Cornell University
Systems Engineering

CORNING

Effectiveness of Systems Engineering Techniques on New Product Development:

Results from Interview Research at Corning Incorporated

Presentation to INCOSE International Symposium
Chicago, IL
July 13, 2010

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Cornell University
Systems Engineering

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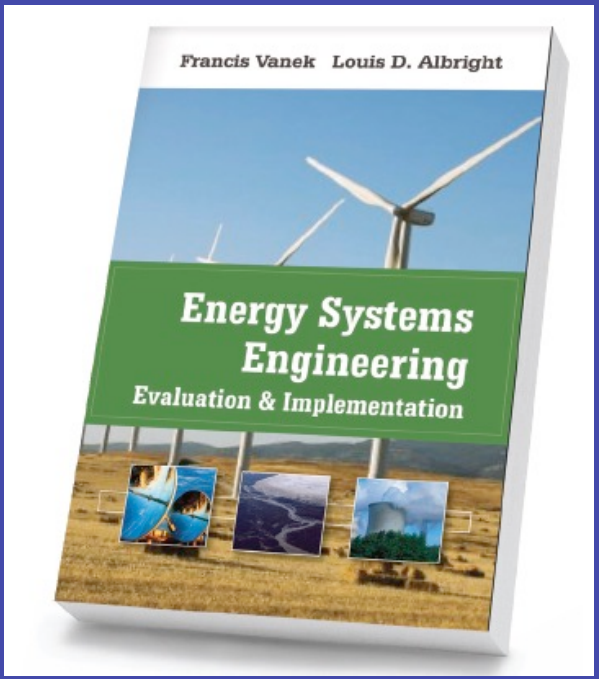
Energy Systems Engineering: Evaluation and Implementation

Features:

- Systems approach to energy
- Major energy sources:
  - Fossil
  - Nuclear
  - Renewable
- Technical and financial feasibility

Flyers available afterward



Opening Thought

"Systems Engineering Process": everyone "knows" it is important….

….but it is very difficult to "prove" that it is effective!

Outline of this talk

- Project Background
- Development of a Methodology
- Application within Corning Incorporated
- Observations and Conclusions

Non-disclosure agreement: Corning projects are identified by number only, and any identifying information has been masked.

Themes

- Heart of the research: 19 on-site interviews in Corning, NY, April 2008 to March 2009

- Two hypotheses for today's talk:
  1. Interview and analysis methodology is effective for learning about SE practice
  2. The methodology specifically applied to Corning shows correlation between use of SE and project performance

Genesis of Project

- Discussion in 2005:
  - Aware of measurement of SE effectiveness in mil/aero sector
  - “What about commercial world?”
- Launch Corning-Cornell project in 2006

SE Effectiveness Research: Challenge Posed and Previous Work

- Sarah Sheard:
  - Limitations on quantifying ROI
- Eric Honour:
  - Previous work comparing multiple projects
- National Defense Industry Association (NDIA):
  - 2007 study of projects in member organizations

Background about Corning Incorporated

Founded
1851

Headquarters
Corning, New York

Employees
Approximately 24,000 worldwide

2009 Sales
$5.4 Billion

Fortune 500 Rank (2009)
414

R&D based in Corning, NY

- World leader in specialty glass and ceramics.
- Create and make keystone components to enable high-technology systems
- Consumer electronics, mobile emissions control, telecommunications and life sciences.
- Sustained investment in R&D at 10%
- 150+ years of materials science and process engineering knowledge
- Distinctive collaborative culture.

Cornell University Systems Engineering

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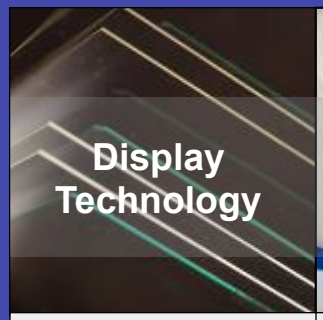
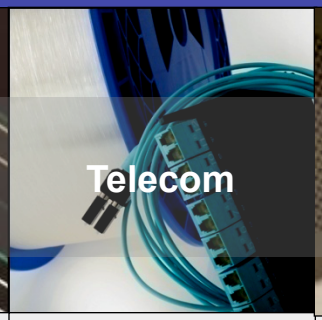
Corning's market segments



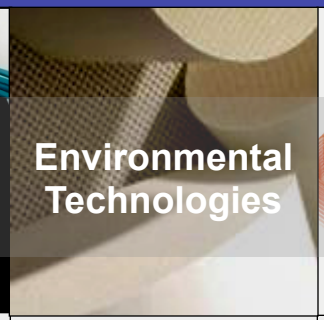
Display Technology

- LCD Glass Substrates
- Glass Substrates for OLED and LTPS-LCD



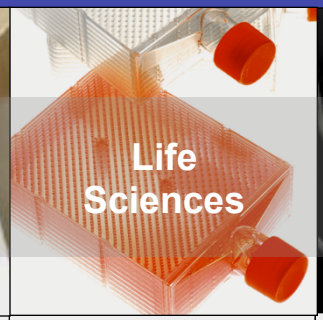
Telecom

- Optical Fiber & Cable
- Hardware & Equipment
  - Fiber optic connectivity products
  - Optical connectivity products



