NO MORE MUDDLING THROUGH

No More Muddling Through

Mastering Complex Projects in Engineering and Management

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Preface

Good engineers and professional managers use a systematic way of thinking. And they are in need of a methodology to guide demanding problem-solving processes in their everyday work. Systems Engineering offers such a methodology. It builds on traditional systems engineering methods from engineering sciences and combines them with modern, systemic management thinking, state-of-the-art problem solving approaches, and complete life-cycle management of products and systems.

In the 1950s and 60s new concepts were introduced to facilitate co-operation in multi-disciplinary teams with a view to developing an optimal complex technical system. A. D. Hall's 'A Methodology for Systems Engineering' (1962) was a landmark in the definition and exemplification of the new approach. At ETH in Zurich a comprehensive methodology named 'Systems Engineering' was then developed (Büchel (1969), Haberfellner et al. (1976), Haberfellner et al. (2002), Züst (2004)).

Competitive titles in the marketplace typically focus on the engineering of purely technical systems covering stages of design, systems engineering management, tools, and applications. They rarely discuss the complete life cycle, or, if they tend more to the soft issues side, lack the engineering and managerial problem solving approach.

The German equivalent of this book has been used extensively since 2000 in higher education at university level in both engineering and management master courses. International students and universities from across Europe keep requesting an English version of the publication, and the initial 50-page summary is not sufficient enough to cover this demand both in quality and in quantity.

This volume also contains three case studies from our collection published in 2002 (Züst R. Troxler P (2002). The cases tell real-life stories of how practitioners applied the methodology to their own projects in their particular circumstances. On purpose, these cases are more like stories than like textbook examples, so the reader can participate in the exciting struggle the authors faced when applying pure teaching to a practitioner's reality. These are not smoothly polished success stories, but real examples with all their ambiguities and contradictions. And yet they tell us how the considerate application of the SE methodology in the hand of a professional will lead to project success.

Rainer Züst
Zurich, spring 2006

Peter Troxler
Aberdeen, Rotterdam, Zurich, spring 2006

Foreword

Systems Engineering has in the past few years become a very popular discipline. Many products of our daily life grow in terms of added functions and often complexity. This concerns consumer goods such as cameras, televisions, automobiles, as much as socio-economic or environmental systems or communication networks. This sometimes only perceived growth in complexity is supported by the enormous capabilities of our modern information technologies and the associated software.

Systems Engineering today has grown from an exclusive technical design or process focus into a holistic or 'end-to-end' discipline. Today's System Engineers deal with technical optimisations, requirements analyses, implementation processes, economic issues, and after sales support matters. But they also analyse large network centric operations, generate complex architectures of systems of systems and evaluate enterprise structures and processes.

The principle value of Systems Engineering originates from its focus upon unbiased trans-disciplinary assessments of all parameters contributing to the design and production of better products. System trade-offs deal with technological, economic and sustainability factors and merge them into solutions, that meet market demands or customer requirements. Systems Engineering has become one of the strongest assets of enterprises since it delivers products that are well engineered and create market success and profitability. 'Modern' Systems Engineering is progressively more model based on and

employs advanced tools and techniques of system simulation throughout the life cycle evolution.

This book is an excellent entry for novice system engineers, for people who want to familiarize themselves with the step-by-step systems engineering process and associated solution methods. It is written in a very practical manner and provides specific advice for practitioners. As President of the International Council of Systems Engineering (INCOSE) I welcome this book into the wider international systems library and wish its English version as much success as its German version has had in past years.

Prof. Dipl.-Ing. Heinz Stoewer, M.Sc.
President of "International Council on Systems Engineering (INCOSE)

1. INTRODUCTION

1.1 Origin and Development of Systems Engineering

In the 1950s extensive, complex, interdisciplinary and large-scale projects – such as landing on the moon – were launched. In the context of such projects, new materials, procedures and technical products were developed; in addition 'socio-technical' questions (human, legal, e.g.) had to be mastered. Diverse technical disciplines and experts were involved in solving these problems. Individuals or small groups could not manage such large-scale projects any more. Therefore a new method became necessary. Different concepts evolved how interdisciplinary project teams could work together and how complex systems could be developed efficiently.

