COST ENGINEERING WITHIN A MODEL-BASED DESIGN PROCESS FOR SATELLITE SYSTEMS

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Abstract. This paper describes a method to integrate cost analysis, cost planning, accounting and systems engineering within one integrated system model. It is called **I**ntegrated **S**ystem **Co**st **M**odel — ISCOM. This model has been implemented in a tool supporting the important early phase of satellite design. The tool is called MuSSat – Modelling and Simulation of Satellite Systems – provides the user with the means to easily and quickly model all aspects – and the various interdependencies between them – of a satellite system and to compare various alternative designs (Wilke, Quirmbach et al. 1999*)*. Basis of the software tool is a modelling methodology developed at the Institute of Astronautics at the Technical University of Munich, which allows an integrated way of product, process and cost planning.

MuSSat supports Target Costing process by allocating Target Costs to functions, objects and processes. Therefore it provides creation of cost tables for all kind of system elements in order to get element specific and actual cost estimation relationships. Thus MuSSat enables a company to improve its performance in the new market segment of commercial satellite applications by supporting integrated concurrent engineering.

INTRODUCTION

Global Situation. In the commercial satellite market the aerospace industry has to be in a position to recognise the changing demands of its customers. This requires active decision making which takes into account customers needs and his willingness to pay for these needs. The systems life cycle costs (LCC) are the most important design parameter. They are strongly influenced by the early phases of product development. More than 70 percent of the LCC are fixed in the design phase while most of the actual expenses occur during the later phases (Production and Launch). But the design process is strongly dominated by engineering departments where cost knowledge is traditionally low. One of the most critical points in the commercial satellite market is the necessity of offering firm fixed price proposals in the early phase of product design process. To reduce the risk resulting of this insecurity a Target Costing process and a high level of cost knowledge is needed. Problems in the traditional way of product planning are (Quirmbach, Wilke et al. 1999):

1. Complex systems have many interacting requirements, design parameter and cost drivers

2. Product- and cost planning are not yet one integrated process. Different disciplines have different data models and tools. Accounting uses ERP (Enterprise Resource Planning) software while engineering needs requirement engineering and modelling tools. Information flow between these tools is complicated.

3. Availability and consistency of design parameters to analyse cost influence. For example the engineers of the solar array subsystem calculate more than ten different power parameters. For cost analysing these different values are often a source of error. But it is important to compare equal product properties.

4. The accounting system allows to allocate cost for

product elements (e.g. components) but not to allocate them to the cost driving product functions or requirements. Value engineering is a way of function cost analysis and is strongly separated from the accounting process. ERP software allows to create a work breakdown structure (WBS) but there is no link to product functions or requirements.

5. Creating and especially maintaining cost tables in order to analyse costs is difficult.

As the customer's requirements are not yet fixed while a prime contractor for a new programme is selected, customers are frequently changing their requirements to asses the design flexibility of different supplier's with regard to cost and efficiency. Thus the possibility to compare many design variants quickly in order to optimise customers cost-benefit ratio will become more and more important. In addition the required cost reduction for commercial satellites systems exceeds 50% of traditional satellites cost. The system costs (SC) are a multivariable function (Wildemann 1982):

SC = f (system performance, configuration, project organisation, schedule and price factors)

Studies have shown that the influence of system performance is about 40% of SC, configuration is about 15%, schedule and project organisation is about 10% each and factor prices are about 5%. 20% of system costs are determined by system environment (e.g. laws, exchange rates,...). Traditional accounting and engineering processes are not sufficient for todays business environment. Rather the necessity of an integrated and interdisciplinary system and cost engineering approach is obvious.

GOALS

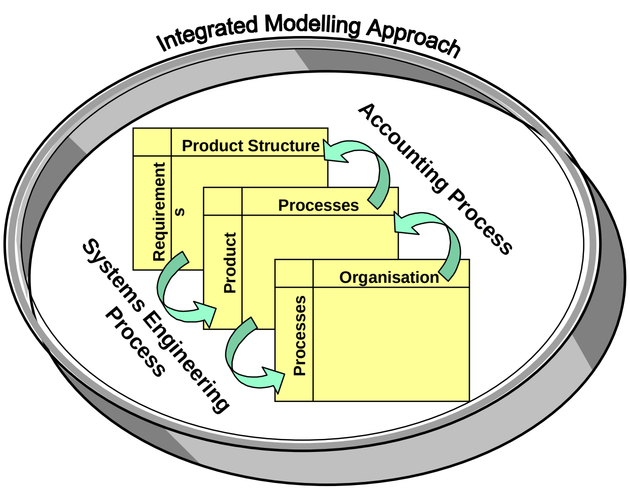


Figure 1. Integrated Modelling Approach

This paper describes a method to integrate cost analysis, cost planning, accounting and systems engineering within one integrated system model. It is called ISCOM— **I**ntegrated **S**ystem and **Co**st **M**odel — and its goal is to support an interdisciplinary design process of satellite systems.

