



University of St.Gallen

Center for Aviation Competence

New evidence on the Role of Systems Engineering

a case study of NASA, COTS and SpaceX

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From insight to impact.

Outline – message:

There's more evidence on the Rol of SE!

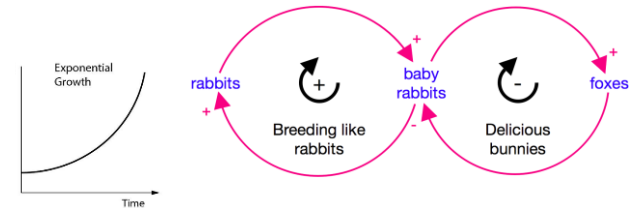
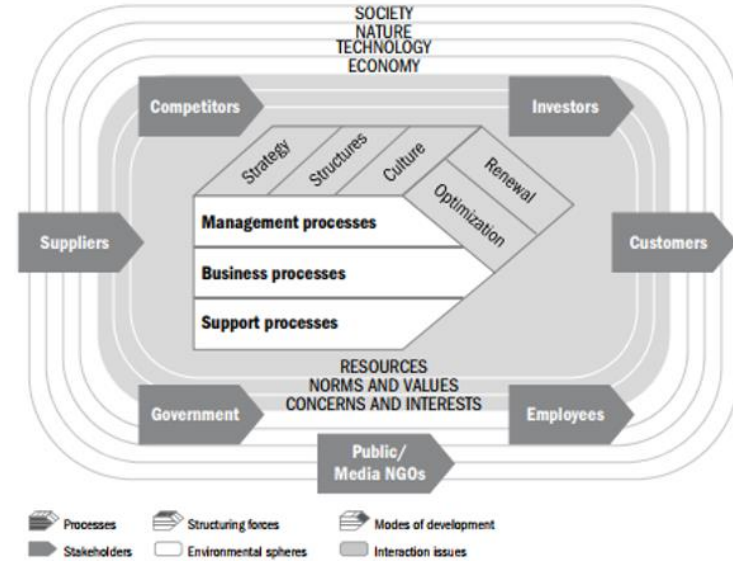
1. Systems Thinking at HSG
2. “What is the Rol of Systems Engineering?”
 - the “popular” evidence
3. “New” or less-known evidence on Rol
 - Disparities in firm R&D productivities (mgmt/econ)
 - PDMA (product development)
4. Rol case study: NASA, SpaceX, and the COTS program
 - Main Systems Lessons Learned
 - Result: cost disparity
5. Conclusion: Rol evidence for Systems Engineering

Systems, engineering at University of St. Gallen (HSG)

- **Systems Thinking** is part of the University of St. Gallen's 'DNA'
 - St Gallen Management Model (SGMM): firm as complex system
 - Assumption: *management = mastering complexity*
 - Systems oriented management science & education
- **System Dynamics** Group (2 professors)
- Institute for **Systemic Management** and Public Governance

Technical and engineering side

- Computer Science
- Center for Aviation (*and Space?*) Competence
 - Houses the Swiss Aerospace Cluster
 - Aviation safety & compliance
 - “Network” industry modelling
 - Expanding to space!
 - ESA-supported *Space for Business* programme



“What is the Rol of Systems Engineering?” The "popular" evidence

SEBoK “Economic Value of SE”:

- Gruhl (cited by Stutzke 2005) – **26 large NASA projects**: *doubling the average amount spent on systems architecting halves the average cost overrun*
- Boehm, Valerdi, Honour 2008 – **161-project COCOMO (software cost) model**: large costs of underinvesting in SE (error fixing)

Others: (nicely reviewed & contextualized by Davies 2013 (Thales), “*Quantification of the Value of Systems Engineering*”)

- **Honour 2004 (LAI), “Value of Systems Engineering”**: many nice statements, based on literature review and integration
 - “*Better/more systems engineering correlates to lower development costs, by 30% or more.*”
 - “*Optimum level of systems engineering is about 15% of a total development program.*”
- **Honour 2013 (PhD), “SE Rol”: “What is the optimum level of SE?”**
 - 90 projects – 50% US DoD, “the rest split between non-US Defence, commercial systems development, space systems”
 - Curve-fitting for overall SE level (with normalizations) results in 14.4% optimal SE level; Rol increases with deviation from this %
- Miller, Floricel, Lessard 2000 (MIT), **The Strategic Management of Large Engineering Projects**
 - Studied 60 large projects; 45% met technical objectives
 - “*the authors emphasize the importance of “solid front-end work” as a crucial success factor*”
- **Elm & Goldenson 2012 (SEI/NDIA), “Business Case for SE”**: 46 government-contracted industry projects
 - survey of 148 systems (& defense) professionals found that *top predictors of project success were project planning, requirements development and management, product architecture*