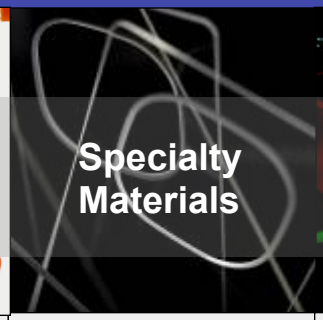
Environmental Technologies

- Emissions Control Products
  - Light-duty gasoline vehicles
  - Light-duty and heavy-duty diesel vehicles
  - Stationary



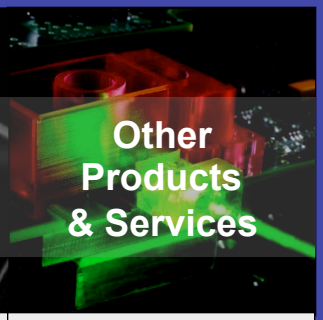
Life Sciences

- Cell Culture & Bioprocess
- Assay & High-Throughput Screening
- Genomics & Proteomics
- General Laboratory Products



Specialty Materials

- Display Optics & Components
- Semiconductor Optics & Components
- Aerospace & Defense
- Astronomy
- Optical Metrology
- Ophthalmic
- Telecom Components
- Specialty Glass



Other Products & Services

- Display Futures
- New Business Development
- Drug Discovery Technology
- Equity Companies
  - Cormetech, Inc.
  - Dow Corning Corp.
  - Eurokera, S.N.C.
  - Samsung Corning Precision Glass Company, LTD (SCP)

Importance of Flexibility in Studying Use of SE Process across Different Firms

The "home-run hitting" enterprise

Versus

The "base hitting" enterprise

Images source: Google images

Background from Literature Review: Search for Evidence of SE Effectiveness

- Main findings:
  - Isolated instances of connection between SE and project success
  - No systematic studies of SE effectiveness in commercial world
- Different from findings in related fields:
  - Total Quality Management (TQM) and Six Sigma

Outline

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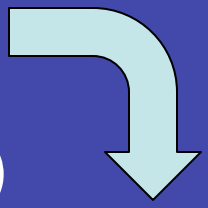
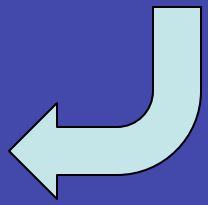
Developing a methodology

1. Ontology (Framework for understanding SE)



2. General approach to studying projects

3. Specific case of Corning Incorporated



1. Ontology: Commonalities among SE standards

Table 5. Systems Engineering Effort Categories Evident in the Standards

SE Categories	ANSI/EIA-632	IEEE-1220	ISO-15288	CMMI	MIL-STD-499C
Mission/purpose definition	Not included in scope	▪ Define customer expectations (Req Anlys)	▪ Stakeholder needs definition	▪ Develop customer requirements (Req Devlp)	Not included in scope
Requirements engineering	System Design ▪ Requirements definition	▪ Requirements analysis ▪ Track requirements and design changes	▪ Requirements analysis	▪ Req'ments development ▪ Requirements mgmt	▪ System requirements analysis and validation
System architecting	System Design ▪ Solution definition	▪ Synthesis	▪ Architectural design ▪ System life cycle mgmt	▪ Select product-component solutions (Tech sol'n) ▪ Develop the design (Tech sol'n)	▪ System product technical req'ments anlys/validation ▪ Design or physical solution representation
System implementation	Product Realization ▪ Implementation ▪ Transition to Use	Not included in scope	▪ Implementation ▪ Integration ▪ Transition	▪ Implement the product design (Tech sol'n) ▪ Product integration	Not included in scope
Technical analysis	Technical Evaluation ▪ Systems analysis	▪ Functional analysis ▪ Requirements trade studies ▪ Functional trade studies ▪ Design trade studies	▪ Requirements analysis	▪ Decision analysis and resolution	▪ Functional analysis, allocations and validation ▪ Assessments of system effectiveness, cost, schedule, and risk ▪ Tradeoff analyses
Technical management/ leadership	Technical Mgmt ▪ Planning ▪ Assessment ▪ Control	▪ Technical mgmt ▪ Track analysis data ▪ Track performance – project plans, tech plans ▪ Track product metrics ▪ Update specifications ▪ Update architectures ▪ Update plans ▪ Maintain database	▪ Planning ▪ Assessment ▪ Control ▪ Decision mgmt ▪ Configuration mgmt ▪ Resource mgmt ▪ Risk mgmt	▪ Project planning ▪ Project monitoring & control ▪ Measurement and analysis ▪ Process and product quality assurance ▪ Configuration mgmt ▪ Integrated project mgmt ▪ Quantitative project mgmt ▪ Risk mgmt	▪ Planning ▪ Monitoring ▪ Decision making, control, and baseline maintenance ▪ Risk mgmt ▪ Baseline change control and maintenance ▪ Interface mgmt ▪ Data mgmt ▪ Technical reviews/audits
Scope management	Acquisition & Supply ▪ Supply ▪ Acquisition	Not included in scope	▪ Acquisition ▪ Supply	▪ Supplier agreement mgmt	▪ Technical mgmt of subcontractors/vendors
Verification & validation	Technical Evaluation ▪ Requirements validation ▪ System verification ▪ End products validation	▪ Requirement verification ▪ Functional verification ▪ Design verification	▪ Verification ▪ Validation	▪ Verification ▪ Validation	▪ Design or physical solution verification and validation
In the standard, but not in agreement with other standards			▪ Operation ▪ Disposal ▪ Enterprise mgmt ▪ Investment mgmt ▪ Quality mgmt	▪ Organ'l process focus ▪ Organ'l process definition ▪ Organ'l training ▪ Organ'l process perf ▪ Causal analysis/resolution ▪ Organ'l innov/deploymnt	▪ Lessons learned and continuous improvement

