Abstract

Students will apply and show their ability to apply systems engineering methods and techniques in practice during the systems engineering master project. During the preparation phase, students determine the project topic and shape the project. During the execution phase they apply and, at the same time, research the application of systems engineering. They capture the evaluation in a paper and a presentation.

Distribution

This article or presentation is written as part of the Gaudí project. The Gaudí project philosophy is to improve by obtaining frequent feedback. Frequent feedback is pursued by an open creation process. This document is published as intermediate or nearly mature version to get feedback. Further distribution is allowed as long as the document remains complete and unchanged.
Abstract

The master study Systems Engineering is completed by performing a master project. This document describes objectives and guidelines for the project and the resulting paper or report.
Objectives of Master Project

Apply SE methods, techniques, and concepts in practice and reflect on its application, while providing value to the industrial sponsor.
The goals of the Final Project are:

- the students have to show their professional competence and the acquired command of the systems engineering discipline by applying it to a selected problem.
- the selected problem has to be relevant in the context of the company in which the student works
- competence is truly put into practice.
- to facilitate the students to make the step from “just applying” to “critical reflection”.
- to verify that students are capable to operate at academic level.
Stakeholders of the Master Project

academic supervisor
coaching
quality
grading

master project

industrial company
sponsor
industrial context
usable results

company supervisor
coaching
industrial case

student
research
paper

academic
industrial
Scoping is Crucial

<table>
<thead>
<tr>
<th>What methods, techniques, tools, concepts</th>
<th>Systems Engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>What (sub)systems, releases, functions, qualities, aspects, disciplines, technologies</td>
<td>industrial</td>
</tr>
<tr>
<td>What timing of activities and deliverables</td>
<td>planning</td>
</tr>
<tr>
<td>What resources (student time, means, advisors)</td>
<td>planning</td>
</tr>
<tr>
<td>What approach, criteria</td>
<td>research</td>
</tr>
</tbody>
</table>
Case Positioning

organizational and operational context

Systems Engineering Master Project
version: 1.8
June 21, 2020
Gerrit Muller

Systems Engineering Master Project
version: 1.8
June 21, 2020
Gerrit Muller
Depth, Breadth and Reflection

**SE body of Knowledge**

**reflection**

**organizational and operation context**
**user needs and system requirements**

**design and realization**

**connect**

**organizational and operational context**

**depth**

**breadth**

**number of details**

**system requirements**
**parts connections lines of code**

**design decisions**

**case**

version: 1.8
June 21, 2020
SETPcaseT
Difference Academic and Industrial Goals

Systems Engineering Master Project
version: 1.8
June 21, 2020
SETPstakeholdersTview
## Process of Master Project

<table>
<thead>
<tr>
<th>Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pick subject</td>
</tr>
<tr>
<td>Secure supervisors (NISE, industry)</td>
</tr>
<tr>
<td>Write proposal, project plan; for paper write abstract</td>
</tr>
<tr>
<td>Perform project; involve supervisors regularly</td>
</tr>
<tr>
<td>Write paper and iterate with supervisors</td>
</tr>
<tr>
<td>Present master project</td>
</tr>
<tr>
<td>Grading by academic and external assessors</td>
</tr>
</tbody>
</table>

Graduation

Publication in journal or conference
Timeline of the Master Project

- **Proposal**
  - system
  - SE need company

- **Abstract**
  - academic approach & contribution

- **Book plan introduction**
  - check structure, style

- **Final paper/report presentation**

Think & explore
- Prepare with coordinator
- Prepare with academic supervisor
- Execute project

<table>
<thead>
<tr>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
</tr>
</thead>
</table>
tentative dates for milestones for IM students

- August: 
  - anticipating in RP how to apply

- June: 
  - approach searching a topic

- August: 
  - research methods prepare academic

- September: 
  - project execution

- February: 
  - academic writing

tentative dates for milestones for IM students
Master Project Milestones

- proposal
  - system
    - SE need company
  - abstract
    - academic contribution
- book plan
  - introduction
    - check structure, style
- final paper/report presentation

Tentative dates for milestones for IM students:
- September
- November
- February
- May

Version: 1.8
June 21, 2020
SETPmilesstones
Plan: Simple PERT Diagram

- **Control system architecture and design**
  - 70%-1.5wks
  - 1 wk

- **Incremental build mathematical models, simulate various inputs**
  - 70%-6wks
  - ~4 wks

- **Analysis and simulation f1**
  - 50%-5wks

- **Analysis and simulation f2**
  - ~4 wks
  - 20%-5wks

- **Verify system performance**

- **Write phase report**
  - 10%-1wks

- **Report layout**
  - 10%-1wks

- **Write draft paper and include findings**
  - 10%-10wks

- **Finalize paper**
  - 60%-2wks

Legend:
- 70% - Case (depth)
- 20% - System and context (breadth)
- 10% - "Meta" reflection and consolidation

- 70% - 2wks ~ 4wks
- 20% - 4wks ~ 4wks
- 10% - 10wks

Note: "Simple" context model, analyze system impact and adapt requirements.
"A good abstract should answer three questions:
What did I do,
what did I learn,
and why is that important?
The key is to identify something or things that can be reused in the future."

