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The Enduring Path to System Success: Investment in Quality Early-phase Systems Engineering

Overview

- Introduction and approach
- Historical SE context and findings
- Contemporary SE context and findings
- Consistency of findings over time
- Findings from Shoal early-phase SE practice
- Revised SE success factors
- Conclusion

Introduction and Rationale

- Systems engineering is commonly resource-constrained, hence:
  - Need to understand where to best allocate SE resources
  - Need to understand the degree to which resource allocation recommendations are enduring
- Valuable to collate evidence of the value of SE for those who have not experienced the evolution of SE over the years
- Approach:
  - Reprise lessons-learned paper and source material from 20 years ago
  - Review intervening literature
  - Elicit contemporary insights from Shoal SEs
  - Comment on the saliency of original success factors
  - Formulate contemporary SE success factors and conclusions from the above

What does history teach us?

Historical SE context & findings

Historical Context – Cook (2000)

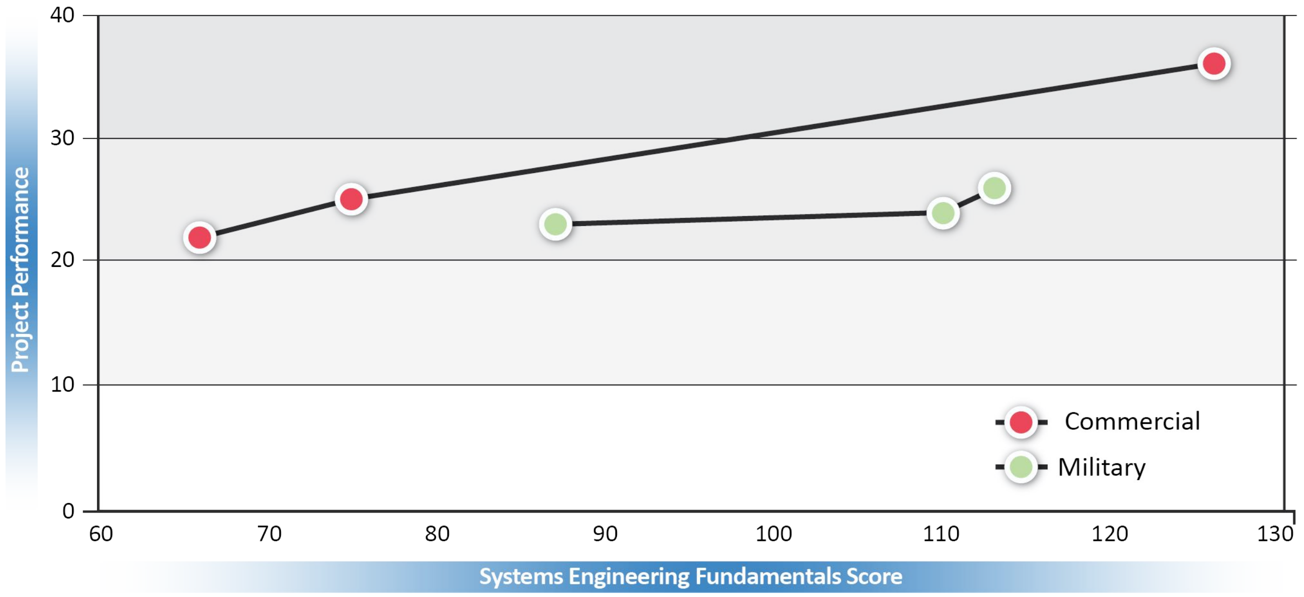
- SE arose in the 1950s and 1960s in response to the increasing cost and complexity of:
    - Telecommunications
    - Defence, and
    - Aerospace acquisition programs
- By the 1980s, SE well accepted in these industries
    - SE was employed within a project context and shared the ‘hard systems’ worldview of project management
- By the 1990s SE was expanding beyond its originating domains and domain-independent standards appeared: eg EIA 632, IEEE 1220, etc
- Worldview:
    - Good SE = working within an organization exhibiting high levels of process maturity

The Theme of Cook (2000)

- Traditional SE arose from the ‘hard’ systems tradition and works well when:
  - Objectives can be defined at the beginning of a project
  - Solutions can be envisaged by all parties
  - The technical, organisational and social environment are stable
  - Stakeholders share objectives
- Broader applicability, and better outcomes, can be achieved by incorporating ‘soft’ systems approaches to understand the organisational needs and social and cultural imperatives of the problem situation.
- Successful systems practice benefits from selection and tailoring of approaches, processes, methods, tools and techniques.