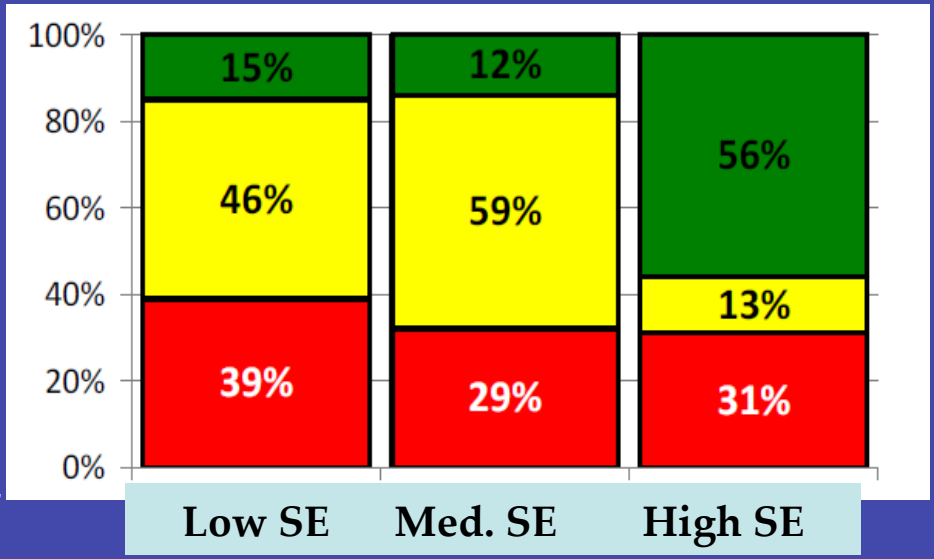
Source: Honour & Valerdi (2006), "Advancing an ontology for systems engineering to allows consistent measurement". Conference on Systems Engineering Research, Los Angeles, 2006.

Eight major areas of SE Input

- Market analysis
  - Renaming of "mission definition"
- Requirements engineering
- Systems architecting
- Systems implementation
- Technical analysis
- Technical management
- Scope management
- Verification & validation

2. General Approach: NDIA Study as Example

- 46 projects from 22 NDIA members
- Found discernable correlation
- Self-reported limitations
  - Use of 'proxies' within organization
  - "Most problematic" part of study
  - Uneven response rate
  - Overall response below expectation



NDIA 'Mosaic Diagram': "Better SE Capability = Better Performance"

Nomenclature Used during Project

- "SE Director":
  - From enterprise side (Corning in this case)
  - Hosted project, lined up interviews
- "Interviewer":
  - From outside (Cornell in this case)
  - Carried out interviews
- "Interviewee":
  - PMs and SEs from specific projects

Designing and Launching Interview Process

- SE Director and interviewer design interview before starting
- Flexibility in methodology:
  - Choose SE techniques based on characteristics of firm
    - Limited time for interviews
    - Focus on key areas
  - Customize questions for firm
  - Scoring questions: 0, ½, or 1 pt

Characteristics of Interviews

- Techniques for improving quality
  - Non-disclosure agreement
  - Directly interview project managers / systems engineers
  - Require interview to show evidence (reports, powerpoints, etc)
    - NOT ALLOWED to take data away from interview
  - Evaluate results AFTER interview
- Retain key statements of interviewees for affinity
  - Techniques for improving quality

3. Specific Approach: Interviews at Corning Incorporated

- SE input component
  - Chose four SE areas for Corning
    1. Market analysis
    2. Requirements analysis
    - SE input component
    - Chose four SE areas for Corning
      1. Market analysis
    2. Requirements analysis
3. Verification & validation
4. Technical analysis (renamed “tradeoff analysis” for Corning study)
   - Progress toward goals

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Presentation of Results from within Corning

Three questions:

Q1. What is the level of SE Input?

Q2. How is the project performing?

Q3. Was there correlation?