Prof. Michael Pennotti, Stevens Institute of Technology
"fast forward" yourself into the future
what do you expect to be the project outcome?

Students write an initial abstract at the start to think through what can happen. At the end of writing the paper, you write the real abstract. The academic supervisor has to accept the initial abstract before starting the project.
## Project Execution

<table>
<thead>
<tr>
<th>Maintain a project log</th>
<th>data, findings, documents, references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keep supervisors involved</td>
<td>regular presentations, regular meetings</td>
</tr>
<tr>
<td>Time box and iterate</td>
<td>case, system and context, reflection and consolidation</td>
</tr>
<tr>
<td>Early feedback on paper</td>
<td>start writing early, elicit feedback early, work incremental</td>
</tr>
</tbody>
</table>
1. Explanation of the subject; what is the goal of the project?

2. Positioning of the subject in the academic context and literature; what does this paper add to the Body of Knowledge?

3. How is the project performed, what has been done.

4. Evaluation of the project, reflection on the results and the project itself.

5. Paper should be submittable to a refereed conference or to a journal; the academic supervisor may accept a report as well.
1. Clearly introduce the problem that the manuscript is discussing/addressing,

2. Discuss the problem background. That is, discuss the research that has been previously conducted by you or others in the field (or related fields) to solve/address the same or similar problem,

3. Develop a succinct argument for the methods or ideas proposed in your manuscript,

4. Present a clear and understandable justification of why the proposed methods or ideas contribute to a superior or different solution to the problem. A clear statement of your contributions is often crucial to reviewers. Clear specify this when possible. And finally,

5. Discuss the likely future directions of the research being conducted by you (your group).

Final Presentation at the end of the project

student presentation of master project
~30 minutes presentation
~20 minutes questioning by examinators
~10 minutes examinators conclude
committee:
• academic supervisor
• at least one other academic staff member of SE
• external assessor
• (optional) company supervisor or representative
• at least 3 people
<table>
<thead>
<tr>
<th><strong>Publication Process</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Company screens paper for sensitive or confidential issues, see <a href="http://www.gaudisite.nl/BuskerudSEpublicationProcedureSlides.pdf">http://www.gaudisite.nl/BuskerudSEpublicationProcedureSlides.pdf</a></td>
</tr>
<tr>
<td>Select target journal or conference, typical choices are:</td>
</tr>
<tr>
<td>INCOSE symposium, CSER, Journal of SE</td>
</tr>
<tr>
<td>Transform the paper into the prescribed format or template</td>
</tr>
<tr>
<td>Review of the paper by NISE and Company, adapt paper</td>
</tr>
<tr>
<td>Submit paper to journal or conference</td>
</tr>
<tr>
<td>Process journal or conference feedback</td>
</tr>
<tr>
<td>Final review by company</td>
</tr>
<tr>
<td>Submit final version</td>
</tr>
<tr>
<td>Visit conference and present paper</td>
</tr>
</tbody>
</table>
If a third party is involved, e.g. a customer or supplier,
then ask the third party to agree with publication procedure:
and ask who will be reviewer for the third party.
Submission instructions

use for all preparation deliverables the following conventions:
filename: SEMP <your name> <subject>.<version>.<extension>
  e.g. SEMP John Student abstract.2.doc
where subject = {proposal | abstract | plan | presentation | paper | ...}

email to: <gerrit . muller@ gmail . com>
subject: SEMP <subject>

"standard" file types preferred, e.g. pdf, jpg, doc, xls, ppt
workshop 1 in June
workshop 2 in August
workshop 3 in September
  Master Project; Writing an Abstract: http://www.gaudisite.nl/MasterProjectWritingAnAbstract.pdf
  Master Project; Execution Phase: http://www.gaudisite.nl/MasterProjectProjectExecution.pdf
Validation of Systems Engineering Methods and Techniques in Industry
Systems Engineering Research Methods (paper)
Published Master Project papers: http://www.gaudisite.nl/MasterProjectPapers.html
Workshop Academic Writing http://www.gaudisite.nl/RPacademicWritingSlides.pdf
Abstract

Research in System Engineering research inherently addresses a mix of technological issues in relation to business, process, organization, and people aspects. We show an inventory of research methods for research done in the “field”, e.g. in industry or similar organization.
Action Research or Industry-as-Laboratory

source of inspiration

challenge problems

apply new engineering methods

research

improve

evaluate

hypothesis

application playground

industry
### Systems Engineer vs Researchers

<table>
<thead>
<tr>
<th>Normal Work</th>
<th>Systems Engineer</th>
<th>Researcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>elicit needs, specify, design, analyze, integrate, test</td>
<td>observe, experiment, argue, evaluate, write</td>
<td></td>
</tr>
<tr>
<td>attitude</td>
<td>explain, educate, sell</td>
<td>question everything, proof opposite</td>
</tr>
</tbody>
</table>

**Attitude**
- Systems Engineer: explain, educate, sell
- Researcher: question everything, proof opposite
Logical Order of Research

industrial problem

research questions

quantified propositions

hypothesis

criteria

options to be researched

industrial goal
Simplified Order for Master Project

industrial problem

industrial goal

SE body of Knowledge

claim

observables

evaluation

research

SERMfromProblemToEvaluation
Step 1: Formulate Claim

Claim: What benefits will your proposed improvements bring?

