Handling the Complexity of Large, Technology-based Business Ventures

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It is argued that the systems engineering methodology, now increasingly accepted as the preferred approach to complex projects also outside defense and aerospace, should be extended into the front end of commercial business ventures, in order to assure that the engineered solution fully meets the business objective.

Many business ventures involve the creation of large, technology-based facilities, such as transport and storage facilities, mines, power stations, and process plants, and their success depends, among other factors, on the degree to which these facilities support the business objectives. That can be seen as the result of a two-stage process; first the conversion of the objectives into requirements on the facilities, and then the design of facilities to meet those requirements. Both of these processes are prone to inadequacies and even outright errors, as is the transmission of the information across the interface between them. It is an interface between two different cultures, business and engineering, and it is not helped by the fact that the means of transmission, a contractual document of some sort, is developed by a third group, the legal profession, which has a different perspective again.

The problems associated with this process are magnified by the increasing *complexity* of the requirements. There are several reasons why the complexity is increasing: Most obvious reasons are the size and multi-disciplinary nature of the projects, as well as the technological sophistication made possible by the rapid development of new technology. Another group of reasons arises from the more stringent regulations and requirements with regard to environmental impact and safety. But the most recent and perhaps the most rapidly growing reason is the involvement of community groups of all kinds, made possible by the ready information exchange offered by the Internet. As an example, the design of a high voltage transmission line takes maybe six months, but the community consultation may take several years.

To handle this increasing complexity, the engineering profession has developed *systems engineering* as a process additional to the traditional, discipline-based (i.e. civil, mechanical, electrical, etc.) design processes and associated management processes. It is perhaps best thought of as a pre-process that reduces the complexity prior to applying the traditional design processes, but it remains involved throughout the whole project. How does it manage to reduce the complexity? By leveraging an observable aspect of how the human brain handles complexity. And it is important to note that complexity is relative to the capabilities of the brain; what is complex to the brain is not complex to a computer, and *vice versa*. You can instantly recognize your mother on a photograph, something that is a complex task for a computer, but try the cube root of a six-digit number! The observable aspect is that when something has too many variables for the brain to perceive and process it as a unit, we automatically subdivide it into more manageable elements, or *chunks*. Nowhere is this more obvious than in organizations, e.g. in the military, with the number of soldiers in a platoon, the number of platoons in a company, and so on. This aspect was first made explicit by Prof. George A. Miller in his seminal paper *The magical number seven, plus or minus two: Some limits on our capacity for processing information*. Psychological Review, 63, 81-97(1956), and a very simple model that provides a possible explanation for why this is so can be found in one of my earlier books, *The Changing Nature of Engineering*, McGraw Hill (1996).

Systems engineering is the consistent application of this insight to large engineering projects. Such projects contain two complex entities; the physical object to be created, and the work required to create it. Both are treated as systems, i.e. as collections of interacting elements, each organized in a hierarchical structure, so as to maintain the "chunking" introduced above. In the case of the object, the elements are modules, equipment, and subsystems and the structure is called the *System Breakdown Structure* (SBS) or also *system architecture*; in the case of the work, the elements are tasks and work packages, and the structure is the *Work Breakdown Structure* (WBS). In the case of the SBS, the interactions between the elements take the form of a transfer of matter or energy; in the case of the WBS the interactions are in the form of information. Systems engineering consists of a number of processes for developing and managing these structures throughout the project lifecycle, and is documented in such standards as ISO 15288 and EIA 632 or in handbooks, such as the *Systems Engineering Handbook* published by the International Council on Systems Engineering (INCOSE).

While systems engineering was, for obvious reasons, first developed and employed within the defense and aerospace industries, it is now being increasingly accepted throughout the engineering community as the preferred approach to complex projects, and there is mounting evidence, albeit mainly qualitative and anecdotal, of the benefits that can be achieved. Eric C. Honour, President of Honourcode Inc, has collected data on 44 projects as part of his ongoing efforts to document the value of systems engineering, and one illuminating result is a quantity called Development Quality (DQ) as a function of the proportion of the systems engineering effort spent on a project, as shown in Fig. 1 (reproduced with permission from *Understanding the Value of Systems Engineering*, in Proceedings of the 14th Annual International Symposium, available online at http://www.incose.org).

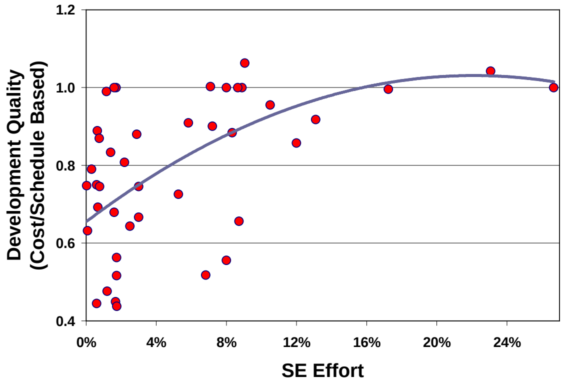

Figure 1 Development quality as a function of systems engineering effort.

In this figure, DQ is defined as the inverse of the average of the actual cost (AC) to planned cost (PC) and actual schedule (AS) to budgeted schedule (BS), or

$$DQ = \frac{2}{AC/PC + AS/BS} ,$$

and the systems engineering effort is the product of the actual cost of performing the traditional systems engineering task and a measure of the quality of that performance, expressed as a percentage of the project cost up to delivery of first article, not including production costs.