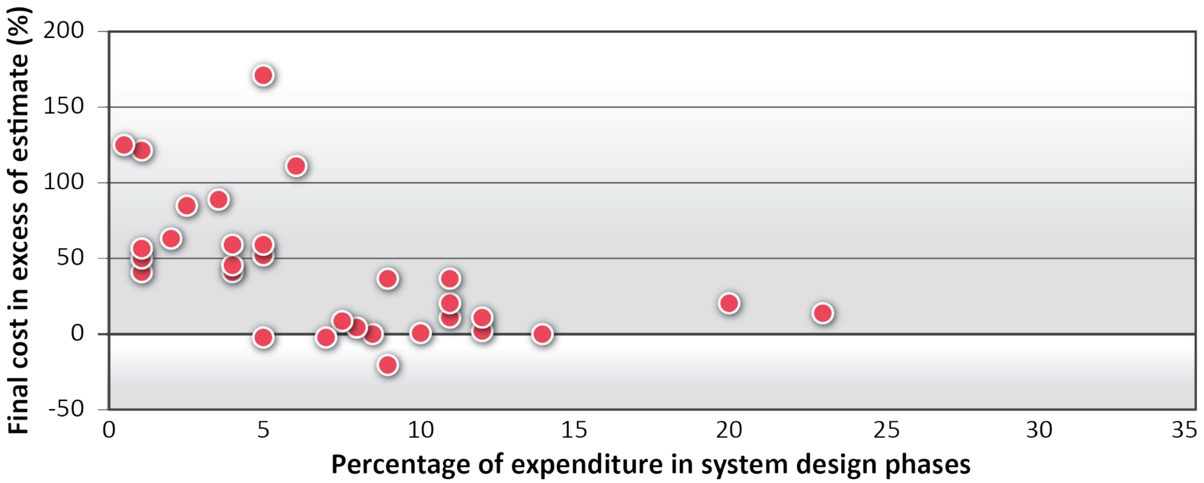
Findings from Original Review (1)

- A correlation was found between the quality and comprehensiveness of SE in the aircraft industry and project performance (Moody, 1998)



Findings from Original Review (2)

- Inadequate expenditure on system design phases is correlated with poor project outcomes



- NASA (1995) shows project overruns are highly likely if expenditure <5%
- UK MoD literature going back to the 1960s recommends 15%

Findings from Original Review (3)

- US and UK Defence project performance data indicates:
  - Projects routinely slipped by 3 to 4 months per year
  - Costs grew by 7-10% per year

- Late 1990s acquisition improvement programs focused on:
  - Increased stakeholder engagement in the early phases of the project
  - Generation of user needs (OCD) in parallel with system requirements
  - Improved estimating
  - Incremental / evolutionary acquisition
  - Re-invigoration and modernisation of SE and project management practices

Findings from Original Review (4)

Statistics from UK Commercial Software Projects (Jackson, 1997)
80% to 90% of systems did not meet their goals
~ 80% were delivered late and over-budget
~ 40% of developments failed or were abandoned
< 40% addressed training and skills requirements
< 25% fully integrated business and technology objectives
Only 10% to 20% met their success criteria

- Software projects routinely exhibit low success rates

  (*n* = 14,000; *n* = 8,380)

Software Project Outcomes (The Standish Group, 1995)		
Outcome	**Description**	**Percentage of projects**
Type 1 Project success	Project completed on time, on budget, with all features and functions as initially specified.	16.2 %
Type 2 Project challenged	Project completed but over budget, over time, with fewer features and functions than initially specified.	52.7 %
Type 3 Project impaired	The project was cancelled at some point during the development cycle.	31.1 %

Findings from Original Review (5)

- Standish *project success potential metric* reflects where best to allocate effort
- Roughly half of the metric is relates to soft aspects

Index	Success criteria	Points
1	User involvement	19
2	Executive management support	16
3	Clear statement of requirements	15
4	Proper planning	11
5	Realistic expectations	10
6	Smaller project milestones	9
7	Competent staff	8
8	Ownership	6
9	Clear vision & objectives	3
10	Hard-working, focused staff	3
TOTAL		**100**

Key SE Success Factors from the 1990s (1)

1. Adhere to SE (SwE) principles and practices
2. Invest in SE in the early design phases (5-15%)
3. Prioritise user and other stakeholder engagement
4. Employ soft systems approaches to facilitate user involvement
5. Focus on stakeholder project goals, user needs and requirements

Key SE Success Factors from the 1990s (2)

6. Take a whole-of-life approach to SE practice
7. Select suppliers with demonstrated capability honed on similar projects
8. Pay attention to interface definition and management
9. Plan system assurance (design assurance, V&V, T&E) in the conceptual design phase

What’s changed in recent years?