"Application of requirements traceability matrix will reduce changes after the definition phase significantly"

Be specific (what, who, when, how much, ...)

Does the claim address the original problem?

Is the claim realistic?

Do the benefits justify the research effort?

Do the benefits relate to the right driver?

20% or 80% would be better

better predictability of delivery
earlier delivery
better quality of delivery
less cost or effort
Step 2: Identify Observables

Observables: What observations or measurements will provide evidence for your claim?

- number of changes after definition phase in past projects without method
- number of changes after definition phase in current project with method

Be specific (what, who, when, how much, ...)

Do the observations relate to the claim?

Can the observations be made during the research period?

How accurate and objective are the observations?

Observe/measure the initial state before changing "zero measurement"
What to Research; Observe Context

- People applying methods and techniques to develop a process supported by stake-holders delivered to artifacts produced to describe system of interest, which concerns objectives have uses concepts and patterns.
### Spectra of Research Methods

<table>
<thead>
<tr>
<th>Artifacts that researcher can produce</th>
<th>Extracting data from other people</th>
<th>How the researcher collects data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sketch</td>
<td>Open interview</td>
<td>Log observations</td>
</tr>
<tr>
<td>Block diagram</td>
<td>Prepared interview</td>
<td>Observation template</td>
</tr>
<tr>
<td>Spread sheet</td>
<td>Open question survey</td>
<td>Structured data collection</td>
</tr>
<tr>
<td>Formal model</td>
<td>Likert scale survey</td>
<td></td>
</tr>
<tr>
<td>Standardized format</td>
<td>Structured reports</td>
<td></td>
</tr>
</tbody>
</table>

- **Free format**
  - Free representation
  - No formal definition
  - Supports: discovery, exploration
  - Difficult for: analysis, comparison, aggregation

- **Standardized format**
  - Standardized data
  - Formalized definition
  - Supports: analysis, comparison, aggregation
  - Might restrict inputs, affect observation
Research Logbook

Word or PowerPoint file
take notes continuously!

date/time
  what
  how
  why
  when
  where
  who

references, e.g. URLs; make electronic copy of any relevant material
all "raw" data, e.g. submitted questionnaires
all intermediate data, e.g. spread sheets with version numbers and dates
<table>
<thead>
<tr>
<th>Kind of session:</th>
<th>Communicate information/status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sell an idea/concept</td>
</tr>
<tr>
<td></td>
<td>Brainstorming/generate ideas</td>
</tr>
<tr>
<td></td>
<td>Decision making</td>
</tr>
<tr>
<td></td>
<td>Solve/discuss problem(s)/issue(s)</td>
</tr>
<tr>
<td></td>
<td>Planning</td>
</tr>
<tr>
<td></td>
<td>KPI/Performance/Action log</td>
</tr>
<tr>
<td></td>
<td>Team building/training</td>
</tr>
<tr>
<td>Physical location of session:</td>
<td>Presentation</td>
</tr>
<tr>
<td></td>
<td>Defined meeting room</td>
</tr>
<tr>
<td></td>
<td>Colleague own office</td>
</tr>
<tr>
<td></td>
<td>In the factory – “on the shop floor”</td>
</tr>
<tr>
<td>Planned session or not:</td>
<td>Planned</td>
</tr>
<tr>
<td></td>
<td>Unplanned</td>
</tr>
<tr>
<td>A3 purpose:</td>
<td></td>
</tr>
<tr>
<td>A3 name/link:</td>
<td></td>
</tr>
<tr>
<td>A3 usage/iteration number:</td>
<td></td>
</tr>
<tr>
<td>A3 usage time with stakeholders:</td>
<td></td>
</tr>
<tr>
<td>Number of participants:</td>
<td></td>
</tr>
<tr>
<td>Did everyone understand the A3:</td>
<td></td>
</tr>
<tr>
<td>Did it answer some of the stakeholders questions:</td>
<td></td>
</tr>
<tr>
<td>Create any new questions/concerns:</td>
<td></td>
</tr>
<tr>
<td>Models changed/added:</td>
<td></td>
</tr>
<tr>
<td>Stakeholder participation:</td>
<td></td>
</tr>
<tr>
<td>Prefer A3 instead of A4:</td>
<td></td>
</tr>
<tr>
<td>Observations/recordings:</td>
<td></td>
</tr>
</tbody>
</table>

from Master Project by Espen Polanscak
### Questionnaire

1. The A3 reports helped in finding requirements.

<table>
<thead>
<tr>
<th></th>
<th>strongly agree</th>
<th>agree</th>
<th>neutral</th>
<th>disagree</th>
<th>strongly disagree</th>
<th>not applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. A3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Presentation data