In the context of the search for methods the book 'Methodology for system engineering', published by A. D. Hall in 1962, received special attention and distribution. Hall's methodical design was taken up and newly interpreted some years later by professor A. Buechel at the ETH Zurich at the beginning of the 1970s. It was then further developed into the independent method Systems Engineering at the Institute for Scientific Management (BWI) of the ETH Zurich by a group of authors (Haberfellner et al. (1976)).

Systems Engineering (SE) is a systematic way of thinking and a method to mange the problem solving processes in the context of challenging socio-technical questions. Primarily, the application of SE is recommended for projects with large object complexity and large size where it is difficult to efficiently develop, implement and control a sustainable solution due to the many parties involved.

Projects where a formal application of SE is recommended are for example:

- New transport systems: for example a new high-speed railway line with trains, line management (all parties involved taken into account), timetables and connections to further transport systems, tariff system and financing.

- Communication systems: for example a new satellite communication system.
- Computer systems: for example a computer architecture including networks and applications.

Large-scale installations of process engineering: for example for the production of genetically modified substances.

The formal application of SE methods is also recommended for certain projects of medium complexity and project size as for example

- Development and introduction of a new manufacturing strategy
- Structure and implementation of a new management system
- Concept for kerbside collection and recycling of recyclables

SE methods clearly are in competition to other general planning methods. In each situation it has to be examined whether SE methods, alternative methods or a combination should be applied.

The SE role in a project should guarantee the development of optimal products. We understand the term 'product' here in its broadest sense – as a 'system of matter and action'. The economic, ecological and social implications of the product have to be taken into account in the system development (see also extended term of technology from G. Ropohl (1991)). Thus the SE function embodies the socio-technical expertise respectively the excellence of the system development and therefore the innovation potential of the company.

In contrast the project management role is responsible for the optimal project design and for its implementation (including the SE work, see figure 1.1). Project management governs the whole project while Systems Engineering primarily supports the development phases of a system.

The SE role is established at the level of company management as an independent, functional department in many larger companies, particularly in the area of air- and spacecraft, computer and large-scale industry in the U.S.A. and in other countries. This department is purposefully involved in projects to support the problem solving process.

In Switzerland, Systems Engineering was applied for the first time outside an engineering context when the Hürlimann commission, a Swiss planning commission, had to deal with the future planning of traffic and mobility in Switzerland. In the standard publication on Systems Engineering (Haberfellner et al., 11th Edition (2002)) the complex project of the planning of the airport of Munich at the beginning of the 1970s is described. In both examples, it becomes evident that a challenging planning task can be managed using Systems Engineering.

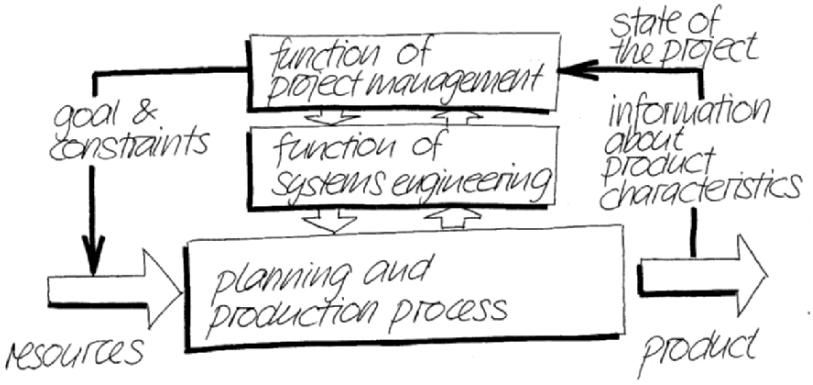


Figure 1.1. Project management and Systems Engineering functions (Züst, Schregenberger (2003)).

Over the years, the method of Systems Engineering was not only presented to industry leaders in workshops but also taught in several courses at the ETH Zurich and other universities, in particular at engineering departments.

Today, ecological aspects are also used in SE. Sustainability is an important postulate for SE projects, for example described in the project ECODESIGN (www.ecodesign.at) and the corresponding book (Wimmer, Züst (2001)).

The international movement for the promotion of Systems Engineering has been in existence for about fifteen years now. The 'International Council on Systems Engineering' (INCOSE, see also www.incose.org) is active worldwide to promotes systems engineering as a method for the development of challenging technical systems. Only recently INCOSE has started to investigate the role of systems engineering beyond its application to engineering projects.

