NAVAL
POSTGRADUATE
SCHOOL

Automating Systems Engineering Risk Assessment

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Agenda

- Introduction and Overview
- Method
- Project Implementation
  - Process and Measurement Frameworks
- Current and Future Work

Introduction

- The Constructive Systems Engineering Cost Model (COSYSMO) is a parametric cost estimation model for systems engineering effort [Valerdi 2005]
- Constructive: a user can tell why the model gives the estimate it does, and helps the systems engineer understand the job that needs to be done
- Expert COSYSMO leverages on the same cost factors to identify, quantify and mitigate risks
- The dual nature of Expert COSYSMO extends the constructiveness into risk management

Tool Overview

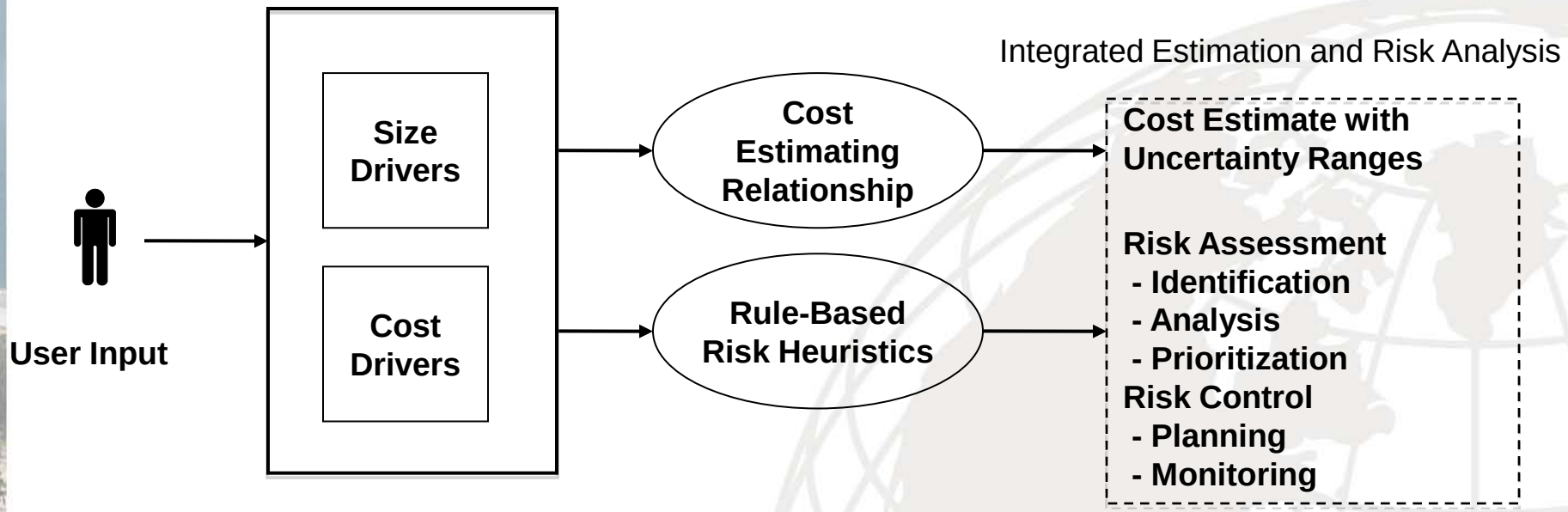
- An expert system tool for systems engineering risk management based on COSYSMO
  - Automatically identifies project risks in conjunction with cost estimation similar to Expert COCOMO [Madachy 1997] and provides related advice
  - Supports project planning by identifying, categorizing and quantifying system-level risks
  - Supports project execution with automated risk mitigation advice for management consideration
- Risk situations are characterized by combinations of cost driver values indicating increased effort with a potential for more problems
- Simultaneously calculates cost and schedule to enable tradeoffs with risk

https://diana.nps.edu/MSAcq/tools/ExpertCOSYSMO.php

or

http://csse.usc.edu/tools/ExpertCOSYSMO.php

Expert COSYSMO Operation



Knowledge Base

- Knowledge base elicitation from seasoned domain experts
- Systems engineering and COSYSMO experts have identified and prioritized risks, and provided advice in a series of six structured workshops supported by surveys
- Devised knowledge representation scheme and risk quantification algorithm with domain experts

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COSYSMO Model Form

$$PM_{NS} = A \cdot \left(\sum_{k} (w_{e,k} \Phi_{e,k} + w_{n,k} \Phi_{n,k} + w_{d,k} \Phi_{d,k}) \right)^{E} \cdot \prod_{j=1}^{14} EM_{j}$$

Where:

PM_{NS} = effort in Person Months (Nominal Schedule)

A = calibration constant derived from historical project data

k = {REQ, IF, ALG, SCN}

w_x = weight for "easy", "nominal", or "difficult" size driver

Φ_x = quantity of "k" size driver

E = represents diseconomies of scale

EM = effort multiplier for the j_{th} cost driver. The geometric product results in an overall effort adjustment factor to the nominal effort.