1. The A3 reports helped in finding requirements.

![Legend]

- **Strongly agree**
- **Agree**
- **Neutral**
- **Disagree**
- **Strongly disagree**
- **Not applicable**

Legend:

<table>
<thead>
<tr>
<th></th>
<th>4</th>
<th>3</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. A3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Evaluation of Surveys

1. The A3 reports helped in finding requirements.

How to assess the outcome? What is "good"?
Mean > 3, e.g. better than neutral?  mean = 3.9
Mode or median?  median = 4, mode = 5
mean, median, and mode are not very differentiating

Net Promotor Score =
(#)promoters - (#complainers) =
(#strongly agree - (#neutral + #disagree + #strongly disagree) > 0  NPS = +1
References

**Action research:**
http://cadres.pepperdine.edu/ccar/define.html

Hilary Bradbury Huang, 2010. *What is good action research?: Why the resurgent interest?* Action Research 2010; 8; 93

**Industry-as-Laboratory:**

Gerrit Muller and W. P. Maurice Heemels, *Five Years of Multi-Disciplinary Academic and Industrial Research: Lessons Learned;* CSER 2007 in Hoboken NJ

**Case Study research:**

**Likert Scale:**

**Net Promotor Score:**


**Tools and support** see: https://min.usn.no/student/tjenester-for-studenter/it-tjenester/
Master Project; Writing an Abstract

by Gerrit Muller    University of South-Eastern Norway-NISE
                  e-mail: gaudisite@gmail.com
                  www.gaudisite.nl

Abstract

An abstract is a brief description of the content of a paper to facilitate readers in deciding to read the paper. This presentation explains how to write an abstract. Normally, an abstract is written at the end of writing a paper. For the master project, we challenge students to write an abstract up front, to stimulate them to think through the entire project, including the expected outcome.

Distribution

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June 21, 2020
status: planned
version: 0
"A good abstract should answer three questions:

What did I do,
what did I learn,
and why is that important?

The key is to identify something or things that can be reused in the future."

Prof. Michael Pennotti, Stevens Institute of Technology
Needed: Time Machine

"fast forward" yourself into the future what do you expect to be the project outcome?

Students write an initial abstract at the start to think through what can happen. At the end of writing the paper, you write the real abstract. The academic supervisor has to accept the initial abstract before starting the project.
Multiple Levels of Academic Abstraction

**meta**^0^  
*bottom line:* system-of-interest  
work over system  
missile  
production line  
turbine package  
control system  
tie-in system

**meta**^1^  
*enabling:* systems engineering methods  
stakeholders and concerns  
ConOps  
operational needs  
need statement  
needs into requirements  
SMART requirements  
concept selection  
partitioning and interfaces  
documenting the architecture  
knowledge management  
conceptual modeling  
budget based design  
tie-in system

**meta**^2^  
*academic:* research of methods  
measuring  
experimenting  
modeling  
surveys  
interviews  
refering to literature  
argining
Value per Meta-level

meta$^0$

*bottom line:* system-of-interest

earning money

meta$^1$

*enabling:* systems engineering methods

re-use
  in future projects
  in other domains

meta$^2$

*academic:* research of methods

validation of method
  re-use
Content of Paper

meta⁰

**bottom line:**

system-of-interest

set the context

where did you apply

domain

system-of-interest

meta¹

**enabling:**

systems engineering methods

what did you apply and why

systems engineering challenge/need

methods, expected benefit

meta²

**academic:**

research of methods

what can we learn based on what findings

observations

argument

SE body of Knowledge

case
Write an abstract
in 3 paragraphs
use 2 sentences per paragraph
100..150 words in total
Abstract

A master project in systems engineering using action research or industry as laboratory requires that the student is both researcher and engineer. In this presentation we give guidelines for the execution phase of the project to ensure that the master project student plays both roles. These roles require quite different behavior. Especially the role of researcher is new for most students.
Discuss *way of working* and *expectations* with your *academic supervisor*.

The following slides are valid for supervision by Gerrit.

Other academic supervisors may have other doctrines.
# Recommendations for Project Execution

<table>
<thead>
<tr>
<th>Recommendations</th>
<th>Suggested Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>maintain a project log</td>
<td>data, findings documents references</td>
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<td>start writing early elicit feedback early work incremental</td>
</tr>
</tbody>
</table>
You have Multiple Roles!