“New” or lesser-known evidence (1/2): management & economics

"The firm characteristic that economists have long believed to affect **R&D performance** is the **degree of integration between R&D and other functions within the firm.**" (Hall & Rosenberg 2010)

- or: connection between engineering, manufacturing, marketing, operations... SE provides this “glue”

Many factors are known to impact R&D performance: e.g. *degree of integration of R&D with other functions*, “*knowledge sharing culture*”

Detailed study of 43 matched pairs of successful and unsuccessful innovations, top 5 success factors (Rothwell et al. 1974):

- close attention to user needs, marketing, **efficient management of the development process**, and ability to use outside tech and discuss with external experts, project management by a senior individual – “*product champion*”

2 classic Harvard studies:

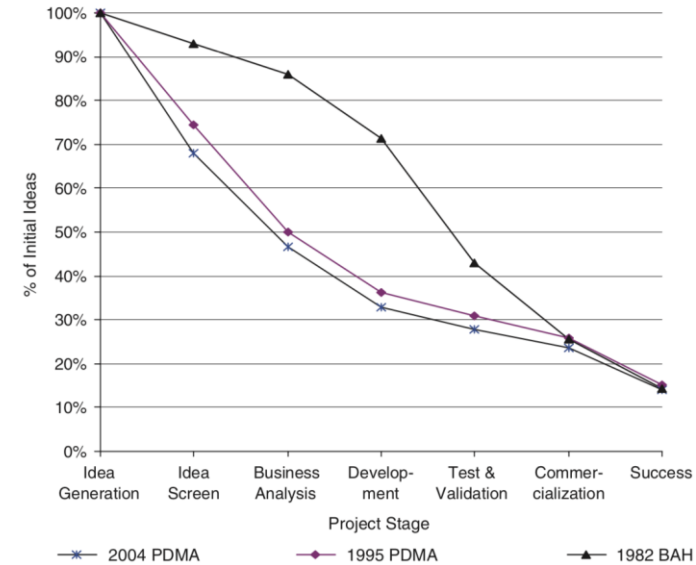
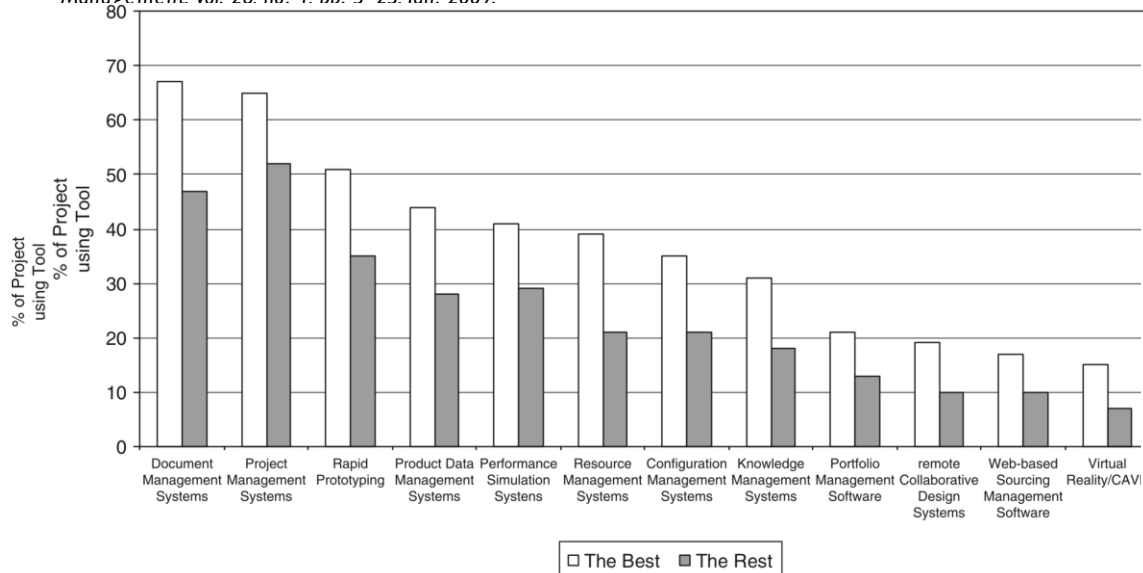
1. Clark et al. 1987 looked at 29 international automotive projects yielded a disparity of **50% in time and 3× in cost**: “**wide disparities in firms’ R&D productivities**”.
2. lansiti (1995) finds similar disparities (**3× variance in productivity**) via “27 projects in high performance mainframe computers”
 - “**Effective organizations** are characterized by a **'system focused' approach**. The approach involves an **emphasis on project specification and concept development**, a number of specific **routines** that **probe the systemic impact of technical options** on the existing capabilities of the organization, as well as the retention of individuals with direct experience of related product introduction efforts.”
 - “[evidence suggests] disparities result from differences in the organization of product development in these firms, including the degree to which tasks are subdivided, how the different phases of the development process are coordinated, how technical problems get solved, the relative autonomy of the project leader, and the nature of the links between product development and upstream applied research.”