Cost Driver Effort Multipliers

	Very Low	Low	Nominal	High	Very High	Extra High	EMR
Requirements Understanding	1.87	1.37	1.00	0.77	0.60		3.12
Architecture Understanding	1.64	1.28	1.00	0.81	0.65		2.52
Level of Service Requirements	0.62	0.79	1.00	1.36	1.85		2.98
Migration Complexity			1.00	1.25	1.55	1.93	1.93
Technology Risk	0.67	0.82	1.00	1.32	1.75		2.61
Documentation	0.78	0.88	1.00	1.13	1.28		1.64
# and diversity of installations/platforms			1.00	1.23	1.52	1.87	1.87
# of recursive levels in the design	0.76	0.87	1.00	1.21	1.47		1.93
Stakeholder team cohesion	1.50	1.22	1.00	0.81	0.65		2.31
Personnel/team capability	1.50	1.22	1.00	0.81	0.65		2.31
Personnel experience/continuity	1.48	1.22	1.00	0.82	0.67		2.21
Process capability	1.47	1.21	1.00	0.88	0.77	0.68	2.16
Multisite coordination	1.39	1.18	1.00	0.90	0.80	0.72	1.93
Tool support	1.39	1.18	1.00	0.85	0.72		1.93

EMR = Effort Multiplier Ratio

Method

- Analyzes patterns of cost driver ratings submitted for a COSYSMO cost estimate against pre-determined risk rules
  - Identifies individual risks that an experienced systems engineering manager might recognize but often fails to take into account
  - Helps users determine and rank sources of project risk. With these risks, mitigation plans are created based on the relative risk severities and provided advice

Method (cont.)

- COSYSMO cost factor combinations used as abstractions for formulating risk heuristics in expert knowledge base
- Example:
  - If *Architecture Understanding* = *Very Low* and *Level of Service Requirements* = *Very High*, then there is a risk
    - Since systems with high service requirements are more problematic to implement especially when the architecture is not well understood
- Risk rules are fired when the risk probability weights are > 0
- For each risk item, risk exposure = probability * consequence
- Risk exposures rolled up per risk taxonomy in knowledge base
- Risk mitigation advice linked to risk items

Taxonomy and Risk Exposure

$$\text{Project Risk Exposure} = \sum_{j=1}^{\#categories} \sum_{i=1}^{\#category\ risks} \text{Probability} * \text{Consequence}$$

