University of Applied Sciences

SAXION

Mechatronics

Research current state of Systems Engineering of involved companies

SESAME

Research group Mechatronics

Enschede, May 31, 2022, version v1.1.4

Research current state of Systems Engineering of involved companies

Authors: Victor Sluiter and Mark Reiling

Table of Contents

List of Figures

No figures included in this document

List of Tables

Authors	Victor Sluiter and Mark Reiling

Version	Description	Saved by	Saved on	Status
v1.1.4	Added sources for pictures	Victor Sluiter	May 31, 2022 2:21 PM	APPROVED
v1.1.3	Added Authors	Victor Sluiter	May 31, 2022 2:12 PM	APPROVED
v1.1.2	Solved some translation errors	Victor Sluiter	Mar 22, 2022 9:29 PM	APPROVED
v1.1.1	Small edits to remove links to original Dutch pages	Victor Sluiter	Mar 15, 2022 9:16 AM	APPROVED
v1.1.0	Translated questionnaire to English	Victor Sluiter	Mar 15, 2022 8:57 AM	APPROVED
v1.0.0	Added Observations section	Victor Sluiter	Jul 7, 2021 12:50 PM	IN PROGRESS
v0.0.1	Draft version with only questionnaire and summary, sent to MB at 2021-06-25	Victor Sluiter	Jun 25, 2021 7:57 PM	IN PROGRESS

Chapter 1 Introduction

In the KIEM SESAME project, we want to know how systems engineering (SE) in small engineering groups can be improved. To get a better understanding of the current SE capabilities, @Mark Reiling and @Victor Sluiter performed a structured interview with three companies that are involved in the SESAME project. These companies work in the domain of mechatronics and robotics.

In this report you will find the original interview questions. After that, a summary of the topics covered during the interviews is shown, and we end with a general impression of the state of SE by the authors, based on the interviews.

The authors would like to thank Hencon, Hollander Techniek and Riwo for their cooperation, honest feedback and the insights they provided into the practical and organizational aspects of Systems Engineering!

Acknowledgement: this work was funded by Regieorgaan SIA

Chapter 2 Questionnaire on SE with companies

2.1 Boundary conditions

Interviews are limited to 1.5 hour per company. Interviewee is the person having the systems engineering **role** in the company (this is not necessarily the **function / job title** !)

Purpose of the questionnaire is to find out what companies are doing on SE at this moment, and what the current obstacles are that might be improved during the SESAME project.

2.1.1 Context of company

Asked per email, in advance

- How many people work ssimultaneously on a project?
- What disciplines / trades are involved in a project?
- What is the average project duration (mean and estimated standard deviation)?
- What is the relation to most of your customers: client - sales, or co-engineering?

2.1.2 Context SE (in management)

Target of these questions is to get an image of the current “State of the Art” of SE within the company, and try to find out what they would like to chnage. Try to find the “Why” of SE

- How would you describe “systems engineering”?
- (Why) would you give SE a larger role in your organization?
- Do you have practical examples of situations that you’d like to prevent with a better SE approach?
- With a blank cheque to evolve SE in your company, what would be different 5 years from now?
- When SE gets more focus, where do you expect to get resistance (internal, external, …)?
- SE is a broad field. What is your highest need now?
    - *first response from companies. If no response received, note reaction to:*
    - Design methodology (“how” to design)
    - Transferrable documentation (internally, externally, over time, between disciplines)?
    - Traceability of decisions (wat & why)
    - Systems Thinking, seeing the big picture and don’t fix the customers' request, but the customers' need.
    - Ask to pick something from pictures below ⬇️

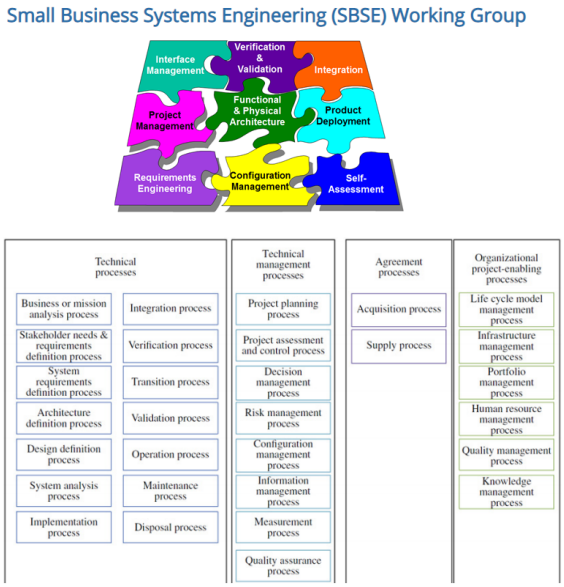

Fig. 2. INCOSE's Systems Engineering processes [3].

