

Systems Engineering, Design Optimization, and Safety Conformity

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Abstract: The high technical complexity and the enormous acquisition and operation costs, i.e. the total Life Cycle Costs, LCC, of scientific instruments for future ELTs generate a demand for use of modern systems engineering and design optimization techniques during all phases of instrument procurement project. The scientific research programs and their results must play the predominant role in the life of any scientific instrument and the majority of the available resources must to be concentrated on the scientific aspects rather than on the production of the tools used to accomplish the scientific goals. This presentation provides an overview on some major management techniques leading to an efficient and most economic execution of instrument development, manufacturing installation and operation projects.

Keywords: Systems Engineering, project management, Life Cycle Cost, LCC, RAMS, design review, IEC 61160, safety, conformity assessment, IEC 15288, IEC 12207, project phase, maintenance, RCM

1. INTRODUCTION

10 years and longer development time, 40 M€ and more development costs are typical figures to be expected for the development of scientific instruments for the 30 to 100m class Extremely Large Telescopes, see Table 1. These numbers are certainly too high to be accepted by the funding sources as well as from a scientific and technical point of view. Astronomical scientific instruments are no serial products and 10 years after the start of an instrument development project the techniques eventually implemented in the instrument are already outdated. The supply of spare parts and know-how to accommodate the necessary maintenance and repair activities during the following decade of instrument operation will not only present major and nearly unsolvable procurement problems, it will also lead to highly expensive and risky modification activities. To avoid these problems an adequate systems engineering approach has to be implemented from the beginning into the instrument development project.

Lessons learned from current Telescope Projects			Goals for future ELTs
Telescope size	4m	8m	30 to 100m
Complexity	1	10 to 20	20 to 40
Cost	1 to 3 M€	5 to 10M€	10 to 20M€, Estimation for MOMFIS: 30-40M€
Development time	2-3yrs	5-7 yrs	5-10yrs Estimation for MOMFIS: 10yrs

Table 1: Resources requirement estimations for ELTs¹

On the other hand the European Commission uses in its FP7 proposal among others the argument

“The costs of research are rising, due in particular to the increased use of expensive instruments and infrastructure”

to justify the enormous increase of the total budget, while the European Parliament insists that

“the improvement of scientific excellence must include the improvement of the scientific performance, efficiency and quality”.

The main goal must be to improve the scientific performance, efficiency and quality and thereby the scientific output by using excellent scientific instruments and to minimize the life cycle costs of these instruments to the absolute minimum. To reach this goal in a most economic way, the careful application of the following technical and management tools is recommended.

¹ Data partly taken from T. Herbst presentation at the Ringberg workshop

2. INSTRUMENT LIFE CYCLE COSTS

The total life cycle cost (LCC) of an instrument is the sum of the costs arising from the instrument procurement (planning, developing, manufacturing, installing) of the instrument plus those costs resulting from the instrument operation, maintenance, upgrading and the dismantling and disposal of the instrument at the end of the life time.

The total amount of the LCC is determined to a large degree already during the early planning, preliminary design and final design phases of an instrument. The amount of LCC can only be slightly modified and influenced during the subsequent manufacturing / construction and the installation, commissioning and operation / maintenance phases, see Figure 1.

