Chicagoland INCOSE chapter

Application of Systems Engineering in Project Management:

Modeling with Metrics

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Overview

- Why Should Engineers Care about Project Management?
- Why Model PM Activities?
- SE & PM Synergies
- Modeling with Metrics
- Audience's Proven Metrics
- Q&A

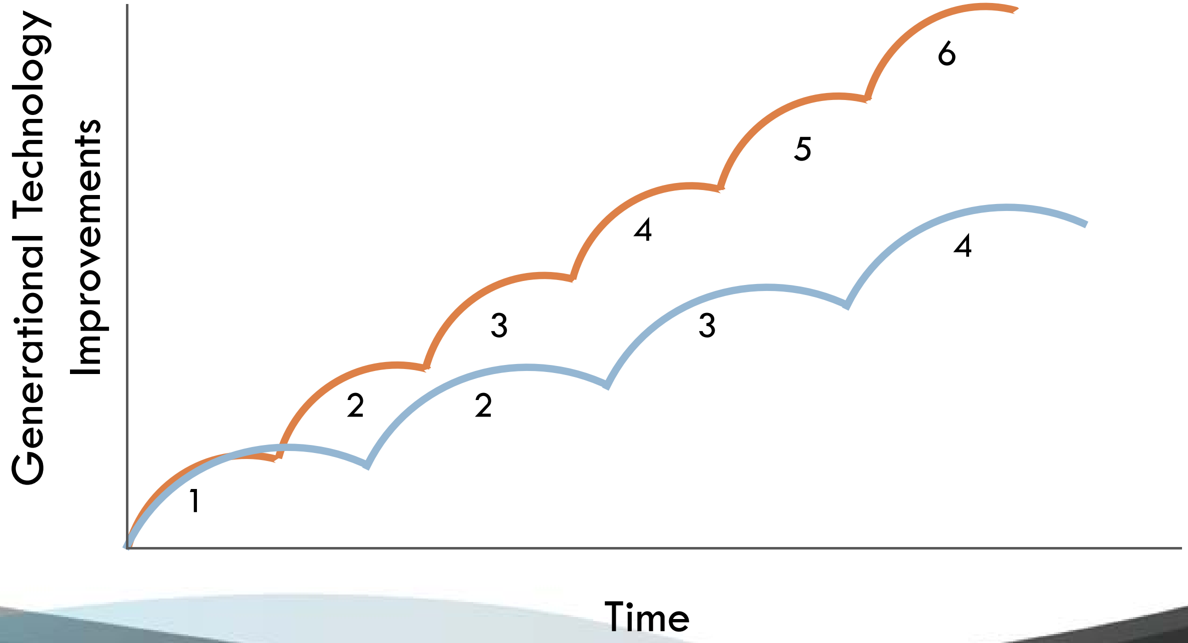
Why Should You Care About PM?

- Typical engineering attitudes toward project management:
  - “Not my job; I’m an engineer, not a project manager”
  - “Project manager = Project mangler”
  - “Suits”
  - “Mahogany row”
  - “Bean counters”

- PM affects everyone!
- You don’t have to be a PM to make good estimates
  - Start this in your group to stand out

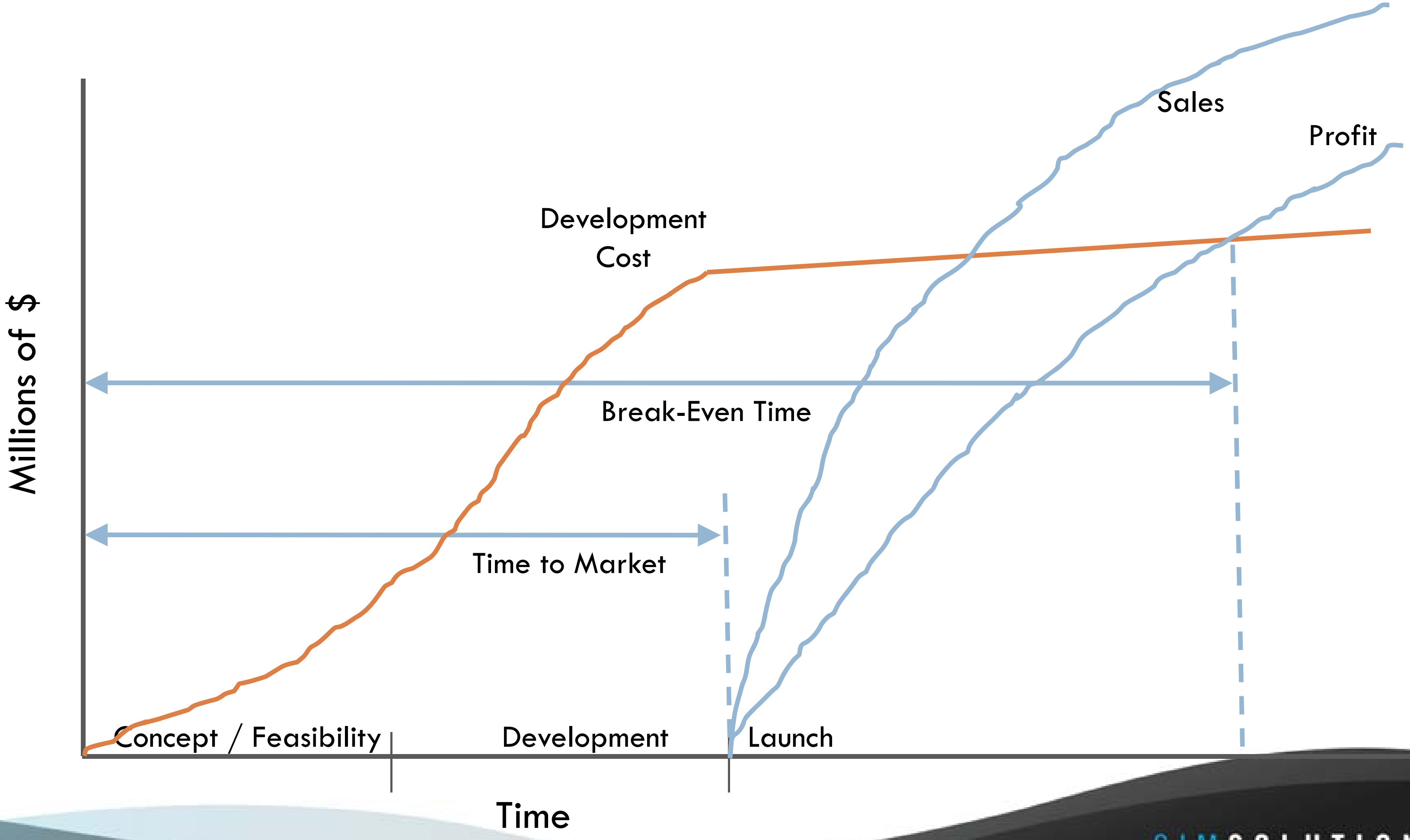
Why Should You Care About PM?

- ☐ Good PM ensures you get to work on cutting edge technologies if you create a fast development cycle
- ☐ Slow development cycle results in designing “me too” products



Why Should You Care About PM?

☐ You'd like to continue receiving a paycheck



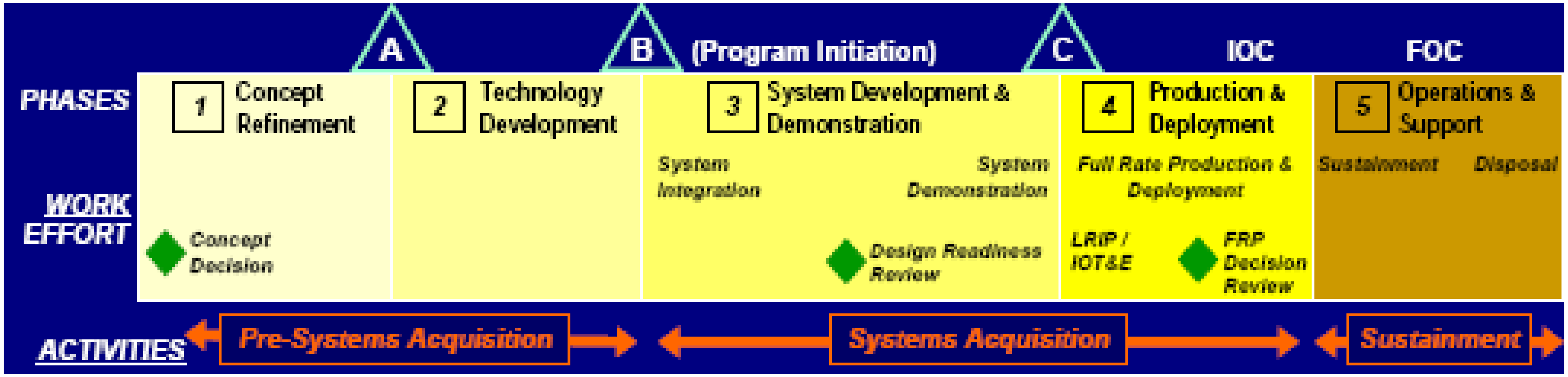
Why Model PM Activities?