Contemporary SE context & findings

Drivers of change (Sillitto et al, 2018)

- **Top-down, greenfield development now unusual** hence the need for a shift in focus from the upfront definition of '*controlled*' systems operating in deterministic scenarios, towards '*learning and evolving*' systems (which might be autonomous) operating in changing and non-deterministic environments, hence the emphasis on '*purpose and success criteria*', before '*needs and functionality*'
- New fields of practice like **SoSE require a wider set of systems approaches**
- **Increasing acceptance that SE needs to start earlier** and help define the problem, hence the ISO 15288 Business or Mission Analysis Process
- **The need to move towards 'SE facilitates effective collaboration'** and away from 'SE takes charge'
- **The need for SE to allow for market-driven developments** as well as customer-driven development
- **Recognition that SE should be transdisciplinary** (Rousseau *et al*, 2018) rather than merely interdisciplinary

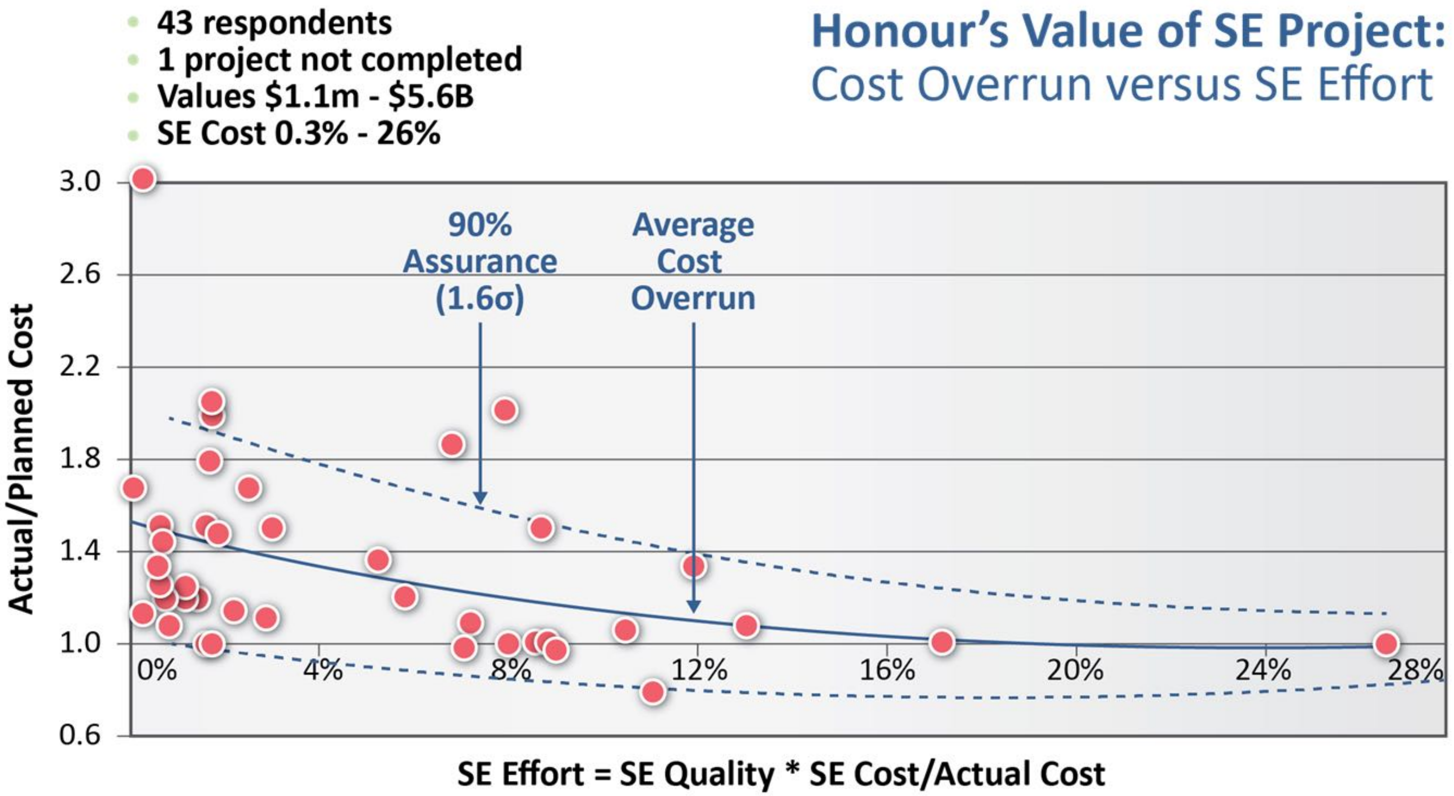
A new definition of SE

The INCOSE Fellows derived a new definition of SE (Sillitto, 2018) …

"Systems engineering is a transdisciplinary approach that applies systems principles and concepts to enable the successful realization and use of engineered systems and whole-system solutions."

