Implementing and Standardising Systems Engineering Practices within a Global Corporation

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Abstract. Developing new products is in many respects the process of identifying and envisaging user needs and bringing those needs into life in a cost-efficient manner, either utilizing existing technologies and solutions, or developing new ones. Product developing organisations are constantly challenged since new products must exceed expectations on quality standards in form, fit, and function – and that they must stand out from competition. This requires people with knowledge in many areas. Consequently, it is a multi-disciplinary process involving many parallel activities, such as product planning, design, production, marketing and after-sale.

Systems Engineering (SE) has become increasingly important in these organizations in order to manage the shear complexity of managing large scale development projects and secure the quality standards for all emergent properties of a system. The main driver for introducing SE is that the complexity and interconnectedness of systems continues to grow and the growing shift of focus to the complete offer rather than the product itself. However, there exist little research summarizing experiences of implementing SE, and there remain uncertainties as to how SE should be tailored to specific settings in order to add value to a development organization. Especially, focus needs to be put on managing the complexity of creating product variety.

This paper summarises our experiences from the continuous work to implement and standardise Systems Engineering practices within a global corporation in the transport solution industry. This includes a review of reports on SE implementations, a short description of the Volvo Group, and a summary of our experiences when implementing SE at various units and organisational levels.

Introduction

Product development organizations are faced with significant challenges when trying to offer customers better suited and cheaper products with high quality. According to Ulrich & Eppinger (2000), some of the characteristics that make it so challenging are: the *trade-offs* that have to be done between conflicting issues; the *dynamics* of the environment (e.g. customer preferences, competition, etc.) making decision-making in constant change a formidable task; the *detail* of the decision-making that is needed; and that this has to be done under such great *time pressure*. These challenges make it difficult to succeed in the development task at hand, and the result does not always mirror the goals and objectives that are initially set up.

The implementation and integration of development processes and support tools across organizations requires careful planning and involves business analysis, information modeling, system selection, education, coaching, etc. The driving force behind implementing and aligning these processes are to improve efficiency, reduce development time, re-use process experience and enhance cross-organizational cooperation. Ideally, during process reengineering, processes should

be created from scratch based on the business and market needs obtainable. Realities, however, often force organizations into redesigning only parts of their process and often only the core processes being redesigned while keeping the interfacing processes intact. For instance, in the automotive industry, there exist strong traditions regarding geometry management, securing manufacturing processes, risk management, etc. Consequently, one cannot talk about a change event – it's a continuous process towards enterprise discipline, through minor implementations, and several compromises must be made during this redesign. The goal for this process should be to build adaptability into the design so the organization can change in order to successfully compete; something Stanford (2007) calls the ability to morph.

There exist some reports on SE implementations. For instance, Dean and Bentz (1997) provide a Road Map for implementing Systems Engineering. De Landtsheer, et al. (2006) summarizes the experiences of the interest group System Engineering Implementation of the Dutch chapter of Incose through a step-by-step guide. Moreover, they summarize the result of a pilot project at Siemens using the step-by-step guide presented. Axelsson (2002) look at the implementation of systems engineering from the bottom up, by focusing on the components (i.e. humans) that actually make systems engineering happen in a firm. Sheard (2000) claims that "systems engineering" can be split into three basic implementations: *Discovery*, a discipline or specialist type that involves significant analysis, particularly of the problem space; *Program Systems Engineering*, a coordination or generalist type that emphasizes the solution space and technical and human interfaces; and *Approach*, a process type that can (and should) be performed by any engineer.

This paper summarizes our experiences when supporting our internal customers to implement and standardize Systems Engineering procedures and tools within the Volvo group.