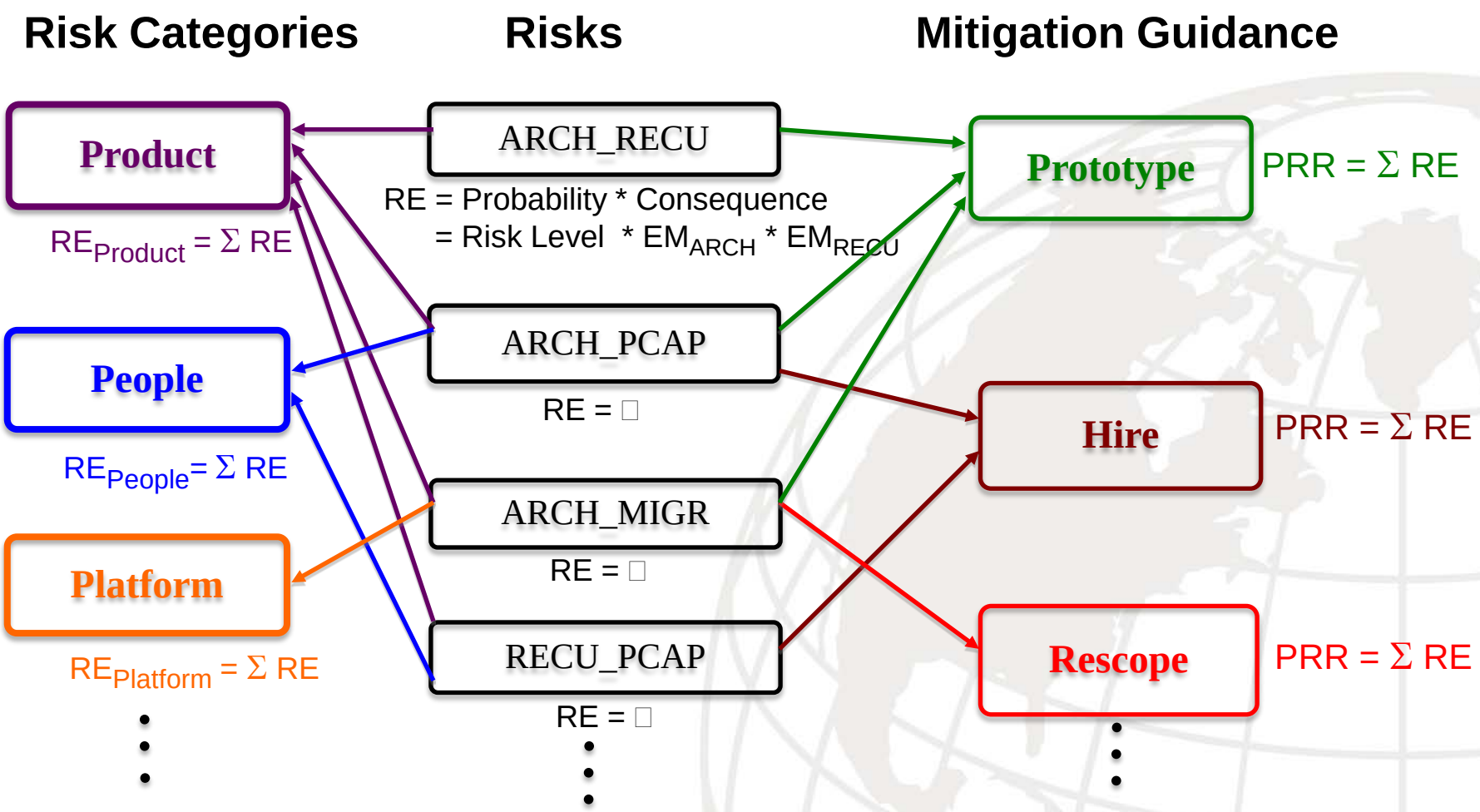
$$= \sum_{j=1}^{\#categories} \sum_{i=1}^{\#category\ risks} \text{risk probability weight}_{i,j} * \text{effort multiplier product}_{i,j}$$

where risk probability weight =

1	moderate
2	high
4	very high

effort multiplier product=
(driver #1 effort multiplier) * (driver #2 effort multiplier) ... * (driver #n effort multiplier).

Risk Network



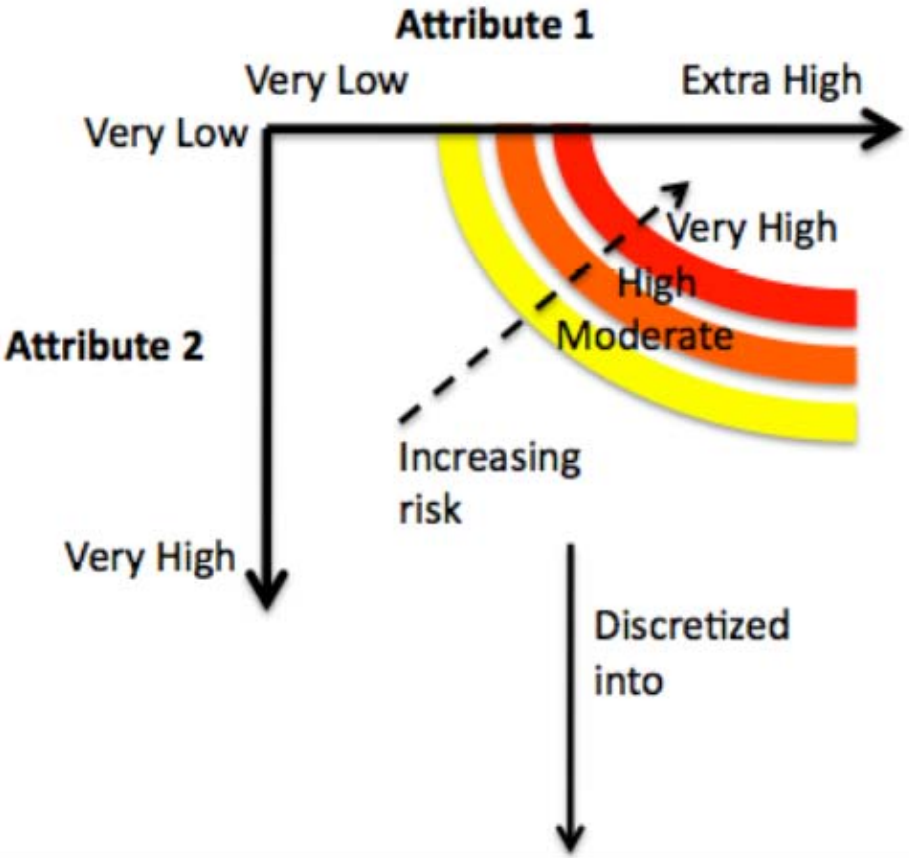
RE = Risk Exposure
PRR = Potential Risk Reduction

