Quantification of the Value of Systems Engineering

Paul Davies,
Systems Design Engineer, Network Rail
Formerly Head of SE Research, Thales UK
INCOSE UK ASEC November 2013

Acknowledgements

- This publication incorporates portions of the Special Report, “The Business Case for Systems Engineering Study: Results of the Systems Engineering Effectiveness Survey,” CMU/SEI-2012-SR-009, (c) 2012 Carnegie Mellon University, with special permission from its Software Engineering Institute.

Why this presentation is important

Sarah Sheard and Chris Miller, “The Shangri-La of ROI” 2000:

> “This paper shows that:
> 1) There are no “hard numbers”;
> 2) There will be no hard numbers in the foreseeable future;
> 3) If there were hard numbers, there wouldn’t be a way to apply them to your situation; and
> 4) if you did use such numbers,
> no one would believe you anyway.”

However, time moves on:

Philip M’Pherson SE Value Programme

NDIA studies 2008 and 2012

The work of Eric Honour

Presentation Outline

Models of Value creation:

Decomposing what we mean by SE, for value purposes, and (relative) quantification of the effect of SE practice

- Project profiles, and cost of rework (Brooks; Putnam; Haskins)
- The NDIA studies (Joe Elm et al)
- Collateral studies (Eric Honour)

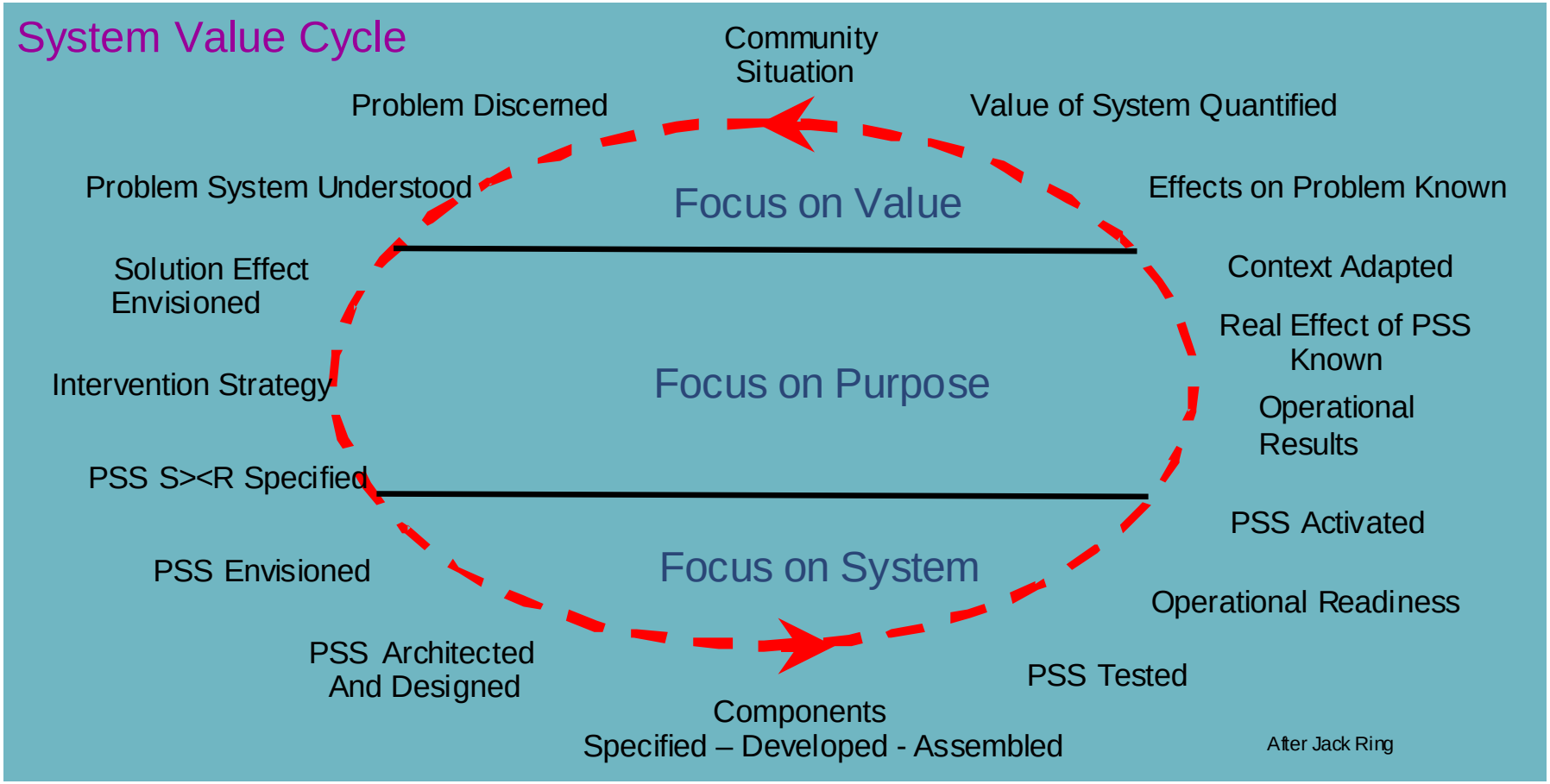
Back-of-the-Envelope Return on Investment Calculations

Typical Organisation Evolution

Measurements of competence

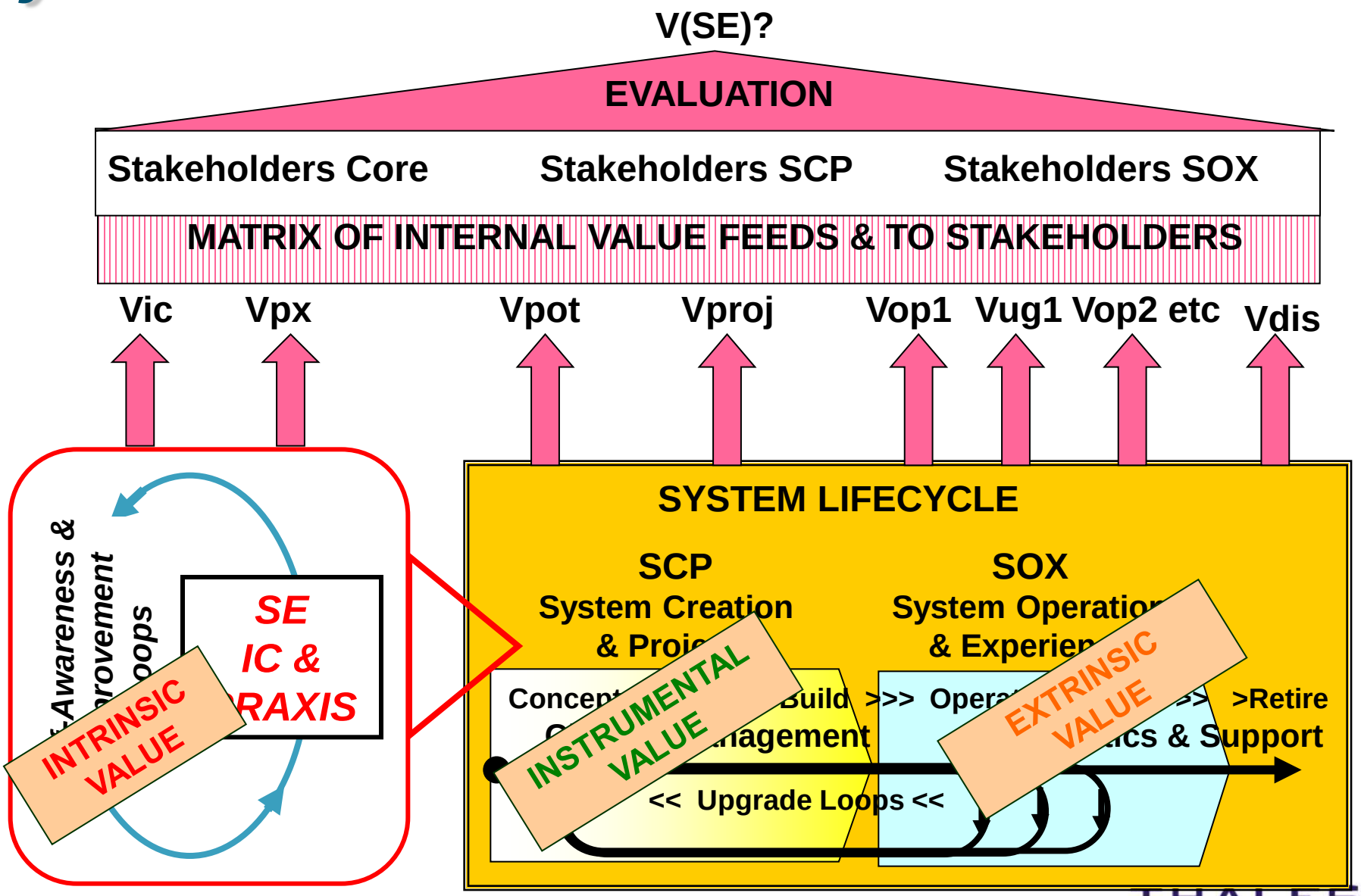
Conclusions

The value lifecycle (Jack Ring 2001)



PSS = Problem (proposed) System Solution

System Value Generation



THALES

The beginnings of quantification

Some things we know

INCOSEUK

How much will the project cost? #1

From a NASA study by Werner Gruhl in 1985 (!), reproduced in an early issue of INCOSE Insight

