Introduction

Although systems engineering has been around for some time, the domain is currently becoming increasingly widespread and attracting the attention of engineers who, rightly, see it as a federating and multidisciplinary approach to dealing with complex systems.

Having emerged in the fields of aeronautics, the aerospace industry and defense, systems engineering is now applied in most economic domains, including transportation, energy and the medical domain, to cite just a few examples. Various factors promote the application of systems engineering in a wide range of domains. Without giving an exhaustive list, these factors include the necessity to avoid beginning each project from scratch by making use of pre-existing resources; the long lifespan of systems integrating technological components with increasingly brief lifespans, necessitating careful management of obsolescence; the need to find appropriate solutions responding to expressed needs, timescales and budgeted costs; and the need to dismantle systems and reduce final wastage.

More broadly, the need to ensure the interoperability of systems with varied origins not designed for interoperability, in order to upgrade existing systems that are not best suited to current operational needs, leads us to apply system-of-systems engineering practices. Several works have already been published covering system-of-systems engineering, presenting theoretical foundations, fundamental concepts, domains of application, methods and tools, modeling and system simulation alongside the standards applied to the domain. In this work, we shall consider the concrete application of these concepts, methods and tools in the context of projects.

The first section of this work is made up of two chapters: *Engineering Large-scale Complex Systems* and *Management of Emergency Situations*.

In the first chapter, we shall consider the characteristics of large-scale complex systems that the reader may be called upon to engineer. Current issues include the passage from an approach to systems as patrimonial resources to a perception of systems as services. This has effects in terms of economic models and engineering models (simultaneous creation and consumption of the service). System resilience is also a major concern; we must now design systems "for uncertainty", taking account of the behavior of the system in relation to its surroundings or beyond its limits. We must also qualify and quantify the "slide" from operational functionality in a system towards a state of failure before major breakdowns occur. Engineering for large-scale systems must be based on a broader understanding of the subject of complexity than is currently the case. "Complexity" covers a range of factors, including interactions, non-linearity, unpredictability, sensitivity to initial conditions and multi-scale characteristics. We shall then look at the seven major challenges of systems engineering and the developments that are necessary to respond to these issues. Finally, we shall consider the impact of these issues in terms of modeling, automatic demonstration, and the design of material and software components of systems.

Chapter 2 is a case study on emergency system management, from an architectural and system-of-systems engineering perspective. The chapter gives a 360° view of all dimensions that must be taken into account when providing a region with the capacity to manage crisis situations, in this case road accidents, in order to reduce accidental mortality and morbidity. Chapter 2 shows how these operational, technical, economic and social dimensions are interlinked, both in the practical use of products and in service provision. Based on a reference operational scenario, we shall demonstrate how to define the perimeter and functions of a system of systems. We shall also show how a functional, modular architecture may be developed for an accident detection system, suited to the segmentation of the market, in order to create a viable economic model, and how to express needs based on the analysis of activities and existing resources. A system of systems includes products, but also services that each have their own specific characteristics, including simultaneous production and consumption of a service. Finally, we shall demonstrate a method of organizing information within an architectural structure in order to ensure coherence, but also to communicate only relevant information to those involved to save them from drowning in a mass of disorganized data.

Part 2 of this book is made up of a number of chapters based on a second case study, the *Antarctica Life Support Facility*.

This case study will show, step-by-step and in detail, the activities involved in engineering the complex system constituted by the Antarctica Life Support Facility: a (sub)system of a fictional mission in Antarctica involving five scientists responsible for obtaining samples from deep underground. This system has a number of significant aspects and shows up particular characteristics of systems engineering, including the definition of perimeters, consideration of the life cycle, links to project management, integration of different disciplines, pursuit of an optimal global solution, etc. This case study is presented in a narrative manner showing both sides of the story. The characters involved in acquisition and supply cross paths, carry out their activities, sometimes with doubts, and do not always succeed at the first attempt; together, they create a suitable solution in an iterative and incremental manner.

Thus, the reader may follow those responsible for acquisition in capturing the stakeholders' needs, their understanding and subsequent construction of a system model including expectations, the lifecycle, operational and physical boundaries and the representation of the domain. We shall then see how this model is represented in a specification, how a contractor is selected to supply the system and how an agreement is established with the contractor. From the other side, we shall see how the supplier designs a suitable solution to respond to needs within fixed budgetary and time constraints. We then show the establishment and initialization of a constructive systems-engineering approach (finding the best solution to the problem) and the links to project management. This illustrates the dual nature of systems design, which includes operational and physical aspects, and the importance and complementarity of the two. We thus show the creation of a constructive model of the system allowing objective evaluation, verification and validation, before going on to show how this design is punctuated by engaging technical decisions based on evaluations, trade-off studies and fine optimizations of system characteristics. Through this, we see clearly that this design process must involve a multidisciplinary approach, as illustrated by two examples of the integration of transversal disciplines in the system design process: operational security and human factors. Finally, we shall demonstrate the need to correctly place integration, verification and system validation processes, to anticipate them and to link them firmly to other engineering processes. Through this case study, then, we shall show the federative aspects of systems engineering, contrary to a compartmentalized juxtaposition of engineering practices and mutually ignorant disciplines.