

Using Cost Models to Capture Project Risk: A Knowledge-Based Approach

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We Share A Goal: Enterprise Excellence

NORTHROP GRUMMAN

BOEING

LOCKHEED MARTIN

**Rockwell
Collins**



Raytheon

USA
United Space Alliance



LAI 
LEAN ADVANCEMENT INITIATIVE™



ULA
United Launch Alliance



 **Pratt & Whitney**
A United Technologies Company

BAE SYSTEMS

 **Sikorsky**
A United Technologies Company

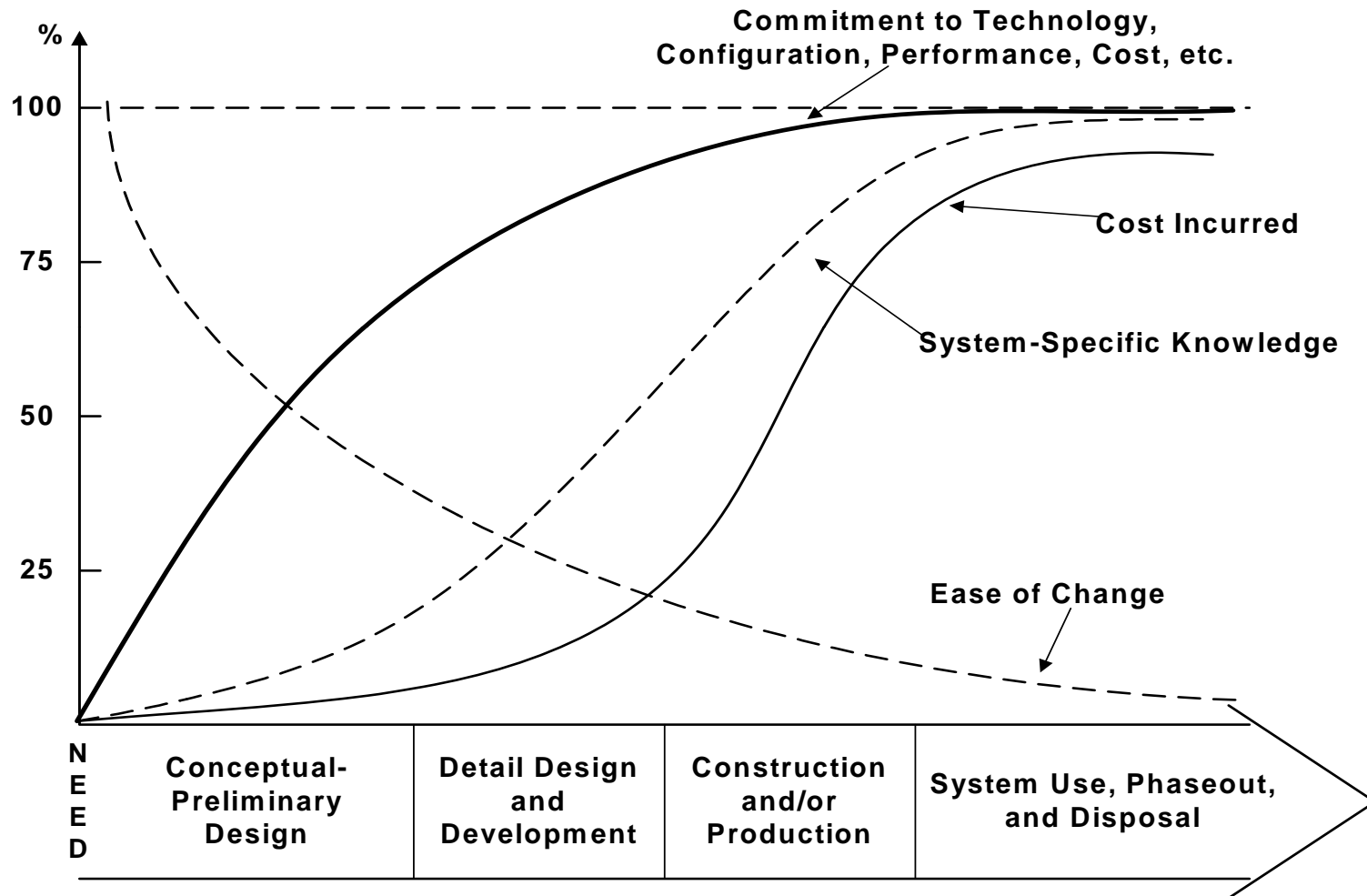