SEBoK Topic
Systems Thinking
Models and Simulation
Product Systems Engineering
Service Systems Engineering
Enterprise Systems Engineering
Systems of Systems (SoS)
Life Cycle Models
Business or Mission Analysis
Stakeholder Needs and Requirements
System Requirements
System Architecture
System Analysis
System Implementation
System Integration
System Verification
System Validation
System Deployment
Operation of the System
System Maintenance
Logistics
Planning
Assessment and Control
Risk Management
Measurement
Decision Management
Configuration Management
Information Management
Quality Management
Enabling Systems Engineering
Related Disciplines

Images from INCOSE; https://www.incose.org/incose-member-resources/working-groups/transformational/SBSE , https://www.sebokwiki.org/wiki/

- Previous research has shown that addin SE will also change company structure (processes, closing feedback loops, more “why”, roles of PM / SE, frontloading of design effort, compliance checks). Is this possible in your company?

2.1.3 Methods / Methodology

Trying to get the current “how” of design and the wish to change

2.1.3.1 Big lines

Are you now using specific existing frameworks / methods / techniques to develop systems?

- If not, why not (culture? better solution?)
- If yes, which ones and what is good / what is problematic?

1. V-model (which?), Agile (scrum?), what artefacts?
2. Architectuur methods / thinking tracks (CAFCR, A3AO, SIMILAR, …)

2.1.3.2 Specifieke aspects

1. Requirements
    a. Do you track changes in requirements? Are changes traceable?
    b. Do you use any specific method / tool to write requirements?
    c. During the project kickoff many requirements problems have been discussed. Do you have any idea what is going wrong in eliciting / writing down requirements? *Note: working with functions? Working with value-based requirements?*
2. “Systems Thinking”
    a. Do you differentiate between problem domain and solution domain (separation of what & how)?
    b. Do you have a “vision” on composition and decomposition of your systems, i.e. why is what functionality where, how to make large parts into smaller modules, how to integrate them?
    c. Do you keep track of systems requirements as “reliability” or “serviceability” during design?
3. Modelling (not simulation per se, but also systems models)
    a. Do you use modelling for your systems?(solidworks concepts, UML, C4, …)
    b. Is that for the complete system, or only for subsections?
    c. Do you also use these models for communication with your external stakeholders?

2.1.4 What are your needs on the short term?

A few questions that are directly asking for the solution. At the end of the interview to prevent “priming” answers to other questions.

In practice, SE deals with methodological design, supported by tools and structurizing the design / life cycle process. What is your current need in this project? Please keep in mind that processes also need compliance….

- What are you waiting for, “bottom up” (tools & techniques first, then process, thinking track “patch”)
- … or “top down” (first determining SE / PM roles, then design process, then tools & techniques, thinking track “full redesign”)
- **NOTE:** some pointers for conversation
    - design methodology that fits you?
    - Suggestion for tools that fit the company?
        - Tools / tricks / tips for documenting certain aspects (reqs, testen) ?
    - Suggestion for tools that make design and design choices clear?
    - Matching ISO 15288 / ISO29110?

2.1.5 Background, literature

- Application Potentials of Systems Engineering for Small and Middle-sized Enterprises
- https://www.sebokwiki.org/wiki/Matrix_of_Implementation_Examples

Chapter 3 Summary of Interviews with companies

Three companies (C3 Techniek, C2, C1) were questioned according to the Questionnaire on SE with companies

3.1 Results

3.1.1 Company Context

Table 1 Summary of companies in research

Company ➡️ ⬇️ Question	C1	C2	C3
How many people work concurrently at a project?	4-7 Eng, 2-8 Assy	2-6 Eng, ? assembly	4-14 Eng, 1-11 Assy
What disciplines work on a project?	Mech. Eng Hydr. Eng Electr. Eng, Softw. Eng, Mech. Assy, Electrical Assy	Software, Hardware, Project lead, Systems Engineer	Sales, Project Lead, HW Eng, Pre-engineering, Software Eng (PC + IA), Mechatr. Assy
What is the duration of a project?	12 +/- 3 months	4 +/- 1 months	6 +/- 3 months
What is the relation with your clients?	codevelopment and contract engineering	Mostly co-engineering	Mostly contract engineering

3.1.2 Context of SE in the company

How would you describe Systems Engineering?

C1

- The process of keeping our customers in control, and knowing what we should build.
- Systems Engineers have a role that's transcending disciplines, side by side with the (less technical) project manager.