Risk Probability Weights

- Non-linear risk probability weights account for fine grained conditions
- Weighting matrices represent iso-risk contours between cost factors:

Requirements Understanding \ Architecture Understanding	Very Low	Low	Nominal	High	Very High
Very Low	4	2	1	0	0
Low	2	1	0	0	0
Nominal	1	0	0	0	0
High	0	0	0	0	0
Very High	0	0	0	0	0

Assignment of Risk Probability Levels



		Attribute 1					
		Very Low	Low	Nominal	High	Very High	Extra High
	Very Low				Moderate	High	Very High
	Low					Moderate	High
Attribute 2	Nominal						Moderate
	High						
	Very High						

Expert COSYSMO Inputs

Expert COSYSMO - Systems Engineering Cost Model Risk Advisor

Model(s): COSYSMO
Monte Carlo Risk: Off
Auto Calculate: Off

System Size

	Easy	Nominal	Difficult
# of System Requirements	19	14	88
# of System Interfaces	4	11	1
# of Algorithms	19	23	16
# of Operational Scenarios	6	7	2

System Cost Drivers

Requirements Understanding	Low	Documentation	High	Personnel Experience/Continuity	Low
Architecture Understanding	Low	# and Diversity of Installations/Platforms	Nominal	Process Capability	Nominal
Level of Service Requirements	Very High	# of Recursive Levels in the Design	High	Multisite Coordination	Nominal
Migration Complexity	Nominal	Stakeholder Team Cohesion	Low	Tool Support	Very Low
Technology Risk	High	Personnel/Team Capability	Very Low		

System Labor Rates

Cost per Person-Month (Dollars): 10000

Calculate

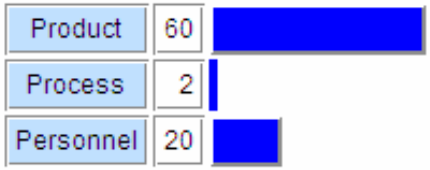
Expert COSYSMO Outputs

Systems Engineering Effort = 3635 Person-months

Effort Distribution (Person-Months)

Phase / Activity	Conceptualize	Develop	Operational Test and Evaluation	Transition to Operation
Acquisition and Supply	71.3	129.8	33.1	20.4
Technical Management	136.0	234.9	154.5	92.7
System Design	370.9	436.3	185.4	98.2
Product Realization	70.9	163.6	174.5	136.3
Product Evaluation	202.9	304.3	450.9	169.1

Risk Summary



Prioritized Risks

High	Medium	Low
requ_arch	requ_serv	requ_team
arch_trsk	requ_migr	requ_serv
arch_pexp	requ_trsk	requ_serv
	arch_serv	requ_serv
	arch_migr	requ_serv
	arch_team	arch_tool
	serv_trsk	serv_migr
	serv_team	serv_pexp
	migr_trsk	serv_tool
	migr_pexp	migr_team
		migr_tool
		trsk_team
		trsk_pexp
		trsk_tool

Risk Mitigation Outputs

- Guidance items ordered by risk exposure:

Risk Mitigation Guidance

The risk mitigation guidance below shows alternatives for consideration in specific project environments.