The Volvo Group

The Volvo Group offer transport solutions to demanding customers around the world. They have a broad range of trucks, construction equipment, and buses. They also provide engines for leisure and work boats as well as diesel-powered generator sets. In addition, they have broad operations in the aerospace industry and also manufacture industrial gas turbines. Other services include financing, leasing, insurance, action service, warranty, rentals, IT solution and logistical operations. At present, the Group's workforce is about 105,000 employees. The majority of employees are based in Sweden, France, Japan, the US, China, Brazil and South Korea.Volvo Group customers are active in more than 180 countries worldwide, mainly in Europe, Asia and North America. Group sales of products and services are conducted through wholly owned and independent dealers. The global service network handles customer demand for spare parts and other services. Currently, production facilities are situated in 19 countries.

Volvo Groups business is characterized by strong brands. The *Volvo brand***,** which has been built up over decades and is one of the world's best known and respected brand. The *Renault brand* is one of the largest European manufacturers of commercial vehicles. The *Mack brand* that is one of the largest manufacturers of heavy duty trucks in North America. The *Nissan Diesel brand* which is one of the world's leading manufacturers of trucks and buses. The *Prevost brand* is a leading North American manufacturer of premium touring coaches and bus shells. The *Nova Bus* brand which is a North American leader in the design, production and marketing of urban transit buses.

The group is organized in product-related business areas (BA) and supporting business units (BU)

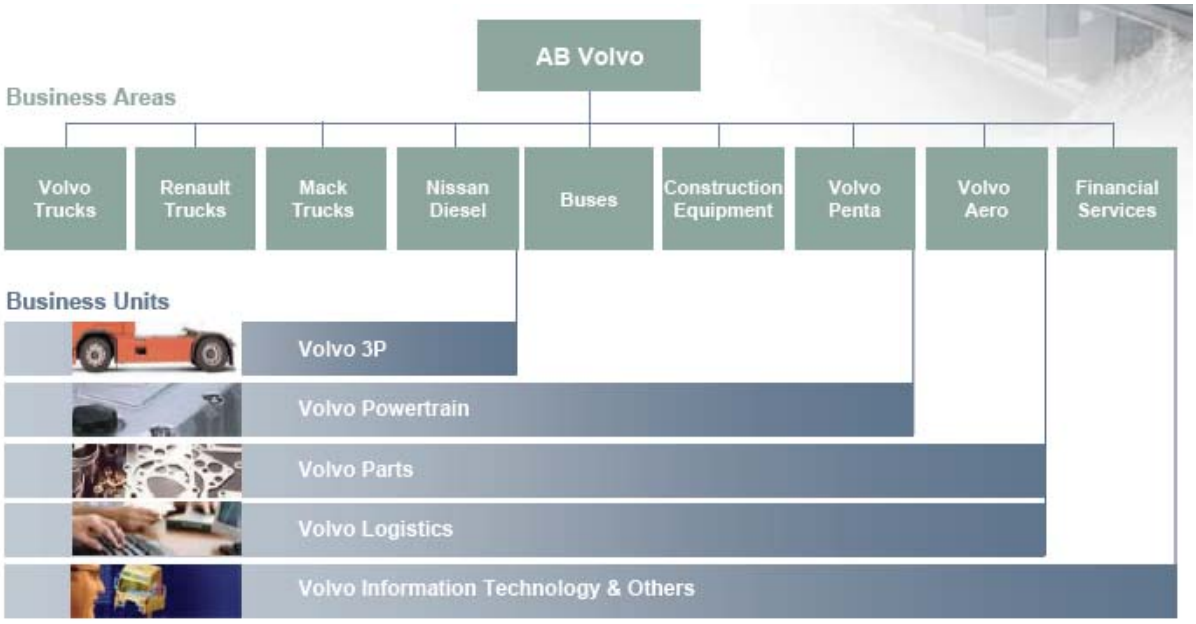

Figure 1. The product-related business areas (BA) and supporting business units (BU) within the Volvo group.

see Figure 1. This organization permits companies to work closely with their customers and efficiently utilize group-wide resources.