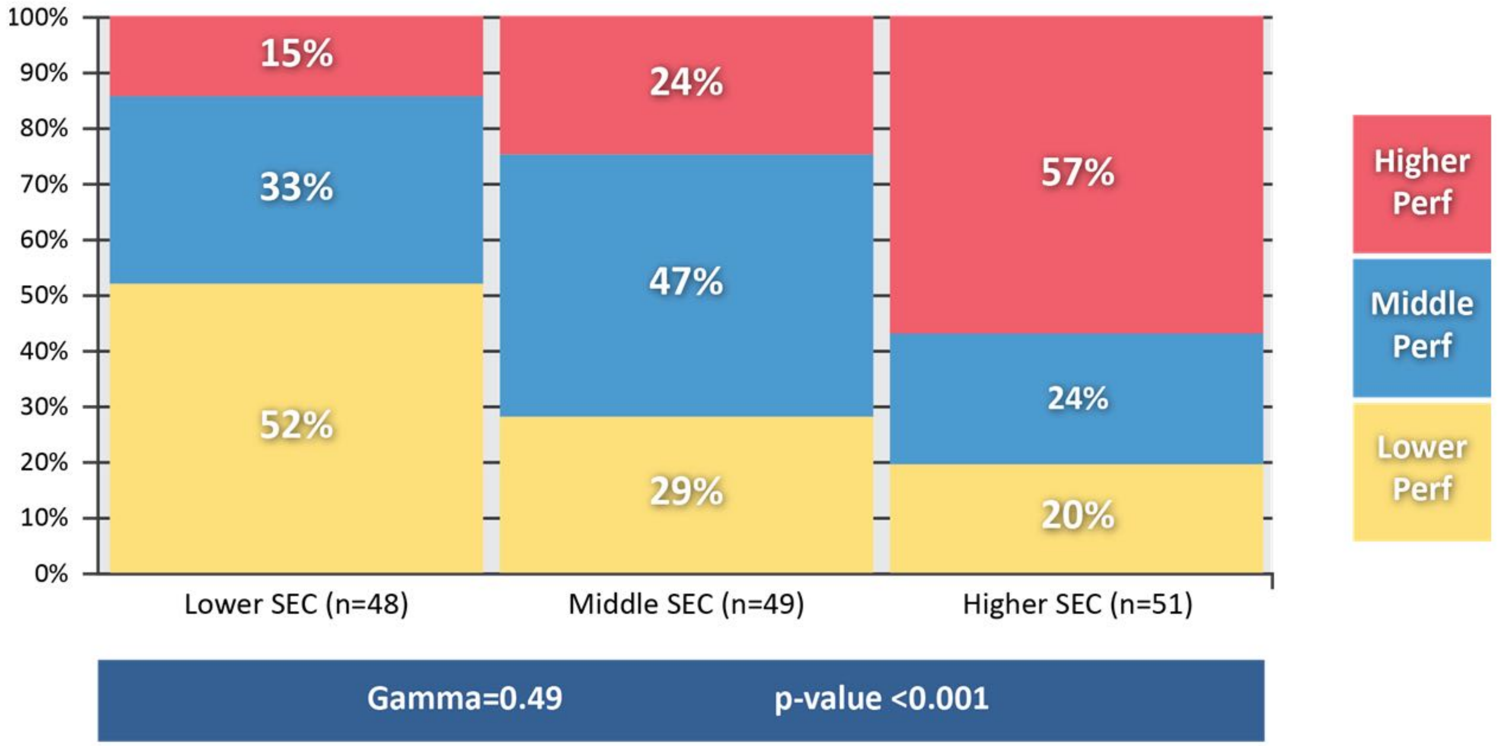
Further Evidence for Early-phase SE Expenditure (1)

- Honour's (2013) SE RoI research, *n* = 43
- Kinnard (2003) recommends10% - 15% expenditure on complex projects before approval