<table>
<thead>
<tr>
<th>systems engineer</th>
<th>researcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>elicit needs, specify, design, analyze, integrate, test</td>
<td>observe, experiment, argue, evaluate, write</td>
</tr>
<tr>
<td>explain, educate, sell</td>
<td>question everything, proof opposite</td>
</tr>
</tbody>
</table>

Master Project; Execution Phase
49  Gerrit Muller

version: 0
June 21, 2020
SERMresearcher
Maintain a Detailed Research Logbook

Word or PowerPoint file
take notes continuously!

date/time
what
how
why
when
where
who
references, e.g. URLs; make electronic copy of any relevant material
all "raw" data, e.g. submitted questionnaires
all intermediate data, e.g. spread sheets with version numbers and dates
Discuss Regularly With Company Supervisor

Focus first on content, then means and then research approach.
Research is an adventurous journey, be perceptive and see where it goes.

Some students in the past called it a rollercoaster....
Abstract

Systems Engineering research takes place in close cooperation with industrial companies. This document describes a *Conduct of Behavior* for Confidentiality of information from the company where the research takes place. Also a *Publication Procedure* is described.
Confidentiality of Information

All information exchanged between researcher and company is to be treated as confidential.

Academic supervisors are not allowed to make any confidential information public without permission of the company.

Exception is information that was already known to the supervisor or is already public.
Publications will always be reviewed by the company where the research has been done.

The review identifies confidential or sensitive issues in the concept paper.

All confidential and sensitive issues have to be solved before the paper can be published.

Companies appoint a contact person who will ensure timely review by the company.
Examples of Issues to be Identified by Review

Business, customer, organizational, or technical confidential information
- market
- name or product
- department
- size
- choice of technology

Not (yet) protected intellectual property
"we use new high pressure sealing concept"

Negative image
"our company does skip reviews"
Guidelines for Review

Identify issues as specific as possible

Suggestions to resolve issues are welcome, but don't prescribe solutions

Detection of content quality problem are welcome, but not the main purpose of the company review.
<table>
<thead>
<tr>
<th>Step</th>
<th>Time Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author submits paper that has been reviewed by supervisors</td>
<td>We recommend to submit the concept at least 4 weeks before publication deadline</td>
</tr>
<tr>
<td>Contact person ensures review within 2 weeks</td>
<td>These steps may be iterated a few times</td>
</tr>
<tr>
<td>Author solves all identified issues</td>
<td>This step normally takes a few days</td>
</tr>
<tr>
<td>Author resubmits revised paper</td>
<td></td>
</tr>
<tr>
<td>Contact person gives permission for publication when all issues are solved satisfactory</td>
<td></td>
</tr>
</tbody>
</table>
Example of Company Review Process

1. the author makes an evaluation/review of the paper to identify potential changes (to remove confidential or sensitive information); this should be a short report with clear notes

2. the paper and this short report are submitted to the person responsible for the review process.

3. KM need 4-6 weeks to ensure a qualitative review.
Abstract

his document gives a number of concrete guidelines for visualizations, such as block diagrams, flow diagrams, graphs, decompositions, et cetera.
Readability

Texts should be readable, in PowerPoint minimum font size 14 pt
(or if you print a slide on A4, put the paper on the floor,
then you should be able to read the text)

Text and background should have sufficient contrast
(black letters on red background tend to be unreadable)
Guidelines for Visualization

Boxes (ellipses, rectangles, triangles, et cetera) should have the same size, unless the size has a clear meaning; don't size the box to the text, since readers might interpret size in a way that you did not intend.

use the layout (left-right, up-down, close-remote) to support the message of the diagram; e.g. flow from left to right or from top to bottom.

design the layout such that there are few crossing lines; this is often kind of puzzle.

version: 0.1
June 21, 2020
VGlayout
Use colors, but limited.

Try to use additional visual support to keep the diagram usable when printed black and white or for color-blind people. Alternate means to add meaning are shape (e.g. rectangles with rounded corners), line thickness, dotted lines, alternate end points or connectors.

In this example the color scale is used functionally; the color indicates the "degree of virtuality".

For readability the Gaudi site uses light background colors and darker colors for text and lines.
Limit the amount of information in one diagram.

Two or three types of information can be combined in one diagram. For example a block diagram that also shows effort, risk or complexity as size of the boxes. Or a flow diagram with annotations where the functions are allocated.
Annotate generic diagrams with specific examples; A generic diagram often captures some valuable insight, however, the examples help readers in understanding the diagram.

Use font size and type to visually differentiate main generic message and supportive specific examples.
Attractiveness

~1985
autonomous subsystems:
- Geo
- Acquisition
- Imaging
- X-ray generation

sales: preferred configurations; arbitrary configurations are more expensive

system integration (SI) in R&D
- SW in all subsystems
- SI is is electro mechanical and configuration parameters

innovation elapsed time several years (f.i., 2 years for digital imaging chain)

Guidelines for Visualization

version: 0.1
June 21, 2020
VGattractiveness
Guidelines for Visualization

Good visualization bring and clarify a message. What is the take away of this visualization for your audience?
architects move from: product to product environment to environment

architects experience: thousands of patterns
design patterns in systems
process patterns in environments
human patterns in environments

Add a legend for shapes, lines, or colors when the meaning is essential for the figure.
Separate information, prevent overload

Don't overload diagrams; if you have tens of boxes then consider simplification or divide in multiple slides plus one overview slide.