Background on Projects Interviewed

- Corning use of "Stage Gate" process
  - Identify project's level of maturity
  - "Stage Gate Review" determines whether or not project passes to next stage
- All projects were either early- or mid-stage
  - Either in progress or shelved
  - Shelved projects: check for archiving of findings

Questions Asked About Market Analysis (SE Area 1)

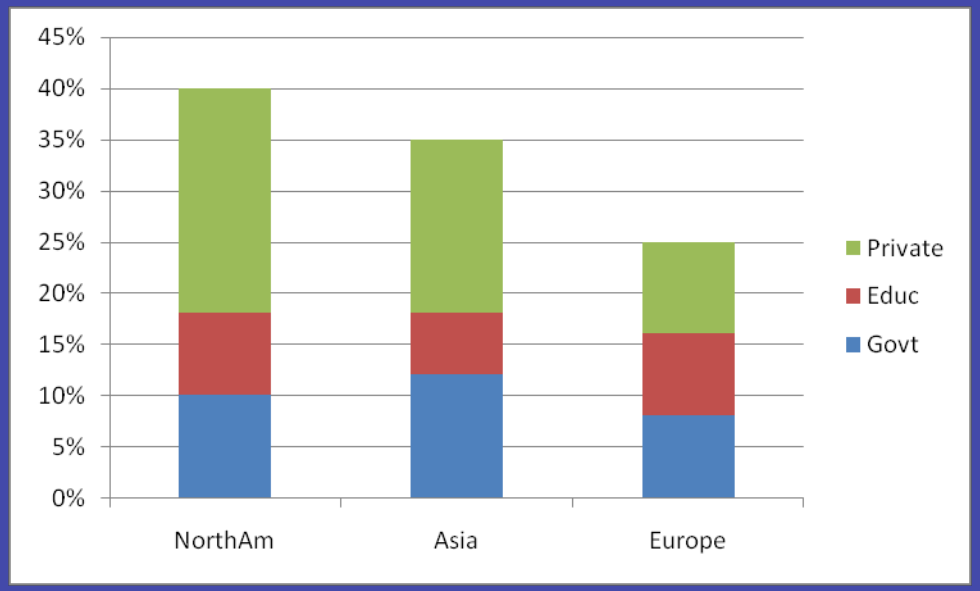
"To what extent did you analyze:

1. "The overall market (including total size, segmentation, or target share)?"
2. "Response of specific prospective customers to the product?"
3. "Position of competitors regarding product?"
4. "What is the current value proposition of the product?"

Example of Response: a Project with strong Market Segmentation Analysis…

"Global market for product X by annual gross value
Total value: $X million/year"

(Simulated Data)

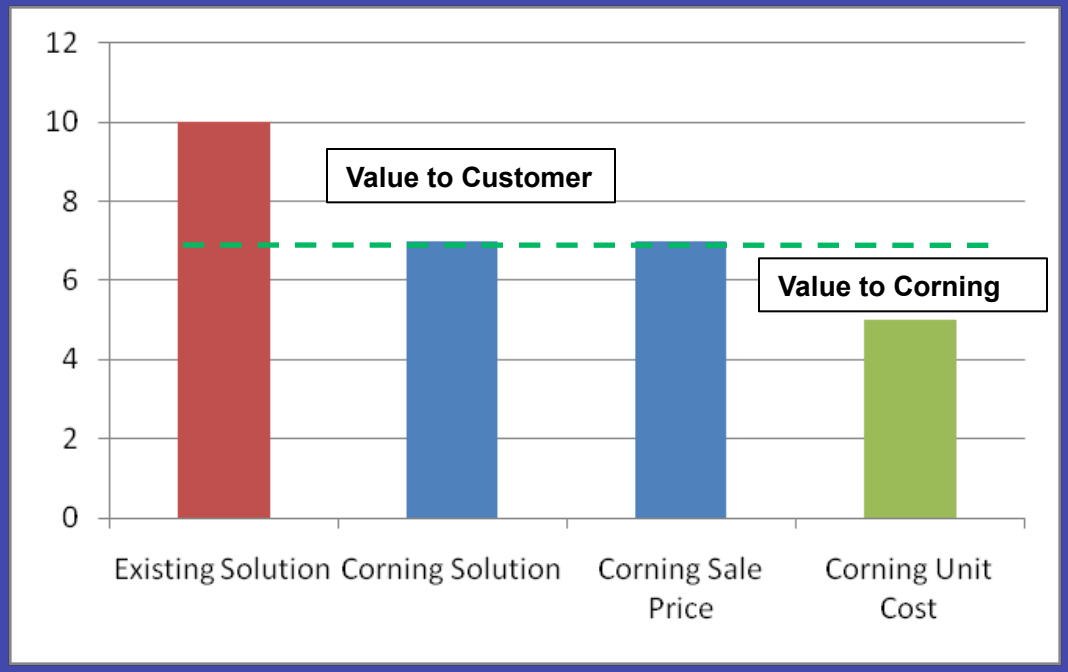


…Detailed Comparison of Offering…

"C.O.O. for PROPOSED product X compared to existing products from Competitors A, B, and C"