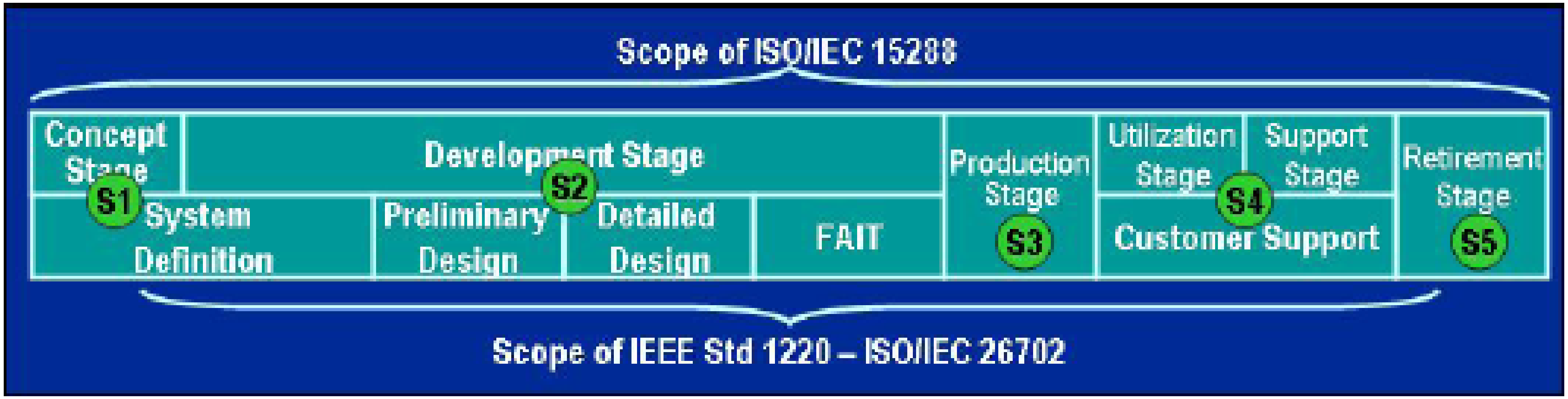
- More predictable budget / schedule
- Less reliant on "tribal knowledge"
- Measure ROI when new tools or training is implemented
- Reuse metrics for future programs
- Control contractor / overtime cost
- Know when to cancel an out of control program
- Reduce stress on development teams
- Accurately predict the launch date
- Set realistic goals
- Know when to ramp up each function
  - Instead of 3 ME's, 6 EE's for the duration of the program, might need more or less of each at different points in the project

SE & PM Synergies

SE Core Competencies	PM Core Competencies
Document user needs	Document business needs
Create detailed requirements	Create detailed budget & schedule
Manage design tradeoffs	Manage cost/schedule tradeoffs
Define system & subsystem interfaces	Define functional group interfaces
Manage product risk	Manage project risk
Validate product results with users	Validate project results with management

INCOSE "SE Leading Indicators Guide"





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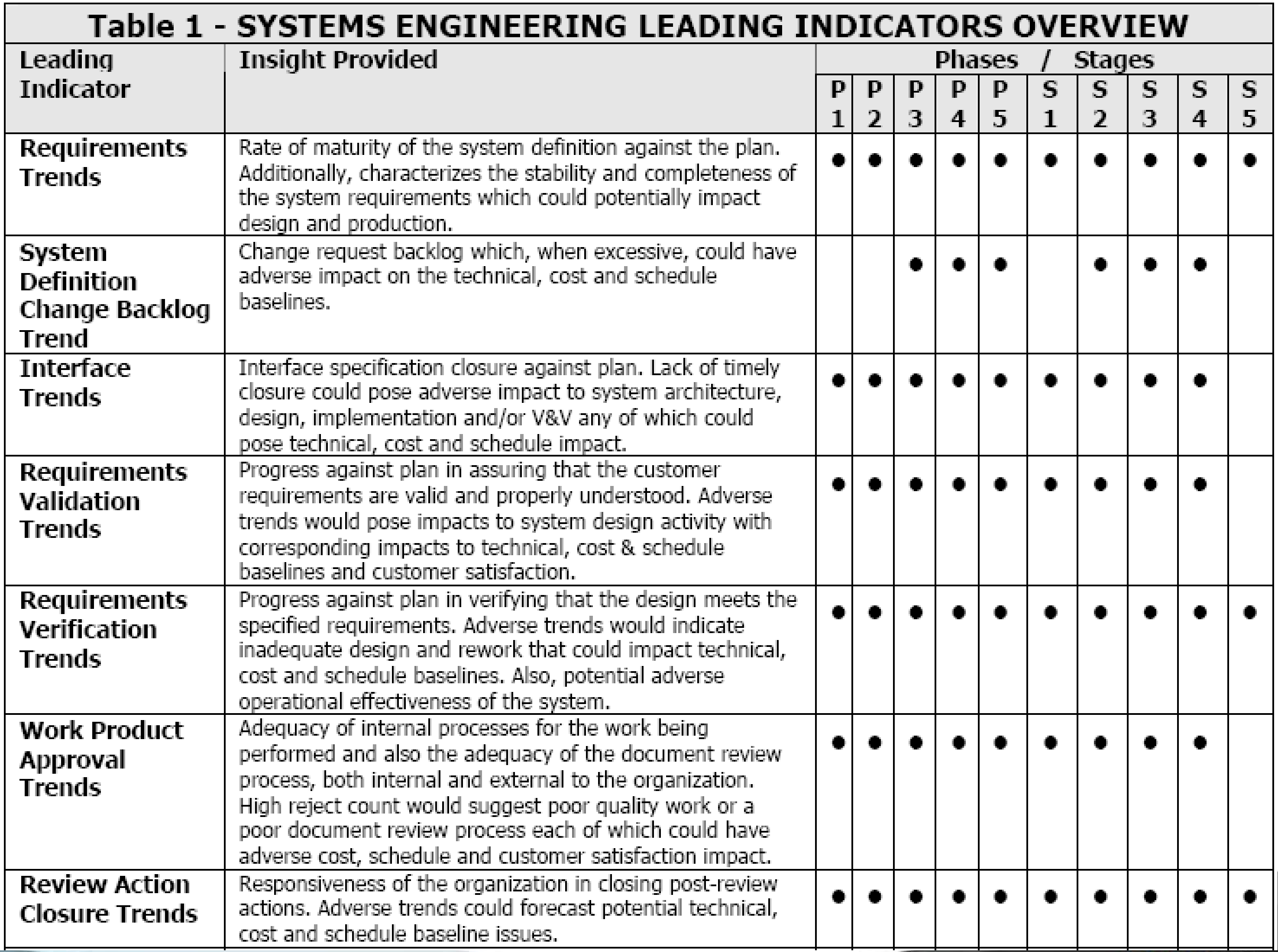
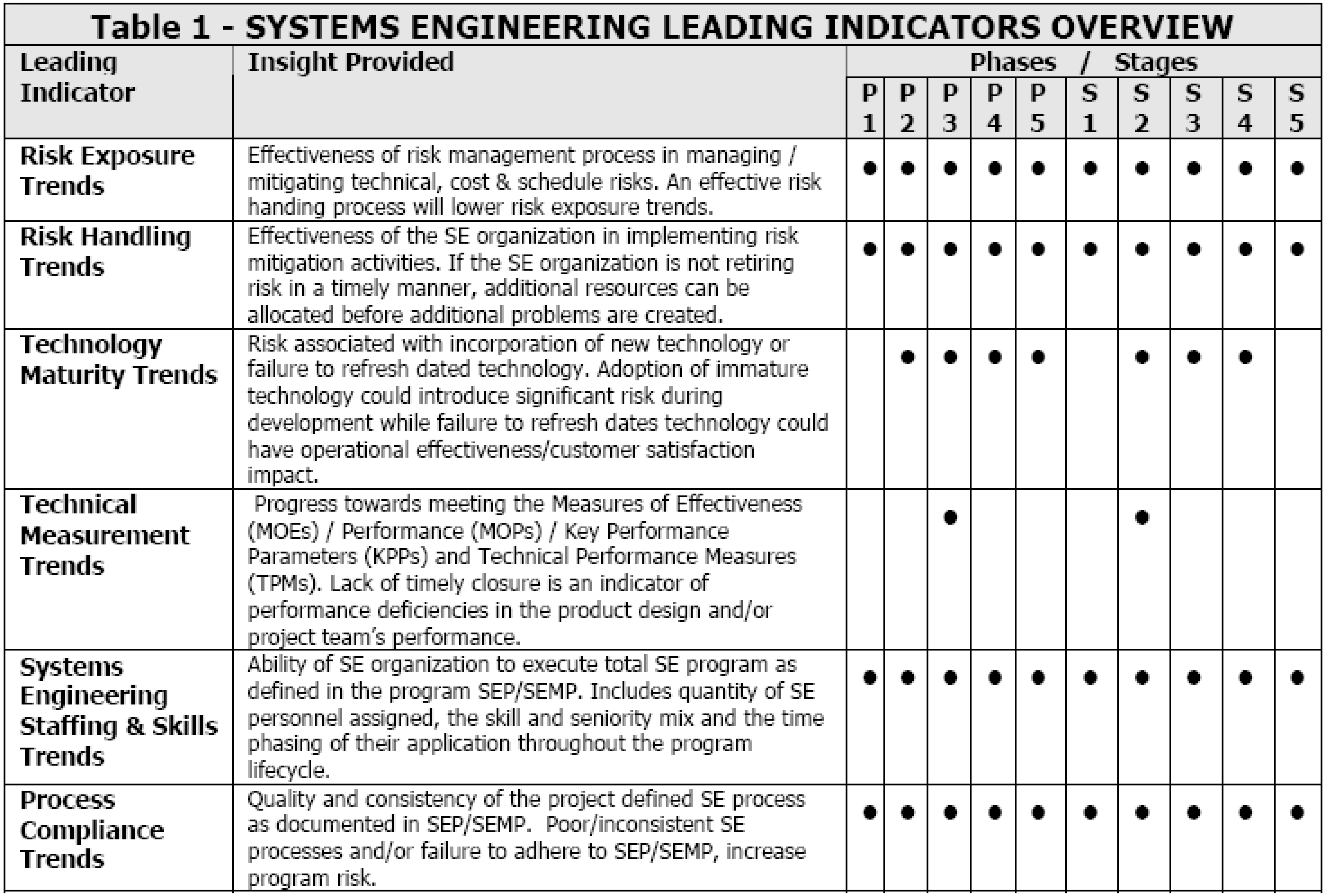