However, even though systems engineering has improved the success rate of large engineering projects, there are still projects where the proponents of the business venture are less than satisfied with the outcome. Based on my own experience and through discussions with colleagues, in most of these cases the problem has not been in the engineering as such; the facilities have performed exactly as they were designed to do, in accordance with the requirements. On closer inspection, the cause of the dissatisfaction could be traced to the requirements in the first place; i.e. to the expression of the business objectives as requirements on a particular facility. And it is not so difficult to see how this can quite easily happen. From the business point of view, the project is primarily an investment opportunity based on providing a service (in the widest sense, including goods) to meet a perceived market need. The characteristics of the service, its cost, reliability, flexibility in the face of changing market needs, environmental impact, etc, are all of great interest and the subject of detailed modeling and analysis, but *how* the service is provided is of secondary interest. If it could be provided by a fairy waving her wand (for an acceptable price), that would in principle be equally as satisfactory as building a facility. The facility is, in essence, the engineer’s solution to producing the service, and so the interface between the two parts of the development process, the business process and the engineering process, should ideally be the definition of the required service, without tying it to any particular facility.

The purpose of an engineered object is an abstract concept, describing only the service it is intended to provide, completely disassociated from *how* it does it and from any physical aspects of the object. This is best illustrated by means of a simple example - removing the cork from a bottle of wine. That is the service required by the user; the physical solution provided by engineers may take many different forms, such as a simple cork screw, a cork screw combined with some mechanism for extracting the cork using a smaller amount of force, a thin, hollow needle attached via a valve to small pressurised gas cylinder, a two-pronged device which is inserted between the cork and the bottle, and so on. For any one of these we can give a description of what the object is, by means of drawings, etc., that would allow it to be manufactured without any knowledge of what its purpose is. We could also give a description of how it works, e.g. in the case of the simple corkscrew by means of such parameters as how many turns are required, what torque is required, how much force is required to extract the cork, etc., and this would allow us to determine if it actually fulfils its purpose, i.e. meets the service requirements. These two descriptions would, of course, both be different for different solutions, but all the solutions have in common their purpose, the service they are intended to provide, also called their *functionality*. I emphasize the inclusion of the word “intended” here; functionality is not a property of any object; it exists prior to any object created to provide the corresponding service.

Now, this is all very well, but in reality it is impossible to get a business venture off the ground without having carried out a bankable feasibility study, which of necessity involves selecting a particular means of producing the service. This selection represents a transition from the space of services to the space of facilities that can provide services, and it is in this transition that we can often find the cause of dissatisfaction with the end result. In the above case of removing a cork the choices are relatively limited (although there would be thousands of variants if all combinations of shape, material, and color were considered); in the case of a major technology-based business venture the number of possible realizations is mind-numbing.

The approach most often taken is to select a few options based on previous experience and identify the preferred option by its greater cost-effectiveness. As effectiveness is defined in terms of meeting the business objectives, it would appear that nothing has been lost in this transition, but a closer scrutiny reveals that, almost invariably, the objectives have been recast using the features describing the performance of the chosen realizations. Again, a very simple example may be the best way to illustrate this: Laundering of clothes is a significant activity in our society; providing that service (i.e. getting our clothes laundered) therefore presents a potential investment opportunity. Our thoughts then automatically focus on the physical activity of laundering, and from there it is only a small step to focus on providing a better washing machine. There are many options, both with regard to technology and with regard to manufacturing, marketing, and sales, and an appropriate application of systems engineering will efficiently find a near-optimal solution in terms of cost-effectiveness. But the effectiveness is now couched in terms of the washing machine’s performance, not in terms of meeting the business objective, which was to maximize the return on investment. Once this has taken place, other options, such as providing a laundry service and dispensing with home washing machines all together, are removed from consideration.

The problems surrounding this transition form business to engineering are well recognized, and in my own sector of engineering, consulting, a great deal of attention is directed towards "understanding the needs of the Client". However, this usually takes place at a point in the life of the project where the Client has already cast his requirements in the form of requirements on a facility, and the engineer is left to, at best, try to understand the underlying business objectives by some form of "reverse engineering" of the requirements. A much better approach would be to apply the analytical, top-down systems engineering approach from the very start of the project, developing the business objectives step-wise in increasing detail, starting with the single objective of maximizing the return on investment. This approach, which can be thought of as *design in the functional domain*, is the subject of my recent book, *Designing Complex Systems*, CRC Press (2008).

There is, of course, at some point still a transition from the business objectives into the space of realizations of these objectives, but because this takes place within the same framework, there is always complete traceability back to the business objectives. Even down to the level of detailed design, the justification for any choice from a set of options is formulated in terms of the business objectives, and the business proponent's satisfaction with the outcome is assured.

Finally, with regard to this assurance, I note that systems engineering is very similar to quality assurance. People and enterprises did high-quality work long before there was any talk of quality systems; what a quality system provides is the assurance that a task will be performed to the same standard (almost) every time. Similarly, complex projects were previously, and some still are, undertaken successfully without systems engineering; what systems engineering provides, besides increasing the efficiency of the process, is the assurance that the business objectives will be fully met (almost) every time.