Metric	Corning	Company A	Company B	Company C
Cap Cost	a1	b1	c1	d1
Op Cost	a2	b2	c2	d2
NumDefects	a3	b3	c3	d3
MTBF	a4	b4	c4	d4
Other metrics	a5	b5	c5	d5

…and Clear Value Proposition…



…will score well in "Market Analysis" SE area

Highlights from SE Areas 2-4

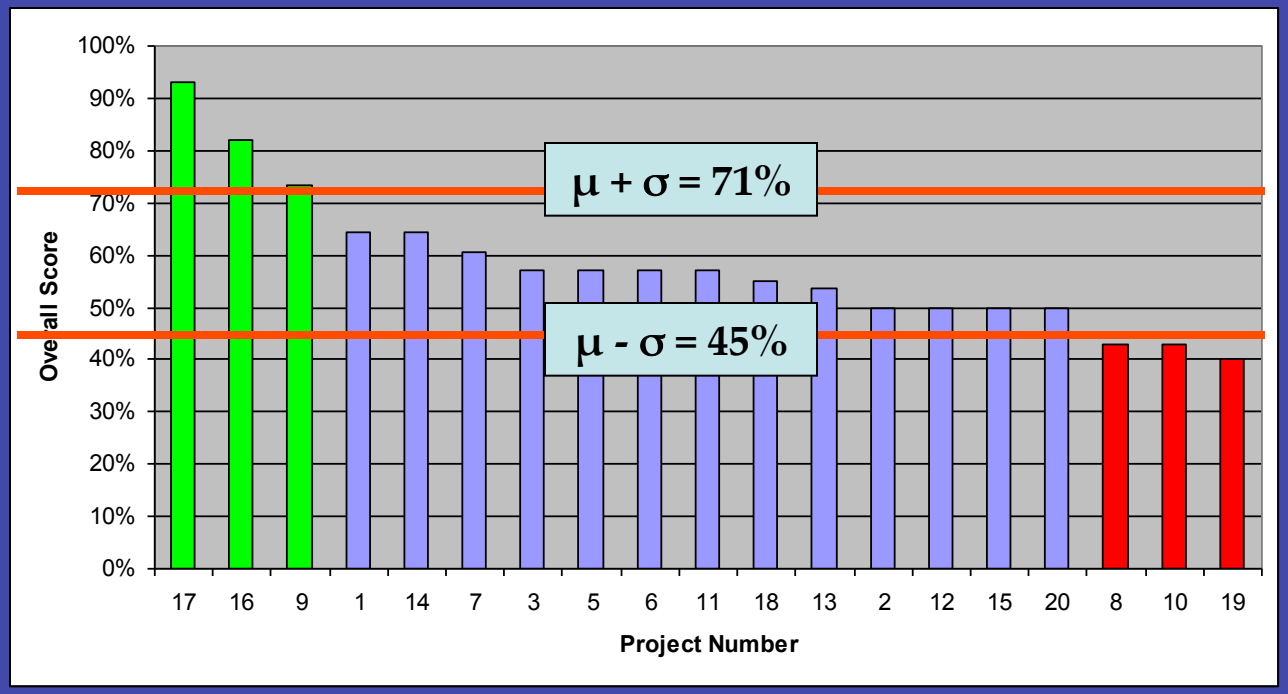
- Won't present remaining 10 questions (for brevity)
- Highlight #1: Trace from value proposition to requirements to testing to tradeoff analyses
- Highlight #2: Scheduling of testing, progress toward meeting requirements, etc.

Results from Evaluation of Level of SE Input

- Projects could earn maximum of 3 or 4 points in each area
  - Scoring reported in terms of percent of maximum
  - Both for each of 4 SE areas and overall score
  - Ex: 7 out of 14 possible points = 50% overall
- Rating of score based on mean & S.D.
  - One SD above mean: threshold for high input
  - One SD below mean: threshold for low input

