision.



Evolution of the cost of learning as a function of time

A very simple example of set-based approach with regard to point-based approach is to find a meeting date between several partners by submitting 1 date per mail, waiting the answers, trying another, … versus using tools like Doodle : you define the design space (the dates) and everybody is reducing this design space according to their availability (in parallel). Then you get a set of good solutions (good dates) that may not be optimal (meaning everybody is available) and you have to apply another selection criteria (maximizing the number of persons, prioritizing presence of some of them, …) to find the final date… Everybody may have experience that the SBCE approach in this case is far more efficient to find a better date quicker…

2. OBJECTIVES OF THE STUDY

The objective of this study are to:

- Demonstrate the interest of SBCE for space mission design
- Propose a model-based approach to enable the application of SBCE to all types of space projects, whatever their complexity
- Prototype a modelling tool
- Study the use of this modelling tool for exploration of trade-off, optimization, simulation, ...

There are two major business objectives:

- extend the design capability beyond the limits imposed by more traditional methodologies and thus encourage the study of increasingly complex missions (constellations, human exploration).
- reduce system life cycle costs (e.g., reduce the number of spacecraft, their capacity, etc.) through a tooled-up design method capable of proposing the best trade-offs as early as possible and guiding their resolution in an optimized manner

3. SBCE METHODOLOGY APPLIED TO SPACE

The objective is to demonstrate the applicability of the method for the space domain at different levels (system, segment, equipment). Methodological guidelines and examplers will be provided tailored to space domain.

Several use cases has been defined (ranging from system to equipment level) and will permit to provide real illustration cases but also to verify that both the methodology and the proposed tooling will scale to the size of real-life problems.

One of the specificities of the space domain is the strong coupling between various systems mastered by very distinct disciplines. This configuration requires the tooled-up methodology to take into account interdisciplinary aspects.

4. MODEL BASED SUPPORT TO SBCE

The study is focussing on the modelling of the so-called *Causal Influence Diagram* (CID).

- *Causal* as the dependency relationship between design variables and performances. This means that a change in the values of the design variables (the cause) leads to a change in the values of the performances (the effect) This causal interpretation of this dependency relationship allows us to consider that the behaviors of the product and its physical characteristics are deductible from the decisions made by designers.
- *Influence* as the multiple factors influencing specifications: designers' choices, manufacturing constraints, operations, etc. The designer's objective is to identify the most influential factors in the first order.

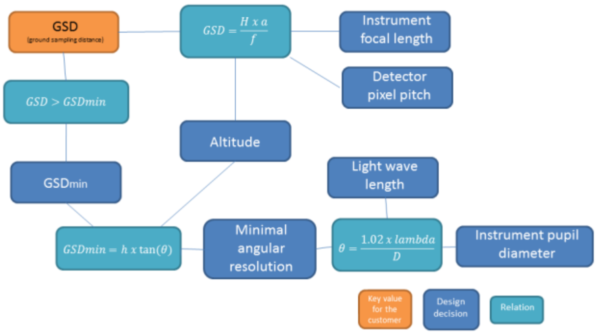
This model thus helps designers structure the interactions between variables and identifying which ones have a first-order influence on the expected effects. It also aims at seeing the design problems in a systemic way by integrating conditions that could have been excluded by more traditional linear and point-based methods.

CID is the central artefact of the method, that makes explicit the chain of relations between key value attributes (KVA) and design variables.

This CID supports:

- Identification of knowledge gaps that has to be learnt by the team before taking decisions;
- Identification of influent parameters and antagonist parameters that are subject to trade-off;
- Support multi-criteria optimisation

For this abstract, we present an (over simplified) example of the relation between the ground sampling distance of an observation spacecraft (one of the important KVA for the customer) and some of the design variables (at spacecraft or instrument level).



A full explanation of this model goes beyond of the scope of this abstract, but it will be part of the intended presentation at the workshop.

The modeller will be built with the same eco-system of the Capella tool and will "out of the box" support all the capabilities of an advanced graphical model editor (configuration management, diff, model transformation support, graphical editing, …).

5. EXPLORATION OF CAUSAL INFLUENCE DIAGRAM

The causal influence diagram proposes a model of the problem to solve by reifying and formalizing the chains of causality between client objectives (KVA) and architectural parameters (Variables).

Managing a CID as a graphical representation of a formal problem model presents several interest easily identifiable: deep discussions between disciplines in the engineering team about objectives, knowledge gaps and tradeoffs, incremental engineering and reusability of knowledge among others. Above these advantages, the CID is a mean to assist engineers in the problem resolution with computational assistance.

The CID may be seen as a graph with objectives (KVAs), variables (Variables) and models (TransferFunctions). This kind of model is a basic algebraic model of a problem that offers the opportunity of leveraging from blackbox optimization and/or solvers when the TransferFunctions allows it.
While blackbox optimizer are the most flexible tools over the models nature to find examples of solutions, the solver may provide a proof there is no solution to the problem (i.e. no technical solution with right performances for given budget and schedule).
We propose to exploit the solvers synthesis capabilities for reducing variables definition domain. Since domains reduction has known limits like over estimation in some common cases or reduction of variables space to an hypercube without any information about the real solution space topology. A workaround to this two limits is providing a visual representation and interactive navigation into the solution hyperspace helping engineers in the understanding the nature of what they are handling. The team can navigate and select interesting solutions spaces to explore then go deeper into the exploration, eliminating iteratively zones and zooming on the remaining solutions keeping assistance of the solver to converge to selected solutions space.
This latter exploitation scheme is exploratory and requires deep investigations and experiments.

6. INTEGRATION IN CURRENT ENGINEERING TOOL CHAIN

This study will propose a way forward for the integration of this model into the complete modelling tool chain.

In particular the CID may be directly interfaced to values contained in an integrated design model (IDM-CIC or COMET). The design variable actual ranges being stored in the integrated model.

7. CONCLUSION AND WAY FORWARD

This study is still on-going and will finish beginning of 2022. We expect at we have a first working prototype of the CID tool available for demonstration at the workshop.

The overall approach is very promising and will permit to structure the work performed by the project teams in particular during the early phases of the projects.

The use of CID is a promising "entry point" for the team for optimisation algorithms that are not currently widely used at system or mission level.