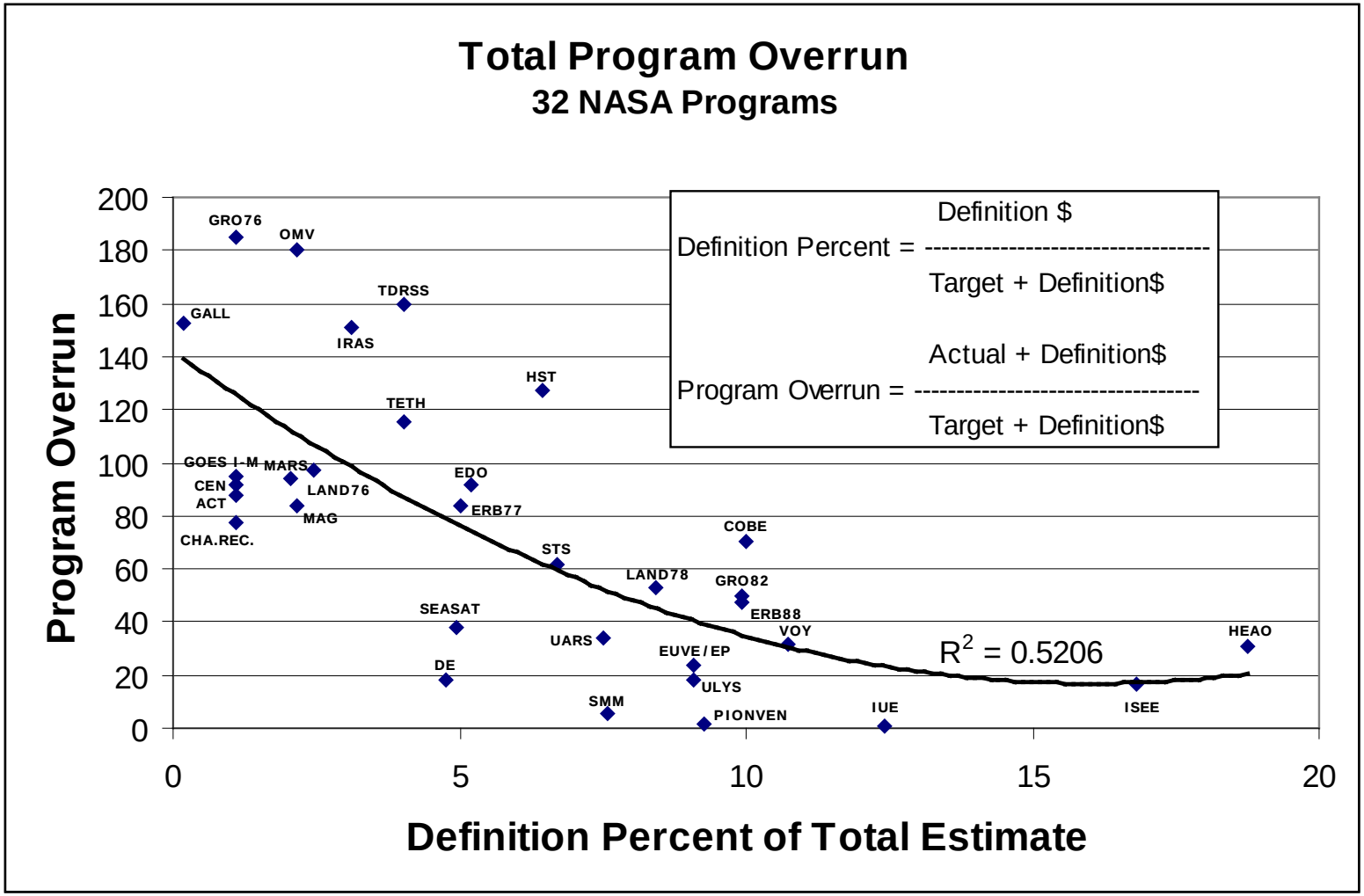
•There's a regression curve through plotted points of project overspend versus spend on *integrated* PM + engineering definition before contract / single option selection – decays from 200% overspend at 1% pre-contract SE, via 60% overspend at 8%SE, to 40% overspend at >15% pre-contract SE

• So you should be spending ~8% of your total dev budget on *integrated* engineering + PM definition before contract / single option selection; above this, we reach the law of diminishing returns

• Note that everybody overspends, but you can reduce the amount of overspend by investment up front.

• NB the 8% doesn't include IVVT – Eric Honour's work recommends 14% overall SE spend

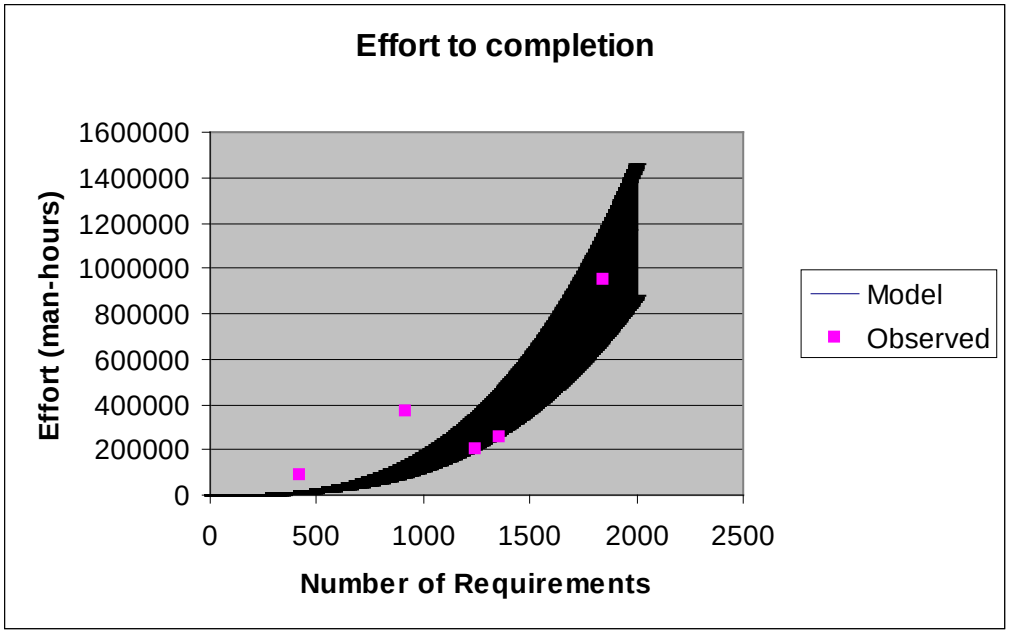
NASA Tracking 1980s



Source Werner Gruhl
NASA Comptroller's Office

How much will the project cost? #2

- Uninformed accountants think that cost goes up linearly with scale (eg number of requirements of a given granularity).
- Most engineers, if they think about it, would say it goes up with the square (consider interfaces)
- Fred Brooks has published the results of large cross industry (software) projects study showing it goes up with the cube



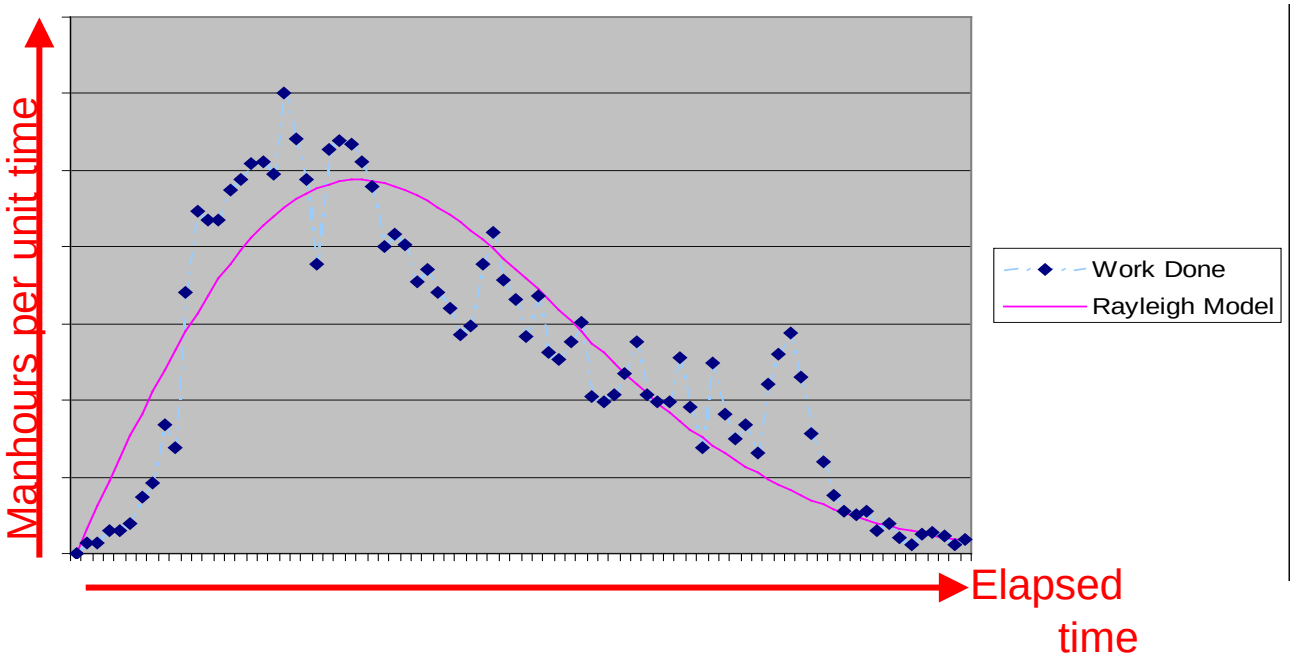
This is a range of real projects data-mined, showing good correlation except one problem project

The size of the uncertainty (error bars) also goes up with the cube (or at least square). Consider the effect of this on contract pricing…

How much will the project cost? #3

Larry Putnam and Ware Myers published an excellent treatment of the characteristic “shape” of project spend versus time, for sufficiently multi-discipline or multi-interface projects. It follows a Rayleigh curve, which can be parameterised for project “size”, complexity and team skill level, plus risk. It always works – a real project shown here, with “spikes” at major review points plus acceptance testing.

Their work also shows that you can’t finish the job quicker by adding more resources, beyond a certain point



How much will the project cost? #4

- From a paper published through INCOSE (Bill Haskins et al) on the cost of fixing errors versus phase at which you discover them
- If it costs you $1 to fix if you discover it at requirements stage, it'll cost $250 if you discover it in operation. A key role of SE is to prevent the latter from happening, and on this rests the ROI of SE.

Cost of Fixing Errors in Your Project

Phase at which Error is detected and fixed	Cost to Fix
Requirements	X1 (reference)
Design	X5
Build	X12
Test	X40
Operations	X250

The cost of projects with / without good SE: Why we can't normalise the results

- Nobody will fund a randomised control trial for a £1 Bn job
- How much new content is there in this programme?
- How good is the team doing the project?
  - How many partners / subcontracts are there? How well are they aligned?
  - What is the individual competence level?
  - *What is the organisational competence level?*
- What is the Acquirer-Supplier relationship like?
  - Are the requirements likely to change?
  - What governs acceptance?
    - Trust? [Or Certificate of Conformance]
    - Detailed testing?
    - Formal (e.g. safety) certification and traceability?
    - General fitness for purpose?
    - Whatever fits in the timescale?
- Politics...

The "NDIA Survey" of Systems Engineering Effectiveness – by SEI (Carnegie Mellon)

- **Very Strong** correlation of high business performance with high organisational systems engineering capability
- **Even stronger** correlation for high challenge projects
- **Very Strong** correlation of project performance with individual SE practices:
  - Program (Systems Engineering) Planning
  - Requirements Development and Management
  - Verification
  - Product Architecture

Note – the study looked at value of projects at the point of delivery. Value to in-service operation may be even higher.

Pros and cons of spending on SE

Does this sound familiar?

The SE efforts on my program are critical because they …

… pay off in the end.

… ensure that stakeholder requirements are identified and addressed.

… provide a way to manage program risks.

… establish the foundation for all other aspects of the design.

… optimize the design through evaluation of alternate solutions.

We need to minimize the SE efforts on this program because …

… including SE costs in our bid will make it non-competitive.

… we don't have time for '*paralysis by analysis*'. We need to get the design started.