This understanding of SE as a method to design socio-technical systems has been at the core of the Zurich school of SE since its beginning.

1.2 Structure and Content of Systems Engineering

Methodical problem solving is about gaining a complete picture of the problem from different points of view. Only then a defined initial condition can be transformed into an optimal target condition (figure 1.2).

This process, i.e.

- analysing and modelling material worlds,
- the definition and structuring of complex goal definitions,
- the heedful development of alternative solutions and
- the analysis and multi-dimensional evaluation of these solutions
- is called problem solving process in SE. It is supported by appropriate methods.

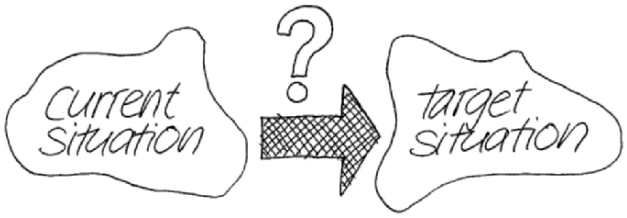


Figure 1.2. Problem solving as a transformation of an initial condition into a target condition.

Systems Engineering postulates a set of principles that have to be applied during system design (figure 1.3):

The successful application of Systems Engineering depends on certain conditions. These are focusing on specific fields of application (challenging questions), the institutional status of the SE role, methods of thinking in systems, and a set of problem solving heuristics.

Systems Engineering relies on two basic methodical concepts. These are:

- Life phase model (LPM): The life phase model describes the purpose and specific content of the individual life phase of a system.
- Problem solving cycle (PSC): The problem solving cycle contains several steps that are necessary in order to develop a solution to any sort of complex problem.

In the context of the Systems Engineering the interaction life phase model and problem soving cycle is of central importance.

Furthermore SE covers an interdisciplinary arsenal of qualitative and quantitative methods to solve specific problems.

This book also follows this structure of SE (as shown in figure. 1.3).

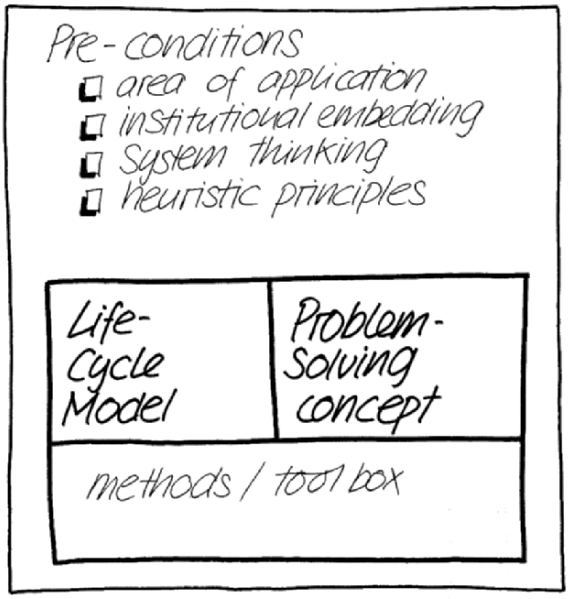


Figure 1.3. Structure and contents of Systems Engineering.

1.3 Content of the Book

The central focus of this book is on the most important, basic methods that have to be taken into account when designing a challenging system, and on their efficient and concrete application (see figure 1.3).

The book is devided into three parts (see figure 1.4.)

Main chapters	***Part of the book***
1. Introduction	
2. Requirements 3. The life cycle model and the problem solution cycle and their interaction 4. Interdisciplinary, universal toolbox	Part 1 ***Systems Engineering Overview***
5. Situation Analysis 6. Goal Definition 7. Search for Solutions 8. Evaluation and Decision	Part 2 ***Problem Solving Cycle***
9. Application of SE Case A: Environmental Management System Case B: Communication Network Case C: Strategic Positioning of a Product	Part 3 ***Cases***

Figure 1.4. Content and structure of the book.