“New” or lesser-known evidence (2/2): product development

PDMA: Product Development & Management Association; 3 large surveys on “*best practices in New Product Development*”

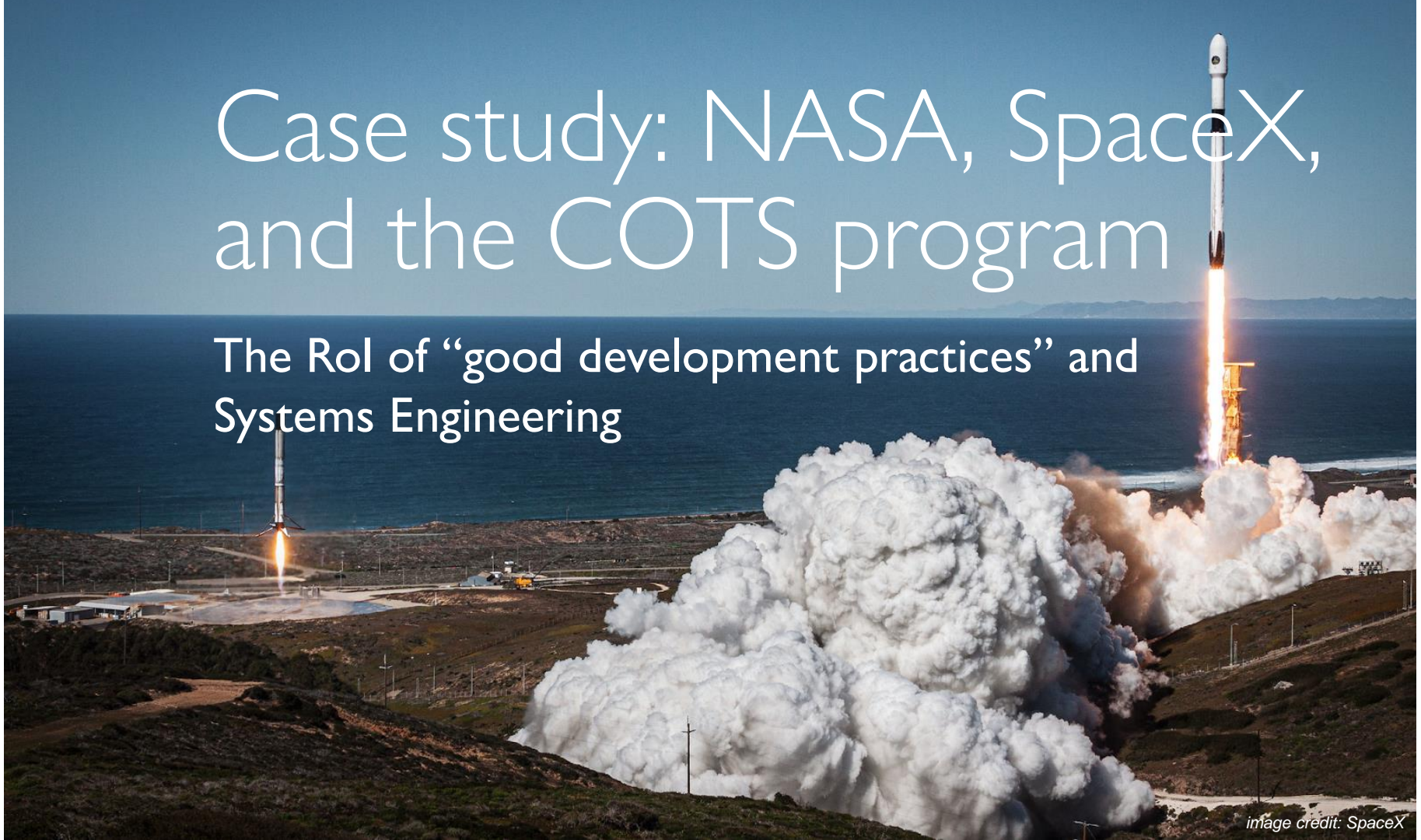
- A cross-industry survey of 416 professionals indicated that “top 25%”-product development firms had 75% new product success rates - vs. 55% average - at higher profit, and less time & cost.
- Famous for “NPD mortality curves” by phase, novelty, etc.
- “top-25%” firms use more *Document and Product Data Management Systems, rapid prototyping and performance simulation systems, remote collaborative design systems, and concept engineering*