Risk Assessment Lessons Learned in the U.S. Department of Defense

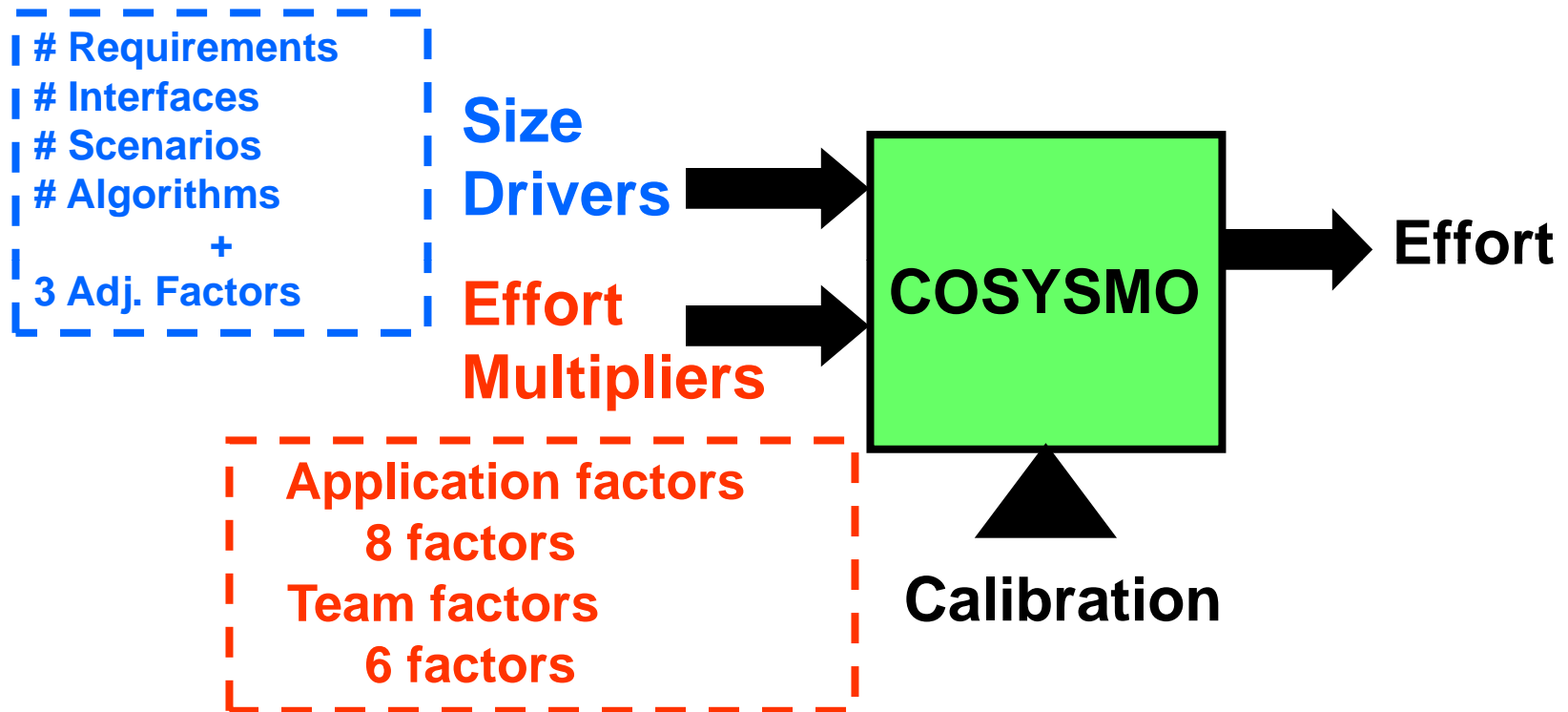
1. **Systems engineering** can be the blessing or the curse
 - Resource estimation methods are being developed
2. **Technology maturity** and **requirements stability** are controllable risks
 - Cost models help understand this relationship
3. **People** risks are often underestimated
 - Experience and capability are not interchangeable
4. By the **time** the risk is identified, it's too late!
 - Need leading indicators (not lagging indicators)