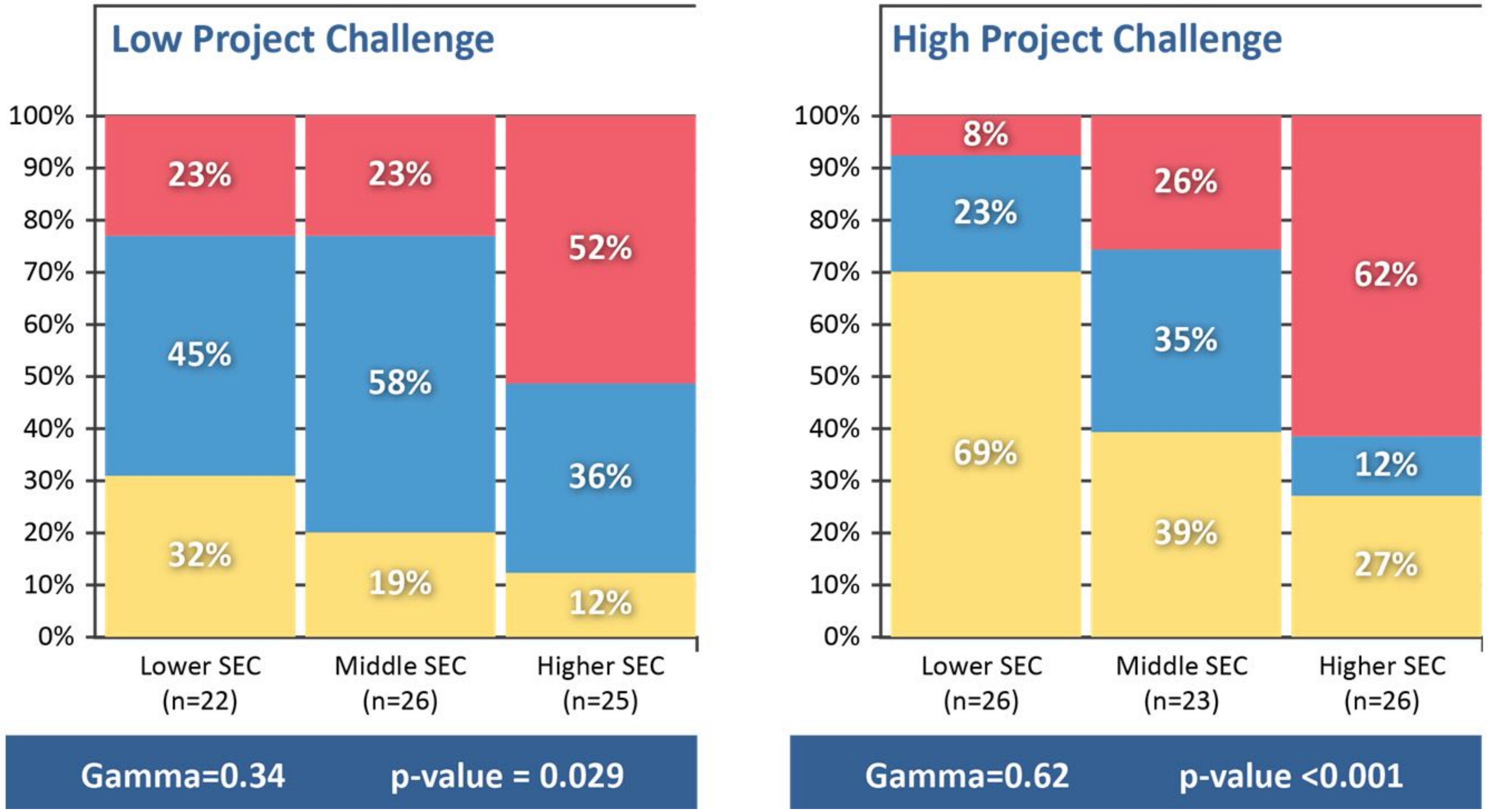


Further Evidence for Early-phase SE Expenditure (2)

- Elm and Goldenson (2012) research, n = 148
- Shows very strong relationship between an organisation's SE Capability and project performance
- Gamma >0.4 = strong correlation
- P-value ~ Probability of this outcome occurring by chance



Further Evidence for Early-phase SE Expenditure (2)
Even stronger evidence when projects are challenging (*n* =148)



"Projects that properly apply systems engineering best practices perform better than projects that do not. (Elm and Goldenson, 2012)"

Distilled Wisdom to Support Investment in Early-phase SE

- DAU Guidebook (2017) citing GAO (2016):

"Our prior best practices work has indicated that if detailed systems engineering is done before the start of product development, the program can resolve … risks through trade-offs and additional investments …"

- GAO (2012):

"Positive acquisition outcomes require the use of a knowledge-based approach to product development that demonstrates high levels of knowledge before significant commitments are made. In essence, knowledge supplants risk over time."