The business areas are, with some 75 percent of the Group's workforce, the nine product-related companies. *Volvo Trucks* that supplies complete transportation solutions to professional and commercial customers in more than 130 countries. *Renault Trucks* that is one of the market leaders in Europe with a rapid international development. *Mack Trucks* that is one of the leading producers of heavy-duty trucks in North America. *Nissan Diesel* that markets light, medium and heavy duty vehicles, buses and bus chassis, engines and vehicle components. *Volvo Buses* that is manufacturing reliable, durable city and intercity buses and coaches offering good overall operating economy. *Volvo Construction Equipment* that is recognized as one of the world's leading manufacturers of construction equipment. *Volvo Penta* that offers complete drive systems and service for leasure boats, workboats and industrial applications. *Volvo Aero* that offers responsibility for the development and manufacture of advanced engine components for aircraft and space rockets. *Volvo Financial Services* that offers traditional financial services such as installment contracts, operating and financial leasing and dealer financing.

The business units are organized globally and created to combine expertise in key areas. They have the overall responsibility for product planning and purchasing, and for developing and delivering components, subsystems, services, and service and support to the Group's business areas. The structure of the Group creates economies of scale in several areas, such as product development, production, parts supply and logistics, as well as in administration and support functions. The business units are *Volvo 3P* where the areas of responsibility are summarized in the three P's: Product Planning, Product Development and Purchasing. *Volvo Powertrain* that is responsible for the development and production of heavy engines, gearboxes and driveshafts. *Volvo Parts* that is the aftermarket solution provider for the Volvo Group. *Volvo Logistics* that provides the following

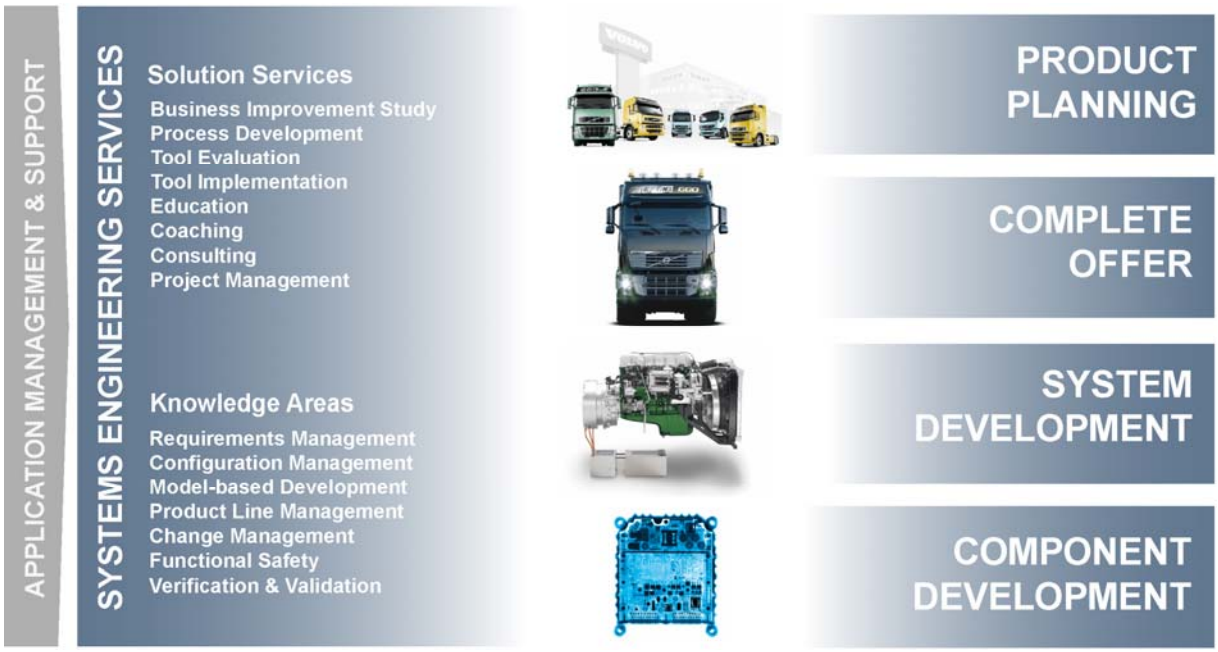

Figure 2. Competence Areas within Electrical and Systems Engineering Services

services: inbound logistics, outbound logistics and emballage. *Volvo Information Technology* that provides solutions for the whole industrial process, from product development to manufacturing to sales, aftermarket and administration.