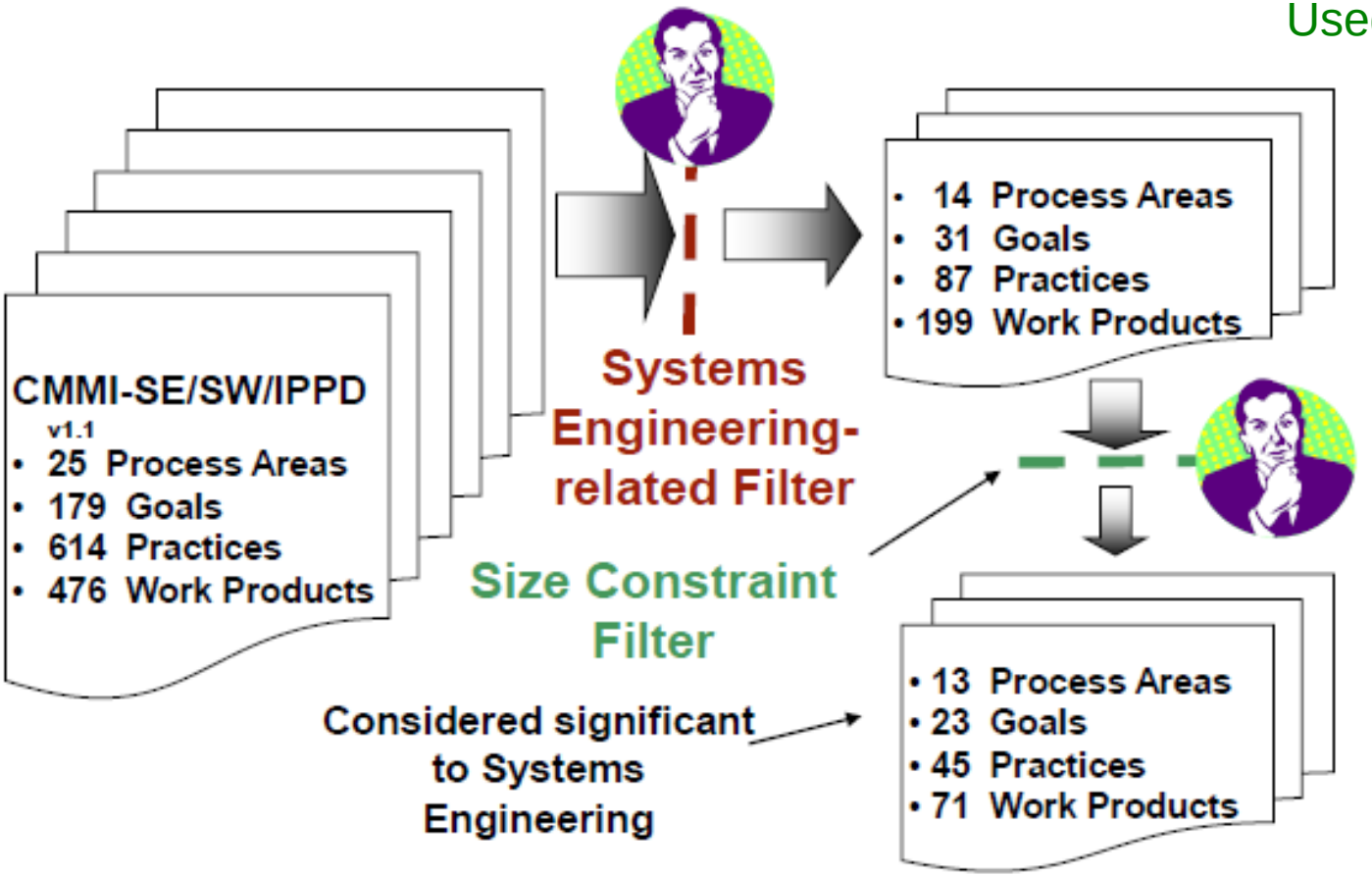
… we don't have the budget or the people to support these efforts.

… SE doesn't produce deliverable outputs.

… our customer won't pay for them.

Artefact-based assessment of SE Practices

How SE was scored –
Processes and work products?
Used effectively?



Assessment of Program Performance

Assess TOTAL Program Performance

- Program Cost, Program Schedule, Technical Performance
- Focus on commonly used measurements

– EVMS, baseline management
– requirements satisfaction
– budget re-baselining and growth
– milestone and delivery satisfaction

Assessment of Other Factors

- **Program Challenge** – some programs are more complex than others
- **Prior Experience** – some teams are more capable than others

Survey scoring method

Anonymous responses to survey questions, facilitated interviews

Scored program performance 1-4

Scored SE effectiveness 1-4
(by area ----→)

All scores *ranked*
- so absolute scores can then be ignored

Then *correlated*
- eliminates bias

Then divided into thirds

Survey questions addressed 11 areas of SE Activities

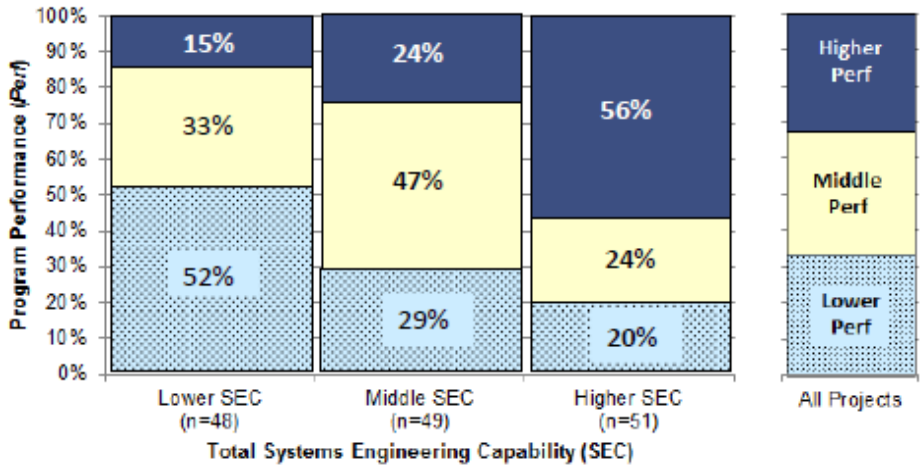
- Program Planning
- Requirements Development and Management
- Product Architecture
- Trade Studies
- Product Integration
- Verification
- Validation
- Risk Management
- Configuration Management
- Integrated Product Teams
- Program Monitoring and Control

The key slide in its entirety

The Bottom Line

INCOSE International Symposium
Philadelphia, PA
June 24-27, 2013

Program Performance vs. Total SE



Gamma = 0.49 p-value < 0.001

Across ALL programs, 1/3 are at each performance level

For Lower SEC programs, only 15% deliver higher performance

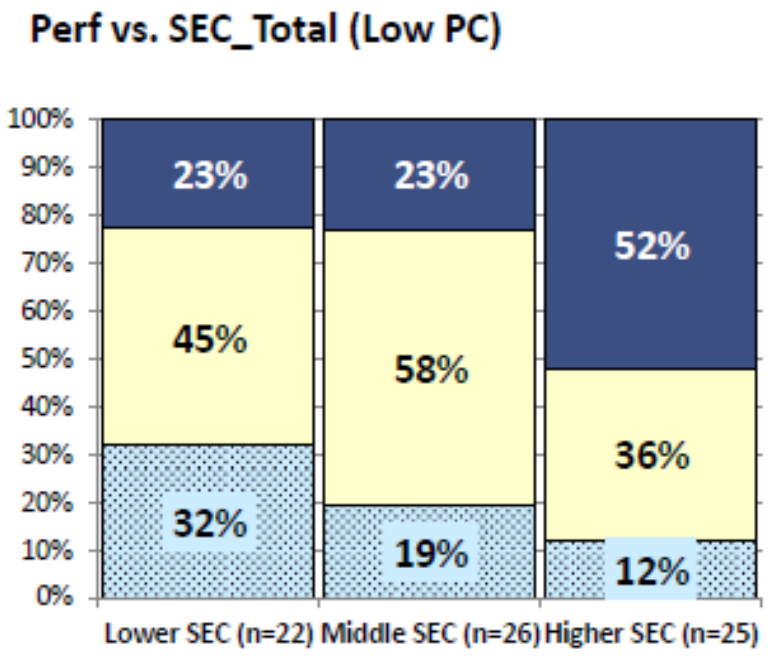
For Middle SEC programs, 24% deliver higher performance

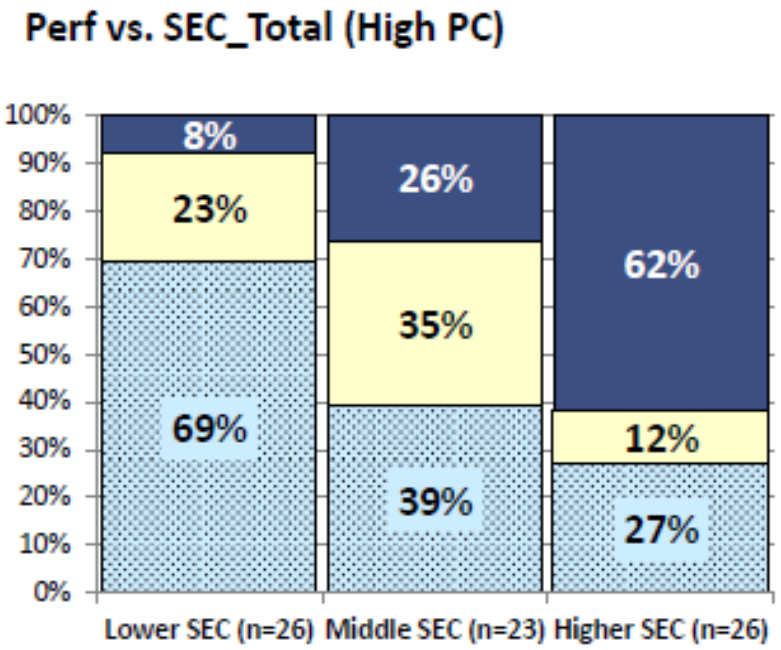
For Higher SEC programs, 57% deliver higher performance

Gamma = 0.49 represents a VERY STRONG relationship

Putting the Systems A team on the job more than trebles your chance of project success compared to the C team