- GAO (2015) analyzed 78 projects to form the view that cost, schedule and performance issues in projects stem … from not enough SE before acquisition to properly understand the capability needs and translate these into detailed technical requirements.

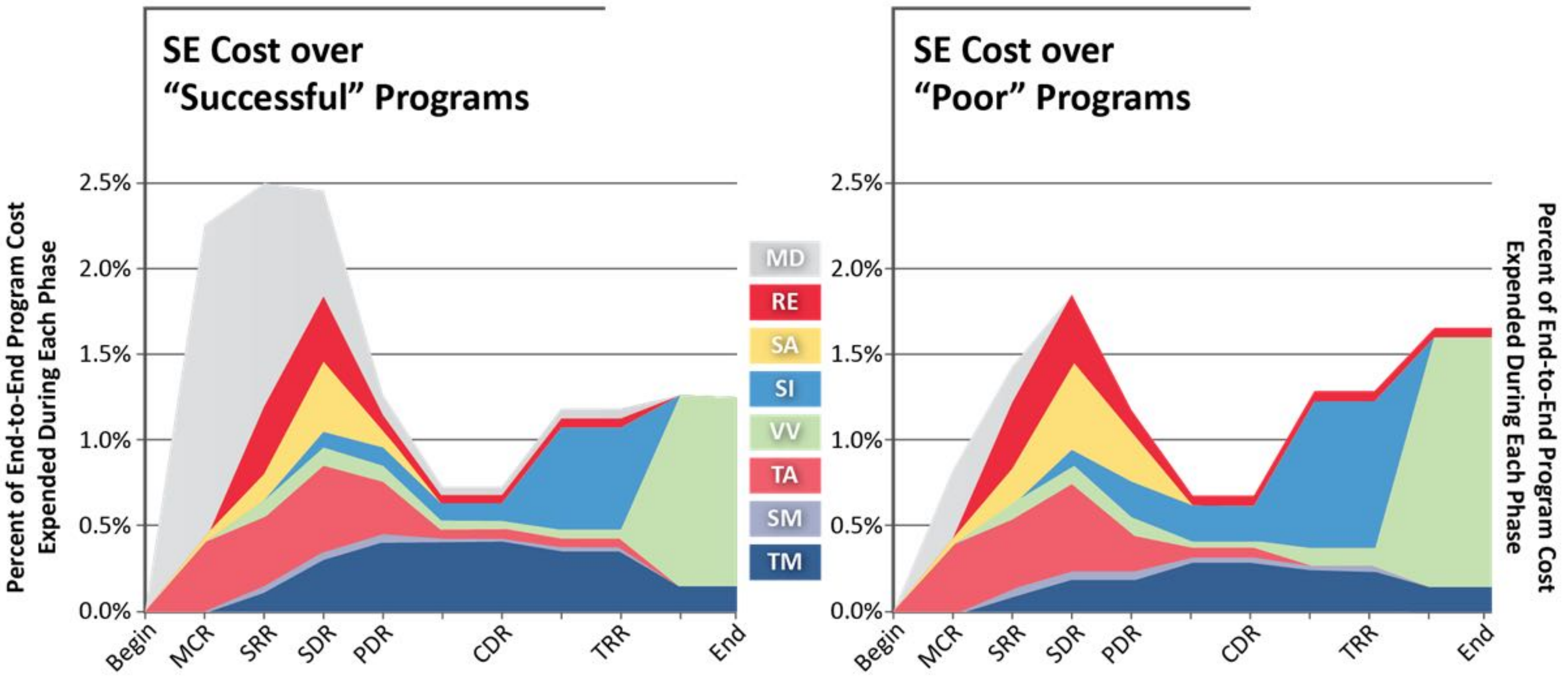
Evidence to Support the Allocation of SE Effort (1)

- Elm and Goldenson (2012) identifies elements most strongly correlated with project success.
- Those in green feature in early-phase SE

Driver	Correlation
Total deployed SE	+0.49 → Very strong positive
Project planning	+0.46 → Very strong positive
Requirements development and management	+0.44 → Very strong positive
Verification	+0.43 → Very strong positive
Product architecture	+0.41 → Very strong positive
Configuration management	+0.38 → Strong positive
Trade studies	+0.38 → Strong positive
Project monitoring and control	+0.38 → Strong positive
Product integration	+0.33 → Strong positive
Validation	+0.33 → Strong positive
Risk management	+0.21 → Moderate positive
Integrated product team realization	+0.18 → Weak positive

Evidence to Support the Allocation of SE Effort (2)

- Honour (2010) compares spending profiles of a set of successful program versus poor programs (n = 53)