Risk Exposure Points	Description	Alternatives
12.9	Requirements Understanding = Very Low *and* Level of Service Requirements = Very High	Get customer involvement early, do trade studies, prioritize requirements
4.9	Requirements Understanding = Very Low *and* Technology Risk = High	Get customers involved, early prototypes, do trade studies, prioritize requirements
4.6	Level of Service Requirements = Very High *and* Technology Risk = High	Mature technology to meet 'illities or any other level of service requirements
4.2	Level of Service Requirements = Very High *and* Stakeholder Team Cohesion = Low	Put people with experience working together to meet the high 'illities
1.9	Requirements Understanding = Very Low	Subcontract, prioritize requirements

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Process and Measurement Frameworks

- Expert COSYSMO implements best practices in frameworks such as the Capability Maturity Model Integration (CMMI) and Practical Software and System Measurement (PSM).
  - Provides practical, concrete artifacts for managing processes and projects
- The duality of Expert COSYSMO in cost estimation and risk management using objective measurements supports many of the CMM-I key process areas.
- Provides Systems Engineering Leading Indicators for continuous usage throughout lifecycle

CMMI Implementation

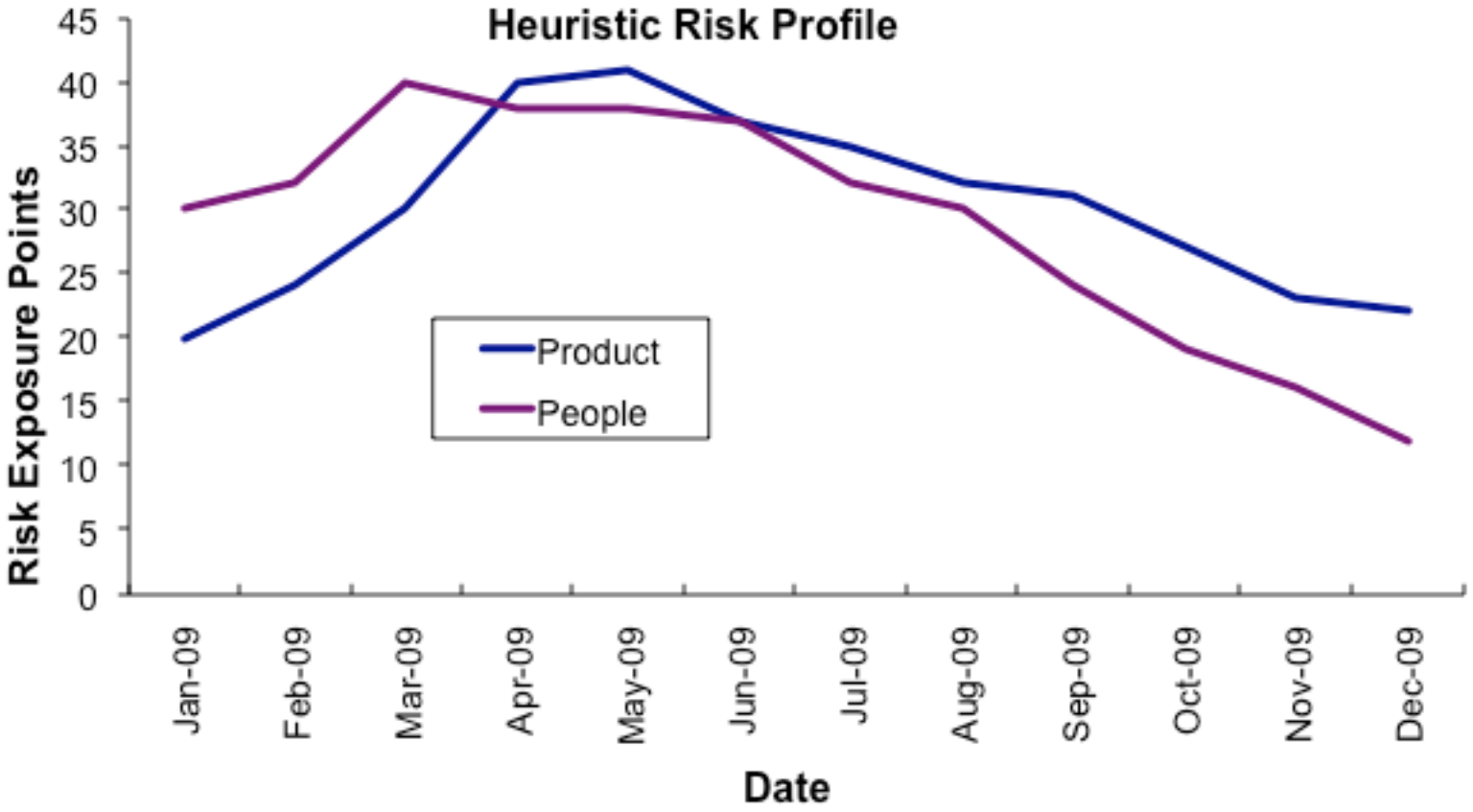
- Expert COSYSMO is a primary enabler for best practices in the **Project Planning** and **Risk Management** process areas
  - **Project Planning (PP)** establishes and maintains plans that define project activities.
  - **Risk Management (RSKM)** identifies potential problems before they occur so that risk-handling activities can be planned and invoked as needed across the life of the product or project to mitigate adverse impacts on achieving objectives.
- Provides essential support for **Decision Analysis and Resolution** and **Measurement and Analysis**
  - **Decision Analysis and Resolution (DAR)** analyzes decisions using a formal process that evaluates identified alternatives against established criteria.
  - **Measurement and Analysis (MA)** develops and sustains a measurement capability that is used to support management information need.
- We have created a detailed mapping to specific CMMI practices

