Introducing and Maintaining Systems Engineering in a Medium Sized Company

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Paper presented at the
Ninth Annual International Symposium
of the
International Council on Systems Engineering
June 6-11, 1999-04-09 Brighton, England

Abstract. This paper describes the introduction of Systems Engineering at a medium sized company and the organisation set up to maintain this capability afterwards. The paper explains the context leading to the introduction and describes the steps taken to formally introduce Systems Engineering. It shows the relation between the organisation of the company and the way elements of the Systems Engineering process are formalised. The paper stresses the necessity that any change in the engineering practices should be shown to fit into the engineering process that is in place and to improve it, and needs a firm backing from senior engineers to be applied. Also, continuous training and review is necessary to keep application of the processes alive.

INTRODUCTION

The company is employing over 400 people, mainly active in the space domain. It is involved in development projects and the products range from launcher structures and solar arrays to complex attitude control systems, robotic systems and earth observation instruments. Customers are about 75% institutional (ESA, Dutch Aerospace Agency) and 25% commercial.

Most of these products are single or low quantity, and production (other than final assembly, integration and test) is subcontracted. The composition of the industrial team is highly variable, as are the customers and prime contractors. This leads to a wide variation of project management and engineering practices throughout the projects.

In the last ten years the tendency has been an increasing autonomy of projects at the expense of the authority of the functional organisation. Consequently company standards risk to be neglected, and are slowly replaced by individual project standards, hence making company wide reuse of best practices difficult.

When in 1990 it was anticipated that a large project, the European Robotic Arm (ERA), a contract for the European Space Agency, would be awarded to the company, it became clear that, due to the sheer size and complexity of the project, this prime contractorship would require organisational measures to improve company standards and minimise the risks involved.

PRIME PREPARATION

To prepare for the prime contractor role in the ERA project a working group was established with senior representatives from all project disciplines. The assignment of this Prime Preparation Working Group was to

- Collect the company's best practices, as were developed within its projects,
- Describe and document them,
- Make them accessible throughout the company.

The means chosen was to write a Standard Project Handbook, organise a review of the material generated by senior experts throughout the company and to collect a (hard copy) data base of examples of these best practices. This was done for all project disciplines.

For the Engineering discipline a large amount of process descriptions, procedures, examples of methods and formats was collected, evaluated and documented. Choices were made to standardise on a minimum set of best practices. The results were evaluated by a panel of senior engineers drawn from projects and disciplines throughout the company with the purpose to establish their usefulness for their particular kind of projects. The general judgement was that much useful material had been brought

together, but the uneasy feeling was, that this material was not well organised.

INTRODUCING SYSTEMS ENGINEERING

At the same time that the Prime Preparation Working Group was at work, the company took out a consultancy with Ball Aerospace from Boulder, USA with the purpose of obtaining an outside opinion on the measures required to be well prepared for the ERA project. One of their findings was that the company was lacking a structured Systems Engineering approach.

The consultant offered participation for a number of the company's engineers to their in-house Systems Engineering Course in the spring of 1991 as an introduction to the field. For the elected participants the course was an eye opener, not because everything was new, but because everything was so well known. Its added value was to offer a means to order and organise the material collected for the Engineering chapter of the Standard Project Handbook; many, if not all, of the elements documented fitted without modification in the Systems Engineering process, as it was presented to us.

A conclusion to be drawn from this may be, that Systems Engineering is just the explicit formulation of normal, but implicit, sound engineering logic and practices. The Systems Engineering process description provides a convenient way, why all these things we normally do are essential to obtain a good product; the new thing it adds, is that we have to do it always and in a disciplined and structured fashion.

After this discovery the following activities were undertaken:

- Rewrite the Engineering chapter of the Standard Project Handbook according to the Systems Engineering process steps,
- Review the result with the panel of senior engineers, re-baptised Systems Engineering Working Group (SEWG),
- Export and adapt the consultant's Systems Engineering Course to the company's environment and context.

The last two activities were primarily aimed at maximising the involvement of the company's community, avoiding the occurrence of the "not invented here" syndrome.

In the fall of 1991 the Engineering chapter of the Project Handbook has been published after review by the SEWG and the first Systems Engineering Courses have been given to some 40 engineers, project managers and functional managers.

To further improve the support for Systems Engineering it was decided that the further courses should be presented by senior employees selected from throughout the company. This way a group of more than 30 employees were committed to see Systems Engineering implemented company wide.

Basically, the Systems Engineering Course is the corner stone of the building; most engineers experience it as the framework, in which they can fit their need for structure and overview, and which makes explicit, what they know already implicitly. It also provides them with a common language to discuss the essential elements of a project.