Table 1 - SYSTEMS ENGINEERING LEADING INDICATORS OVERVIEW

Leading Indicator	Insight Provided	Phases / Stages									
		P 1	P 2	P 3	P 4	P 5	S 1	S 2	S 3	S 4	S 5
Requirements Trends	Rate of maturity of the system definition against the plan. Additionally, characterizes the stability and completeness of the system requirements which could potentially impact design and production.	●	●	●	●	●	●	●	●	●	●
System Definition Change Backlog Trend	Change request backlog which, when excessive, could have adverse impact on the technical, cost and schedule baselines.			●	●	●		●	●	●	
Interface Trends	Interface specification closure against plan. Lack of timely closure could pose adverse impact to system architecture, design, implementation and/or V&V any of which could pose technical, cost and schedule impact.	●	●	●	●	●	●	●	●	●	
Requirements Validation Trends	Progress against plan in assuring that the customer requirements are valid and properly understood. Adverse trends would pose impacts to system design activity with corresponding impacts to technical, cost & schedule baselines and customer satisfaction.	●	●	●	●	●	●	●	●	●	
Requirements Verification Trends	Progress against plan in verifying that the design meets the specified requirements. Adverse trends would indicate inadequate design and rework that could impact technical, cost and schedule baselines. Also, potential adverse operational effectiveness of the system.	●	●	●	●	●	●	●	●	●	●
Work Product Approval Trends	Adequacy of internal processes for the work being performed and also the adequacy of the document review process, both internal and external to the organization. High reject count would suggest poor quality work or a poor document review process each of which could have adverse cost, schedule and customer satisfaction impact.	●	●	●	●	●	●	●	●	●	
Review Action Closure Trends	Responsiveness of the organization in closing post-review actions. Adverse trends could forecast potential technical, cost and schedule baseline issues.	●	●	●	●	●	●	●	●	●	●

INCOSE "SE Leading Indicators Guide"



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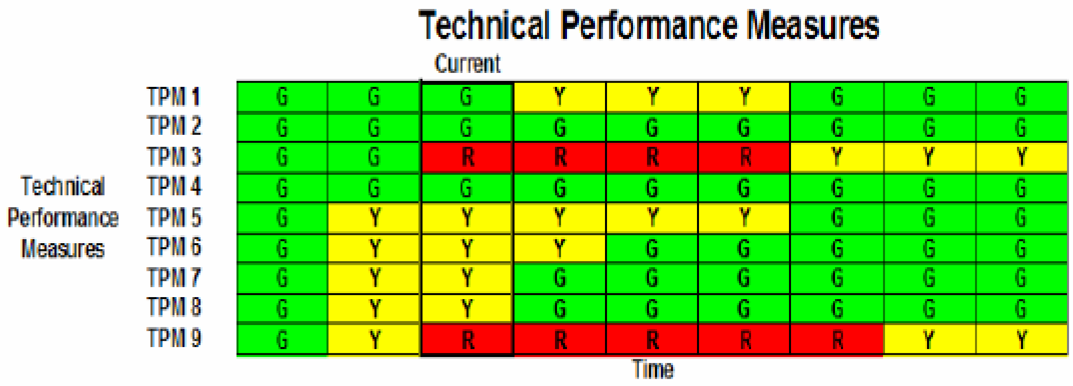
Leading Indicator	Insight Provided	Phases / Stages									
		P 1	P 2	P 3	P 4	P 5	S 1	S 2	S 3	S 4	S 5
Risk Exposure Trends	Effectiveness of risk management process in managing / mitigating technical, cost & schedule risks. An effective risk handing process will lower risk exposure trends.	●	●	●	●	●	●	●	●	●	●
Risk Handling Trends	Effectiveness of the SE organization in implementing risk mitigation activities. If the SE organization is not retiring risk in a timely manner, additional resources can be allocated before additional problems are created.	●	●	●	●	●	●	●	●	●	●
Technology Maturity Trends	Risk associated with incorporation of new technology or failure to refresh dated technology. Adoption of immature technology could introduce significant risk during development while failure to refresh dates technology could have operational effectiveness/customer satisfaction impact.		●	●	●	●		●	●	●	
Technical Measurement Trends	Progress towards meeting the Measures of Effectiveness (MOEs) / Performance (MOPs) / Key Performance Parameters (KPPs) and Technical Performance Measures (TPMs). Lack of timely closure is an indicator of performance deficiencies in the product design and/or project team's performance.			●				●			
Systems Engineering Staffing & Skills Trends	Ability of SE organization to execute total SE program as defined in the program SEP/SEMP. Includes quantity of SE personnel assigned, the skill and seniority mix and the time phasing of their application throughout the program lifecycle.	●	●	●	●	●	●	●	●	●	●
Process Compliance Trends	Quality and consistency of the project defined SE process as documented in SEP/SEMP. Poor/inconsistent SE processes and/or failure to adhere to SEP/SEMP, increase program risk.	●	●	●	●	●	●	●	●	●	●

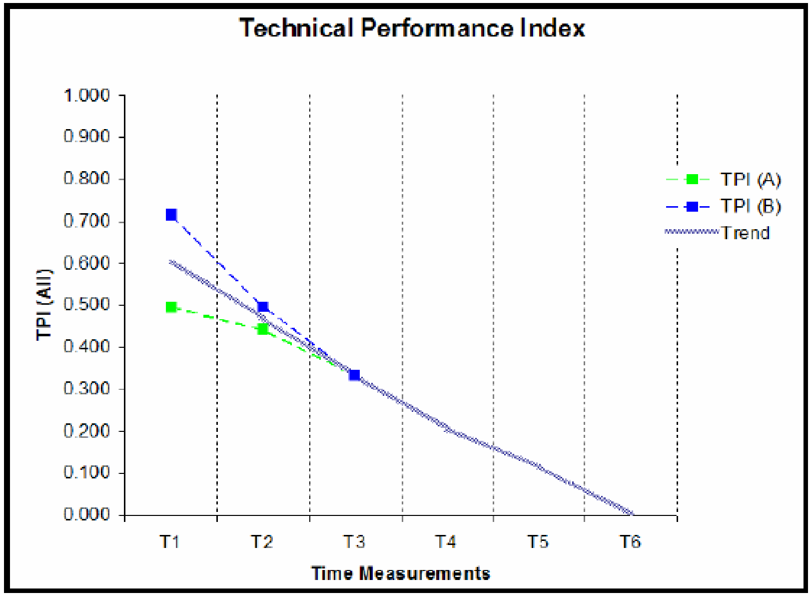
INCOSE “SE Leading Indicators Guide”