Mission Concept Review - **MCR**
System Requirements Review - **SRR**
System Design Review - **SDR**
Preliminary Design Review - **PDR**
Critical Design Review - **CDR**
Test Readiness Review - **TRR**

Successful (~on cost)

- More mission/purpose definition
- More technical leadership/management
- More Systems Engineering

Poor (Overran cost)

- More systems integration
- More verification and validation
- Less Systems Engineering

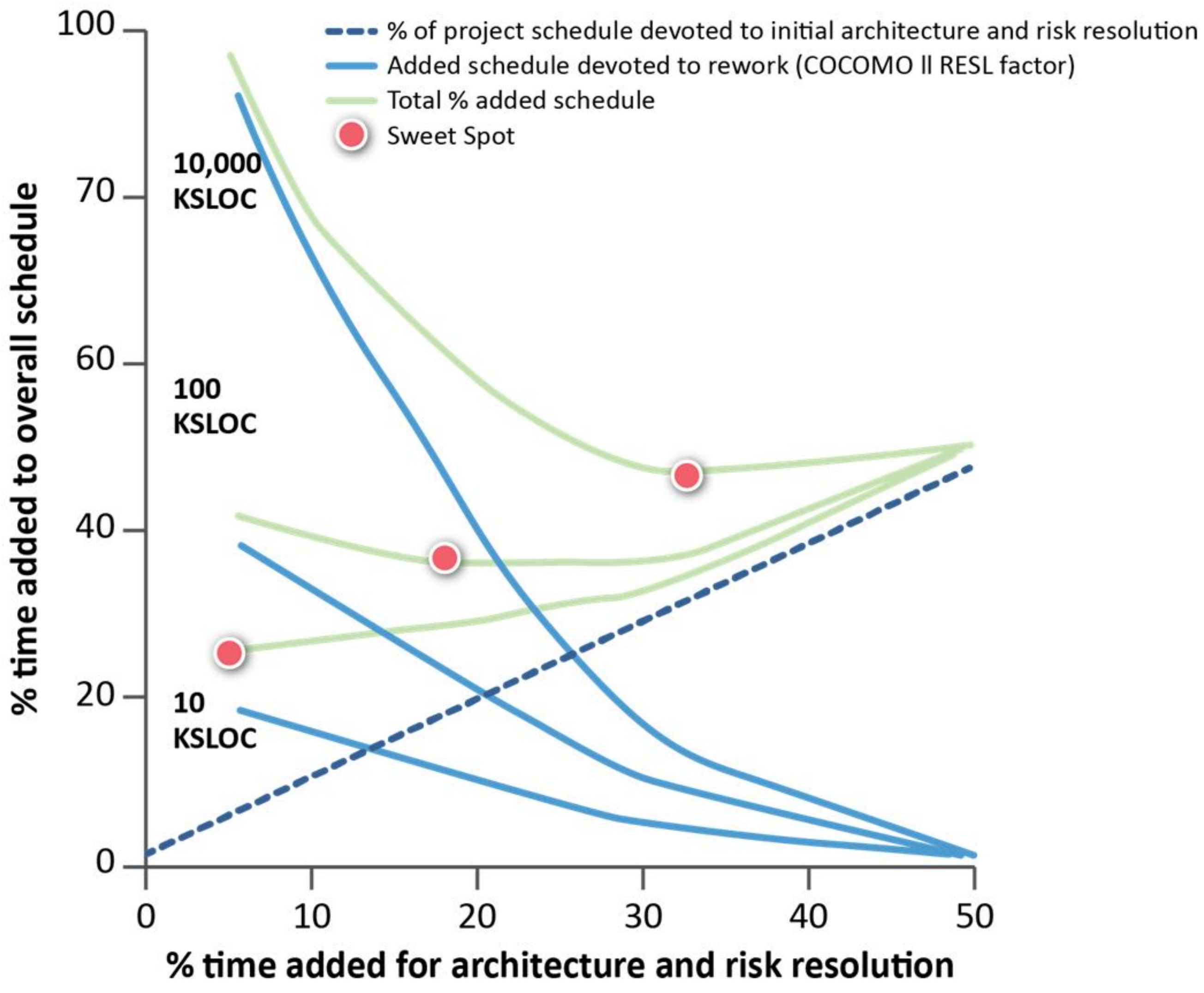
Evidence to Support the Allocation of SE Effort (3)

- Honour (2013) indicated optimal investment in SE activities
- Early-phase activities are shown in green
- Notice that total recommended investment on SE aligns well with historical guidance