Consider to add one overview slide when dividing over multiple slides.
Texts should be readable: use sufficient font size.
Text and background should have sufficient contrast.
Shapes, such as boxes, should have the same size.
Use the layout (left-right, up-down, close-remote) to support the message of the diagram.
Design the layout such that there are few crossing lines.
Use colors, but limited.
Design the diagram such that it still works when printed in black and white.
Limit the amount of information in one diagram.
Two or three types of information can be combined in one diagram.
Annotate generic diagrams with specific examples; use font size and type to visually differentiate generic from specific.
Use 2D/3D drawings or photos limited.
Ensure that the message of the visualization is clear.
Add legend to explain shapes, colors, line types, axes, etc.
Abstract

System Engineering research addresses methods, techniques, models and formalisms that should advance the engineering practice of systems. This type of research inherently addresses a mix of technological issues in relation to business, process, organization, and people aspects. We discuss the challenge of validating this type of research. We look at different research and validation methods.
Figure Of Contents™

- Problem exploration
- Background of SE research
- Research method and validation
- Hypothesis and criteria
- Conclusion

- Why discuss validation?
- Why what
- How who
- Where when
- How to do & validate
- Sharpen research

Systems Engineering Research
problem exploration

- background of SE research
- research method and validation
- hypothesis and criteria
- conclusion

why discuss validation?
why what
how who
where
when
research method and validation

how to do & validate
hypothesis and criteria

Systems Engineering Research

sharpen research conclusion
Reflection from my PhD thesis

What architecting methods enable the creation of successful products in a dynamic market developed in a heterogeneous industrial context, satisfied customers thriving business in time within economic constraints, uncertainty rules need for innovation agility required, some poor, some excellent, mostly average normal distribution of engineering skills.

views, stakeholders, applications, concerns, needs, expectations, interests functions, features, qualities, requirements, systems, technologies, standards, disciplines suppliers, sites, cultures, employees, educations, tools, legacy, other vendors, legislation.
How do we validate Systems Engineering research given that most context factors are soft and uncontrolled?
problem exploration

background of SE research

research method and validation

hypothesis and criteria

conclusion

why discuss validation?

why what

how who

where when

how to do & validate

sharpen research

Systems Engineering Research
Soft problems can be approached with a scientific attitude

soft is not in conflict with scientific attitude

research question
hypothesis
heuristics
principles
facts
analysis
evaluate
open debate
body of knowledge
cases

— make explicit
— substantiate
— try to validate

systems engineering research validation
version: 1.0
June 21, 2020
RORMscientificAttitude
Different Types of Research

- Mono-disciplinary
- Multi-disciplinary

10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^7

field research:
make implicit methods explicit

Borrow & Adapt approach:
adapt existing mono-disciplinary method

delta-approach:
extend existing body of knowledge with well founded increments

A' - A - N

N

A

version: 1.0
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INSEresearchMethods
And another Dimension of Research Types

observational research
- best practices
- heuristics
- classification
- ontology

theory development
- metrics
- formalisms
- techniques
- models
- methods

everal research
- theory evaluation
- theory evolution
- fundamentals
- principles
- methodologies

fundamental research
- optimizations
- rigorous proofs
- first principle based
Systematic Know-how to cope with Growing Complexity

- More performance and functionality causes more complexity and requires more effort.
- Active work on systematic methods reduces effort and the need for a lot of creative effort.

Creative
Systematic
Repeated Creative
New Creative
Creative
Year X
Year X+4
Year X+4
Technology Management Cycle

1. Exploration of new ideas
   - Literature search
   - Creative option generation
   - Try out

2. Application of technology
   - Industry as laboratory

3. Consolidation of know how
   - Reflection
   - Write articles
   - Create courses
SE research requires application

- Exploration of new ideas
- Application of hard technology
- Consolidation of know how
- Exploration of new ideas
- Application of soft technology
- Consolidation of know how

Product Development

Research

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ARMcyclePDvsResearch
Example Boderc Stakeholders
Project as Carrier for Capability Development

- Single domain result
- Carrier to develop capabilities
- Feedback from industrial context
- Transferable know-how

Project as Carrier for Capability Development
Methodology

**Formalisms** languages/syntax: for example, differential equations, timed or hybrid automata, finite state machines, et cetera

**Models** instantations of formalisms to understand, explore, optimize or verify specification or design

**Techniques** to get the required information from models: e.g. performance

**Methods** to provide guidelines how to use formalisms, create models, use techniques and apply tools

**Tools** to support efficient application of formalisms, techniques and methods
Moving in the *meta* direction

- **meta**\(^0\): *bottom line*: product creation
- **meta**\(^1\): *enabling*: architecting method
- **meta**\(^2\): *pro-active*: research of architecting method
- **meta**\(^3\): *scientific foundation*: method to research architecting methods