Cost Commitment on Projects



Blanchard, B., Fabrycky, W., *Systems Engineering & Analysis*, Prentice Hall, 1998.

Constructive Systems Engineering Cost Model



Systems Engineering Processes

EIA/ANSI 632, *Processes for Engineering a System* (1999).

- **Acquisition and Supply**
 - Supply Process
 - Acquisition Process
- **Technical Management**
 - Planning Process
 - Assessment Process
 - Control Process
- **System Design**
 - Requirements Definition Process
 - Solution Definition Process
- **Product Realization**
 - Implementation Process
 - Transition to Use Process
- **Technical Evaluation**
 - Systems Analysis Process
 - Requirements Validation Process
 - System Verification Process
 - End Products Validation Process



COSYSMO Data Sources

Boeing	<i>Integrated Defense Systems (Seal Beach, CA)</i>
Raytheon	<i>Intelligence & Information Systems (Garland, TX)</i>
Northrop Grumman	<i>Mission Systems (Redondo Beach, CA)</i>
Lockheed Martin	<i>Transportation & Security Solutions (Rockville, MD) Integrated Systems & Solutions (Valley Forge, PA) Systems Integration (Owego, NY) Aeronautics (Marietta, GA) Maritime Systems & Sensors (Manassas, VA; Baltimore, MD; Syracuse, NY)</i>
General Dynamics	<i>Maritime Digital Systems/AIS (Pittsfield, MA) Surveillance & Reconnaissance Systems/AIS (Bloomington, MN)</i>
BAE Systems	<i>National Security Solutions/ISS (San Diego, CA) Information & Electronic Warfare Systems (Nashua, NH)</i>
SAIC	<i>Army Transformation (Orlando, FL) Integrated Data Solutions & Analysis (McLean, VA)</i>
L-3 Communications	<i>Greenville, TX</i>