SE activity	Investment
Optimal total SE investment	**14.4%**
Mission / Purpose Definition (MD)	1.3%
Requirements Engineering (RE)	2.0%
System Architecting (SA)	3.9%
System Integration (SI)	2.8%
Verification and Validation (VV)	2.4%
Technical Analysis (TA)	1.8%
Scope Management (SM)	1.4%
Technical Management / Leadership (TM)	3.9%

Evidence to Support the Allocation of SE Effort (4)

- Boehm et al (2008) show that the allocation of SE to architecture and risk reduction should be a function of software size
- Bigger, more complex programs require considerably more time and effort in early-phase SE



Additional SE Success Factors Identified in the Literature

1. Use of MBSE is highly correlated with good project outcomes
2. SoSE-type thinking is becoming mainstream
3. A solid systems architecture is vital for project success
4. Systems practice should always be evidence-based: this comes from systems analysis
5. Use systems design to retire risk

Success Factors Derived from Shoal Group Design Practice

- Early, ongoing and effective stakeholder communications is needed to make the SE process and the design itself accessible
- Early-stage SE must support iteration and change as stakeholder views and expectations develop and change … which they inevitably will
- Project objectives and associated measures (MOE, MOP, etc.) need to be identified as early as possible to ensure that outcomes meet stakeholder expectations
- End-to-end traceability of project objectives and associated measures through the design is important in maintaining stakeholder confidence in 'fitness for purpose' and that unnecessary requirements ('gold plating') are being avoided
- Flexibility of SE application (tailoring) is needed to suit project and stakeholder circumstances, particularly in environments where SE practice is unfamiliar
- Integration of SE activities with broader project work is vital to ensure alignment of the design with broader project objectives, which are often quite political in larger, more prominent projects
- Adequate domain expertise is needed almost from the start to ensure practicality of system architecture but must be balanced to avoid 'jumping to solution'

Contemporary SE Success Factors

SE Success Factors
1. Adhere to systems engineering principles and practices; this will save money.
2. Tailor SE processes and frameworks to suit project and stakeholder circumstances, particularly in environments where SE practice is unfamiliar.
3. Prioritize user and other stakeholder engagement throughout the life of a project, commencing as early as reasonably possible.
4. Take a whole-of-life perspective to SE practice.
5. Generously invest in SE in the early design phases.
6. Ensure key SE activities receive priority attention: 6.1. Focus on stakeholder project goals, user needs, project requirements and associated measures. These need to be clear, traceable, and testable and be managed to deal with inevitable evolution and change. 6.2. Value the quality of the system architecture; it is the key to technical success. Invest more in architectural design as projects increase in size, ensuring adequate domain expertise is applied. 6.3. Employ model-based systems engineering because it promotes good SE practice and improves project outcomes. 6.4. Underpin important project decisions with solid systems engineering analysis which includes performance analysis, trade-studies, effectiveness analysis, and related analytical activities. 6.5. Focus and allocate SE effort to achieve early risk retirement through SE activities such as architectural design, systems analysis, technology risk mitigation, integration planning, and system assurance. 6.6. Prioritize interface definition and management; it is vital for project success. 6.7. Plan system assurance (design assurance, verification and validation, and test and evaluation) in the conceptual design phase.
7. Select suppliers with demonstrated capability honed on projects of a similar scale and complexity.

What’s stayed constant?

Comparison of old to new

Consistency of Findings over Time

Success Factor	Supported by Recent Research
1. Adhere to SE (SwE) principles and practices.	✓✓✓
2. Invest in SE in the early design phases (5-15%)	✓✓✓
3. Prioritise user and other stakeholder engagement. Employ soft systems approaches to encourage user involvement.	✓✓✓
4. Focus on stakeholder project goals, user needs and requirements - Employ soft systems approaches to facilitate user involvement	✓✓✓
5. Take a whole-of-life approach to SE practice	✓✓✓
6. Select suppliers with demonstrated capability honed on similar projects	✓✓✓
7. Pay attention to interface definition and management	✓✓✓
8. Plan system assurance (design assurance, V&V, T&E) in the conceptual design phase	✓✓✓

Conclusions

- SE success factors from 20 years ago are equally valid today; some new ones added
- Solid evidence exists that investment in SE, in particular in the early phases, is highly-correlated with good project outcomes
- Solid evidence exists that SE provides a demonstrable return on investment
- Quantitative evidence exists on where to apply scarce SE resources
- Increasing awareness that SE should be involved with identifying, categorising and addressing systems issues well before the system specification is produced
  - Fellows definition of SE supports this
  - Essential in SoSE engineering, market-driven developments, evolutionary developments
- Success in tackling broader systems challenges requires multimethodologies that integrate soft systems approaches into the conventional SE and PM framework

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