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Application of technology
Consolidation of know how
Exploration of new ideas
architecting method

**meta**\(^0\) research method
problem exploration

background of SE research

research method and validation

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why discuss validation?

why what

how who

where when

how to do & validate

sharpen research

Systems Engineering Research

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SERVlogoMethodValidation
Scope versus Feasibility and Value

"impossible"

validation
feasibility

mathematical proof
simulation
experiment

critical factors
formalism
implementation
analysis

more analysis
and evaluation

practical
valuable
method or
technique
usable by practitioners
less money, time, effort
better performance, ....

more analysis
and evaluation

action research

feasible

technical
valuable

design or
model is
stable
accurate
fast

method or
technique

works

more analysis
and evaluation

practical

industrial value

high

"easy"

feasibility

design or model
works

systematic
reflection

data collection
argumentation

more analysis
and evaluation

practical

industrial value

low

Systems Engineering Research Validation
89  Gerrit Muller

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SERVvalidationGraph
Different Research Methods

- Continuous interaction
- Observe only
- Experiment

- Industry
- Research laboratory
- Consortium

- Industry as laboratory
- Retrospective analysis
- Industrial workshop and courses
- Academic research
- Academic workshop and courses

- Where/who

Systems Engineering Research Validation
90 Gerrit Muller
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SERVresearchMethods
Different Research Methods (2)

- **Method**
  - Large industrial project >100 man

- **Method Trial**
  - Large industrial project >100 man

- **Architecting Research by Analysis**

- **Active Architecting Research**

- **Active Architecting Research**

- **Architecting Research Feedback**

- **Method Trial**
  - Course setting

- **Method as Framework**
  - Workshop setting

- **Retrospective Analysis**

- **Industry as Laboratory**

- **Trial in Research Environment**

- **Feedback from Courses**

- **Feedback from Workshop**
Industry as Laboratory

source of inspiration
application playground
industry

challenging problems
apply new engineering methods
research

observe results
evaluate
improve

hypothesis
problem exploration

background of SE research

research method and validation

hypothesis and criteria

conclusion

Systems Engineering Research

why discuss validation?

why what

how who

where

when

how to do & validate

sharpen research
From Industrial Problem to Validated Research

industrial problem \rightarrow industrial goal

- research questions
- quantified propositions
- hypothesis
- criteria

options to be researched
Successful architecting and architecting method

Architecting

problem know how

solution know how

stakeholders
expectations, needs, concerns, constraints

result satisfies

PCP team
architect, project leader, engineers, product manager

method enables

architecture

preceding architecture

human context

business context

technology context

Systems Engineering Research Validation
95 Gerrit Muller

version: 1.0
June 21, 2020
CAMsuccessfulArchitecting
From hypothesis to criteria

resulting architecture satisfies stakeholders

1. product is a commercial success
2. product family is sustainable commercially successful

method enables PCP team to create architecture

3. architects benefit from deploying submethods
4. project leaders, product managers and engineers are able to use the outcome of the submethods
why discuss validation?
why what how who
where when
how to do & validate
hypothesis and criteria
sharpen research

problem exploration
background of SE research
research method and validation
conclusion
The Final Result

research question, hypothesis, criteria, method
research positioning

theory
casus (problem, goal, context)
experiment
analysis

evaluation, validation

conclusion, recommendations
and the Chaotic Route

et cetera et cetera
Recommendations

time-box research reflection, e.g. one day per half year
be sharp in industrial problem and goal,
research question, proposition and hypothesis
does your claim address the original needs?
does your validation address the claim?
be modest with claim
be critical in evaluation
test claim and evaluation with others
Further Reading; chapters from PhD thesis:

- “Research in Systems Architecting”
  [Link](http://www.gaudisite.nl/ArchitectingResearchMethodPaper.pdf)

- “Research Question and Hypothesis”
  [Link](http://www.gaudisite.nl/CriterionsForArchitectingMethodsPaper.pdf)

- “Evaluation of the Architecting Method”
  [Link](http://www.gaudisite.nl/ARevaluationPaper.pdf)

- “Reflection on Research Method to Study Architecting Methods”
  [Link](http://www.gaudisite.nl/ReflectionOnResearchMethodPaper.pdf)
Further Reading; other related Gaudisite documents

- “A Multi-Disciplinary Research Approach, Illustrated by the Boderc Project”

- “Industry and Academia: Why Practioners and Researchers are Disconnected.”