Therefore the model

- shall support the user to determine the cost driver of all system elements like requirements, functions, product tree and processes on any hierarchical level.
- shall support the Target Costing process and allocation of Target Costs to functions, product tree and processes.
- shall enable to create cost tables and cost functions for all of these system aspects.
- must be applicable for technical models as well as for accounting objects. The modelling approach has to include all kind of technical and economic parameters and their relations.
- shall support the evaluation of alternative design solutions to become more objective.
- shall allow to save all kind of project data and ensure the data consistence out of the working process. This shall enable the creation of key indicators and cost estimation relationships for all aspects of the satellite system.
- shall be applicable in the software tool MuSSat.

APPROACH

Modelling Basics. To be able to model any complex system there has to be a set of formal components to describe a system. To keep those components applicable regardless of the system they are applied to, they have to describe a system on a very abstract level. All definitions refer to Figure 2:

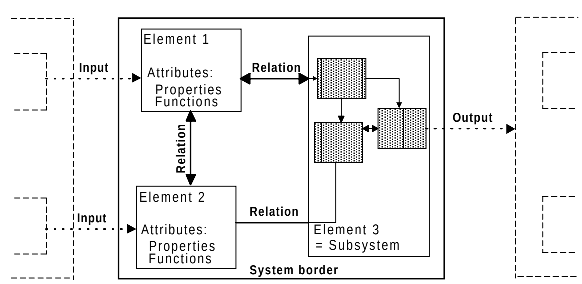


Figure 2. System Definition (IGENBERGS 1993)

(Igenbergs 1993) defines a system as follows:

- a system consists of elements
- elements are described by their attributes, i.e. properties and functions
- elements can interact via relations
- an element can be a system, i.e. it can be a subsystem

A system is any object that can (mentally) be separated from its environment. The system border represents the separation between the system and its environment. Where the bounding has to be drawn is determined by the actual problem statement. Thus the borderline has to be adaptable to a changed problem definition. It is the primary purpose of the system boundary to reduce the complexity of any real system to a manageable level.

Within the last years a couple of applications have been developed based on this global definition (Kreichgauer 1994 and Walter 1994).

(Negele 1998 & 1999) developed a systemic approach to the modelling of product development systems — ZOPH. He distinguishes between four major systems within the product development:

- Zielsystem (requirements, customer needs etc.)
- Objektsystem (all aspects of the deliverable items)
- Prozeßsystem (processes, activities etc.)
- Handlungs(-träger)system (resources, organisation structures, equipment etc.)

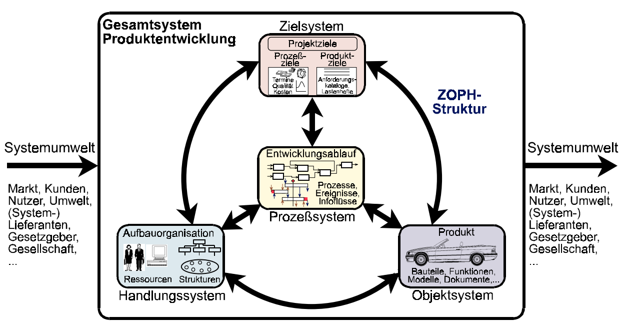


Figure 3. ZOPH-Model (NEGELE)

Because of its homogeneous coverage of all product and process data this modelling approach provides the generic basis of ISCOM.

Target Costing. Target Costing is a japanese approach of cost management and planning which has been developed at Toyota. (Sakurai 1989) defines:

"Target Costing can be defined as a cost management tool for reducing the overall cost of a product over its entire life cycle with the help of the production, engineering, R&D, marketing, and accounting departments."