Systems Engineering Leading Indicators

- The *Systems Engineering Leading Indicator Guide v. 1.0* focuses on leading indicators for evaluating the goodness of systems engineering on a program
- A leading indicator may be an individual measure, or collection of measures, that are predictive of future system performance before the performance is realized.
- Expert COSYSMO provides indicator data for Risk Exposure Trends and Risk Handling Trends

Risk Exposure Trends

- Heuristic risk profile can be tracked at different levels of risk taxonomy

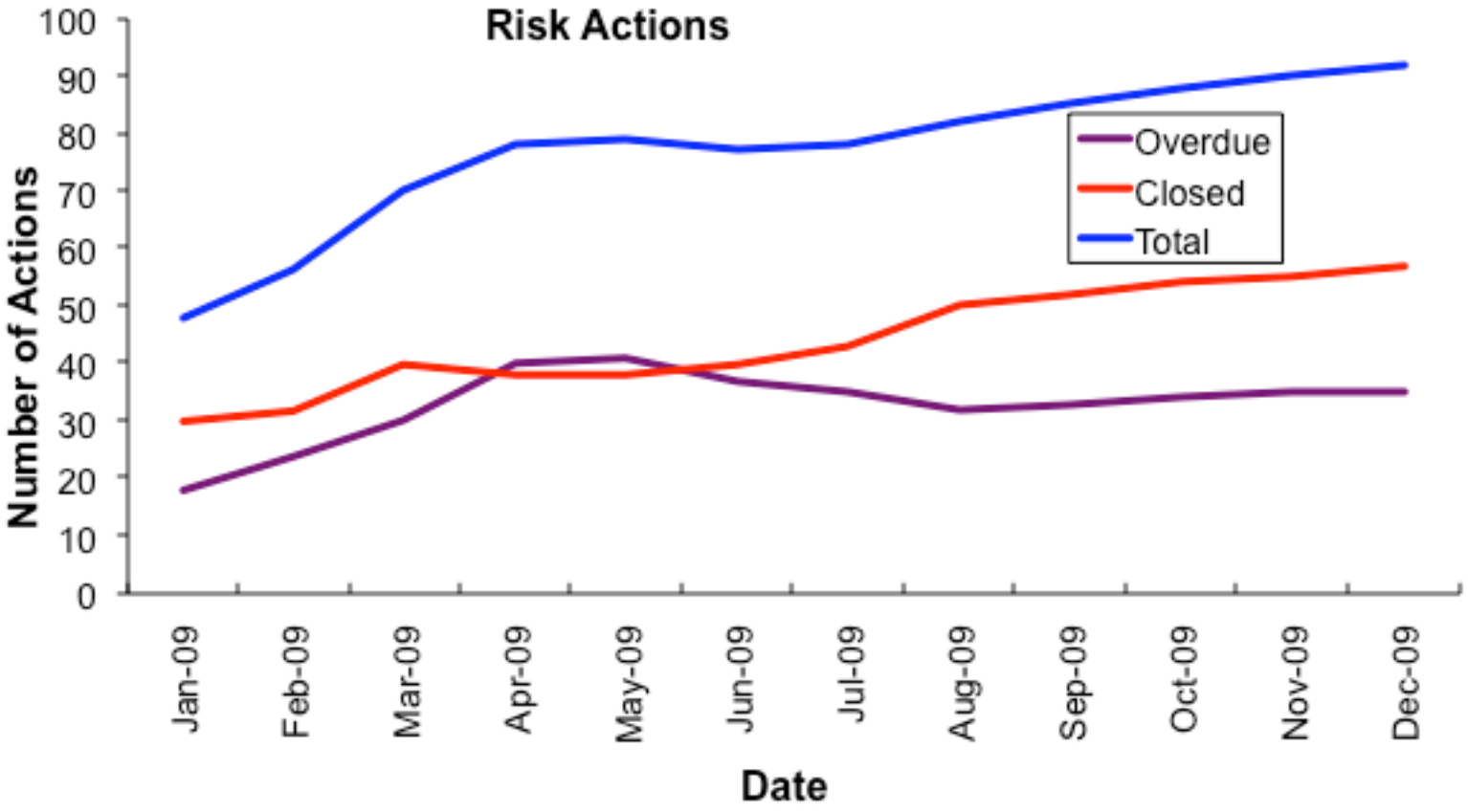


Risk Exposure Trends (cont.)

- Risk burndown tracked as mitigation actions are executed and other changes occur

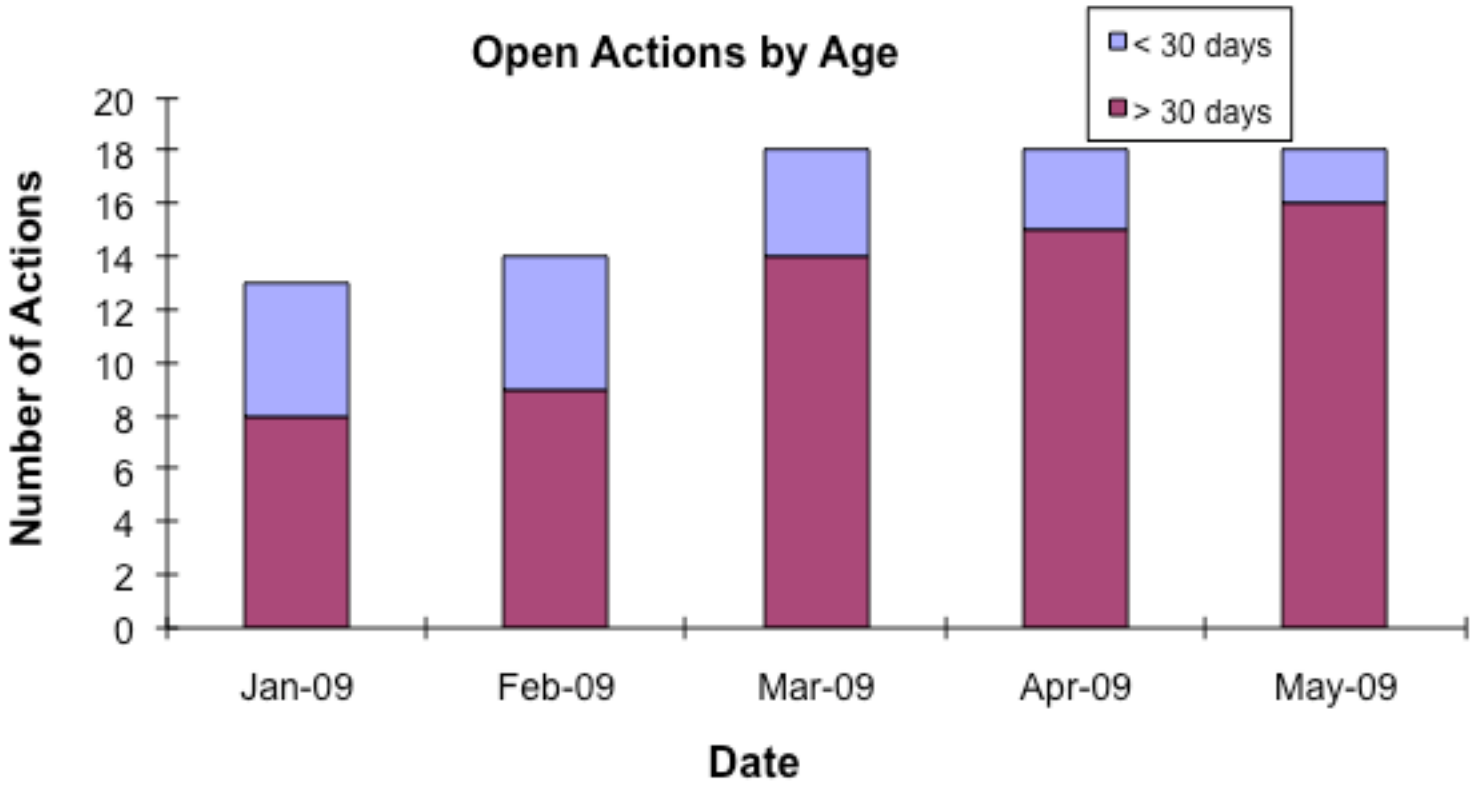
Risk Handling Trends

- Tracking guidance action item trends



Risk Handling Trends (cont.)