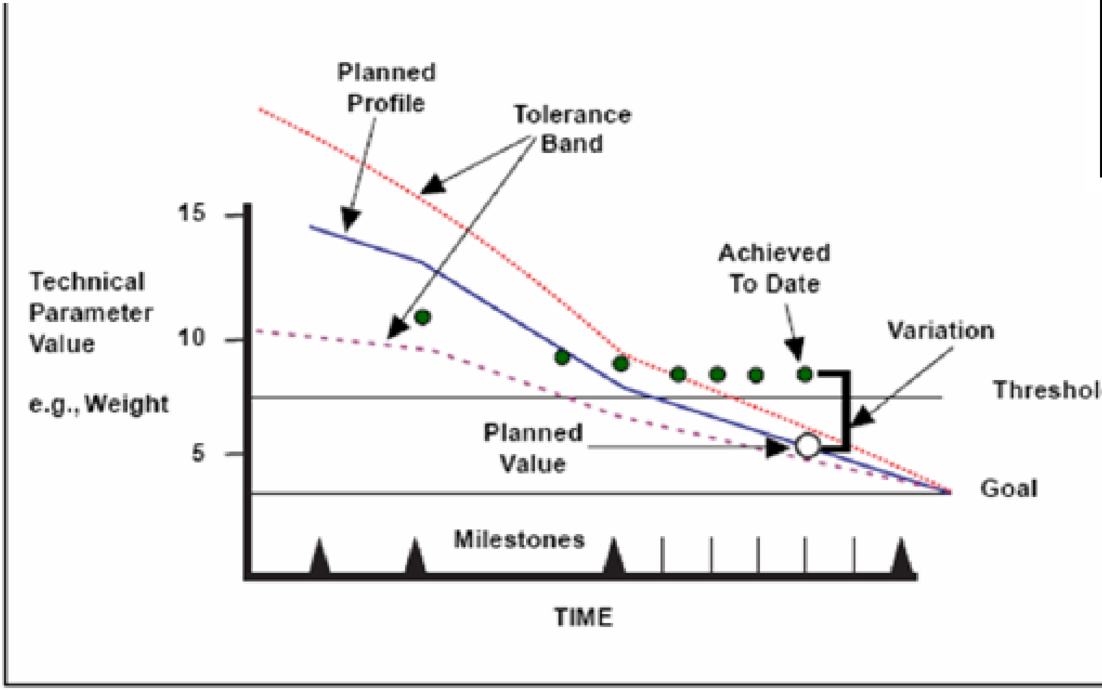


Technical Performance Measures

				Current						
	TPM 1	G	G	G	Y	Y	Y	G	G	G
	TPM 2	G	G	G	G	G	G	G	G	G
	TPM 3	G	G	R	R	R	R	Y	Y	Y
	TPM 4	G	G	G	G	G	G	G	G	G
Technical Performance Measures	TPM 5	G	Y	Y	Y	Y	Y	G	G	G
	TPM 6	G	Y	Y	Y	G	G	G	G	G
	TPM 7	G	Y	Y	G	G	G	G	G	G
	TPM 8	G	Y	Y	G	G	G	G	G	G
	TPM 9	G	Y	R	R	R	R	R	Y	Y

Time





Formal Estimation Methods

- COCOMO 81
  - COnstructive COst Model
  - Based on 1970's/early 80's software methods
  - Software estimation effort largely based on # lines of code
  - Estimate effort, development time, and people required
  - Estimations based on a function of project type:
    - Organic, Semi-detached, & Embedded projects


Complexity

    - Effort Adjustment Factors available for more complex model
      - Memory constraints, personnel capabilities, etc.

Formal Estimation Methods

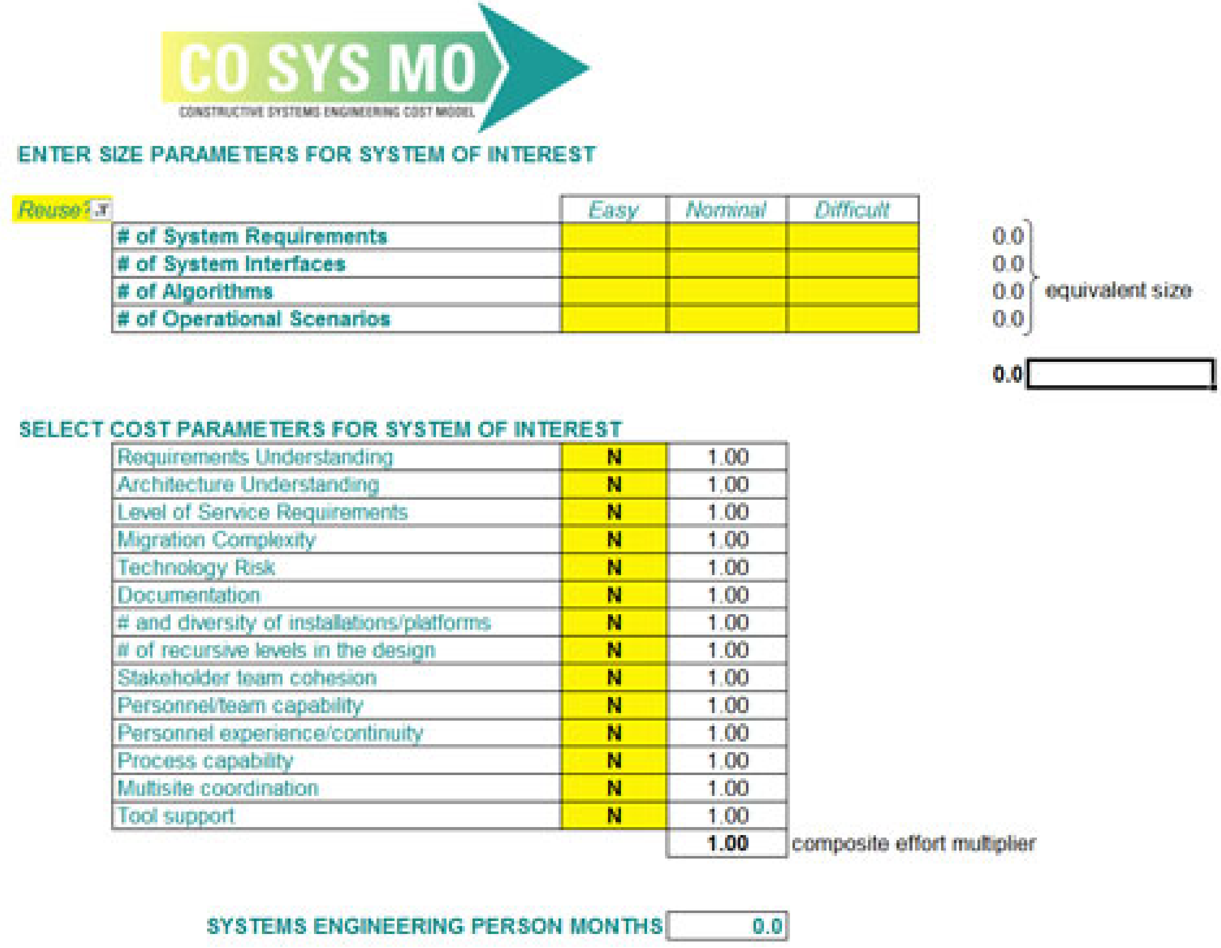
- COCOMO II
  - Estimate the cost, effort, and schedule of modern software projects
  - Incorporates modern software development practices, including reusability, signifant time spent in planning & architecture development, & team cohesion
  - Utilizes cost and schedule adjustment factors for process maturity, team cohesion, tools, experience, etc.