The Target Costing process can be separated in three phases:

1. Setting Target Costs
2. Allocating Target Costs
3. Realising Target Costs

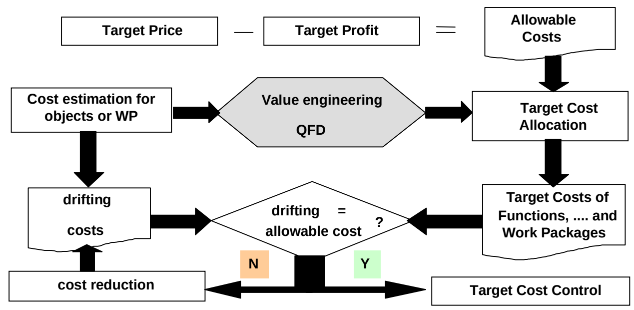


Figure 4. Target Costing Process

The process as shown in Figure 4 is based on a market driven target price. The target costs are the difference of Target Price and Target Profit. The allocation of Target Costs onto the product components is the critcal task in this process. The Engineering data to be used within the Target Costing Process is not clearly defined in the relevant literature. Methods like Quality Function Deployment (QFD) can be used to allocate customers needs to product functions and then to system components (Seidenschwarz 1993). But Systems Engineering provides different levels of abstraction (e.g. function tree, product tree and matrices). The methodology discussed above enables to describe all these system structures. In so far systems engineering and Target Costing shall be part of an integrated and interdisciplinary design process. This process including cost allocation, cost analysis and cost estimation should formally be supported within the integrated model.

Model requirements. Analysing the satellite business and the target costing process, the following requirements for an integrated system cost model have been identified:

- The model has to include all different types of elements (e.g. product functions, object structure, work breakdown structure (WBS), activity network, organisation structure and resources)
- The model shall include different types of properties and relations
- It must be able to allocate costs for each system element and include all cost sources
- Each element has directly allocated cost, total

direct and indirect cost as well as cost inputs from their children and output to their parents

- All kind of elements are reusable for different projects and variants

To further improve user acceptance all models existing in the various departments of the company are transferred step by step to MuSSat to enable the users to work with exactly the models they used before. If the models can not be transferred to MuSSat (special programmes or dynamic simulation tools) interfaces are to be implemented to access those models and programmes from MuSSat.

MODELLING STRUCTURE

The goal of this modelling approach is to allocate cost to all kind of elements from the resources, cost centres, processes, product elements and functions up to the requirements. Especially the influence of requirements and product functions to system costs is important within the early phase of product design. Therefore it must be able to analyse characteristic cost drivers for all kind of elements and to compare elements by their common properties.

Object Oriented Model. The reusability of elements for different projects is an important advantage of the modelling method. It is possible to copy elements and to change, add or delete properties and functions. They have their own evolution and mutation. But elements are defined by their properties and functions (see above). To keep elements manageable and comparable the following principles of the object oriented analysis (OOA) and design (OOD) are used for the modelling method (Quirmbach, Wilke et al. 1999):

- Each element is an object (instant) of a class

- Objects inherit properties and functions of their classes

This approach is useful to manage the evolution of the different elements and classes and allows to compare different elements by their common class properties. Different types of solar arrays (flexible or rigid panels) can be compared by their cell area, number of cells, mass, reliability and so on.

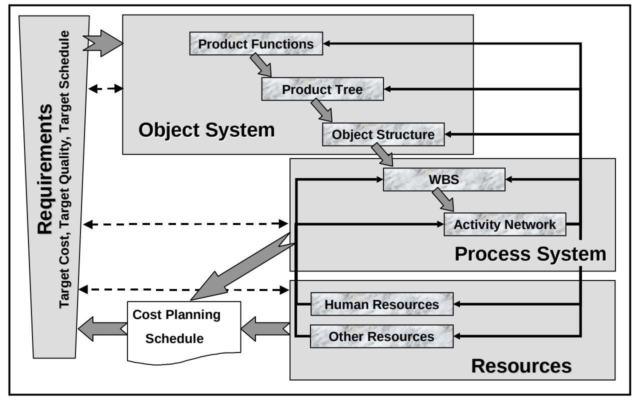


Figure 5. Model structure

Figure 5 shows the model structure and the modelling process. The most important classes of the model are:

- Requirement elements
- Product function elements
- Object elements (incl. Product Elements)
- WBS Elements
- Activity Elements
- Organisation Elements
- Resource Elements

Each object of these elements can be a cost accounting element and has one property type which includes all cost categories and cost sources of the enterprise accounting system. All Elements have directly allocated cost (DAC) and total direct cost (TDC). TDC of an element are calculated as the sum of all DAC of this element plus the TDC of all its children. E.g. Solar Array (product element) has DAC form WBS Elements (e.g. integration, acoustic test etc.) and TDC from its children (e.g. Solar Cell Assembly). Costs originated by higher level elements can be distributed to lower level elements. These costs are called indirect cost (IDC). This theory derived from traditional accounting theory is applicable to all kind of system elements identified above.