- Guidance action item statuses by age



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Current and Future Work

- Adding size-related and COSYSMO 2.0 reuse risks
- Refactoring the guidance portion of the risk network so individual PRRs are automatically calculated
- Linking to other Systems Engineering Effectiveness Measure tools
  - Expert COSYSMO provides feasibility evidence artifacts with estimate rationale
- Add rules to detect COSYSMO input anomalies
- Considering 3-way risk interactions
- Collect and analyze empirical systems engineering risk data from projects to enhance and refine the technique
  - Perform statistical testing
- Domain experts from industry and government will continue to provide feedback and clarification
  - Supporting surveys and workshops will be continued

References

- Madachy R., *Heuristic Risk Assessment Using Cost Factors*, IEEE Software, May 1997
- Madachy, R. and Valerdi R., *Knowledge-Based Systems Engineering Risk Assessment*, University of Southern California Center for Systems and Software Engineering Technical Report, USC-CSSE-2008-818
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- Software Engineering Institute, *CMMI for Development*, *Version 1.2*, Technical Report CMU/SEI-2006-TR-008, 2008
- Valerdi R., *The Constructive Systems Engineering Cost Model (COSYSMO)*, PhD Dissertation, University of Southern California, Los Angeles, CA, May 2005

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CMMI Backup Charts

Project Planning Goal/Practice Coverage

- SG 1 Establish Estimates
  - SP 1.1 Estimate the Scope of the Project
  - **SP 1.2 Establish Estimates of Work Product and Task Attributes**
    - System work breakdown described in cost model elements with attributes
  - SP 1.3 Define Project Lifecycle
  - **SP 1.4 Determine Estimates of Effort and Cost**
    - Based on estimation rationale using models and historical data
- SG 2 Develop a Project Plan
  - **SP 2.1 Establish the Budget and Schedule**
    - Based on the developed estimates to ensure that budget allocation, task complexity, and task dependencies are addressed

Project Planning (cont.)

- **SP 2.2 Identify Project Risks**
- Identify and analyze project risks to support project planning including:
  - Identifying risks
  - Analyzing the risks to determine the impact, probability of occurrence
  - Prioritizing risks
- SP 2.3 Plan for Data Management
- SP 2.4 Plan for Project Resources
- SP 2.5 Plan for Needed Knowledge and Skills
- SP 2.6 Plan Stakeholder Involvement
- SP 2.7 Establish the Project Plan

- SG 3 Obtain Commitment to the Plan
  - SP 3.1 Review Plans that Affect the Project
  - SP 3.2 Reconcile Work and Resource Levels
- SP 3.3 Obtain Plan Commitment

Risk Management Goal/Practice Coverage

- SG 1 Prepare for Risk Management
  - SP 1.1 Determine Risk Sources and Categories
    - Provides a risk taxonomy with risk sources
  - SP 1.2 Define Risk Parameters
  - SP 1.3 Establish a Risk Management Strategy
- SG 2 Identify and Analyze Risks
  - SP 2.1 Identify Risks
    - Automates a risk identification checklist
  - SP 2.2 Evaluate, Categorize, and Prioritize Risks
    - Categorizes and quantifies risks with expert knowledge-base
- SG 3 Mitigate Risks
  - SP 3.1 Develop Risk Mitigation Plans
    - Identifies beginning risk mitigation actions for further exploration and implementation
  - SP 3.2 Implement Risk Mitigation Plans

Other Process Area Support

- The Expert COSYSMO method comprises measurements that may be specified and implemented for the **Measurement and Analysis** process area
- Provides quantitative evaluation methods for usage in **Decision Analysis and Resolution**
  - Various decisions based on Risk Exposures and Potential Risk Reductions of actions (to be coupled with costs of actions)
- May also provide management data for **Quantitative Project Management (QPM)** that formally monitors measurements for achieving project and process objectives