G. Barczak, A. Griffin, and K. B. Kahn, “PERSPECTIVE: Trends and Drivers of Success in NPD Practices: Results of the 2003 PDMA Best Practices Study,” *Journal of Product Innovation Management*. vol. 26. no. 1. pp. 3–23. Jan. 2009.



Case study: NASA, SpaceX, and the COTS program

The Rol of “good development practices” and
Systems Engineering



COTS intro, goals, evidence



COTS: *Commercial Orbital Transportation Services* – SpaceX and Orbital Sciences

- NASA program 2006-2013, \$800M investment into commercial launch vehicles
- 2-step acquisition strategy (with CRS: *Commercial Resupply Services*) from cost-plus to fixed-price contracts
- Outcome: "two new U.S. medium-class launch vehicles and two automated cargo spacecraft"
 - NASA: *unqualified success* vs. traditional cost-plus, e.g. the \$12 billion Orion (spacecraft) contract

Evidence: 13+ in-depth NASA video interviews of key personnel (on youtube!)

- 8 NASA staff: program director, managers, requirements lead, a lead engineer...
- 4 Orbital Sciences staff: division director, program manager, chief engineer...
- x SpaceX staff (*not online*)
- 1 FAA person

Rare data: private sector (best?) practices + (some) public sector scrutiny!



COTS outcomes – and comparison (NAFCOM, Rasky)

NAFCOM: NASA Air Force Cost Model:
standard estimator, based on all past
mission data

Dan Rasky: NASA senior scientist
(thermal protection system) embedded at
SpaceX in 2008-9.



COTS outcomes – why?? How?? (1/2)

Rasky's summarized reasons:

- 1. incentives!** of contracts ("lazy" cost-plus), of people (stock options)
 - Ex: engineers prioritizing system-level concerns
- 2. flat, start-up, software-based** structure;
 - Self-organizing, less formal, cheap communication & coordination, few & clear goals
- 3. collaborative design environment, with rapid prototyping & "sparse matrix" engineering**
 - Sparse matrix: "go fast" decision based on 51% of evidence – risk-taking
 - Speed of acquiring, processing, checking information
- Other points (explored in [15-video playlist](#))
 - Collocated, with manufacturing and talent pool;
 - Non-traditional requirements approach (far fewer!);
 - Speed, from software development practices
 - Mentor-apprentice
 - Focused organization (few products) eases coordination



COTS outcomes – why?? How?? (2/2)

Others' proffered reasons

Small size of programme office; “insight not oversight”

- NASA had no resources to duplicate / slow technical effort
- “Political cover”, and “low-stakes”: *main* NASA program was Bush's Constellation Program (later canceled)

Dramatic reduction in requirements set

- Standard NASA practice: *thousands* of requirements of unclear origin, copy-pasted
- *Exceptionally for COTS*, NASA went through line-by-line, found owners and questioned each requirement
- Immensely reduced set (To Be Investigated further)

Accelerated timeline for follow-on service contract (CRS), allowed overlap

- “*crucial to success*” (contractors), vs. “*much faster than we wanted, forced to because Shuttle retiring*” (NASA) (!!!)

Preliminary analysis:

- Software Engineering methods vs. Aerospace Systems Engineering?
- “Proper” division of Systems Engineering role? (clear, singular System Architect)
 - Closer to industry style?
 - No duplication of SE effort; no weakening of SE power through division

Conclusions

- Messages: ***There's more evidence on the Rol of SE!***
 1. Existing evidence on the Rol of SE often does not fully compute an Rol #, rather focused on “right amount”, qualitative factors
 2. There are good lesser-known sources of Rol evidence, e.g.:
 - From economics and management: quantified disparities in firm R&D productivities, and links to SE
 - Evidence coming from outside the field! Stronger?
 - Product development: practices linked to SE improve odds
 3. Rol case study: NASA, SpaceX, and the COTS program
 - Dramatic case study contrasting methods, with open data
 - 10× cost disparities between methods. Why?
 - Thought: **speed** - cost is mostly salaries – speed is key
 - Learning is knowledge digestion / time – speed is also key

Vielen Dank.

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