PROGRAM CONCEPT

MuSSat is an integrated tool for an interdisciplinary proposal team. A relational Database has been chosen to realise the program and the database design is defined by the modelling methodology. The use of MuSSat within a proposal process is shown in Figure 6:

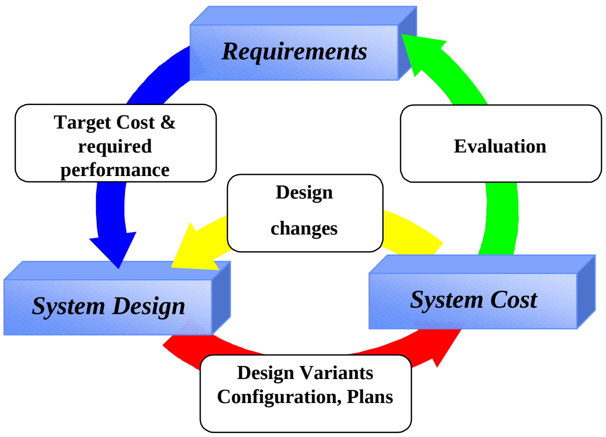


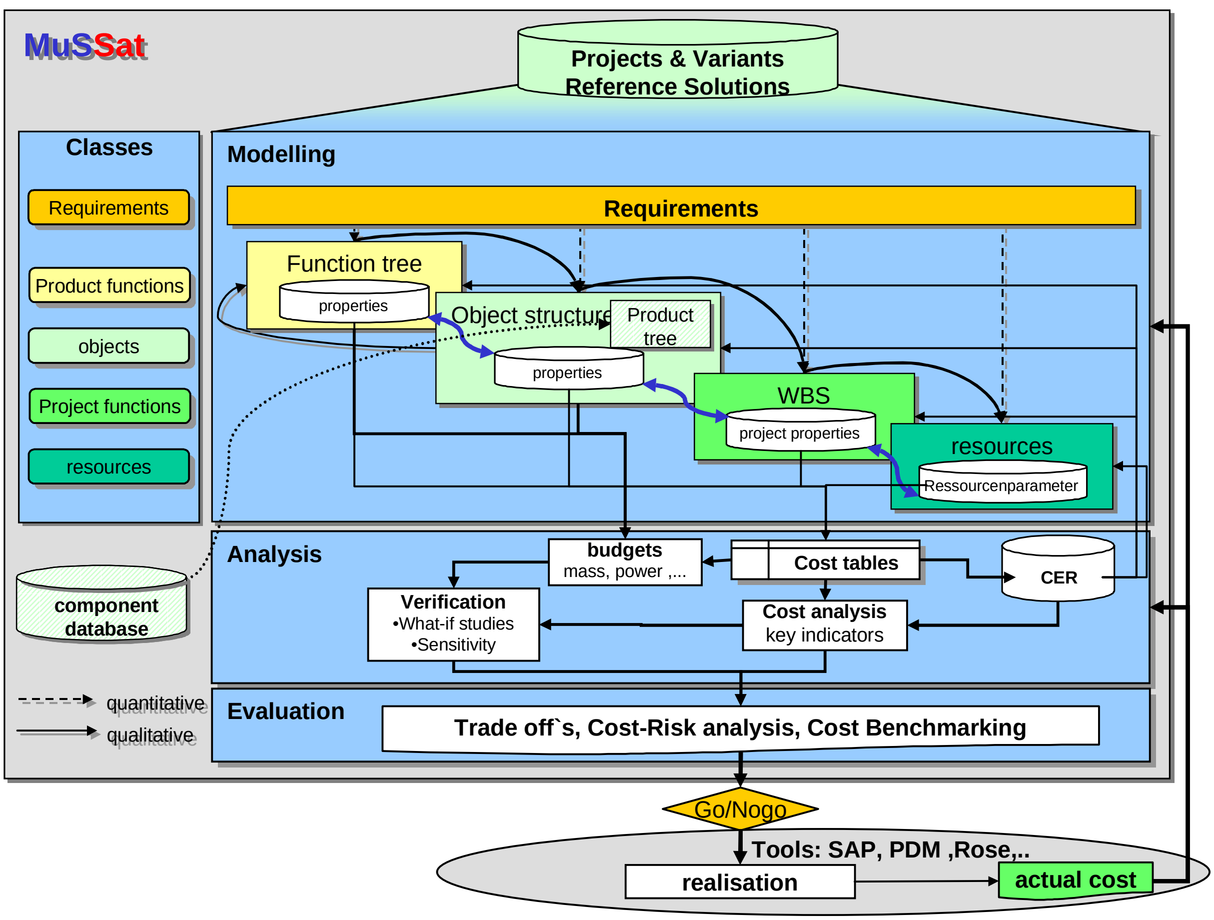
Figure 6. Proposal Process in MuSSat

The tool has an import and export interface to R3 ERP software of SAP™. Thus cost analysis, CER's and key indicators are also based on actual cost. Work Breakdown Structures and their planning data can be transferred to and from SAP's Project System (PS).

MuSSat allows to generate cost estimation relationships (CER) for any level of the different system elements; for a solar cell as well as for a complete solar array. Therefore the user is able to analyse all kinds off technical and economic parameters of different projects and variants within cost tables (c.f. Figure 7). This approach allows to get actual CER's based on the latest data of other projects and variants. For example the user is able to determine learning curves for all kind off objects and work packages. The tool enables top down cost estimates as well as bottom up cost planning for alternative variants. The less product and process experience is available the more detailed the cost estimation will be performed. Procurement costs can be taken from an integrated component database. A WBS can be generated quickly or imported by SAP™. Cost splitting is not only provided between recurring and non-recurring cost, but the user has also the possibility to differentiate between any cost breakdown he needs. The quality of the generated cost functions can be determined by different factors, standard deviation, Person's correlation squared, and others. The most critical point concerning risk of the cost estimation is development of new technology. For example the use of new solar cells can lead to higher production losses.

Budgeting over schedule includes escalation factors. In combination with management of milestones this allows an detailed cash flow analysis and calculation of project's expected internal rate of return.

Figure 7. Program concept of MuSSat



CONCLUSION

The Integrated System and Cost Model which has been presented in this article is useful and applicable for modelling complex systems. MuSSat is designed to be used by an integrated and interdisciplinary design team to quickly develop proposals for commercial satellite applications. The proper environment to use MuSSat is Dornier's Satellite Design Office (SDO) similar to the Project Design Centre at NASA's Jet Propulsion Laboratory (Shisko 1997).