Systems Engineering Services within Volvo Information Technology is a consultancy and application group focusing on Systems Engineering. The group engages people with a broad competence and experience within the automotive industry when it comes to Product Development, Systems Engineering, and IT applications. The group offers solution services, such as process development, tool implementation, project management and coaching in many areas, such as requirements management, configuration management, etc. These services are offered to organizations, ranging from product planning, complete offer-, system-, and component development, see Figure 2. Most customers are found within the Volvo group.

Systems Engineering implementation within the Volvo Group

Systems Engineering is definitely not something new within the Volvo Group. Many traditional SE activities are there; they are just more or less connected and sometimes not properly aligned. But during the last ten years SE responsibility has been more in focus and valued in the project set-up. For instance, there are implemented processes, methods, tools and roles for:

- Setting project targets;
- Translating targets to complete offer requirements;
- Negotiating requirements between involved actors;
- Balancing requirements in relation to possible system solutions;

- Selecting system solutions;
- Translating complete offer requirements to system requirements, and;
- Verification and Validation.

And these aspects are in most cases cared for, by SE responsible in the PD organization.

However, there are always needs to improve and there are efforts towards becoming more front-loaded in order to focus even more on *why* and what before running into *how*, increasing the possibility to tailor and optimize the process for different project size and scope, connect SE processes with interfacing areas, and even more align process within the group.

Traditionally, new SE practices have been introduced in pilot projects within a single Business Area/Business Unit. A lot of lessons have been learned during these pilots. As always when a new way of working is introduced there is a resistance – why replace something that is working today and that everybody is aware of. In one of the pilots a new process and a new tool was introduced and the pilot it self was one of the largest project ever executed. SE was considered to be a crucial ingredient for success in this case. But it should have been wiser to introduce the process and the tool in steps, and probably even more important, a smaller pilot should have been chosen.

> Proposition 1: Choose your implementation pilot carefully, considering the nature of SE it must be a challenge in order to increase the organisations capability.

> Proposition 2: Consider a roll-out plan that takes the implementation in several steps. However, it is crucial that the total SE vision is covered from the beginning.

In another case there was a well defined process but it was not aligned with the organization. Roles were assigned to persons, which the persons were more or less unaware of, at least when it comes to responsibilities, mandate and obligations. The main reason for this was that the process was not properly confirmed and distributed within the organization. It's crucial that the organization is aware of the process and what the consequences of implementing it will be.

> Proposition 3: Secure commitment from top-management.

> Proposition 4: Involve process stakeholders early and do not exclude the "opposition".

> Proposition 5: Do not underestimate the need for coaching and education.

A common challenge is to increase the quality of the input for the project. The interface between Product Planning and Product Development must be clear. If the input, the targets, from Product Planning is poor it will influence the whole project. A lot of time and energy will be spent on trying to understand what the targets really mean. If the input is bad the output will most probably also be bad.

> Proposition 6: Although SE attracts engineers involve marketing and product planning in order to secure high quality targets as input for the SE process.

In another pilot all requirements were equally important, no prioritization was needed. It ended up with thousands and thousands of requirements which were too hard to manage. After this requirements are prioritized in all projects.

> Proposition 7: Emphasise a set of key requirements in order to provide a shared cognitive map for the development, as well as to facilitate subsequent evaluation activities (Almefelt et al., 2006).

During these pilots MS Excel was used to document requirements. After a while when the amount of requirements grew it became very hard to read and to get an overview of the Excel spreadsheet. In the end the Excel spreadsheet became so large that it was impossible to overlook the requirements. Today an established requirements management tool is used. However, the excel sheet made it possible to make early changes on the process and documentation procedures as experiences was gained.