Result for Overall Project Input: Ranking by Percent of Possible Points

$\mu = 58\%$
$\sigma = 13\%$

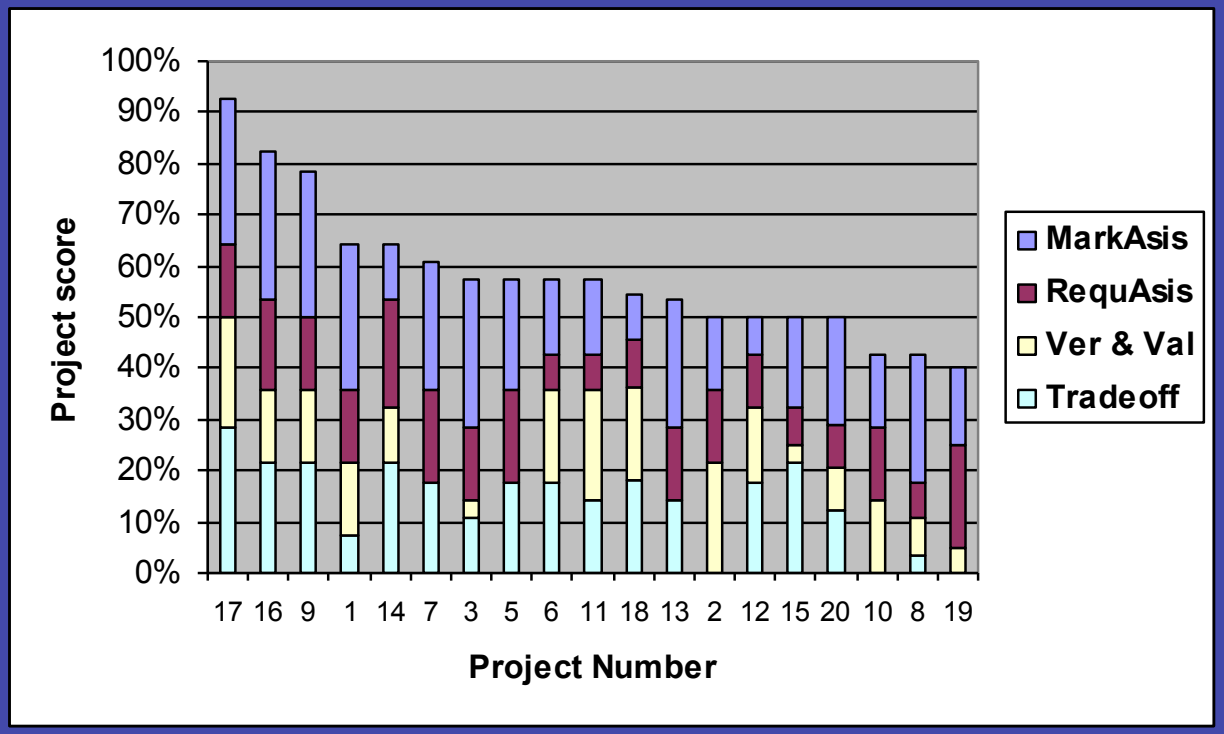


Code for Level of SE Input: Green = High, Blue = Mid, Red = Low.
Breaks at +/- 1 SD from mean

Contribution to Overall Percent Score by SE Areas 1 thru 4:

Highest Average: Market

Lowest: Tradeoff



Variability in SE input observed. What about performance?

Characterizing Project Performance

- Original goals: use project data
  1. Adherence to schedule, budget, staffing
  2. Projection of likely product success based on development to date
- Available data did not support
  - Lack of differentiation for point #1
  - Difficult to make projections for point #2
- Substitute: subjective evaluation. Possible ratings:
  - "Satisfactory"
  - "Struggling"
  - "Superior"
- Corroborated with performance data where possible
- Preliminary assessment:
  - Agreement to revisit with Corning in early 2011

Project performance: A "satisfactory" project

- Steady progress toward maturity
  - Occasional delays, small cost overruns, etc
- Looking at documentation reveals small shortfalls
  - Expected product requirements not met on schedule
  - Memoranda or Powerpoint shows reveal minor "glitches" in everyday project life
- 13 out of 19 projects

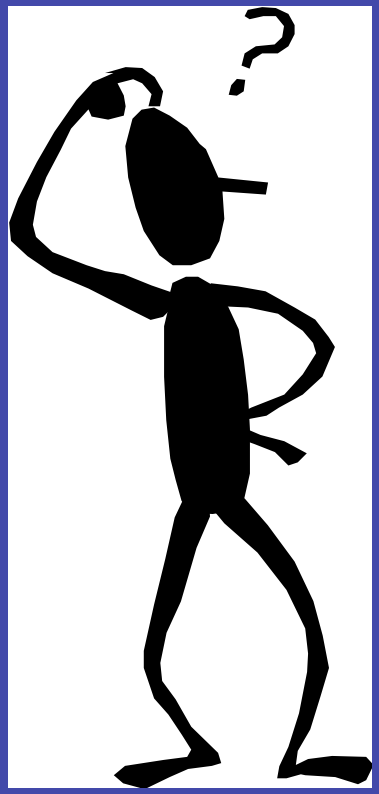
Project performance: A "struggling" project

- Characteristics:
  - Schedule delays or cost overruns beyond the "noise" level
    - Major intervention and rework
  - Chronic difficulties in communicating with customer or upper management
  - Failure to progress through stage gates over extended period
- 3 out of 19 projects

Project performance: A "superior" project

- Characteristics:
  - Faster-than-expected progress through Stage Gate process
  - Accelerated growth in customer interest
  - Documentation suggesting strong ROI potential once complete
  - Awards won in design competitions
- 3 out of 19 projects

So How Does SE Input Match Up Against Project Performance?