Policy & Contracts



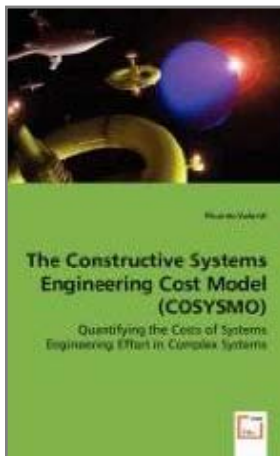
Commercial Implementations



COSYSMO Model


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


10 Academic Theses



Proprietary Implementations

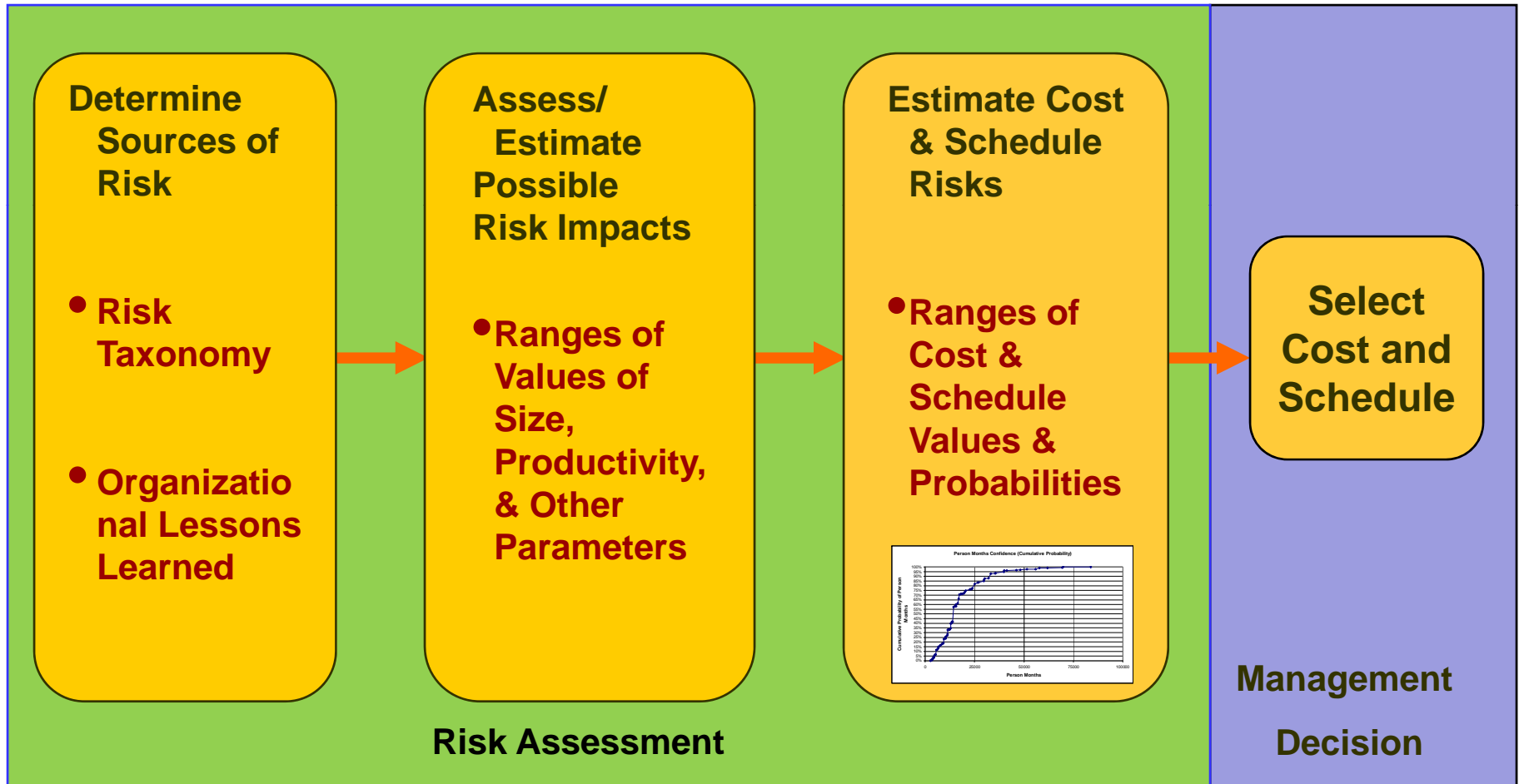
- SEEMaP
- COSYSMO-R
- SECOST
- Systems Eng. Cost Tool