> Proposition 8: Do not over-estimate a RM/SE tool, there is a lot of work to be done before process excellence can be achieved.

In practice SE practices has been introduced individually at some BA/BU's during several implementation steps, and has eventually spread as achieved benefits has become evident. In general, the V-model (Figure 3) describes the levels of SE operations. Although, it is impossible to present a genuine material covering the Return Of Investment (ROI) for implementing SE. In the following sections, some experiences from these implementations on various levels in the organizations will be presented. Furthermore, the challenges of incorporating SE on a corporate level will be discussed.

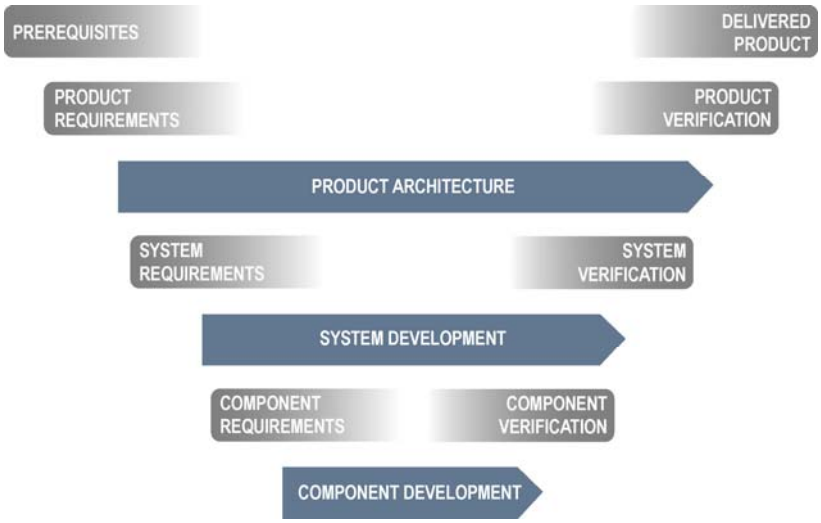

Figure 3. The V-model

Product Planning. On a product planning level efforts has been made to involve all stakeholders in a development project, document the expected targets in pre-defined feature areas and making sure that targets are written in a good way to minimize misunderstandings etc.

Complete Offer. On a complete offer level huge effort has been put to secure the establishment of requirements based on the targets from product planning. The main factor in these processes has been to secure an agreement between all involved actors – to come to a well balanced requirement specification addressing the scope for the complete offer in relation to project resources. This involves prescribed activities and practices, document templates, and tool support. But most importantly it has involved role descriptions in order to make sure that the process is performed by people that has the right experience and has well-communicated authority and responsibility. For instance, the requirements work is facilitated by a requirements manager, property experts are

addressed in specific fields and vehicle architects responds from a solution perspective in this process. The main challenge in this process is to make sure that the requirements management work drives value and don't get to bureaucratic. Considering the mature industry, many projects takes shortcuts in their RM work. Consequently, one tries to minimise the number of requirements in a projects by for instance only specifying delta requirements, exclude project/process requirements. Another challenge is to manage the sheer variety of product offerings, making the decision making delicate.

Product Architecture and Systems Development: On the Product architecture level requirements from Complete Offer are broken down into customer visible features with value.

Customer features and their requirements give the input for both the testers in order to specify test cases for features and for architects in order to model and adapt the product architecture, its systems, subsystems and components. A lot effort has been spent in order to improve the design and the maintenance of architectures. Processes, methods and tool support have been implemented in order to support the architects´ work in terms of connecting design models with system requirements, functional allocation, reuse and variability of components, and configuration management which gave great benefit to our customers.

From our experience the reuse of requirements can be managed, but might produce communication problems: The understanding of requirements will probably lack and thereby effect the review of requirements. The ownership of reusable requirements is very important when it comes to handshakes and deliveries combined with changing these requirements.