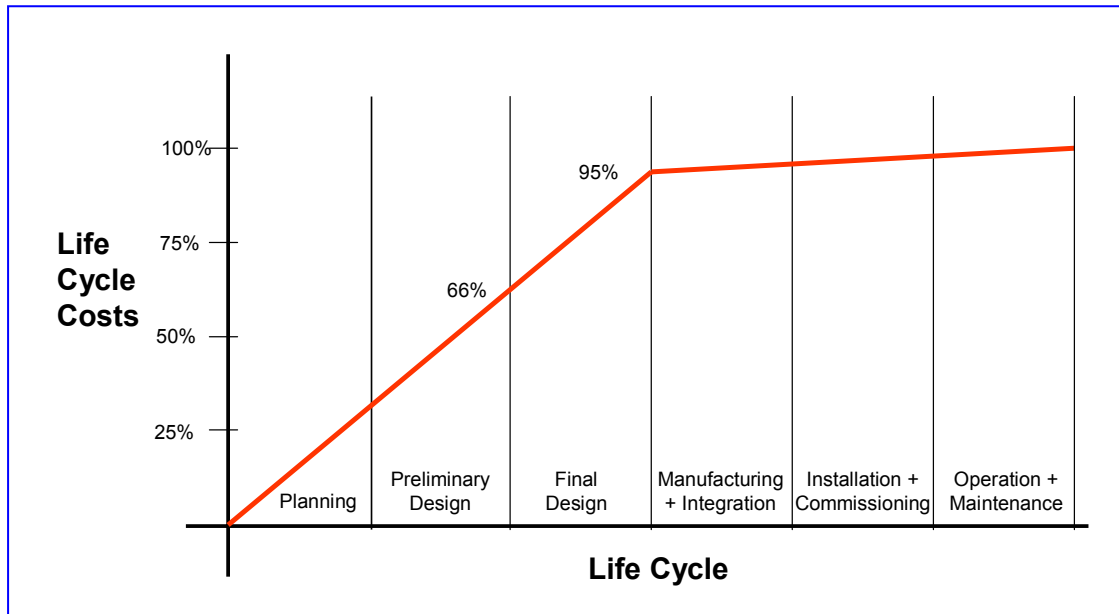


Figure 1 Stages of Life Cycle Costs Commitment

The definition of the acceptable total LCC is one of the predominate tasks of the project management and systems engineering team at the beginning of a project for an ELT scientific instrument. This does not only include the definition of the instrument development, manufacturing, assembling, integration and verification (AIV) costs, it requires also the detailed knowledge of the installation environment and the definition of the operation and maintenance concept. In particular the definition of a valid operation and maintenance concept is of eminent importance since the operation and maintenance cost are normally by factors higher than the costs for the procurement and installation of the instruments.

One of the factors having a major impact on the operation and maintenance costs is the expected life time of a scientific instrument. Based on the evolvement of available industrial technologies, a development time of up to 5 years and “moderate” development costs, a life time of scientific instruments of up to 10 years was anticipated for the 4m to 10m class telescopes. If the development time of ELT scientific instruments extent to 10 and more years and the development costs reaches levels of 30 to 40 or even 50M€, the question of a minimum acceptable life time and the maximum acceptable operation and maintenance cost has to be reconsidered and discussed. The adoption of modern maintenance strategies like Reliability Centered Maintenance (RCM) may help to solve the problem. The most important fact is to consider the instruments reliability, availability, maintainability and safety (RAMS) characteristics in an adequate way from the beginning of the instrument project and already during the requirement definition phase. The awareness among all project participants of the importance and the impact of the RAMS characteristics on both, the availability of the instrument for scientific research and the total life costs has to be increased in order to reduce the total LCC of ELT instruments to an acceptable level.

3. SYSTEMS ENGINEERING

Although Systems Engineering (SE) is a discipline created already in the middle of the last century in order to be able to cope with the growing complexity of technical systems, it found only quite recently its way into the astronomical telescope and instrument technology and engineering world. There are still a lot of training and familiarization processes and activities necessary to educate the involved engineers and managers to a level of knowledge adequate to the complexity of modern telescopes and instruments and to the standard level in other high-tech industries. The approach of implanting SE into astronomical infrastructure projects started effectively in the beginning of the 90th of the last century with the creation of a job for a product assurance (quality and safety) manager in the ESO VLT Project. The VLT PA Manager detected very quickly that he could not do his job without the cooperation with a professional systems engineering, and he urged the VLT Project Manager to establish SE as key function in the project management team. 15 Years later SE was the first time subject of a separate conference at the 2004 SPIE conference “Astronomical Telescopes and Instrumentation”.

It is the right time now during the first discussion of ELT scientific instruments concepts and realization ideas to implement a competent systems engineering function into the individual project teams in order to execute and support the main SE tasks at the beginning of a project:

- to identify the real User Needs
- to transfer the User Needs into scientific–technical requirements (Instrument Performance Specification)
- to estimate the total life cycle costs
- to identify realistic instrument reliability and availability requirements for scientific operations as well as acceptable down times and maintenance operations (incl. logistic support), and the safety legislation to be followed,
- to establish a preliminary project execution planning including project phases, milestones and the overall verification / validation scenario.

There are two international standards explaining the life cycle of a product from a Systems Engineering point of view:

- ISO/IEC 15288 Systems Engineering – System Life Cycle Processes, and
- ISO/IEC 12207 Information Technology – System Life Cycle Processes

These standards are applied extensively by the high-tech industry in order to execute projects in a systematic, thus most economic way and to avoid and solve problems within a minimum of time, with minimum costs, with predefined quality, and with lowest and controllable risk.

There is no real difference in the engineering or management of technical projects in astronomy and industrial projects of similar sophistication in aerospace, marine or other high-tech industries. Why not using procedures and processes in managing astronomical infrastructure projects which have proven in the profit oriented industry to be most effective?

4. DESIGN OPTIMIZATION & RISK MINIMIZATION

Systematic design optimization activities have to be initiated and performed in a preplanned manner in the scientific instrument design and development cycle in order not to jeopardize the schedule of the entire project. This requires a strict project phasing from the beginning and predefined review activities at the end of each project phase. The standard project phases are.

1. Requirement Definition Phase
2. Preliminary Design / Conceptual Design Phase (Feasibility Demonstrations)
3. Full Scale Design and Development / Final Design Phase
4. Manufacturing / Construction Phase incl. Assembly, Integration and Verification
5. Installation & Commissioning Phase
6. Operation & Maintenance Phase
7. Disposal Phase

For each of these project phases project management and systems engineering have to prepare project phase specific “Baseline Configuration Data Files” containing the technical, schedule and financial basis for the execution of the particular project phases. During and at the end of each project phase the achieved progress is compared with the data contained in the Baseline Configuration Data File. Deviations from the defined goals are detected immediately and counter measurements can be initiated on time, leading to a minimization of the risk of expensive technical, financial and schedule slippages.