Formal Estimation Methods

- COSYSMO
  - MIT-developed Systems Engineering effort estimation
  - Developed in conjunction with INCOSE
  - Modeled after ANSI/EIA 632 standard for SE tasks
  - Life cycle phases modeled after ISO/IEC 15288

Formal Estimation Methods

- COSYSMO



CO SYS MO

CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL

ENTER SIZE PARAMETERS FOR SYSTEM OF INTEREST

Reuse?	Easy	Nominal	Difficult	
# of System Requirements				0.0
# of System Interfaces				0.0
# of Algorithms				0.0
# of Operational Scenarios				0.0

equivalent size

0.0

SELECT COST PARAMETERS FOR SYSTEM OF INTEREST

Requirements Understanding	N	1.00
Architecture Understanding	N	1.00
Level of Service Requirements	N	1.00
Migration Complexity	N	1.00
Technology Risk	N	1.00
Documentation	N	1.00
# and diversity of installations/platforms	N	1.00
# of recursive levels in the design	N	1.00
Stakeholder team cohesion	N	1.00
Personnel/team capability	N	1.00
Personnel experience/continuity	N	1.00
Process capability	N	1.00
Multisite coordination	N	1.00
Tool support	N	1.00
		1.00 composite effort multiplier

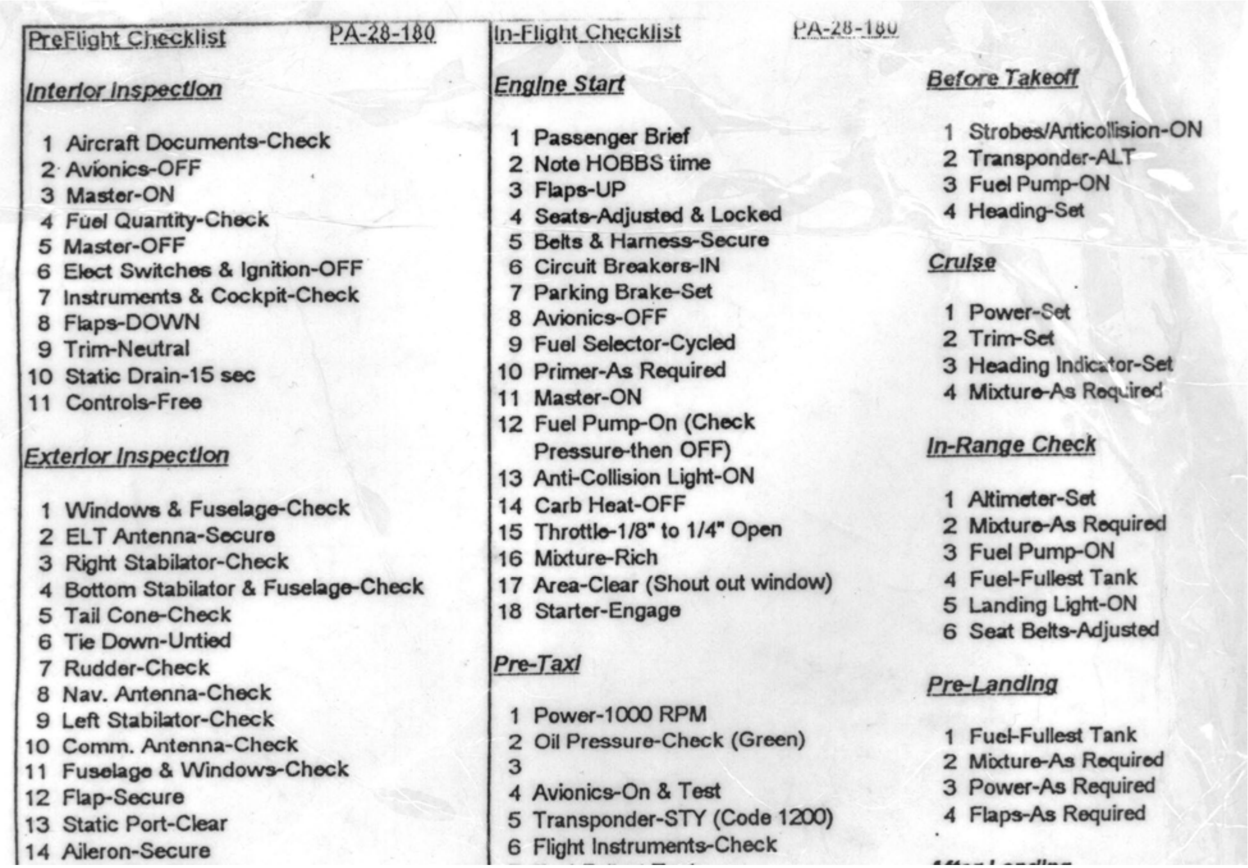
SYSTEMS ENGINEERING PERSON MONTHS 0.0

Modeling With Your Metrics

- "Actuals"
  - Good estimates come from good historical "actuals"
    - Work Breakdown Structure (WBS)
    - Budgets
    - Schedules
- No use in discussing modeling project management if you don't record previous & current project
- "Investing for Dummies"© example
    - "Investing means that you have money and you put it away for future use. If you put your money in your mattress, you've chosen an investment that pays no interest and is subject to theft and fire!"

Work Breakdown Structure (WBS)

- Pilot's checklist



PreFlight Checklist PA-28-180

Interior Inspection

1 Aircraft Documents-Check
2 Avionics-OFF
3 Master-ON
4 Fuel Quantity-Check
5 Master-OFF
6 Elect Switches & Ignition-OFF
7 Instruments & Cockpit-Check
8 Flaps-DOWN
9 Trim-Neutral
10 Static Drain-15 sec
11 Controls-Free

Exterior Inspection

1 Windows & Fuselage-Check
2 ELT Antenna-Secure
3 Right Stabilator-Check
4 Bottom Stabilator & Fuselage-Check
5 Tail Cone-Check
6 Tie Down-Untied
7 Rudder-Check
8 Nav. Antenna-Check
9 Left Stabilator-Check
10 Comm. Antenna-Check
11 Fuselage & Windows-Check
12 Flap-Secure
13 Static Port-Clear
14 Aileron-Secure

In-Flight Checklist PA-28-180

Engine Start

1 Passenger Brief
2 Note HOBBS time
3 Flaps-UP
4 Seats-Adjusted & Locked
5 Belts & Harness-Secure
6 Circuit Breakers-IN
7 Parking Brake-Set
8 Avionics-OFF
9 Fuel Selector-Cycled
10 Primer-As Required
11 Master-ON
12 Fuel Pump-On (Check Pressure-then OFF)
13 Anti-Collision Light-ON
14 Carb Heat-OFF
15 Throttle-1/8" to 1/4" Open
16 Mixture-Rich
17 Area-Clear (Shout out window)
18 Starter-Engage

Pre-Taxi

1 Power-1000 RPM
2 Oil Pressure-Check (Green)
3
4 Avionics-On & Test
5 Transponder-STY (Code 1200)
6 Flight Instruments-Check

Before Takeoff

1 Strobes/Anticollision-ON
2 Transponder-ALT
3 Fuel Pump-ON
4 Heading-Set

Cruise

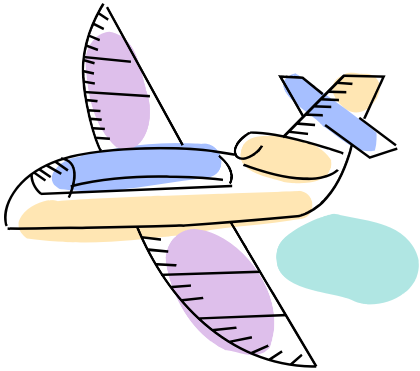
1 Power-Set
2 Trim-Set
3 Heading Indicator-Set
4 Mixture-As Required

In-Range Check

1 Altimeter-Set
2 Mixture-As Required
3 Fuel Pump-ON
4 Fuel-Fullest Tank
5 Landing Light-ON
6 Seat Belts-Adjusted

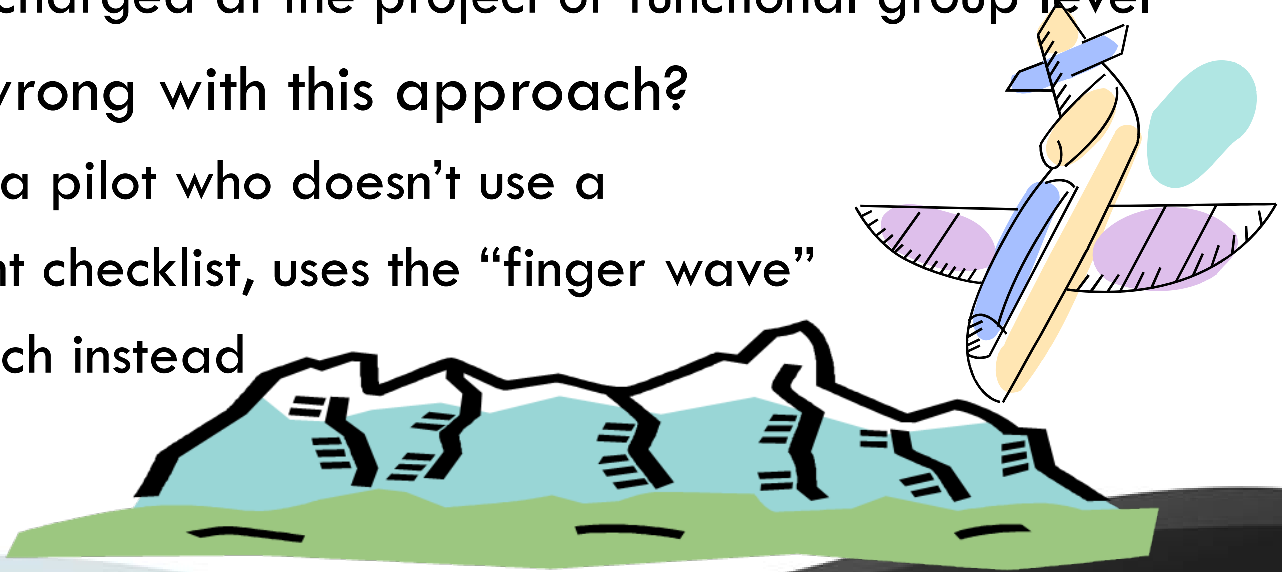
Pre-Landing

1 Fuel-Fullest Tank
2 Mixture-As Required
3 Power-As Required
4 Flaps-As Required



Work Breakdown Structure (WBS)