At the system development level defined systems, subsystems and components are specified in more detail so that they can be ordered from suppliers. The version controlled exchange of requirements with suppliers offers a great possibility to minimize costs for both parties (the customer and the supplier). The process for exchanging requirements existed since longer. Using the de facto standard RIF for the exchange of requirements between different tools gave us benefit, but still offers a lot of room of improvement. The base of and exchange is a shared information model which still lacks with a lot of suppliers. Furthermore the RIF standard itself lacks the definition of information models on both sides of an exchange.

Component Development. On Component level external and internal supplier get an order as a specification of a subsystems or a component. Since Volvo invests a lot in using the Autosar standard a lot of effort has also been spent defining the processes in how to systematically specify Autosar software components and their interfaces. Of big benefit here was the clear definition of process activities and responsibilities.

Test and Verification: traditionally test & verification is done in a very thorough and systematic way. But since the complexity of systems and components and thereby number of signals keeps growing the test managers are even more challenged to have clearly defined requirement releases.

Although there might exist variant management mechanisms at different of the above described levels, a very big challenge still is the management of product lines and thereby continuous handling of variability. Another very important challenge is the connection of project management to other Systems Engineering disciplines in order to plan projects and track the status of projects.

Bringing Systems Engineering onto a Corporate Level

The globalization of companies has only just begun. In this sense, strategies such as transfer, merger, acquisition, sourcing and collaboration are becoming the growing trend. This will inevitably lead to new type of organizations within companies, based on collaboration, value sharing, innovations, and global division of labor. Considering the close collaboration between many BA/BU's within the group, and the merger with new companies, there is a continuous challenge to align common core processes and make sure that process experience are shared globally. However, the true challenge lies in reducing cross-organizational conflicts that reduces efficiency, without diminishing the unique features of individual organizational units. Often, it is these unique features that create operational excellence in the specific area of operation.

Why have a common Corporate Development Process? Although operational procedures are highly connected to the specific area of operation, there are several benefits of aligning processes in-between different areas. For instance, a common process enables:

- *Economies of scale*. Investments on process development can be shared globally.
- *Common projects*. Enhances cooperation and communication in common projects on corporate level.
- *Transfer of knowledge*. Common framework (incl. responsibilities, organization, etc) for Product Development project enables sharing of Best Practice.
- *Transfer of resources*. Facilitates sharing and exchanging of competencies and resources, including consultants and suppliers.
- *Usage of common tools*. Common processes increases the possibility to use common support tools such as PDM or SE/RE tools.

In addition, a common process makes it possible to set a strategic vision on operational excellence in order to change the product development culture.

Changing the Culture. Considering a mature product and the focus on components in the automotive industry, it becomes natural that engineers start to focus too early on solutions, or worse a single solution – and forgets detailing the true scope of the project. The mayor problem when it comes to implementing SE is that it is very much about "*The way we do things around here*".

According to Barry Johnson (2006), some problems seem to resurface periodically because they are never solved, and these may be better managed by recognizing their polarity. Each potential solution, or pole, has an upside and a downside. When we focus on one pole solely, over time the downsides of that pole become more and more troublesome. When the tension from the downside grows large, crusaders for the opposite pole, begin espousing its benefits. We may then switch to focusing on the second pole and ignore the first. But with time, the downsides of the second pole become increasing problematic. Until finally, the first pole seems clearly better and we change our focus again. Rather than trying one solution without considering the strengths of a seemingly opposite solution, Barry Johnson suggests we begin by understanding advocates for the opposition. Consequently, one cannot manage the polarity until one understands the polarity in its entirety. When focusing only on the upside of our original solution and the downside of the alternative, we are only seeing half of the picture.