C2

- Making complex systems applicable with simple and (re-) usable building blocks.
- Engineering the system to deliver a system to a customer that does what the customer needs
- Support for sales to convey technical issues between development team and customer

C3

- Combining industrial systems to a complete solution in a structured / smart way
- Using structured ways to develop quality within time

What would SE improve / what situations of the past would be prevented?

- Projects get more complex & challenging. Transfer of design reasoning between designers (of different disciplines / over longer time periods) is often failing (why did we make design choices, what was difficult?)
- Projects start when specifications are 80% complete. Sales is happy they sold something, while engineering is still struggling with the question of what exactly was sold.

- Successful integration of subparts developed by subgroups
- Systems that were working OK at a test system in the factory, but resulted in many integration problems at the customer's location. We want to get better at understanding how customers use our systems.
- Better discrimination in roles / responsibilities of PL / Systems Engineer
- Better recording and communication of requirements and limitations [of systems] and system boundaries.

- We're good at brainstorming but not in systematic design. Tools like A3AO might help.
- At this moment customers set up the requirements. We're looking at how we can develop better concepts than those prescribed by our customers (and keep track of concepts we didn't choose).
- Get better at recording & communicating requirements and limitations of SoI. Example: people working on a system where everybody knows it will become too expensive; some requirements were not so "hard".

With a blank cheque, what would you do on the subject of SE?

- Change to a streamlined process to get total clarity of what the customer expects, no surprises. Run projects within time and budget, get calmness in the execution of projects.

- Add more SE to projects. Goal: to create more calmness in the execution of projects by using SE. Get more clarity at the start of projects, prevent requirements from "popping up" unexpectedly. Ad Hoc changes now create frustration for all project participants. Goal: take the customer along during development and deliver better products.

- **Not** setting up a separate SE department! Maybe use a day in the week to study SE literature, learn from other companies. After 5 years, we've got a team of engineers that have a smooth-running process that amazes both the competitors and our customers!
- we'll be better at seeing risks, we'll be better at documenting our knowledge

What is the highest need that needs to be dealt with now?

- Get fewer changes during the project, and if things change, be able to communicate the consequences to the customer and the internal organization
- Documenting in general. First prio: internal engineering. Especially the traceability of decisions.
- Support of PL without a technical background to get higher quality acquisition. Prevent escalations within projects
- Increase "systems thinking"; what reusable blocks do we already have? Work at more generic / reusable modules → develop for a larger market-specific customer, or for a bigger market?
- Add traceability to make design decisions traceable.

Is it possible in your organization to change company culture to include SE (frontloading effort, change PM role)

- Yes, that's possible. We're already changing the sales process by having a pre-ProductOrder-meeting with technical staff

---

- If people get taught why: yes. We're used to optimizing processes.

- Resistance in the organization might be in engineering → focusing on methods that might reduce creativity?
- Our organization is very decentralized and people like that. Enforcing top-down might not work, but doing something cool with a few people and gradually spread that experience should enthusiasmize colleagues.

3.1.3 Methods / Methodology

Do you currently make use of existing frameworks / methods to design?

- Design by “common sense” and gateway checks
- Lots of procedures, but we’re very “flexible”, which is both positive and a trap.
- Aftersales and spares are important to take into account during design.
- Not using any architecting methods, probably because we don’t know them. Also: “Just do it” mentality.

- V-model
  - Mostly when the client is clear about requirements, mechatronic work
  - For industrial safety aspects
  - requirements, functional of functional-technical design, then technical test, functional test. Functional design is made very early in the design process.
- Agile / Scrum
  - Mostly used for SW & research work
  - The customer involved with choosing deliverables
  - 3-week sprints
- Curious how hardware and Agile could come together. Products are changed while they’re being developed, how to handle this?

- DevOps
- V-model:
  - Requirements, Functional design (already quite technical), Interface descriptions as technical design, FactroyAcceptanceTest (partly simulation) & Site Acceptance Test
  - Note: FAT & SAT not always made at the same time as making the requirements
- no specific tools used, looking for tools to make decisions within the current team

Remarks on some “loose ends”

Requirements

- C2: Eliciting requirements is something you can be “good at”. You can see it as a sport to get to the right edge cases; “would you be happy if I gave you <example of a system that surely wouldn’t work but fits the requirements>”? Try to get the implicit things explicit.
- C2: Other tricky things: keep requirements up-to-date, and manage the expectations of the client and design team.
- C3: traceability of requirements is document with date & version #. Sufficient
- C3: We don’t have a requirements syntax. Mostly using a table, requirements are -often- measurable.
- C1: In the early stage of development no requirements are written down.
- C1: Requirements document gets revision date & description “you get more info if it’s done well”. New development: adding “clarification list” to keep track of what has been changed w.r.t. the original product order.