- Typical project planning
  - PM starts with a brainstorming planning session
  - Each functional leader attempts to think up all the tasks required
  - PM assembles similar tasks into a custom WBS
  - Time is charged at the project or functional group level
- What's wrong with this approach?
  - Akin to a pilot who doesn't use a preflight checklist, uses the "finger wave" approach instead

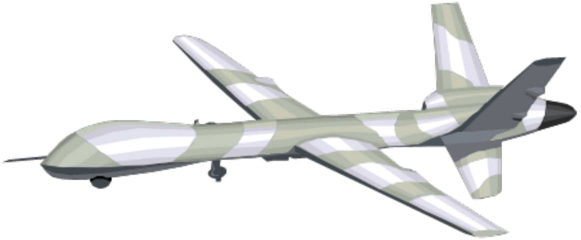


Work Breakdown Structure (WBS)

- Highly effective project planning
  - Define basic WBS shell based on similar activities for ALL product development projects
  - PM starts with basic WBS, then tailors it as needed
  - Time is charged to the WBS element, project, and function
  - Previous project “actuals” information is available to all team members
  - Estimates are based on a repeatable predictive model
  - Models are continuously being refined

Reusable WBS Example #1

- Business: Aircraft modification & systems integration
  - Common WBS elements for nearly all programs:
    - CONOPS / User Needs
    - Design / Production:
      - Equipment rack installations
      - Oxygen system modifications
      - Air conditioning system modifications
      - Floor / heavy structure modifications
      - Antenna installations, ….etc
    - Test:
      - Ground testing
        - EMC / tempest testing
      - Flight testing
    - Post-delivery support



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Reusable WBS Example #2

- Business: Medical device OEM
  - Common WBS elements for nearly all programs:
    - Design
      - CONOPS /User needs
      - Power distribution
      - GUI
      - Sensor I/O architecture
      - Data storage
      - Thermal management
      - Case / structure development
      - External system interface
    - Testing
      - Standards testing
      - Verification testing
      - Usability testing
      - Clinical trial
    - Design xfer to Production

Why Reuse WBS's?

- If all projects use a common WBS template, it's easier to create models based on similar programs
- PM's & team members are less likely to forget tasks
  - Each function can model their efforts based on similar efforts from the past

- Reuse same naming convention for each WBS
  - Ex: WBS = Data storage (DDS)
    - All team members working on Data Storage development for any new product will charge their hours to a charge code corresponding to the "DDS" WBS element
    - When pulling Actuals for your next project, simply look for hours or $ charged to "DDS" from any previous project

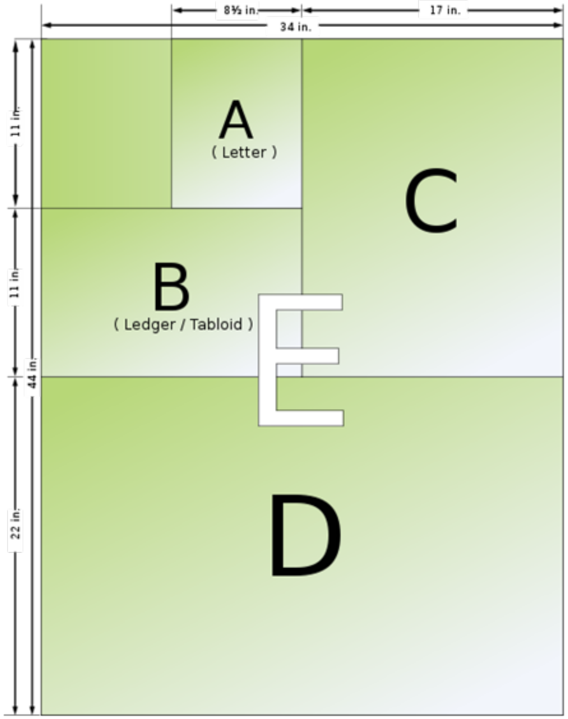
Project Budget Planning

- Gather internal estimates from all functions for each standard and custom WBS element
  - Each department or function submits detailed bids based on repeatable model, just as if it were being externally subcontracted
  - PM compares bids to previous actuals
  - PM challenges unrealistic bids / estimates
    - Keeps everyone honest
    - PM should challenge unrealistically low estimates too
      - If it took 1500 hours/3 engineers/6 months to develop the heavy floor structure last time, PM should question the estimate for 500 hours/1 engineer/2 months for the current project

Proven Budget Models

- **# Hours per square foot of engineering drawings**
  - Create estimate of # drawings of each drawing size required

Name	in × in	mm × mm	Square Feet
ANSI A	8½ × 11	216 × 279	**0.65**
ANSI B	17 × 11 11 × 17	432 × 279 279 × 432	**1.30**
ANSI C	17 × 22	432 × 559	**2.60**
ANSI D	22 × 34	559 × 864	**5.19**
ANSI E	34 × 44	864 × 1118	**10.4**
ANSI J	34 x 48 to 144	864 x 1219 to 3658	**11.3 to 34.0**



Proven Budget Models

- **# Hours per square foot of drawings**
  - Each square foot of drawing requires a repeatable level of CAD design, stress analysis, reviewer time, BOM generation, & production support, assuming a large number of drawings will be created
    - Use a separate model for electrical drawings / schematics vs. mechanical drawings
    - Individual drawings may take more or less than the modeled time, but in aggregate, the drawing factor model is very repeatable
  - Create estimate of # drawings of each drawing size required, based on previous drawing trees / BOM's

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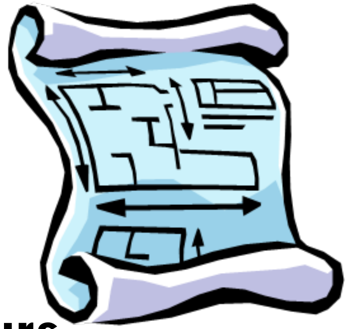
Example: New Equipment Rack Installation

- Mechanical Drawing Estimate
  - One 3-sheet “long” J-size installation drawing
    - 1 drawing x 3 sheets/dwg x 34.0 ft^2 / sheet = 102 ft^2
  - Twelve 2-sheet E-size assembly drawings
    - 12 drawings x 2 sheets/dwg x 10.4 ft^2 / sheet = 250 ft^2
  - Twenty 2-sheet E-size detail drawings:
    - 20 drawings x 2 sheets/dwg x 10.4 ft^2 / sheet = 416 ft^2
  - **Total mechanical drawing effort estimate:**
    - 102+250+416 = 768 ft^2
    - Mechanical drawing model: 2.5 hrs/ft^2
    - Hourly estimate: 768 ft^2 x 2.5 hrs/ft^2 = **1920 hours**