A lesson learned from this early phase, and which has been confirmed since then, is that support for Systems Engineering shall be sought from its direct users, the engineers, rather than from project managers and senior management. This last group is more pre-occupied with the (identifiable) cost of it than the improved quality, and hence decreased risk, what its implementation delivers.

Another lesson learned was, that the "standards", as laid down in the Standard Project Handbook should rather be used as guidelines and a checklist, as each project requires its own specific sizing and adaptation of the general rules, methods and tools.

MAINTAINING SYSTEMS ENGINEERING

The development of the company's organisation into small business units meant the end to the Prime Preparation Working Group, as it was felt that each Product-Market Combination required its own way of running a project. This has led to a decrease of the uniform reuse of company best practices in the fields of Project Management, Project Control, Contracts and Subcontract Management. However the application of Systems Engineering practices within the projects has been maintained, although the degree of standardisation had to be adapted and additional effort was needed to ensure cross-fertilisation between projects and business units.

For these reasons and to answer other demands of the company's engineering community some additions have been made to the basic package of Systems Engineering activities described in the previous section.

Additional Courses. Quite early it appeared, that the Systems Engineering Course appealed most to those project team members, which had already a number of years experience and hence had sufficiently hands-on experience with the normal project problems. Also, young engineers were slightly put off by the relatively large emphasis on the Systems Engineering process and Engineering Management aspects in the course.

This led to the definition and development of a Systems Engineering Selected Items Course, addressing the more practical side of Systems Engineering methods and tools as are Functional Analysis, Requirements Analysis, Interface Definition and Modularity, Concept Selection and Trade-Off and (still) Work Flow Definition and some Design Data Management methods. In addition to an explanation of the principles involved this course puts emphasis on hands-on training with the methods and tools involved. The intention is to familiarise all engineers with terminology and methods, while

showing them by means of practice the potential for their daily work.

Systems Engineering Help Desk. Although Systems Engineering expertise and knowledge was reasonably well distributed throughout the company, the need for a central point of contact soon became apparent, amplified by the continuing development of the company into rather independent business units. A Systems Engineering Help Desk has been created as the central point for Systems Engineering matters. The staffing was recruited from experienced Systems Engineers, which dedicate part of their time during a number of years serving as Help Desk crew.

Help Desk tasks are:

- Maintain the Engineering chapter of the Project Handbook, including actual examples and formats,
- Create and maintain a Systems Engineering Library,
- Identify, obtain and support Systems Engineering tools from internal and external sources,
- Identify, organise and provide Systems Engineering training and courses (also from external sources),
- Organise and co-ordinate the Systems Engineering Working Group,
- Organise workshops on Systems Engineering items of interest,
- Provide Internal Design Review (IDR) team members for Systems Engineering aspects,
- Provide consultancy on Systems Engineering aspects to projects,
- Maintain external relations with institutes relevant for the field of Systems Engineering.

The Help Desk tasks are distributed to individuals throughout the company and involve about 25 people.

In recent years some more tasks have been added:

- Provide on-line information on Systems Engineering on the company's Intranet,
- Perform (on the project's request) Systems Engineering audits,
- Provide coaching to young engineers, which are potential Systems Engineers.

Audits. The Systems Engineering audits are a means to keep the projects "sharp" in their Systems Engineering effort and come on top of the (scheduled) Internal Design Reviews. The auditor, an experienced Systems Engineer recruited for the audit within the company, assesses whether the project exercises the Systems Engineering functions in a balanced way, when compared to project scope, size and objectives, rather than checking whether standard procedures are followed. The audit addresses the following issues:

- Are the Systems Engineering functions performed and if not, why not and is this acceptable?
- Is the way Systems Engineering functions are performed documented in whatever form and is this accessible to all project team members?
- Is the project aware where it stands in terms of (technical) performance, risk and progress?
- How does the project think it can improve shortcomings identified?

The audit takes only a few weeks, and generally results in an improvement plan generated by the project and a delta-audit some months later to check whether the improvements work. Typically two projects are audited each year.

Systems Engineering Coaching. As described above the company operates very much based on self-contained business units or even projects. Even although the formal company organisation recently has been changed towards a mix of a functional organisation with two operational units, the culture of small, independent projects still remains. Within the projects there is a tendency to keep team members time after time on the same job, as they perform it the most efficiently. This entails the danger of decreasing job satisfaction and increases the risk, that talented engineers in general, but Systems Engineers in particular leave the company. In recent years it has become clear that in such an environment ensuring a sufficient supply of Systems Engineers requires additional measures. A solution is sought in better application of job rotation and more careful scouting of Systems Engineering talent.