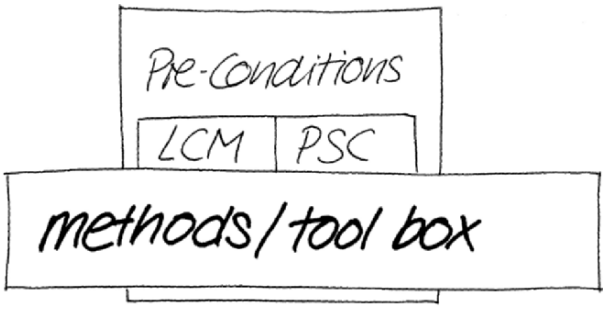
Part 1: Systems Engineering Overview: the methods of Systems Engineering as a whole. The description of the two basic concepts life phase model and problem solving cycle and their interaction.

Additionally we show which requirements are necessary for a successful application of SE and how management and engineering methods can be aligned with SE.

Part 2: Problem Solving Cycle: An important basic concept of SE is the problem solving cycle. This is described in detail in part two. This part focuses on the steps situation analysis, goal definition, search for solutions, evaluation and decision.

Part 3: Cases: Finally, three real planning examples are described. SE users talk about their experiences, about the difficulties and distress but also about the highlights and successes of the application of SE in their professional life. The main focus of the three cases is on the application of the problem solving cycle, the life phase model and their combined application.

2. PRE-CONDITIONS



Each general problem solving method such as the method of Systems Engineering (SE) is based upon specific conditions that are:

- the focus of its area of application,
- institutional embedding,
- the systems thinking approach,
- a set of heuristic principles.

2.1 Area of Application

Systems Engineering (SE) is a general method to solve complex and new design problems in the area of technology development. The application of SE is recommended when the problem is related to several areas of expertise and therefore a systematic consideration of different perspectives is required.

Terms:

'Problem' and 'Problem solving':

These explanations are selected from various definitions of the term 'Problem' in different specific fields: 'A problem exists if an individual wants to achieve a certain objective but does not know how to achieve this objective' (Süsswold (1956), p. 10). 'We speak about problem solving when the means to achieve an objective are unknown or the known means have to be combined in a new way and also when no clear idea about the objective exists, (Dörner et al.(1982), p. 303).

‘Complexity’:

Among the numerous attempts to define the term ‘complexity’ we prefer this definition by G. Klaus: ‘Complexity is a character of a system defined by the type and number of relations existing between the elements, in contrast to the elaborateness of a system that is related to the number of different elements’ (Klaus, Liebscher (1979)).

A few reflections about the relation between revenue and expense are shown in figure 2.1 before getting into the formal application of SE.

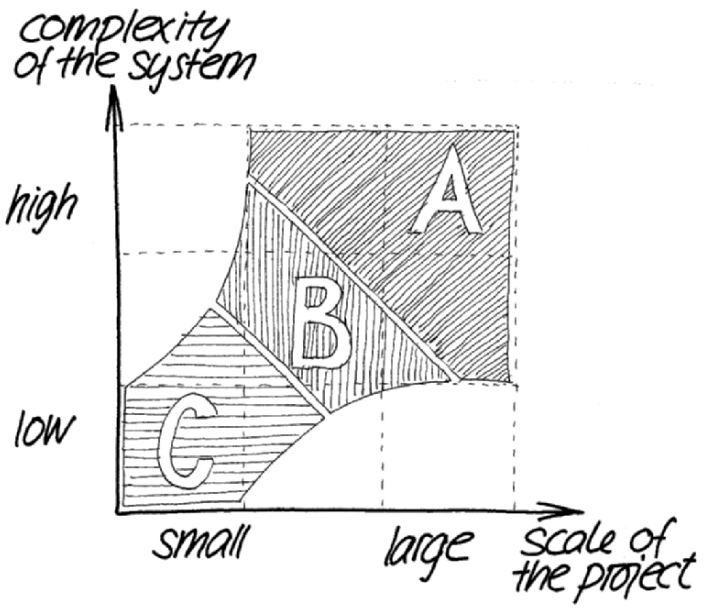


Figure 2.1. Qualitative characterisation of projects as a function of the scale of the project and the complexity of the system, to assess the appropriate application of SE methods.

Area A: Dominant Position of Systems Engineering

The formal application of Systems Engineering for the optimal system design was originally planned for area A shown in figure 2.1. It is made for very extensive and interdisciplinary projects using