Example: New Equipment Rack Installation

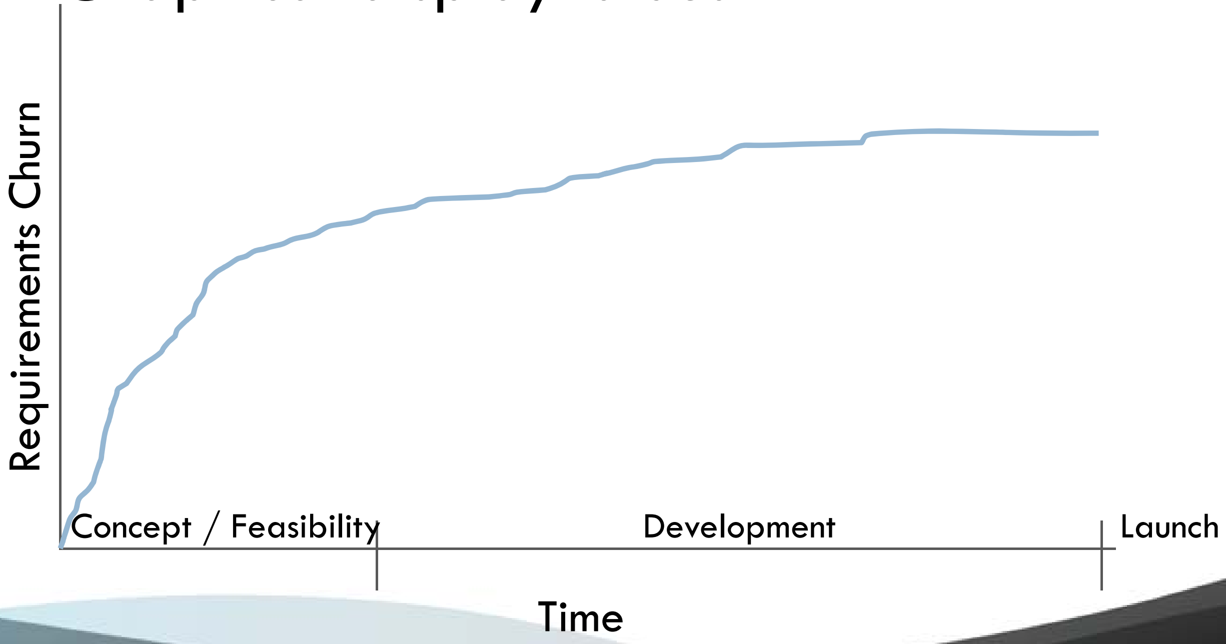
- Electrical Drawing Estimate
  - One 2-sheet “long” J-size wiring installation drawing
    - 1 drawing x 2 sheets/dwg x 34.0 ft^2 / sheet = 68 ft^2
  - Two 1-sheet E-size circuit breaker installation drawings
    - 2 drawings x 1 sheet/dwg x 10.4 ft^2 / sheet = 21 ft^2
  - One 3-sheet E-size electrical schematic drawing:
    - 1 drawings x 3 sheets/dwg x 10.4 ft^2 / sheet = 31 ft^2
  - **Total electrical drawing effort estimate:**
    - 68+21+31= 120 ft^2
    - Electrical drawing model: 1.85 hrs/ft^2
    - Hourly estimate: 120 ft^2 x 1.85 hrs/ft^2 = **222 hours**

Proven Budget Models

- **# hours per document page created**
  - Most applicable to Systems Engineering deliverables
  - Create a separate model for each document type:
    - User Needs / CONOPS document
    - System / Subsystem Requirements document
    - Functional / Structural architecture decomposition document
    - Verification / Validation Test Protocol
  - May want to use a different factor for each document type, based on the complexity of the program
    - Breakthrough / Disruptive technology, Next generation platform, Derivative / incremental development project

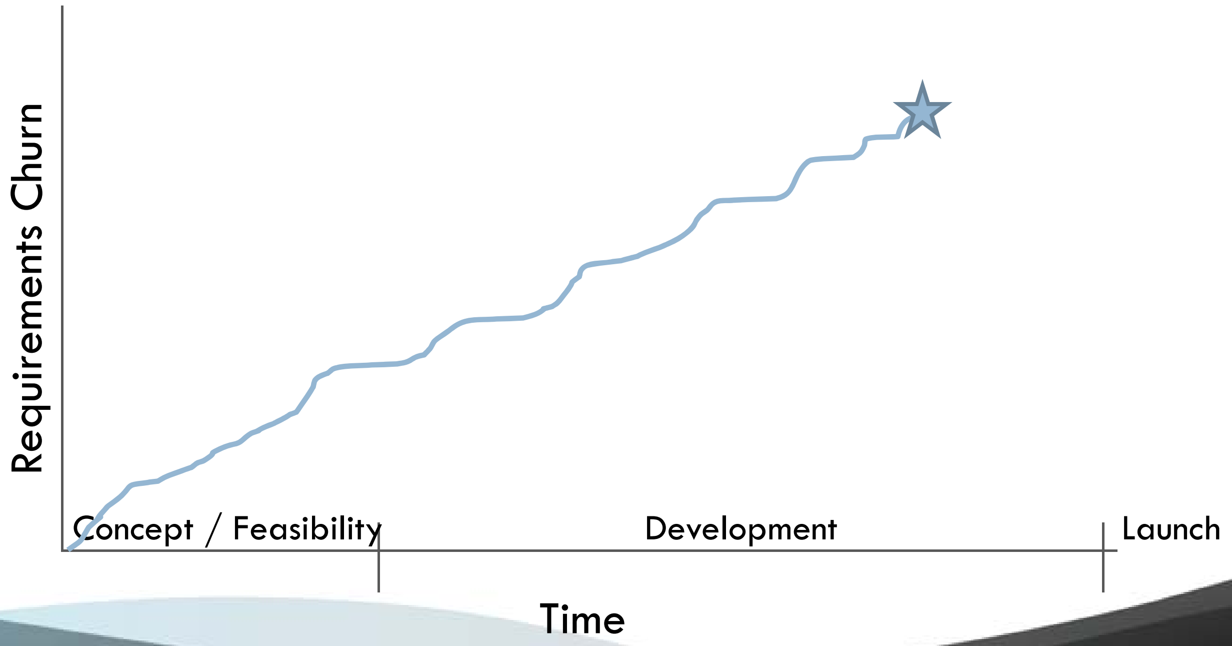
Proven Schedule Models

- **Requirements churn rate (new, modified, deleted)**
  - Slope of line is most useful
    - Compare current slope to the same slope on a previous program, then look at the time to launch from that point
  - Graphical display is best



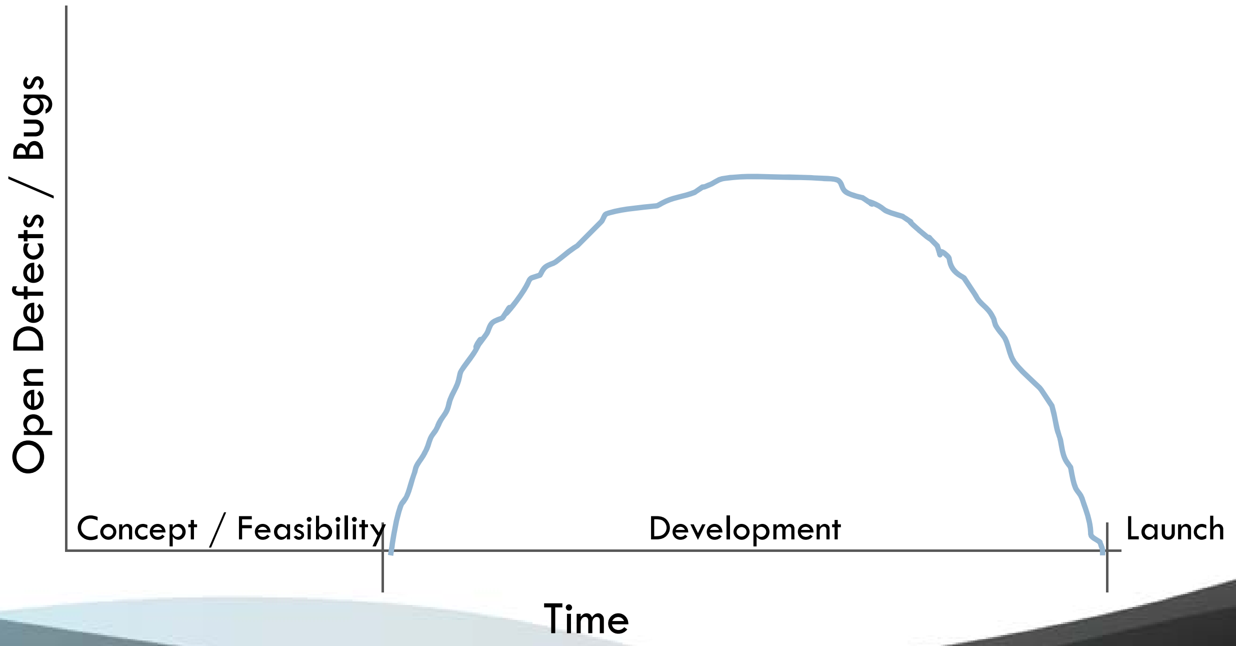
Proven Schedule Models

- **Requirements churn rate (new, modified, deleted)**
  - What does it mean if the slope of requirements churn looks like this when you're supposed to be 1 month from starting V&V testing?