Together with the two operational units and the engineering unit an approach has been set up to systematically identify Systems Engineering talent, to test and educate that talent on Systems Engineering related jobs and to provide them with a dedicated Systems Engineering coach, when they embark on their first, independent job as a Systems Engineer. Coaches are assigned from the group of all qualified Systems Engineers within the company. For them the coaching is in principle part of their job. This system is just in its first year, and not yet fully implemented. Especially the project managers consider the coach primarily as an extra (and expensive) team member, which costs them money, and of which the output is difficult to measure. Also, they resent loosing their most talented personnel part-time to a job that is not directly contributing to the profit of their project. This attitude makes it difficult to ensure sufficient availability of coaches.

The outcome of this conflict of interests is still uncertain, but it is expected that the gain to be obtained from this approach on the long run will be properly weighted against the short-term penalties for the projects.

Figure 1 shows the Systems Engineering capability maintenance and development infrastructure as it is at this date at the company.

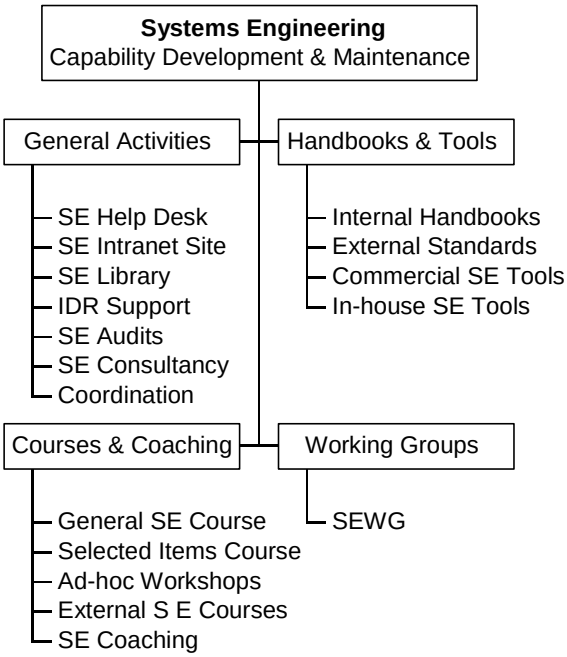

Figure 1. Systems Engineering capability maintenance and development infrastructure

MANAGING THE SYSTEMS ENGINEERING INFRASTRUCTURE

The effort required maintaining and developing the Systems Engineering capability in the company is managed by a yearly planning cycle. This is both necessary to match the effort with the available funds and to ensure the involvement of the many employees, which perform the tasks.

Main inputs for new activities come from the Systems Engineering Working Group which reflects the interests of all units involved.

Generation of the yearly plan is no problem. What is however difficult is to get the involvement of the people in charge of tasks in the plan at the correct time. Here there is still a great conflict between project priority and the maintenance and development of engineering capability

STATUS OF THE IMPLEMENTATION

Table 1 gives a summary of the implementation and its results to date.

item	*result*
SE Intranet site	Implemented; request from users to make much SE documentation on-line available
SE Library	Implemented; problem is accessibility in the decentralised company structure
IDR Support	About 50% of SE support requests for Internal Design Reviews goes through the SE Help Desk
SE Audits	One to two projects are audited each year; the request for audit depends very much of the Systems Engineer in charge of the project.
SE Consultancy	About two requests per week for consultancy are processed by the Help Desk
Internal Handbooks	Implemented; need however adaptation to changed external conditions
Commercial SE Tools	Limited number of tools available; difficulty is that each project has different needs
In-house SE Tools	Quantity of tools for multi-project use is growing, but it remains difficult to make sure that they are sufficiently documented for that purpose
General SE Course	About 240 people have completed the course, of which 20 were subcontractor employees and 45 people have left the company since starting the course; appreciation is 8 on a scale of 10
Selected Items Course	About 150 engineers have completed the course, of which 20 have left the company since starting the course; appreciation is 8 on a scale of 10
Ad-hoc Workshops	Two three workshops a year are held; they address subjects ranging from Risk Analysis and Design-to-Cost to various workshops on tools
SE Coaching	Activity started this year; difficult to get coaches assigned
SE Help Desk	Functions, but it requires a special kind of missionary engineer to make it work

Table 1. Systems Engineering implementation status

In summary it can be said that the status of implementation is satisfactory. However, there is room for improvement. Especially the discipline in applying Systems Engineering consistently within the projects should improve and the priority conflict between project work and engineering capability maintenance and development should be resolved.