The Effect of Program Challenge

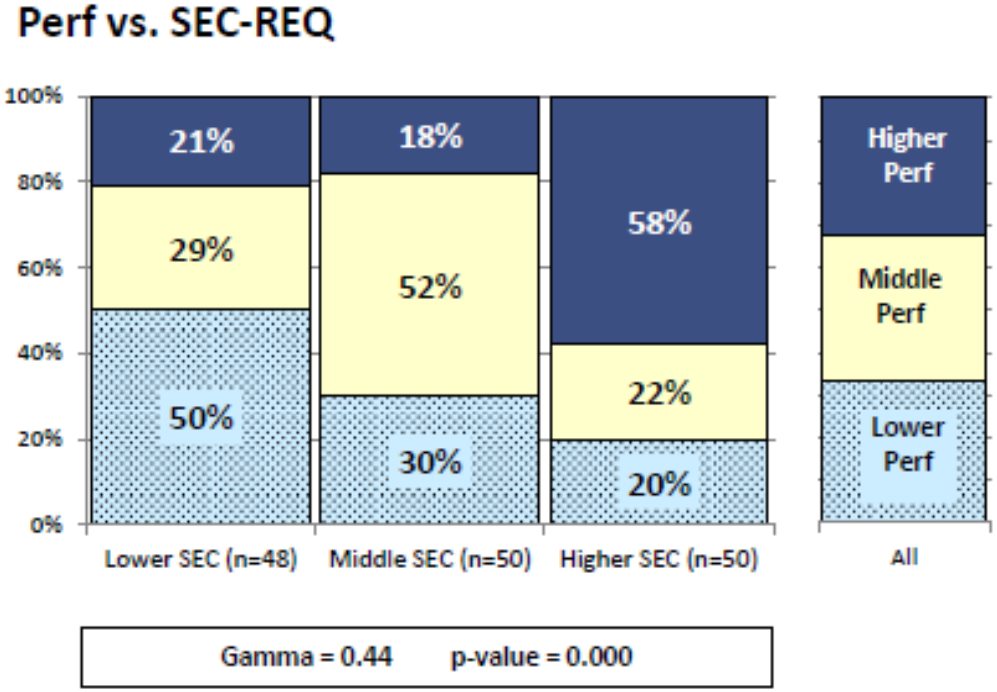


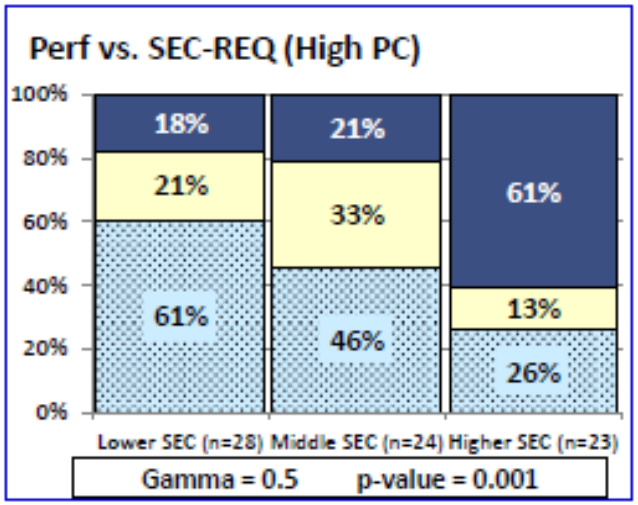


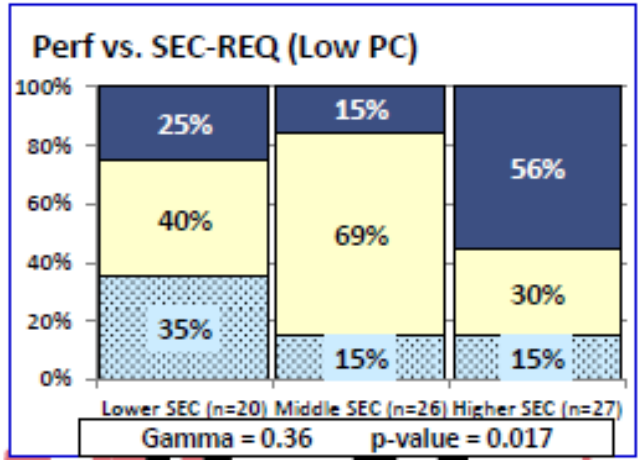
Improving the Systems C team to B team standard on a job with a low degree of difficulty doesn't give you that much. However, the A team doubles your chance of success.

If you put the Systems C team on a job with a high degree of difficulty, you stand a 92% chance of not getting a good outcome

3 x 3's for each SE practice, eg Requirements



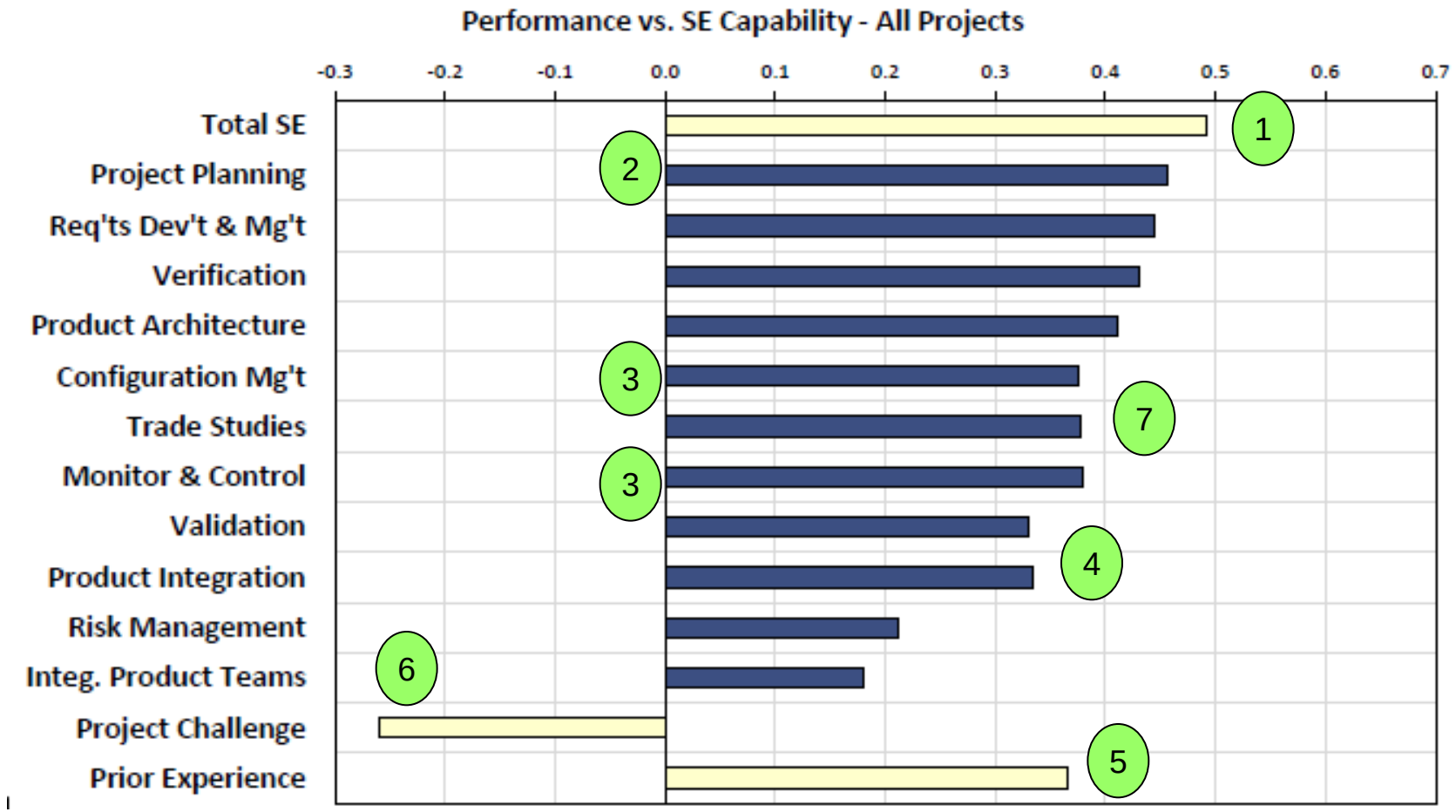




The relationship:

for the set of all programs	0.44 = Very Strong
for the set of High Challenge programs	0.50 = Very Strong
for the set of Low Challenge programs	0.36 = Strong

Summary of correlations



Notes to previous slide

1 Correlation is stronger now than in the 2008 study. The whole (ie all SE practices together) is greater than the sum of the parts.

2 Correlation was much weaker in 2008. Joe claims better sampling; I suspect bias (anonymised data, PM respondents included in 2012)

3 Likewise in 2008 PM&C correlation was –ve! And CM was much lower

4 Relatively low; hold this thought, see later in the presentation

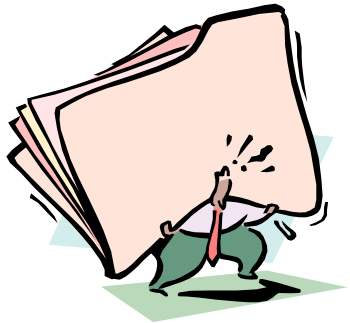
5 Higher for low-challenge projects, lower for high-challenge projects

6 The harder the challenge, the worse the expected business performance.

7 Trade studies and architecture came out top in 2008 study (when only SEs responded?) hold this thought for later.

Basic Industrial Economics

- How much will it cost to implement “appropriate” systems engineering?
  - Including recruitment / training / skills maintenance



- How much is it *likely* to cost if it is not done?
- What is the *marginal benefit?*
- Is it worth it?
- Should we just invest in the competences with the highest potential payoff?

Calculating the Return on Investment

Assumptions

- The distribution of our SE capability (high, medium, low) is similar to the NDIA study
- We can use representative Gross Margin figures for H/M/L thirds of our projects
- Need to estimate the %age of development effort spent on SE
- Need to estimate the %age of project cost spent on development effort
- Ignore corporate overheads as fully amortised over all project costs and rates
- Improving your SE capability will lead to a concordant improvement in performance

… bearing in mind that

- The median size of project in the NDIA study was $488M
- Your A team might be only as good as the NDIA study average C team,
- or vice versa

Two examples

Company Alpha

	%
Top third Gross Margin	25
Middle third Gross Margin	15
Bottom third Gross Margin	10
SE as % of Dev effort	12
Dev as % of business cost	10

Company Omega

	%
Top third Gross Margin	15
Middle third Gross Margin	5
Bottom third Gross Margin	-5
SE as % of Dev effort	20
Dev as % of business cost	25

	SE C Team	SE B Team	SE A Team
Overall projects	13.9	16.0	19.6
High challenge projects	12.4	15.7	20.0
Low challenge projects	15.7	16.4	19.6

Gross margin percent

	SE C Team	SE B Team	SE A Team
Overall projects	1.3	4.5	8.6
High challenge projects	-1.1	3.7	8.6
Low challenge projects	4.1	5.4	9.0

Improvement strategies

Strategy A – fire the C Team, and recruit higher-performing replacements at 25% higher salaries

Strategy B – take 10% of your B team out for one year's intensive training (eg Masters degree with in-house project) each year, on a scrolling basis

Effects of the strategies

Company Alpha

	%
Top third Gross Margin	25
Middle third Gross Margin	15
Bottom third Gross Margin	10
SE as % of Dev effort	12
Dev as % of business cost	10

	Cost	Benefit	ROI
Strategy A	0.50	2.05	4.10
Strategy B (2nd year)	0.09	0.37	4.15
Strategy B (5th year)	0.04	1.46	33.18

Company Omega

	%
Top third Gross Margin	15
Middle third Gross Margin	5
Bottom third Gross Margin	-5
SE as % of Dev effort	20
Dev as % of business cost	25

	Cost	Benefit	ROI
Strategy A	2.08	3.20	1.54
Strategy B (2nd year)	0.37	0.41	1.12
Strategy B (5th year)	0.18	1.64	8.95

Honourcode, Inc.