The tool is being developed since February, 1998. The tool was put in use by Dornier Satellite Systems GmbH in October 1999. The first projects have been evaluated. This experience has shown that the approach described above enables to compare a lot of design solutions from a technical and economic point of view. This increases the quality of a proposal. Yet the most important factor within this kind of process is the team and its experience. Because of the better design transparency for all disciplines due to MuSSat, the tool supports better team integration and system understanding.

So far MuSSat can cover all expactations. This due to an effictive cooperation of Institute Astronautics of Technical University Munich and Dornier Satellite Systems GmbH. Further steps will be the adapting to users wishes.

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BIOGRAPHY

Oliver Quirmbach is research assistant within a cooperation of Daimler Crysler Aerospace and German Aerospace Research Center. He recieved his M.S. degree in Aerospace engineering in May, 1997. During his studies he focused on systems engineering and economics. Currently he is working on a project aimed at developing a tool for integrated systems and cost engineering within a model-based design process for satellite systems. The project is a joint effort of the Institute of Astronautics and the Dornier Satellite Systems GmbH, which is a subsidiary of Daimler Chrysler Aerospace.

Martin Wilke is research assistant at the Institute of Astronautics at the Technical University of Munich. He received his M.S. degree in Aerospace engineering in January, 1998. During his studies he focused on systems engineering by making a student thesis and his master thesis in the field of systems engineering at the Institute of Astronautics. Currently he is working on a project aimed at developing a tool for the model-based systems engineering of satellite systems. The project is a joint effort of the Institute of Astronautics and the Dornier Satellite Systems GmbH, which is a subsidiary of Daimler Chrysler Aerospace. He is a founding member of the German Chapter of INCOSE.

Eduard Igenbergs is Professor of Astronautics and Director of the Institute of Astronautics at the Technical University of Munich. He has a Ph.D. and a masters degree in mechanical engineering. He had a dust counter experiment on the japanese HITEN spacecraft to the moon and a space debris experiment on board the german BREMSAT. Another dust counter experiment is currently flying to mars with the japanese Planet-B spacecraft. He developed the Munich Space Chair (MSC), a body restraint system on board MIR. He has been teaching and researching in the field of Systems Engineering for more than 15 Jears.