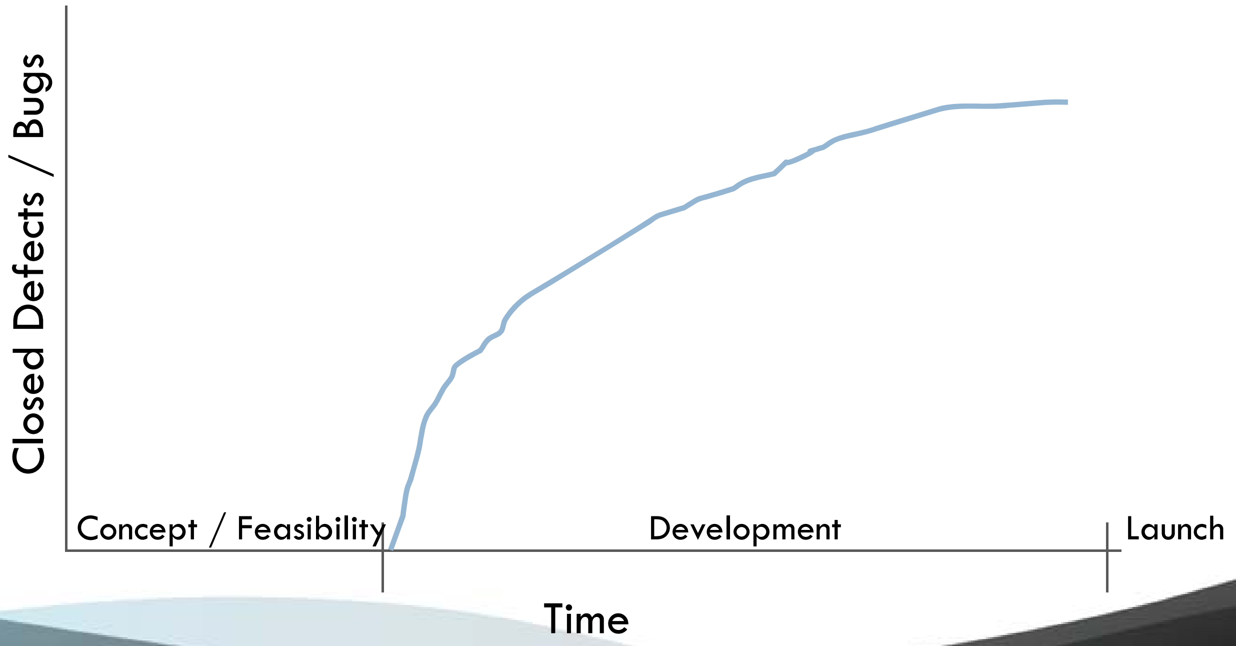
Proven Schedule Models

- # New or Open SW/HW defects
  - No unresolved defects when close to launch
  - Slope of unresolved defects determines if you're solving more anomalies than you're finding



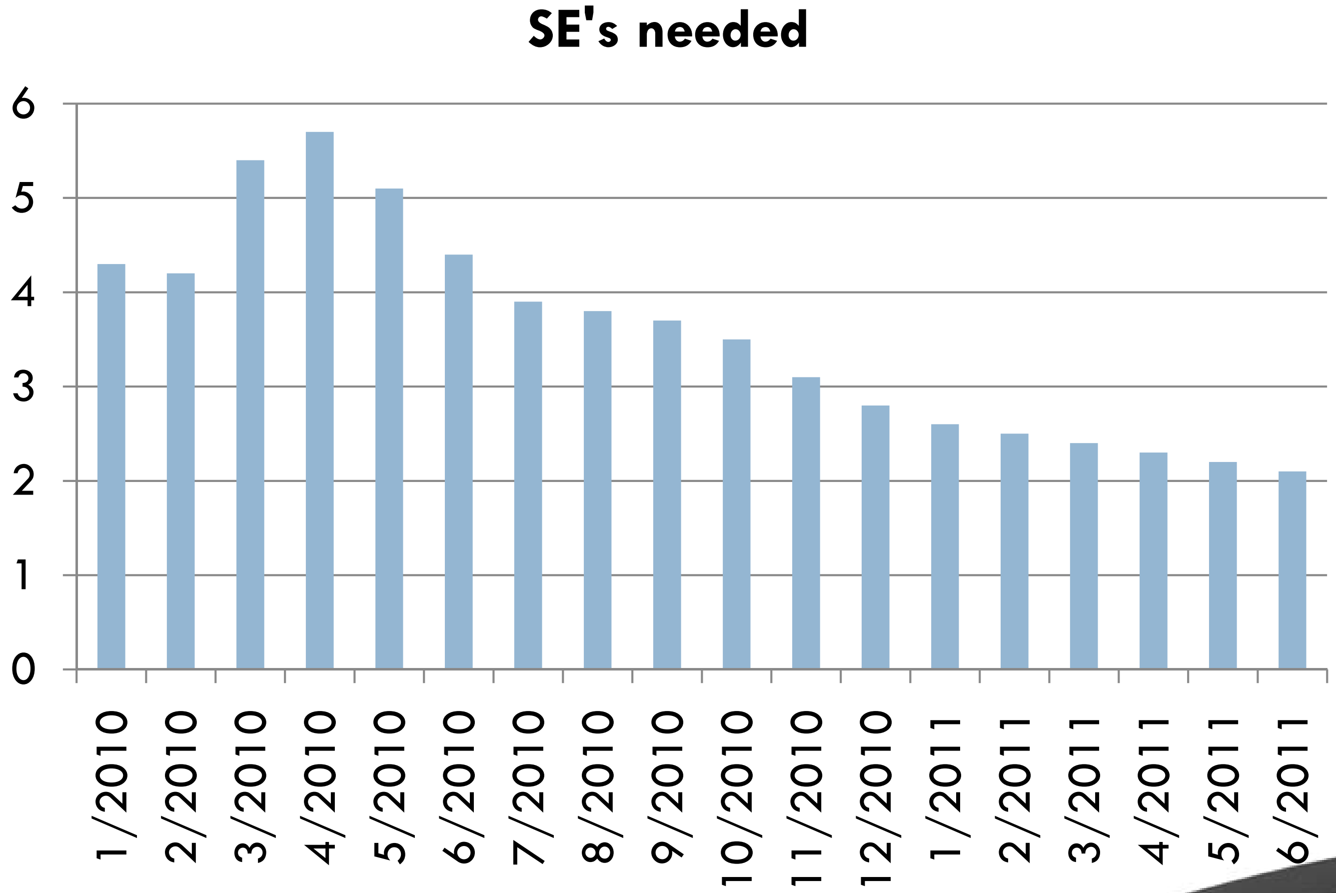
Proven Schedule Models

- **Closed or Resolved SW/HW defects rate**
  - Defect tracking model can predict Time to Launch based on previous time to launch at a given # of open defects



Proven Schedule Models

- ☐ “Going out of business” forecasting curve



Modeling for Project Complexity

- May want to use a different model for each document type, based on the complexity of the development program

		PROCESS CHANGES			
		NEW PROCESS PLATFORM	NEXT GENERATION PROCESS	DEPARTMENTAL PROCESS CHANGE	INCREMENTAL PROCESS CHANGE
PRODUCT CHANGES	NEW PRODUCT PLATFORM	Breakthrough / disruptive technologies			
	NEXT GENERATION PRODUCT		Next generation platform		
	ADDITION TO CURRENT PRODUCT FAMILY			Incremental development	
	INCREMENTAL FEATURES OR ENHANCEMENTS				

Opportunities for Modeling

- Warranty cost f (Customer satisfaction)
  - % of units returned
  - Lawsuit damages
  - MTBF/ MTBS
- Schedule f (Key Performance Indicators)—actual vs. target
  - Weight, fuel efficiency, calculations per second, etc.
- Employees needed per engineering discipline
  - f (“Going out of business” forecasting curve)
    - Hiring, layoffs can be based on this curve

Opportunities for Modeling

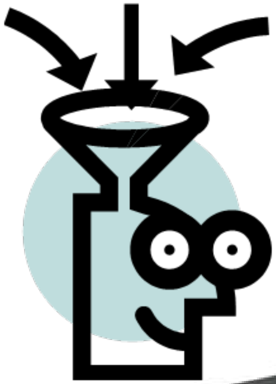
- # of new technologies / inventions needed
  - Assume a new product development program will require many new inventions
    - Hypothesis: Development effort increases exponentially with each new invention needed
    - If too many inventions are required, modeling is difficult
- Target market region churn rate
  - Assume marketing dept changes their mind on which region/country should be the target market
    - Hypothesis: Predictable schedule delay & development budget increase each time target market region changes, based on user preferences in desired market

Opportunities for Modeling

- Effectiveness of New Product Introduction
  - # Projects started vs. # projects completed
  - % of sales coming from new products
  - Frequency of new product introduction
- Manufacturing cost
  - Cost of materials & tooling f (similar projects, by subsystem)
  - Rework cost f (Production first pass yield)

Take Action

- There is still much need for improvement in modeling PM in many companies. No one-size-fits-all model will work for every project or every company. Must be tailored to your company's experience, and revisited to track the accuracy of the model after project completion.
- Consider establishing an internal Engineering Metrics Working Group



Your Proven Metrics

- What metrics have you used to model Project Management activities?

References

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Questions and Discussion

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