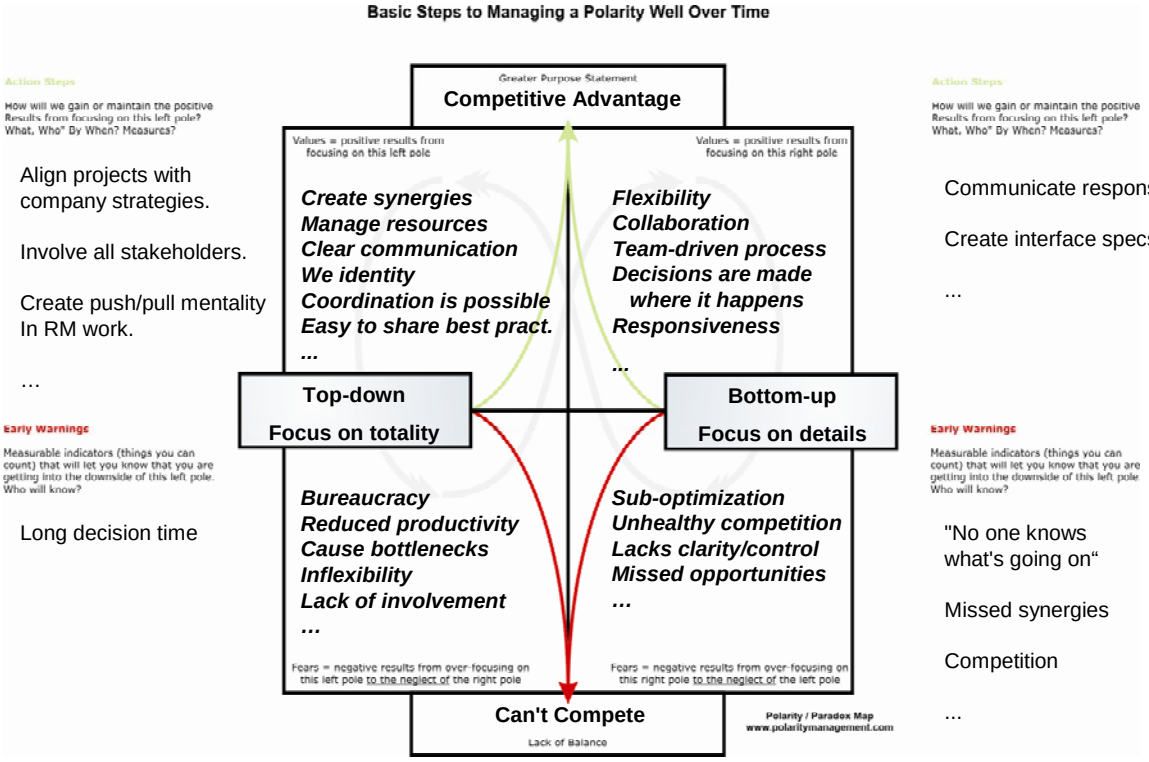

Figure 4. Polarity Map of SE polarities

The paradoxes when implementing SE can be illustrated using polarity maps (Polarity Management, 2008). For instance, the implementation of SE in an organisation is much about managing the polarities between *focus on totality* vs. *focus on details*, i.e. top-down or bottom-up, see Figure 4. This is a naturally a choice that one cannot make. In this sense, focusing on totality creates benefits (upper left) as well as negative results (lower left) and vice versa focusing on details creates benefits (upper right) as well as negative results (lower right).

When implementing SE procedures it is important to remember that supporters believes in the benefits from focusing on totality because they have experienced the down-side of focusing to much on detail, and vice versa the opponents believes in the benefits by focusing on details because they have experienced the down-side of focusing to much on totality. Our suggestion is to try to understand the polarities in an organisation and create an implementation plan that considers both perspectives.

Recommendations for SE implementation

Our experience from implementing a new process or tool is that it takes a lot off effort and energy. It is always a huge step within an organization when something is changed.

Process implementation: Systems Engineering can mean different things to different people, that's why it is import to define what Systems Engineering really mean to the customer. Which Systems Engineering disciplines are included? Is it only requirements management or is it requirements management and verification or is it something else. If a clear definition of Systems

Engineering exists, a lot of discussions and misunderstandings will be avoided.