Systems Engineering Return on Investment (SE-ROI)

Dr. Eric Honour
+1 (850) 479-1985
ehonour@hcode.com

All SEROI data has been corrected for the effect of different programs using program characteristic parameters; contact Honourcode at BetterSE@hcode.com to apply these corrections to your data.

University of South Australia | Defence and Systems Institute

Funding provided by
- ***Honourcode, Inc.***
- ***DASI (Univ of South Australia)***

Eric's research question: "How much SE is enough?"

Methodology

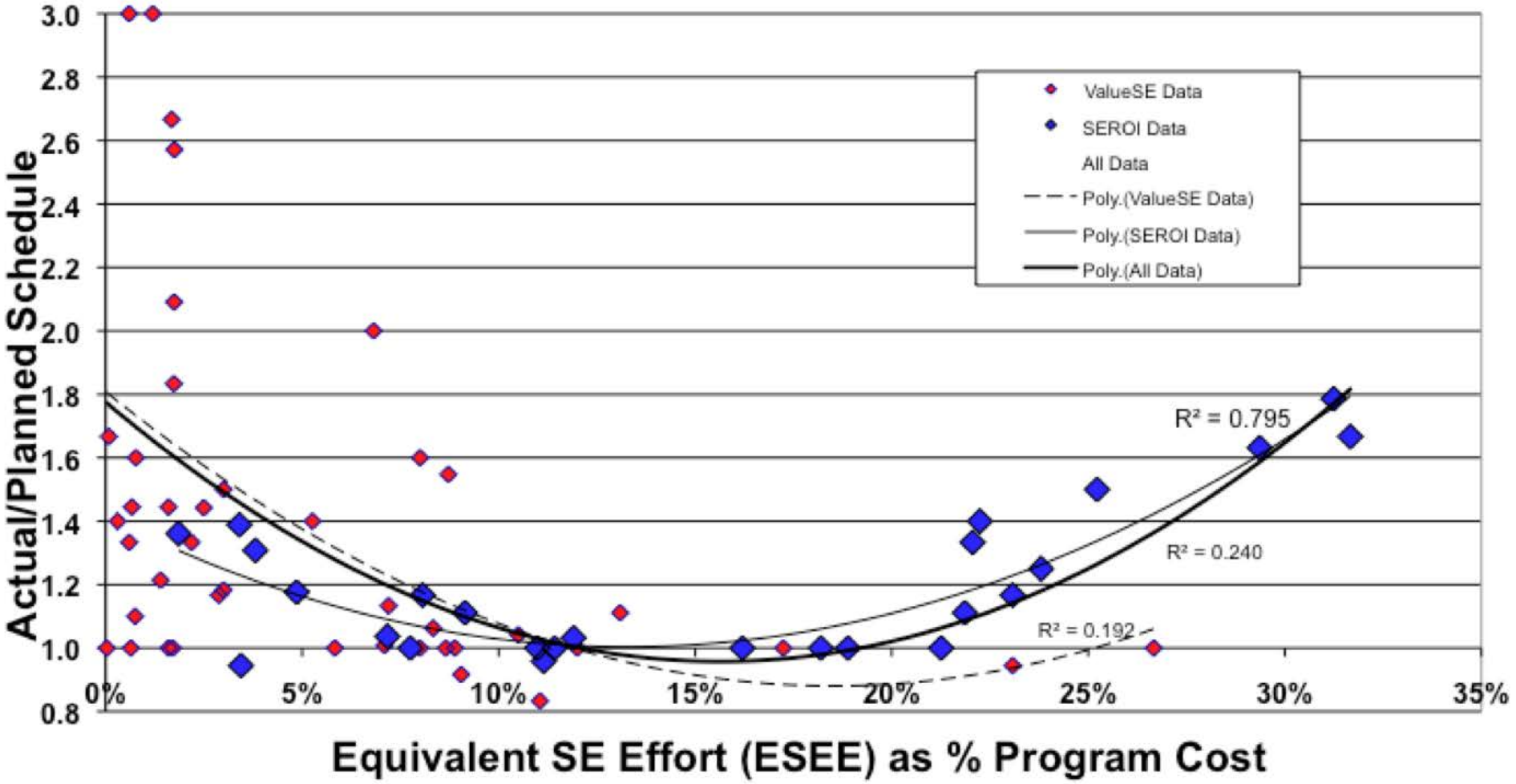
- Different categorisation of SE activities – rigorously mapped to 5 x standards
- 90 projects – not anonymised, but data closely and independently scrutinised
- 50% US DoD, the rest split between non-US Defence, commercial systems development, Space systems
- Curve-fitting for overall SE, plus by activity; attempt to re-normalise for "SE quality", and for project challenge / level of difficulty
- Analysis of variance along / between curves to examine likely effect of more or different split of engineering effort

Major Results

- **Strong quantified relationship between SE and program success *(Correlation r^2 → 80%)***
  - **Optimum SE activity for median programs is 14.4% of program cost**
  - **Median programs use much less than the optimum; ROI to re-allocate additional effort into SE is 3.5:1**
  - **Relationships also exist for eight subordinate SE activities such as Mission/Purpose Definition, Requirements Engineering, System Architecting, etc.**
- **No correlation between SE activities and technical quality**
  - **Over-emphasis on requirements defeats creating better systems, even within the same cost and schedule**
- **Estimation method now available for optimum program SE effort, based on program characteristics**
  - **Characteristics modify the optimum between ~8% and ~19%**
  - **Optimizing level of Technical Leadership/Management simultaneously optimizes cost, schedule, and stakeholder acceptance.**

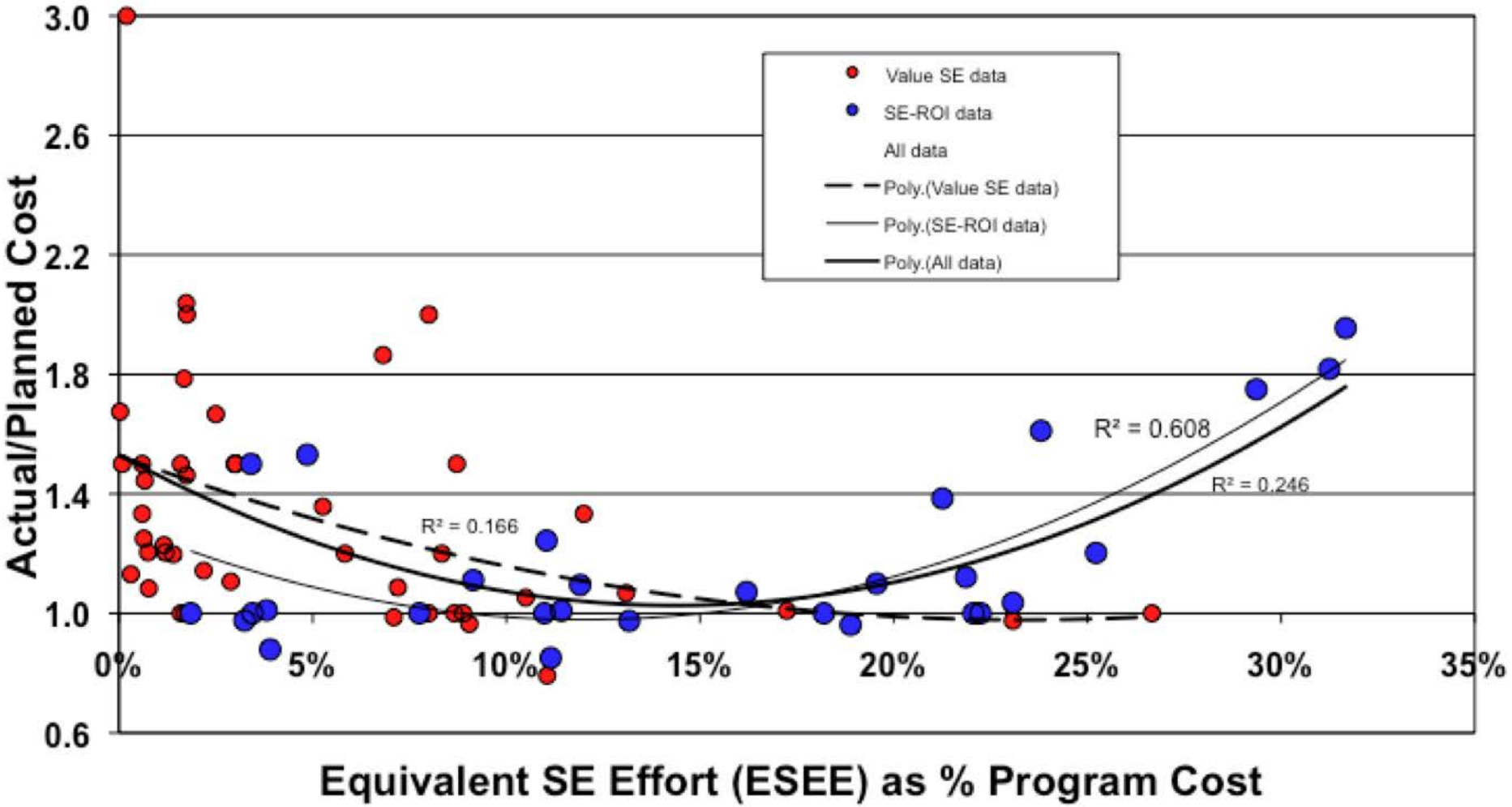
Honour, EC, Systems Engineering Return on Investment, PhD thesis, Univ South Australia 2013