Comparison: Focus on Superior and struggling Projects

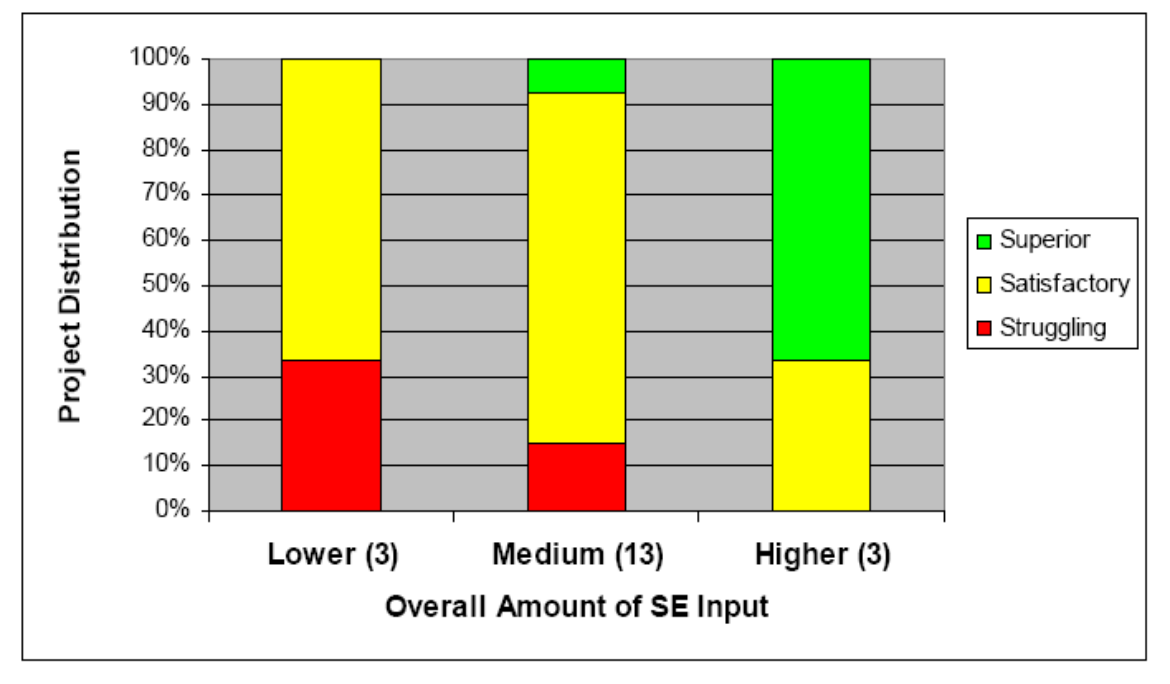
- Satisfactory Projects: Usually near mean SE score
- Superior Projects: Consistently high scores across board
  - Average Overall SE Input for 3 projects = 83%
  - All other projects (16) = 53%
- Struggling Projects: Fall short on one or more SE Inputs

Comparison: Superior vs. Struggling

Proj:	1	9	17	Satisfactory Projects	7	8	11
Mkt:							
Reqs:							
V&V:							
Trade:							
PROJ PERF:							

Mosaic Diagram of Overall SE Input: Some Degree of Correlation

Interpretation: correlation is lumpy but perceptible.



Could Project Maturity Explain Degree of SE Input and Project Performance?

- Struggling projects might also be early stage
  - As projects pass stage gates, maturity leads to better performance
- Comparison of struggling and superior projects
  - 2 out of 3 struggling projects in Stage 3
    - Other one had advanced to S3, then returned to S2
  - Superior projects: 2 in Stage 3, 1 in Stage 4
- Conclusion: does not explain in this case

Interpretation of Findings

- Medium or high SE input does not guarantee high project performance
  - But it CAN help project to progress smoothly
- Struggling projects can have overall SE Input score at or near average
- BUT, low SE Input scores in 1 or 2 areas can be correlated with struggling performance
  - Matches anecdotal evidence from project history

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Observations from the Interview Research Process

- SE Director should not "telegraph" performance of project to interviewer
- Interviewer should not "telegraph" underlying SE Input under study to interviewee
- Pre-interview phone call to establish rapport
- Review of data useful to interviewee also
  - "Where did that value proposition go anyway?"

Evaluation of Hypothesis 1: Effectiveness of Methodology

- Yes, the methodology is effective:
  - With NDA in place, interviewees spoke candidly
  - Requirement to show documentation improves accuracy and is manageable
  - Time commitment manageable for interviewer: 20 interviews over ~1 year, 1 or 2 interviews per visit
    - For interviewer at a distance, challenge of scheduling
  - Interviewer should come from outside firm
- Approach is repeatable at other firms
  - Choice of SE techniques and questions to ask is flexible

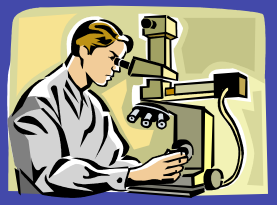
Evaluation of Hypothesis 2: Correlation within Corning

- Within the limits of our number of surveys & preliminary assessment of performance, we uncovered evidence that
  - Superior projects had higher average SE input than satisfactory or struggling
  - Struggling projects had low SE input in at least 1 of 4 SE Input areas
- Findings support greater emphasis on SE input
  - "Precautionary principle": if lack of SE leads to failure some of the time, investing in SE is worth it