The process must have acceptance within the organization, otherwise the implementation won't be successful. Start with the top-management, if they accept it and can work as ambassadors for the process chances are big that the implementation will be successful. After this, try to communicate the process and the idea of it to as many persons within the organization as possible. At every occasion that occurs take the opportunity to present and explain the process. After a while when persons have seen and heard about the process a couple of times and maybe started to experience the benefits of the process it will be accepted. Define the roles in the process and make sure that persons are appointed to them. This will drive the implementation forward.

Identify the Systems Engineering enthusiast, this is a person that people listen to and that has a strong belief in the process. During the implementation it will be a lot of ups and downs, and the process will be questioned by many persons within the organization. In this scenario it is very important to have a Systems Engineering enthusiast who can face all opponents and try to convince them that the process is the right way to go.

The input to the process is crucial; product planning has to be involved in the Systems Engineering work. Often we hear that Systems Engineering is something that product development should work with not product planning. We believe that this is wrong, product planning must be involved. If the input is poor the output will also be poor. The recommendation is to spend a lot of time and effort on explaining for product planning why they must be involved in the Systems Engineering work.

We further recommend implementing the process in steps. We have experience from implementations where customers have tried to implement the full, complete SE process and the result has been poor. On the other hand implementations where customers have implemented the process in steps have been very successful. We believe that it is important to get all stakeholders input "a wish list", this will give the total input, the whole picture. At the same time all stakeholders will be pleased that their input has been taken care of. After this it is important to cut the whole picture into parts, steps, that can be implemented one at a time. Start with the core part and as soon as this is successfully implemented and accepted within the organization go for the next step.

Another important aspect to consider is that the organization has to realize that the result from implementing a Systems Engineering process will not be visible directly. It may take a couple of years before they can see the real benefits of Systems Engineering. Patience is a word often used when it comes to process implementation.

Tool implementation: From our experiences at Volvo and other companies better tool support is most often requested when it comes to improve Systems Engineering. And even if many might think of the expression "a fool with a tool, is still a fool" we recommend you to see this is as a chance to improve processes and methods (see also Weber and Weisbrod 2003). The customisation of a specific tool is often cost intensive and needs a business case towards the sponsors and a specific tool implementation project. Collecting the needs and problems of your customers and visualising these e.g. in data flows in swimlanes or in information models will soon conflict your customer with unambiguities in processes and methods. From our experience customers who formerly requested to solve all their problems in a tool appreciated a clear definition and communication with tool workarounds.

As for the process implementation the definition of your real stakeholders, their roles and importance are of immense importance for your project. For further efficiency of your project and satisfaction of your customer especially make sure that you have:

- a manager in place who strongly supports you, thus securing the commitment of the organization
- a coach in order to continously train users and get their feedback, and
- key users which later secure the implementation of your implemented process and tool improvements.

We further recommend you to specify clearly measurable goals and derive metrics (see Potter 2002) right at the beginning of your tool implementation project and execute measurements during and after the project.

One of the most important parts of a process/tool implementation project is the steady communication of project planning, of requirement contracts to implement a tool and of changes throughout the complete project.

Almost of great benefit for us and our customers were tools which offer the definition of a meta-model. Using these kind of tools improved on the one side the communication with our customers on the other side supported the maintenance of the data. We strongly recommend you to use a standard tool and adapt it to the customer needs in small releases. By this you strengthen the involvement and thereby satisfaction of your customer.

Since the specific implementations have been done within single business areas/units there is a need to align processes in-between different areas/units and specify the interfacing processes in common projects.

Conclusions

Our experience from implementing a new process or tool is that it takes a lot off effort and energy. It is always a huge step within an organization when something is changed. In addition to the propositions and experiences provided in this paper we would like to recommend that during a SE implementation, one should:

- Focus on creating effects in the organisation rather than implementing as many SE practices as possible and track your performance regarding those effects.
- Focus on implementing adaptable SE practices in order to accomplish continuos change in your organisation rather than maintaining a static organisation.
- As responsible for the implementation be part of the process in order to drive the implementation – in other words take part in the actual SE work.
- Understand that it is very much about changing the culture – in the end it is all about people.

Acknowledgement

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