- “How to Characterize SW and HW to Facilitate Predictable Design?”
  http://www.gaudisite.nl/PerformanceEngineeringPaper.pdf

- “The Informal Nature of Systems Engineering”
Abstract

Research in System Engineering requires a mixture of research methods. It is a challenge to capture the various aspects in a logical flow. The research methodology is also a significant challenge. This presentation shows examples of past research of visualizing the paper flow and the research methodology.
Eldar Tranøy won the Best Student Paper Award at INCOSE 2014 in Las Vegas with the paper

“Reduction of Late Design Changes Through Early Phase Need Analysis”

available at http://gaudisite.nl/
INCOSE2014_Tran%C3%B8y_Muller_ReductionOfLateDesignChanges.pdf

The following slides show some of the attempts of finding the flow for this paper by Eldar Tranøy and the academic supervisor.
Meta Levels and Scopes by Supervisor

Systems Engineering Body of Knowledge

Meta\(^0\) system-of-interest

SE BoK generic SE processes

Eric Honour’s research

Meta\(^1\) SE methods

SubSea Oil&gas SE processes

SubSea Oil&gas domain

Meta\(^2\) research methodology

Eldar’s research

SubSea Equipment Supplier

Vigdis subsea installation

AkSo’s SE process

Meta (abstraction) level

scope
Vigdis Cost
Overruns

Analysis of variation orders

missing customer needs

Historic data interviews

missing needs analysis

Analysis of SE effort

process allocation proposal

benchmark

expert interviews and review

explanation of AkSo's processes

literature
The Book Plan that Eldar Made at the Start

Note: in the final paper, the Honour paper moved to the beginning and forms the frame for the entire paper.
Linda Lønmo wrote the paper

“Concept Selection - Applying Pugh Matrices in the Subsea Processing Domain”

for INCOSE 2014 in Las Vegas

available at http://gaudisite.nl/
INCOSE2014_Lonmo_Muller_ConceptSelection.pdf

The following slide shows the visualization of the research methodology by Linda Lønmo.
Example Research Methodology by Linda Lønmo

Legend:
- Part of normal project work
- Academic domain
- Interaction with project teams

from: “Concept Selection - Applying Pugh Matrices in the Subsea Processing Domain” by Linda Lønmo
Anders Viken wrote the paper

“Creating and Applying A3 Architecture Overviews: A Case Study in Software Development”

for INCOSE 2018 in Washington, DC, USA


The following slide shows the visualization of the research methodology by Anders Viken.
Example Research Method by Anders

1. **Documentation issues**
2. **Software need or issue**
3. **Requirements generated**
4. **Adjust requirements**
5. **Adjust software**
6. **Apply in session**
7. **A3 Store**
8. **Adjust A3s**
9. **Consolidate observations**
10. **Analyze observations**
11. **Ask for feedback**
12. **Consolidate survey answers**
13. **Analyze survey answers**
14. **Perform Survey**
15. **Create A3s**
16. **Observe**
17. **Survey**
18. **Observation Template**
Example Book Plan that Else Dalby made

### Industry Evaluation of a SW Test Framework Implemented at Unit level

- **Title + authors** - ¼ page
- **Abstract** - ¼ page
- **Introduction** - 1 page
  - Introduction to Company
  - Problem statement - testing is costly and time consuming
  - Introduction to method - framework with automated testing
  - Introduction to the case - JUnit test framework
  - Short how the original problem will be solved
  - How the method serves the goal
- **Current situation and problems** - 2 pages
  - Explain deeper the reasons why the department is interested in framework + automate testing (1 page)
  - How testing of SW is done in the department today (1 page)
- **Research methodology** - 1¾ page
  - Action research
  - Industry-as-laboratory
  - How I did my research - experiment + interviews + literature
  - How reliable and objective are the results of my research?
- **Literature review** - 1 page
  - Automated testing framework domain – what has been done?
- **Main body** - 6 pages
  - JUnit testing framework (1 ¼ page)
    - How and what to test with JUnit
    - How and what to test with EasyMock extension
    - How testing of SW in the department is performed in the experiment (3/4 page)
  - Observations and findings (1 ½ page)
  - Summary of data collected in the experiment and during interviews
  - Cost and effort (1 ½ page)
    - Analysis of data collected – Is the case "JUnit implementation" a success? Best practices, limitations, benefits, drawbacks. (How well is the problem solved?)
    - Use of test frameworks in industry (1 page)
    - Results – Evaluation of the SE method based on analysis of the data collected from the case. (How well does the method fit and serve its goal?)
- **Conclusions** - 1 ½ pages
  - Repeat: mention that the JUnit test framework can be recommended to the department with some restrictions
  - Repeat and summary from results how well the SE method fits and serves the goal of reducing cost and time of testing
  - Repeat and summary from results about limitations, benefits and drawbacks to the method
- **Reflection (1/2 page)**
  - Lessons learned
  - Mention of how the research methodology worked out
- **Future research** - 1/2 page
  - Research to be done next is to find the error reduction rate with use of a test framework versus manual testing
  - Long term research was limited due to time constraints, therefore it was hard to find data about how much money we can save with automated testing and how much resources the automated test frameworks will cost us to maintain
  - Experiment with implementation of JUnit in more than one unit was limited due to effort and time constraint
- **References** - 1 page

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Else Dalby's Book plan of her master project in 2013