Before a project phase can be considered as successfully finished the results of the phase should undergo a formal design review process. Although many of the current astronomical infrastructure projects are already using design reviews as standard management tools, it seems that not all of the present users are really familiar with the usage of this tool for the benefit of the entire project.

The International Electrotechnical Commission, IEC, has published just recently (October 2005) a new international standard dealing with this subject: IEC 61160 Second edition 2005-09, Design Review. The purpose and intention of this standard is described by the IEC as follows:

“This International Standard makes recommendations for the implementation of design review as a means of verifying that the design input requirements have been met and stimulating the improvement of the product's design. The intention is for it to be applied during the design and development phase of a product's life cycle. It provides guidelines for planning and conducting a design review and specific details concerning contributions by specialists in reliability, maintenance, maintenance support and availability”.

Independent of how a design review is actually performed, the main goal is to check by using a formalized systematic scrutinizing process the conformity of the project phase result with the definitions contained in the project phase related Baseline Configuration Data File. In order to be most effective project external experts not involved in the day-to-day business activities should be involved in the scrutinizing process of the normal instrument design and development documentation. No extra documentation except some papers necessary for organizing the reviews should be prepared. One advantage of using external experts is that they are not just checking the capability of the design to fulfill the specified requirements; they will bring – due to their expert knowledge – new ideas into the project which might lead to a design simplification and / or optimization, i.e. cost minimization. The project manager and the systems engineer must carefully evaluate any “new idea” with respect to the real scientific and technical benefit and the costs and time needed for the implementation. However, routine design reviews at the end of each project phase offer the opportunity to have the design and development results checked by independent experts and thus to detect failures and nonconformities in the design. The risk of producing products which do not meet the user requirements and to waste money in the continuation of the development of these products is minimized in an optimum way.

5. INSTRUMENT SAFETY CONFORMITY

In addition to the scientific and technical requirements deducted from the scientific needs, the requirements related to the safe use and operation of the scientific instrument play an equally important role in the design, manufacturing installation and operation of the instrument.

The state-of-the-art occupational safety and health as well as the product safety requirements have to be respected from the early beginning of instrument procurement cycle. Due to the international environment characterizing the today's astronomical research activities the place and the observatory for which the scientific instrument will be developed, the knowledge of the governmental safety legislation of the country in which the instrument will be operated, any specific observatory safety requirements and regulations, and the governmental requirements of the country in which the instrument will be build have to be known when preparing the instrument technical specification.

Fortunately the occupational safety and health requirements do not differ very much in the modern western industrial countries and due to the world wide international trade activities also the technical equipment safety requirements of the large economic markets of the world, like USA and European Community are similar, they are well known and respected in all countries wishing to participate in these economic markets.

All important markets have introduced the “Safety Conformity Assessment” approach to enable and foster the *free movement of goods* which is essential for the functioning of the individual economic markets. The markets have established market wide applicable safety requirements / legislations. Only products fulfilling the safety requirements / legislations may be placed on the market and put into service. This means that for all products which shall be placed on the market and put into service the conformity with the market specific safety requirements has to be assessed and demonstrated. Since “*placing on the market and putting into service*” includes the handing over of the product to a third person, the user, the safety conformity assessment approach applies also to any kind of scientific instruments.

Being aware that an astronomical scientific instrument for ELTs have - from a safety point of view - to be considered as a normal industrial product for which the producer is obliged to demonstrate the compliance with the legal safety requirements, the project manager and the systems engineer have to make themselves familiar not only with the applicable safety requirements and legislation but also with the processes and procedures to be followed for correct safety conformity assessments and demonstrations.

At the present stage of definition of ELT scientific instruments it is recommended to take the following activities into account and to consider them in an adequate way throughout all future live cycles of the instrument:

- definition of applicable safety legislation
 - national governmental regulations of place of installation / operation
 - observatory specific requirements
 - own institute safety regulations
- definition of verification requirements
- definition of Safety Conformity Assessment Process
- implementation of requirements into the Instrument Specification
- consideration of requirements in instrument planning

6. SUMMARY

At this early stage in the definition and discussion of scientific instruments for ELTs, the consideration of the following management tools and procedures:

- the introduction of state-of the-art Systems Engineering processes
- the proper consideration of those factors related to the long and costly operation phase, namely the reliability of the instrument and thereby it’s availability for scientific research activities, the maintenance and logistic support needs,
- the preplanning of design reviews and design optimization cycles in the design and development process,
- and the adequate respecting of the occupational safety and health as well as equipment safety requirements and regulations

will be most effective and will substantially reduce the total LCC and development risks. By applying these tools, processes and procedures the responsible project manager and systems engineer demonstrate their professional way of acting and their most economic and careful use of the funding resources.