Systems Thinking

- C2: Composition / decomposition is mostly done on “gut feeling” and experience. No systematic approach (yet).
- C2: Vague terms like “serviceability” and “reliability” should be quantified.
- C3: Serviceability is often translated to “Machine should get an uptime of *x”*, “only use A-brands”, sometimes also by giving a service contract.
- C1: Serviceability is mostly specified as service intervals, and a spare parts proposal.

Modelling:

- C3: using UML state diagram, flow diagrams, interface speccifications, database / data models.
    - The statics of the robots are modelled by C3, dynamic modelling / simulation is often done with supplier
    - Busy with looking at using modelling / simulation to show to customers.

What are your short term needs?

C1: Move from “engineering to order” to “configure to order” where needed.

C2: vision on how to combine agile and hardware development

C3: change bottom-up → First tools and techniques, then processes.

Chapter 4 Observations from the interviews

Some general observations from @Victor Sluiter and @Mark Reiling from the interviews

- Systems Engineering is a broad topic, it's hard to describe it, which also seems to make it hard to find an "entrance" on how to start with it. It seems there's a mix of "a set of tools" and "a way to tie multidisciplinary stuff together"
- In all three companies there's a strong preference to improve their process, from acquisition to support, and they strongly feel that SE can help here. All companies have indicated that they can change their process in order to add "more SE", but this needs to be added from the bottom up, gradually improving the process.
  It seems that, looking at the Capability Maturity Matrix (Paulk) companies want to increase their SE capability maturity level. Our estimate is that current level is either 1 or 2, and increasing to 3 or even 4 *in the area of SE* is what these companies want.

Implications of Advancing Through CMM Levels.

	Level 1	Level 2	Level 3	Level 4	Level 5
Processes	Few stable processes exist or are used.	Documented and stable estimating, planning, and commitment processes are at the project level.	Integrated management and engineering processes are used across the organization.	Processes are quantitatively understood and stabilized.	Processes are continuously and systematically improved.
	"Just do it"	Problems are recognized and corrected as they occur.	Problems are anticipated and prevented, or their impacts are minimalized.	Sources of individual problems are understood and eliminated.	Common sources of problems are understood and eliminated.
People	Success depends on individual heroics.	Success depends on individuals; management system supports.	Project groups work together, perhaps as an integrated product team.	Strong sense of teamwork exists within each project.	Strong sense of teamwork exists across the organization
	"Firefighting" is a way of life.	Commitments are understood and managed.	Training is planned and provided according to roles.		Everyone is involved in process improvement.
	Relationships between disciplines are uncoordinated, perhaps even adversarial.	People are trained.			
Technology	Introduction of new technology is risky.	Technology supports established, stable activities.	New technologies are evaluated on a qualitative basis.	New technologies are evaluated on a quantitative basis.	New technologies are proactively pursued and deployed.
Measurement	Data collection and analysis is ad hoc.	Planning and management data used by individual projects.	Data are collected and used in all defined processes.	Data definition and collection are standardized across the organization.	Data are used to evaluate and select process improvements.
			Data are systematically shared across projects.	Data are used to understand the process quantitatively and stabilize it.	

95-357 drw 12B

© Carnegie Mellon, Software Engineering Institute, Software Development Capability Maturity Model (CMM)

- The highest need for improvement now seems to be in the sales / acquisition phase of the project, where realistic expectations need to be communicated between customer, sales and

technical perspectives. Agreements made in this phase are sometimes unclear, or the context of the agreement is unclear leading to designs that do not match customer expectations.
- The second highest need we see is the need to document internally among engineers why certain design choices have been made.

4.1 Plans to move forward

As a “solution” to match the companies “needs” within their context we see multiple options

- Learn to use some techniques that are already well unerstood and documented. With help of the research group, we can try to find some tools and techniques to make a start in SE. Examples could be N2 diagrams, EARS / Planguage requirements syntax, use of ADRs, A3AO, … This could be done within the SESAME KIEM. Recommended learning material is “Systems Design and Engineering” by Bonnema et. al.
- We also see a “longer term” solution, which will not fit within the KIEM. The companies are interested in getting a tight coupling between disciplines, and further develop from “Engineer to Order” to “Configure to Order”. Tools that support either Model Based Systems Engineering or Product Line Engineering might really help, but require trained “operators” to build and maintain these tools and their internal models. Because some of these tools also integrate with other tool platforms (Dasault has an MBSE solution that integrates with SolidWorks, for example), the choice of tools is also highly dependent on the current context of software applications and licensing. It is interesting to note that INCOSE has opened up a Tools database that might help here: http://www.systemsengineeringtools.com/