Possible Next Steps

- Repeat methodology within other firms
  - Help SE Directors to create firm-specific case for SE
  - Further test adaptability of interview technique
- Develop meta-analysis of SE effectiveness
  - Use results from multiple firms
  - Multi-project, multi-firm data set
- Develop materials on metrics and measurement in INCOSE systems engineering handbook

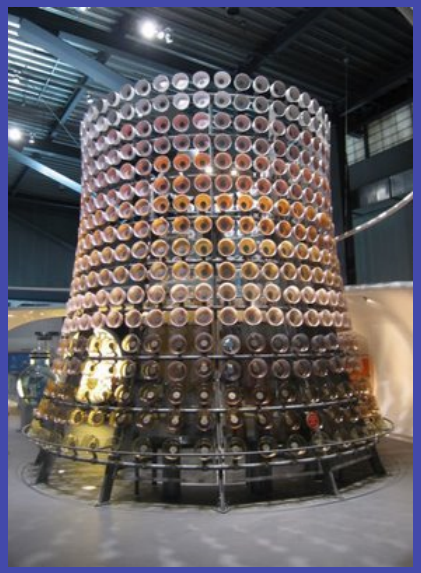
What is the Value of SE? Parting Quote Gathered from Interview



- Affinity grouping of retained quotes from interviewees
  - Quotes as well as scores are integral part of data gathering
  - "Gist" of quote instead of verbatim transcript
- From affinity group "quotes in support of SE":

"I came onto the project in midstream as a newly added systems engineer. When I started, I found the approach to testing to be unfocused and responded by introducing 'design for testability': A general test description would appear as soon as requirements were set out. I considered bringing focus to the testing process to be the job of the systems engineer. Technical people responsible for testing responded positively to the change: they could see its appeal right away."

Thank You for Attending!



Corning Museum of Glass
Corning, NY

Cornell University
Ithaca, NY

Q&A, Discussion

Source: www.cmog.org, www.cornell.edu ;

Backup Slides

Additional Resources

- This Powerpoint show:
  - Link on DropBox
- Full final report: "Corning-Cornell SEROI Study"
  - Link: **Link to full report on DropBox**
- Conference paper for IS 2010 Chicago:
  - Link on DropBox

Comparison of UHFs at Boeing:

Compared to UHF1, UHF 2-3 achieved:

- More product complexity for similar cost
- Shorter integration test cycle
- Shorter overall project duration

Project Trait	UHF* 1	UHF 2 & UHF 3
Overall use of SE techniques	Not used significantly	Used significantly
Role of SE in relationship with project subcontractor	No significant role. Periodic design reviews.	Full-time systems engineer on site of major subcontractor
SE approach for requirements	Not significant	Complete, detailed, integrated requirements, written by multi-organizational team of customers
SE approach to design	Hardware and software specifications. Processes and interfaces not included.	Functional specifications driven by requirements specification. Specifications address hardware, software, processes, and interfaces
Unit/integration test approach	Based on design. Not a priority during early project life cycle	Based on functional specifications. Designed early in project life cycle.
Systems acceptance test approach	Tests defined in high-level project plan. Not as detailed as SE approach.	Tests defined directly from requirements specification acceptance criteria and functional specifications
Overall effect of SE, as reflected in time requirements for stages of projects.	Total duration 104 weeks. Time from design to production ready 52 weeks. Integration test 16 weeks.	Total duration 36 to 48 weeks. From design to production ready 20 to 30 weeks. Integration test 10 weeks.

Questions Asked About Requirements Analysis (SE Area 2)

1. "What are the Technical Performance Measures (TPMs) for evaluating product?"
2. "What is the 'trace' of the value proposition to the TPMs?"
3. "What is the anticipated schedule for achieving TPMs, if one exists?"

Questions Asked About Verification & Validation (SE Area 3)

1. "Do you have a test plan for product development?"
2. "What is the trace from the TPMs to the testing procedures?"
3. "What is the schedule, if any, for carrying out required tests designated in the test plan?"

Questions Asked About Tradeoff Analysis (SE Area 4)

1. "What are the *criteria* and *alternatives* used in tradeoff analyses?"
2. "What is the trace from the product TPMs to the tradeoff analysis?"
3. "What documentation did you produce of research before and selection rationale after the analysis?"
4. "What evidence can you provide of stakeholder involvement in the tradeoff analysis?"

Review of Individual Area and Overall SE Input as Basis for Comparison

- Mean scores by area
  - Market Analysis = 75%
  - Requirements = 59%
  - Verification & Validation = 53%
  - Tradeoff Analysis = 49%
- Overall SE Input
  - 71% or more: high SE input
  - 45% to 71%: medium SE input
  - 45% or less: low SE input

Comparison: Focus on Superior and struggling Projects

- Satisfactory Projects: Usually near mean SE score
- Superior Projects: Consistently high scores across board
  - All 3 projects: HI input for market analysis
  - Projects 1 & 9: MED input on Reqs/V&V/Tradeoff
  - Project 17: HI on all but Requirements
- Struggling Projects: Fall short on one or more SE Inputs
  - Project 7: LO input on V&V
  - Project 8: LO input on requirements
  - Project 11: LO input on market + requirements