CRITICAL SUCCESS FACTORS

Although we have no proof of the contrary, we think that we may draw from our experience the following conclusions:

- Always use the elements of Systems Engineering present in the established engineering practices of the company. Do not fuzz about other names or definitions: if a practice complies with a Systems Engineering function, just use it as is.
- Ensure a basis for the application of Systems Engineering with senior, recognised project engineers. Bring them together in informal groups and make them the focal point of the company's Systems Engineering function. They are the drive in Systems Engineering implementation.
- Obtain the commitment of project and functional middle management on the principle of Systems Engineering application; without at least the benefit of the doubt from their side short term project pressure will always get priority. They are the facilitators for Systems Engineering implementation.
- When reviewing the projects Systems Engineering effort, never concentrate on formality or standards, but always on functionality. If a function is performed well, the means used are irrelevant.
- Make sure all engineers know what Systems Engineering attempts to achieve, which methods and tools it may use to achieve its goals, even if they are not Systems Engineers and do not necessarily have to apply them themselves. This way you ensure that a team effort on Systems Engineering is possible.
- Make maximum use of the champions of Systems Engineering in your organisation; they will make sure Systems Engineering is done, not the Management Directives issued.
- Be persistent and take your time. Even in a development environment, where Systems Engineering elements are readily recognised as useful for the day-to-day work, an implementation phase of two years or more is short.

These findings correspond well with the conclusions drawn by other authors (Jackson, 1996).

AREAS OF IMPROVEMENT

Points requiring constant attention and improvement are:

- Getting lessons learned and other documentation documented in such a form, that they can be actually transferred to other projects, and doing this during the project in stead of afterwards (in that last case it generally is not done)
- Making methods and tools accessible for other projects (documenting them, generalising them) and actually transferring that knowledge to those other projects.
- Giving sufficient priority of long term engineering capability maintenance and development relative to short-term profit generating project work.

SOME OTHER ADDED VALUE

The intensive attention to the introduction of Systems Engineering in the company has brought some other spin-off. As we understand now far better the Systems Engineering process and the natural resistance engineers exhibit, when asked to adapt their habits, it has become far easier to implement Systems Engineering processes and methods in other areas than aerospace engineering or to support its implementation in other industries.

With partners in our projects we have been able to introduce cross-enterprise working standards and we have been able to support the introduction of Systems Engineering in areas, where it certainly is not common place, for instance medical industry (Bol, 1997) and railway and civil engineering (Beek, 1997).

GENERAL APPLICABILITY OF THE SCHEME

The case described in this paper is related to the introduction and maintenance of Systems Engineering in a medium sized company. A relevant question is whether the scheme used is portable to smaller or larger companies. The answer, as always, is: “Yes, but …”

In our opinion the critical success factors will be the same in any company. The general scheme will work, but the implementation will be different, taking into account the scale of the company. For example in a large company a Systems Engineering Working Group as the “soul” of the Systems Engineering effort will be less effective, as the working group members will be more representatives of their units than active champions working from within their projects.

For a small company some elements in the scheme create possibly to much overhead; it may be too expensive for example to offer regular in-house courses. However, some of these training activities may be absorbed in a systematic coaching scheme.

In short, the method and scheme of introducing and maintaining Systems Engineering in a company must be adapted to the size and the character of that company; in this respect it is not different from adapting the Systems Engineering effort in a project to its size, complexity and character.

CONCLUSIONS

It has been shown, that the introduction of Systems Engineering in a company requires a close coherence with existing engineering practices. A second important success factor is to aim the activities primarily on the engineers using them, and to create champions from this group ensuring the maintenance and development of the Systems Engineering capability.

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BIOGRAPHY

Robbert J. Hamann. Rob is a Senior Systems Engineer at Fokker Space BV, which he joined in 1974. He is in charge of organising and co-ordinating the company's application of Systems Engineering. He studied Aerospace Engineering at Delft University of Technology, the Netherlands, and Princeton Graduate School, USA. At Fokker Space he has been involved in many projects, lastly as a Systems Engineer of the ISO Attitude and Orbit Control Subsystem and the European Robotic Arm for the International Space Station.
He teaches courses on Systems Engineering and Engineering Management at Delft University of Technology and at the Ecole des Mines de Nantes, France.

Wim van Leeuwen. Wim has a Masters Degree in Avionics at Delft University of Technology. He is a practitioner of Systems Engineering since he joined Fokker Space in 1982 and has been involved continuously in the development of Systems Engineering within the company. He is a member of the Dutch Chapter of INCOSE from the start in 1996 and nowadays also consults non-space projects on the introduction and tailoring of Systems Engineering practices.