Schedule vs. SE Effort

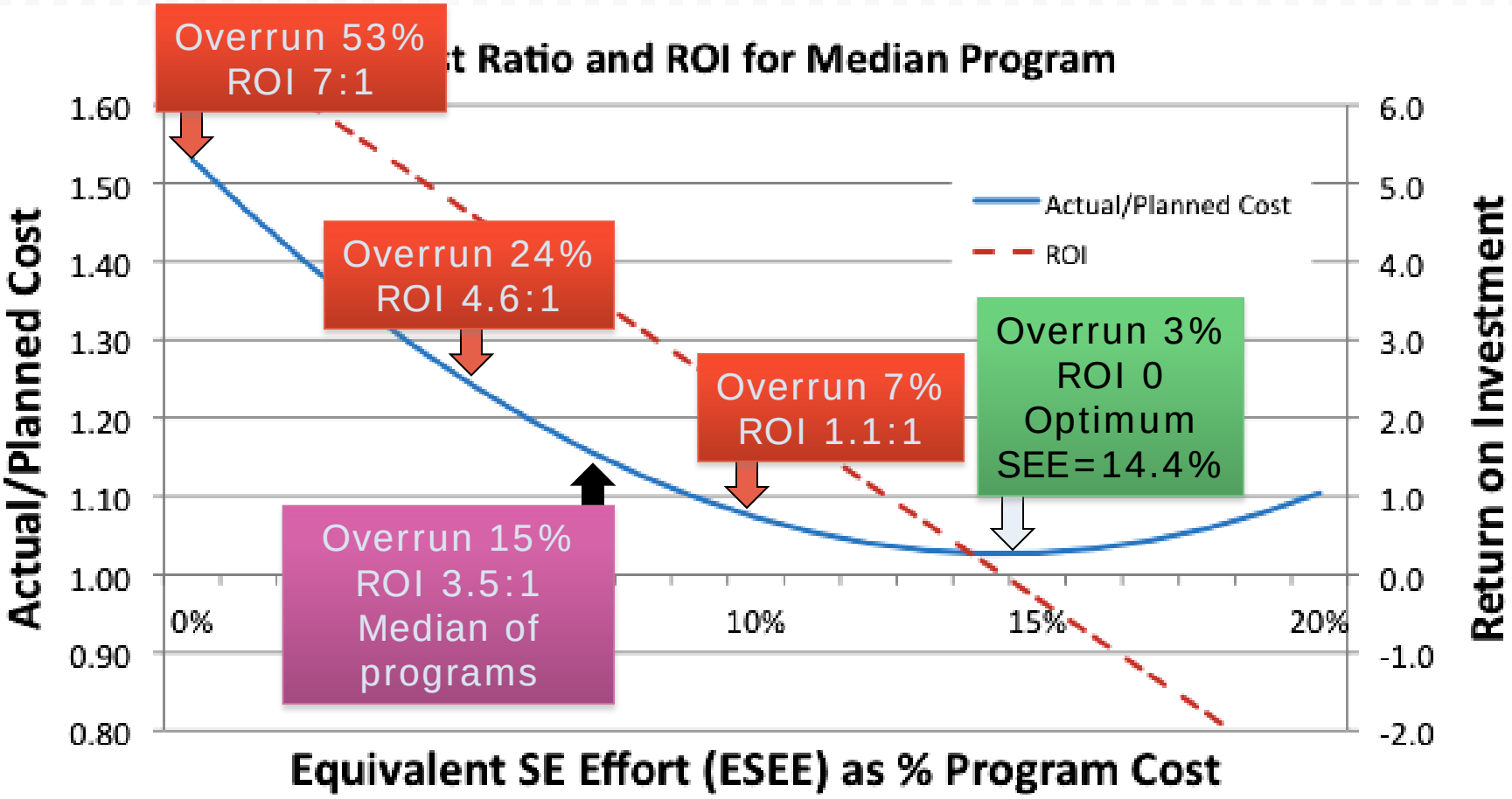


Honour, EC, Systems Engineering Return on Investment, PhD thesis, Univ South Australia 2013

Cost vs. SE Effort



Return on Investment

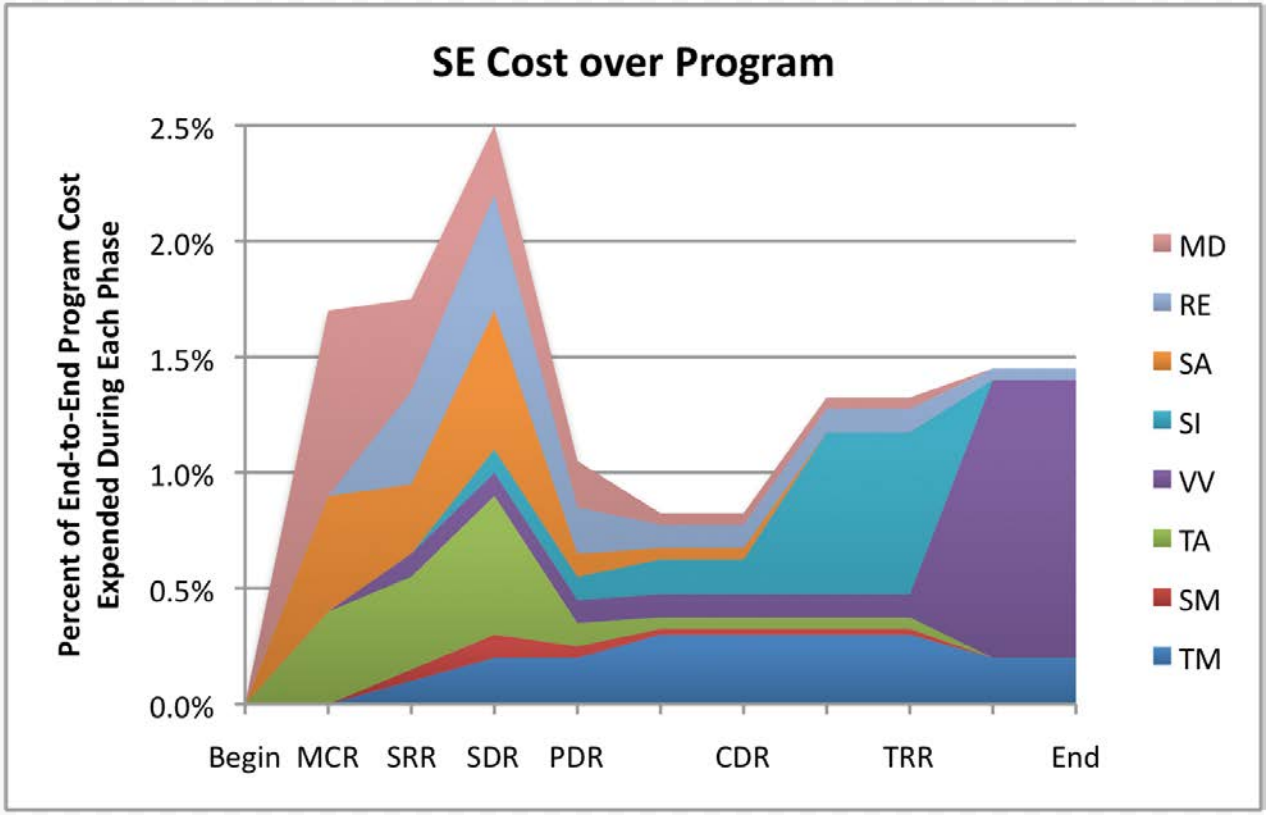


Honour, EC, Systems Engineering Return on Investment, PhD thesis, Univ South Australia 2013

Breakout by SE Activities

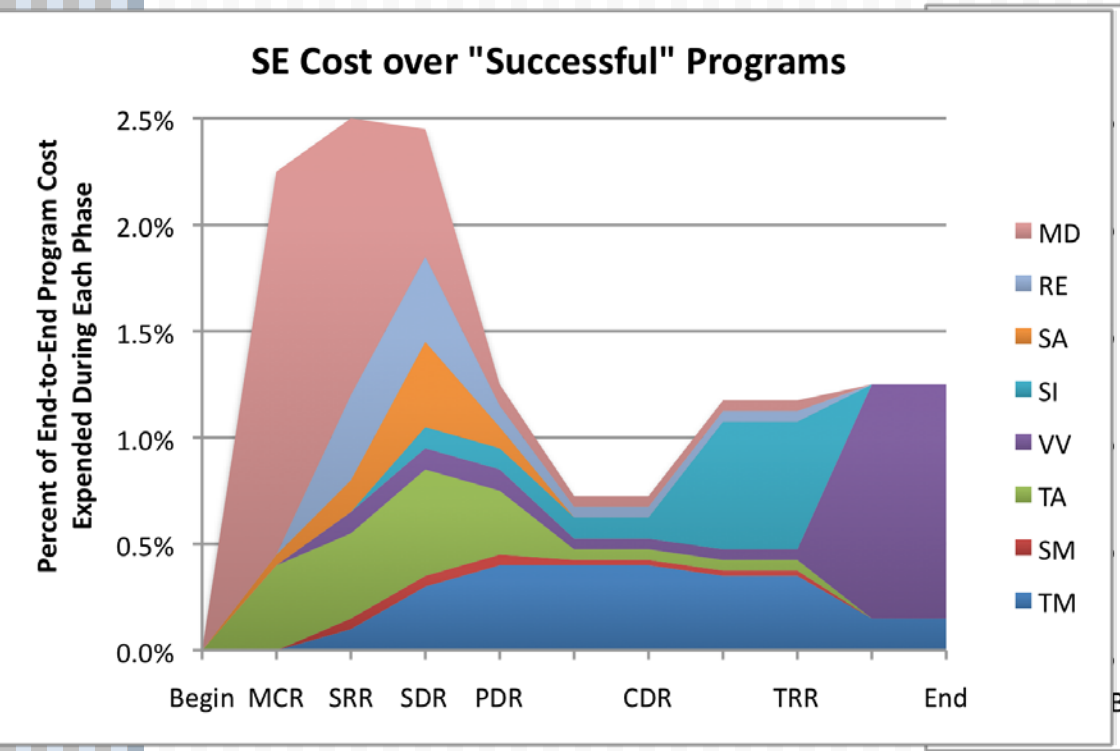
MD Mission/Purpose Definition
RE Requirements Engineering
SA System Architecting
SI System Integration
VV Verification & Validation

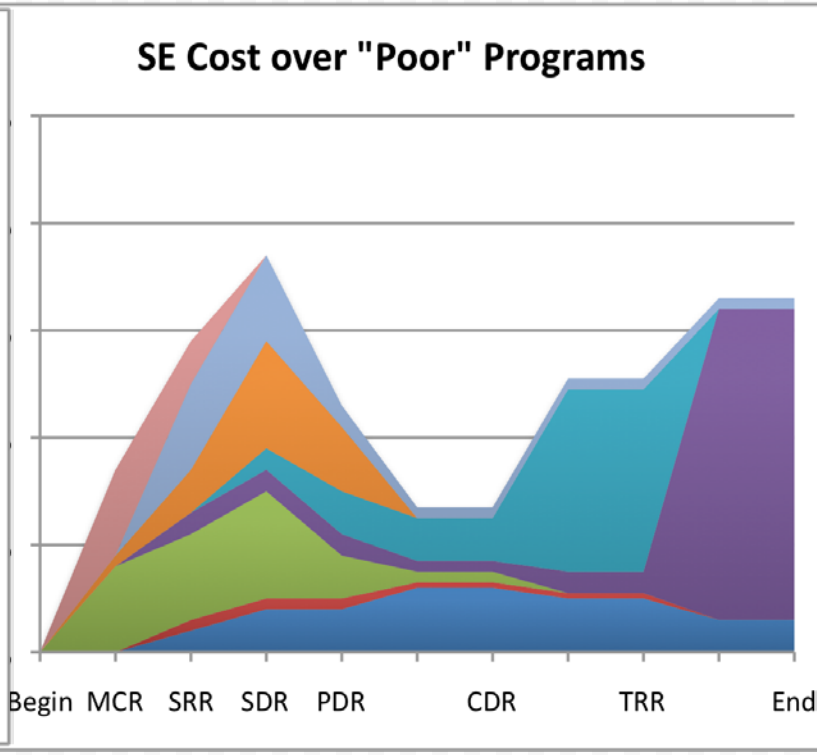
TA Technical Analysis
SM Scope Management
TM Technical Leadership/Management



Honour, EC, Systems Engineering Return on Investment, PhD thesis, Univ South Australia 2013

Breakout by Success





Successful *(~on cost)*
- More mission/purpose defn
- More tech leadership/mgmt
- More Systems Engineering

Poor *(overran cost)*
- More system integration
- More verif & valid
- Less Systems Engineering

Honour, EC, Systems Engineering Return on Investment, PhD thesis, Univ South Australia 2013

Comments on Eric's research

gleaned from interview December 2013, plus email correspondence

Principal Component Analysis reveals that there is still bias in the data – towards the good end of business outcomes. Moderated to some extent by challenging "too-good" data

Again, 2 surveys at different times, good correlation between them. Same median project sizes.

No transportation projects. Survey responses from "Principal Contractor" point of view – doesn't cover contracting (eg Govt) client, or full depth of supply chain, except indirectly

Relative to M'Pherson model – value assessed at point of project delivery, so VOX still under-researched

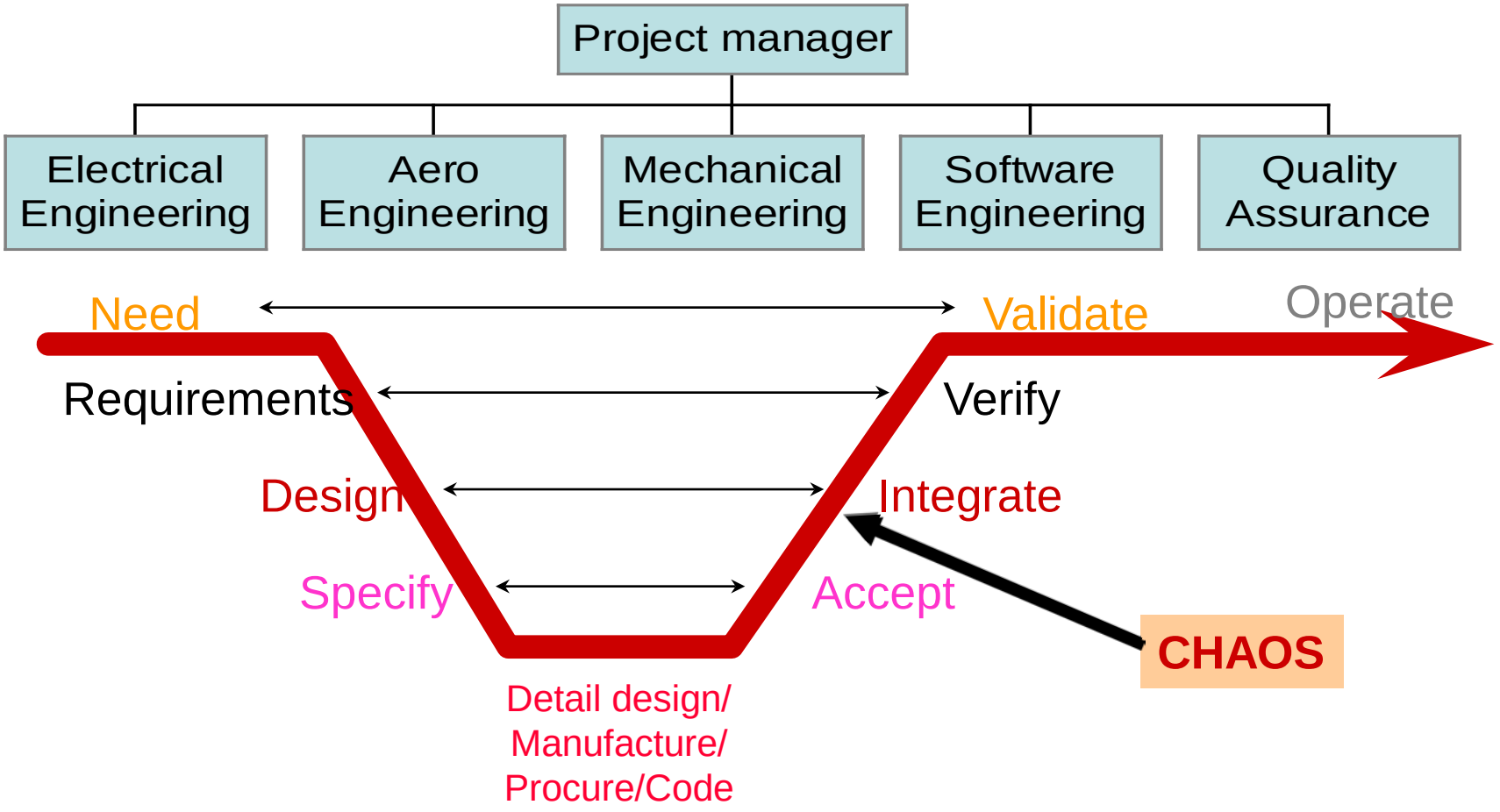
Comments on what is going on beyond inflection points: "paralysis by analysis"; over-focus on requirements may lead to inferior solutions

Correlation between the studies

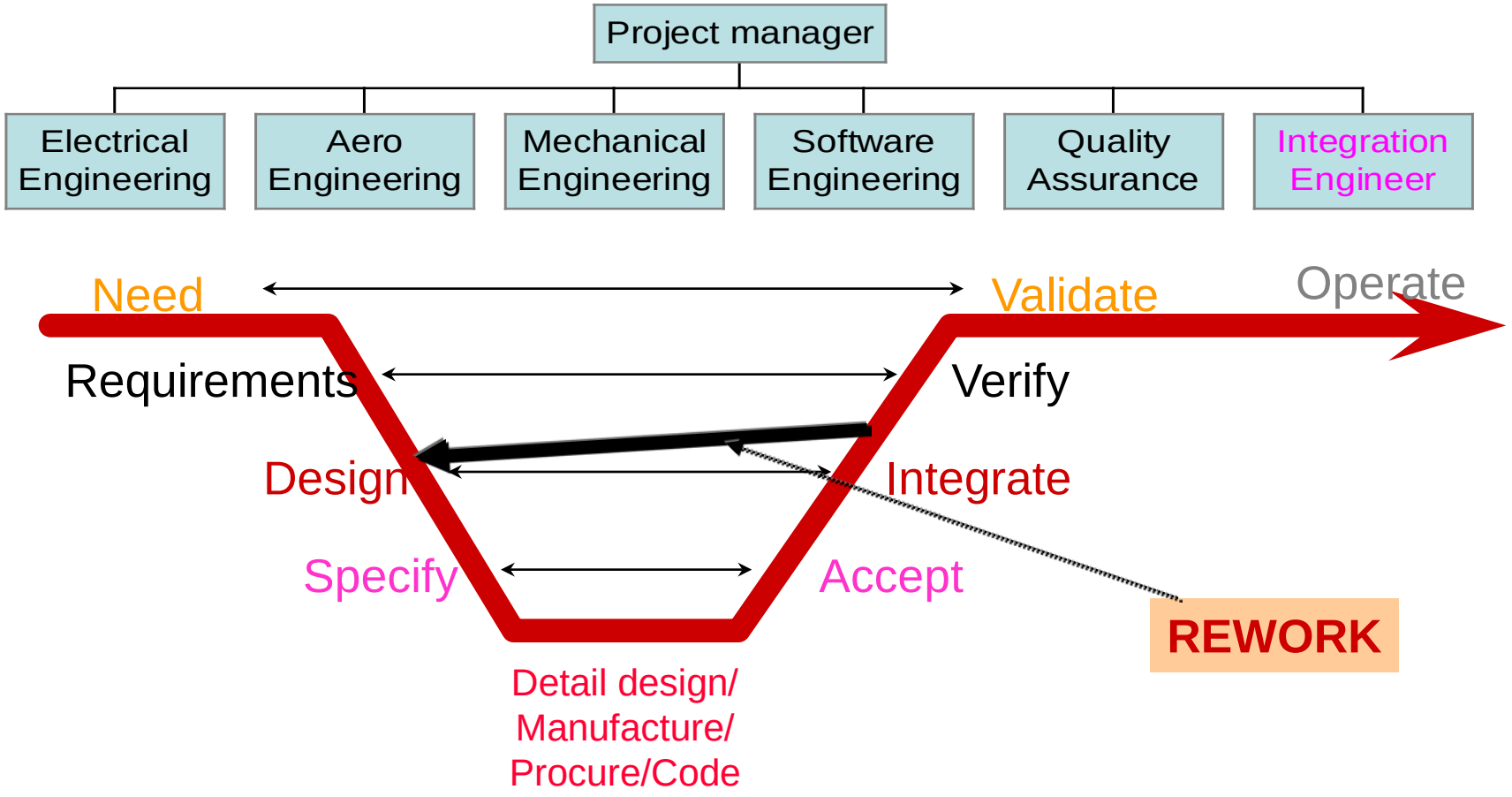
- ✓ If you're spending <2% of your development effort on SE / integrated engineering activities, then ROI of improving / augmenting your SE is 7:1 or better
- ✓ Optimum allocation of SE does depend on project size and complexity, and your business model; but your ROI on improvement / augmentation does not flatten out until >10%. Eric Honour recommends 14%; my inference from Joe Elm's study is that it can still pay dividends at 20%.
- ✓ Agreement on what makes the biggest difference – Management of Engineering activities (Elm), Technical Leadership / Management (Honour)
- ✓ Next biggest is Requirements (Elm) or Mission Definition (Honour, not explicitly considered by Elm)
- ✓ Different measures of statistical significance, but positive correlation of SE with business benefit in both cases (stronger in Honour study)

Typical Organisation Evolution

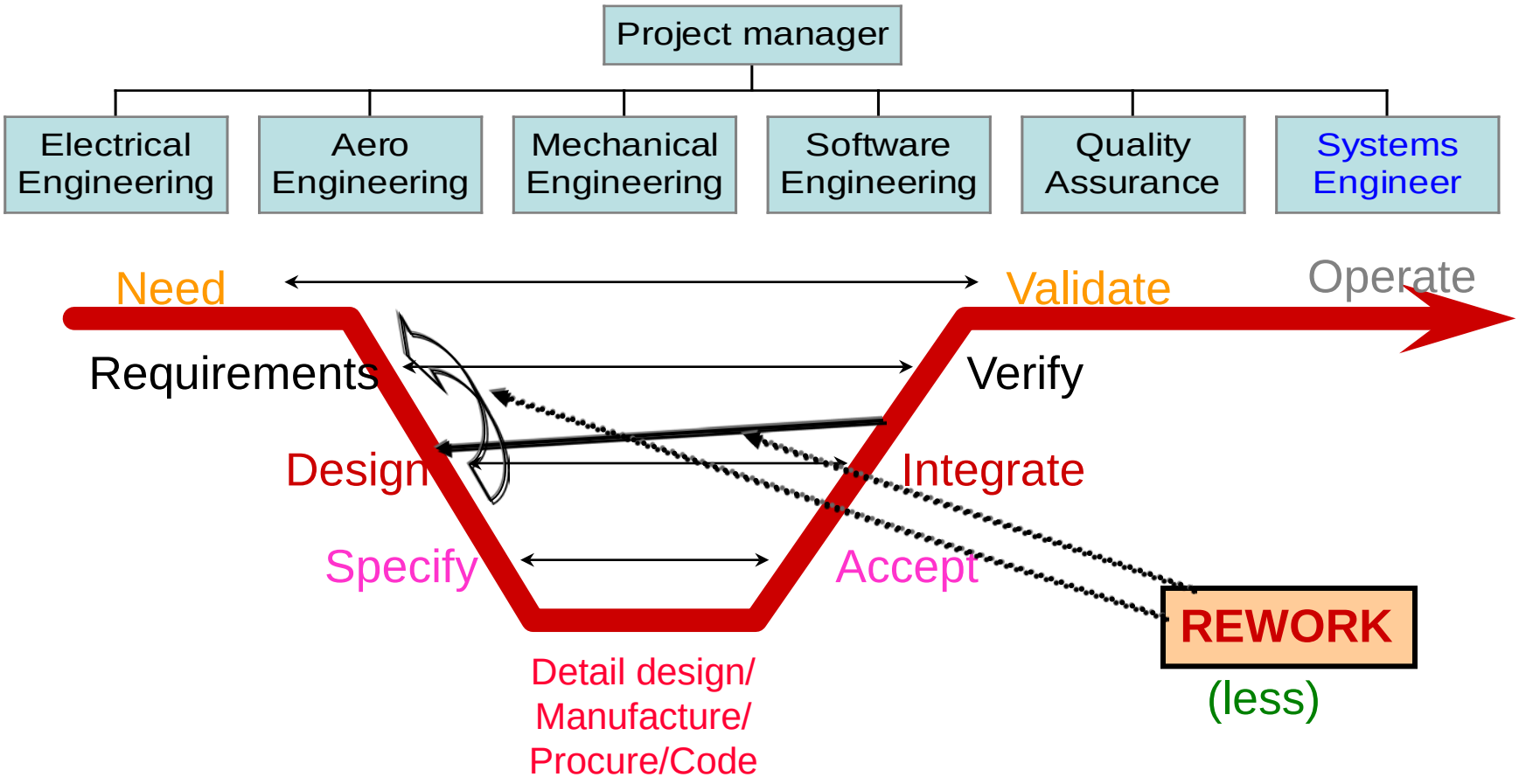
Typical Organisation Evolution (1)



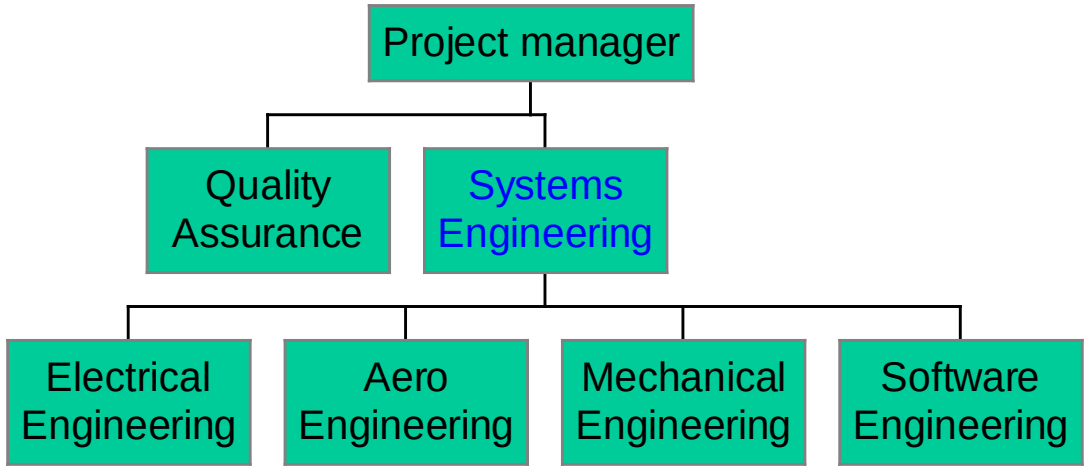
Organisation Evolution (2)

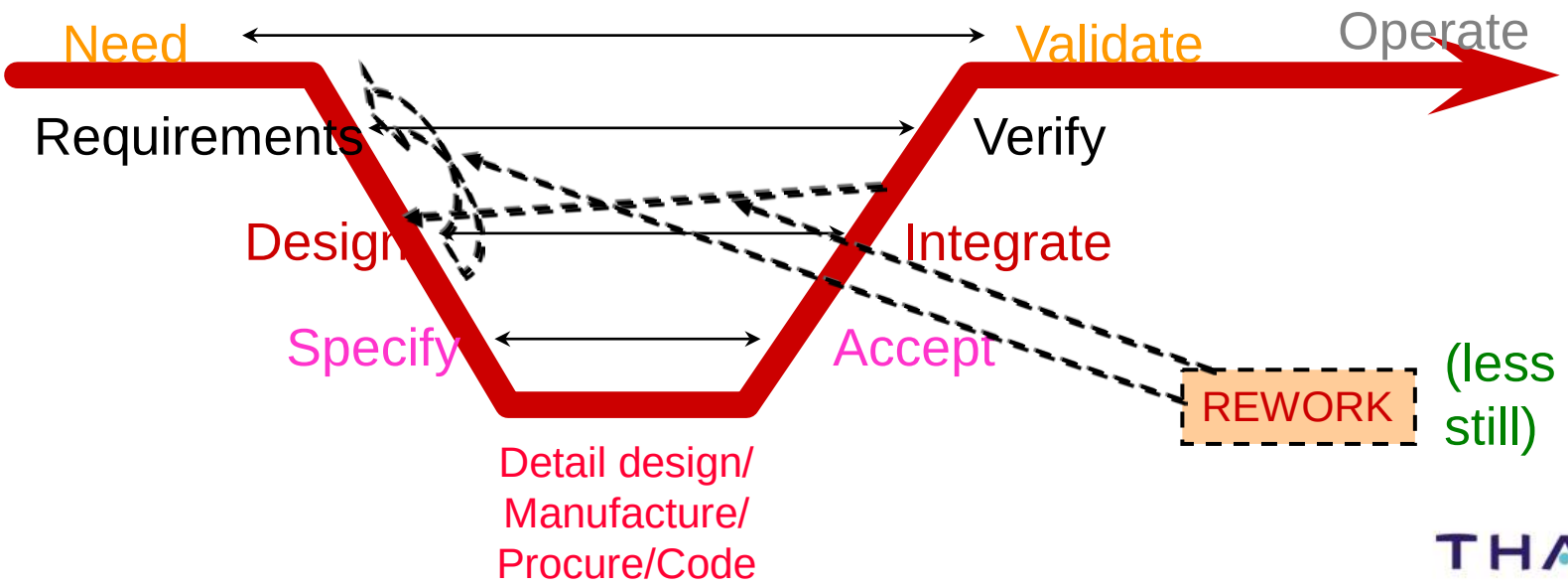


Organisation Evolution (3)



Organisation Evolution (5)

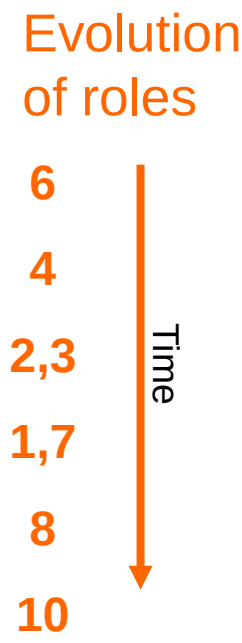




(Twelve Systems Engineering) Roles

Sarah Sheard classic paper 1996

Role	Abbr.	Short Name
1	RO	Requirements Owner
2	SD	System Designer
3	SA	System Analyst
4	VV	Validation/Verification Engr.
5	LO	Logistics/Ops Engineer
6	G	Glue Among Subsystems
7	CI	Customer Interface
8	TM	Technical Manager
9	IM	Information Manager
10	PE	Process Engineer
11	CO	Coordinator
12	CA	Classified Ads SE



There is a definite time order in which an organisation becomes ready to accept the necessity for each role. So we get the Glue and IVVT engineers first, because that is where the problems are first observed. Then we get (system, or integrated engineering) analysts and designers, to address the observed problems.

Then we move back up the V to sort out requirements, and elicit these better by talking to customers. Finally we get (SE) Technical Management and Process capture and optimisation.

It has to happen in this order; else you are pushing water uphill with a rake
The reason some of the earlier practices (eg integration) show less ROI than other is because they are *precursors* necessary to be achieved before higher-geared benefits can be realised.

THALES

How good is your organisation at supporting Systems Engineering?

How good are your Systems Engineers?

INCOSEUK

Individual SE Competence

The INCOSE SE Competence Framework:
Used properly, very good at assessing the individual, *but:*
Needs extending to include
- behavioural competences
- and Domain competences

THALES

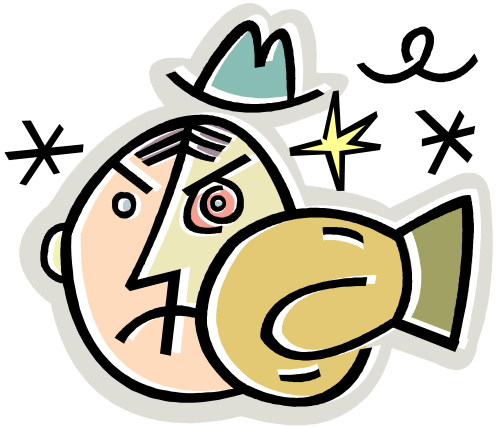
Organisational Competence - Some words on CMMI

CMMI levels 3 and above can only (in theory) be reached by organisations with a homogeneous “House Style”

But an organisation with several diverse business models (eg low and high volume products, services, consultancy) can be heterogeneous yet profitable

The correlation of CMMI with profitability needs to be treated with caution, e.g. viewed at a local / project team level (as per NDIA / Elm).

Some words on the value studies



CORRELATION IS NOT THE SAME AS CAUSE AND EFFECT!

This is the required response to journalists, and to business managers who leap to conclusions. Don't make the same mistake. ROI figures need to be treated with caution; improvement in capability *may not necessarily* lead to business performance improvement.

"The Liars Club" is a System Dynamics archetype – a description of behaviour when a group collectively signs up to a proposition that privately no member of the group believes.

(1) This was not a random selection of projects, it was clustered towards better-performance end.
So difference between bad SE and good SE may be even higher than reported (unclear)

(2) And when trying to pitch for funding to improve SE capability, beware the archetype telling you there isn't a problem that needs fixing.

BEWARE THE LIARS CLUB!

THALES

Conclusions

- We can begin to answer the question “How valuable is SE to the organisation?”
- We can begin to answer the question “What is the ROI in improvement in SE capability?”
- We can deduce an order in which capability investments should be made...
- ... and it isn’t the order of maximum ROI
- ... and there are no absolute answers - you need to do (quite a lot of) work to calibrate your own organisation
- BUT showing MDs and FDs the patterns in organisational evolution and the ROI figures will get their attention

Questions?