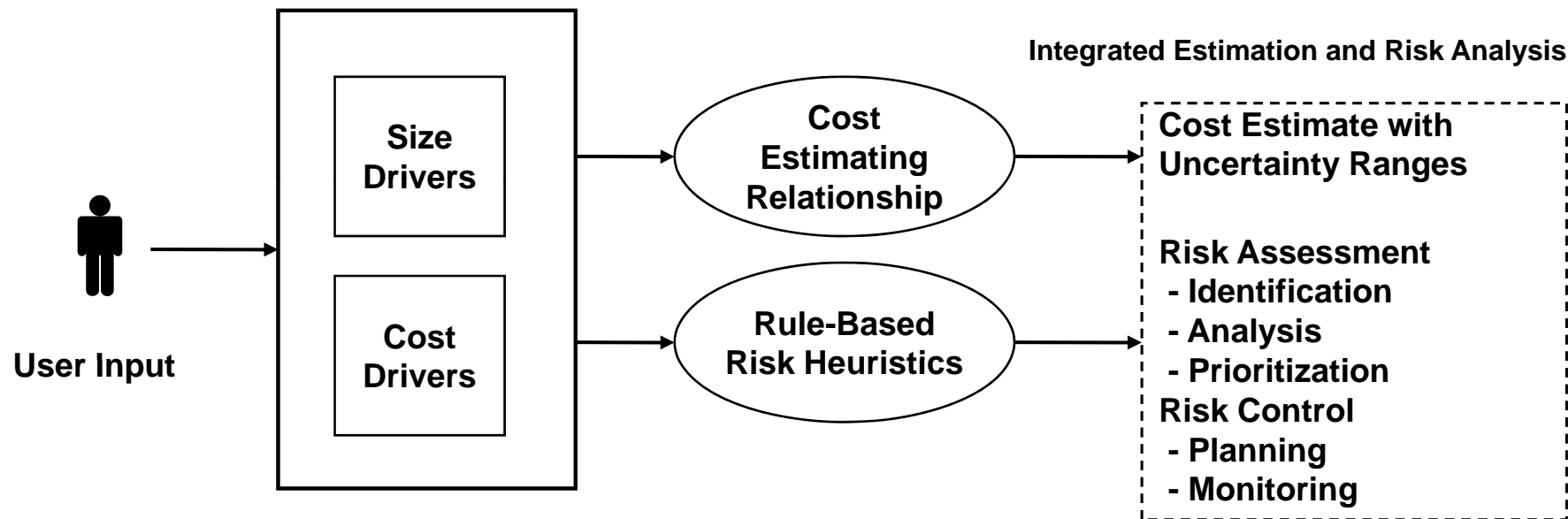
Academic Curricula



Traditional Cost and Schedule Risk Estimation



Expert COSYSMO Operation



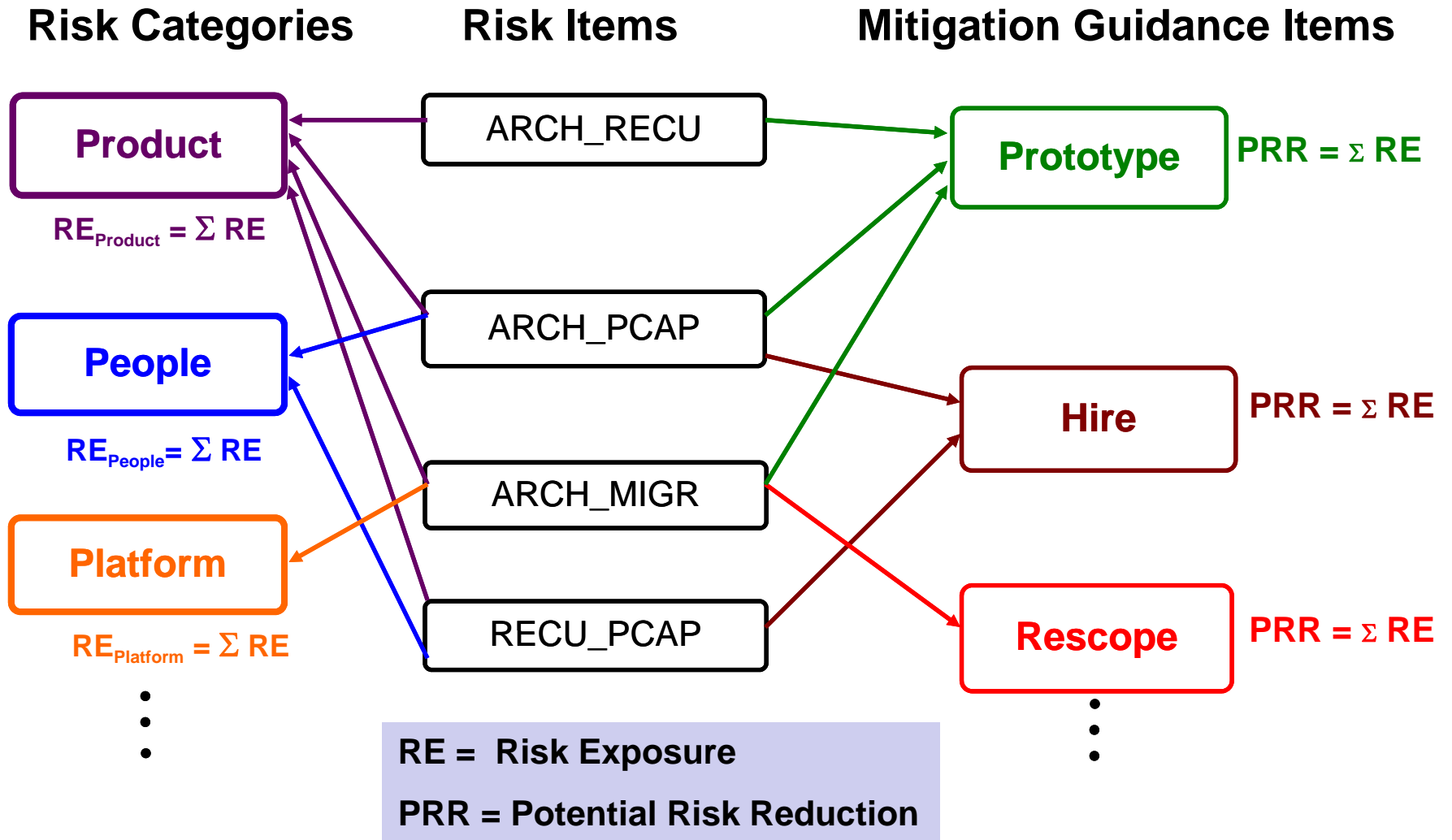
Madachy, R. & Valerdi, R., Knowledge-Based Risk Assessment for Systems Engineering: Expert COSYSMO, working paper, 2009.

Initial Risk Conditions

	SIZE	RQMT	ARCH	LSVC	MIGR	TRSK	DOCU	INST	RECU	TEAM	PCAP	PEXP	PROC	SITE	TOOL
SIZE (REQ + INTF + ALG + OPSC)		21	21	9	12	5	4	7	10	8	9	11	7	6	7
Requirements Understanding			17	9	7	8	3	5	9	5	10	8	5	4	1
Architecture Understanding				9	10	12	3	7	11	6	11	11	5	6	4
Level of Service Requirements (the ilities)					5	7	4	5	3	6	4	4	2	3	2
Migration Complexity (legacy system considerations)						8	1	10	1	4	7	7	3	5	4
Technology Risk (maturity of technology)							2	8	6	4	9	5	3	3	5
Documentation match to life cycle needs								2	3	4	4	2	6	2	3
Number and Diversity of Installations or Platforms									4	3	5	6	4	8	5
Number of Recursive Levels in the Design										4	8	7	7	2	5
Stakeholder Team Cohesion											7	9	3	8	3
Personnel/team capability												12	9	8	5
Personnel Experience and Continuity													10	8	3
Process Capability														5	8
Multisite Coordination															8
Tool Support															

high risk small x = 0.5; big X = 1
 medium risk n = 19
 low risk

Valerdi, R. & Gaffney, J., Reducing Risk and Uncertainty in COSYSMO Size and Cost Drivers: Some Techniques for Enhancing Accuracy, 5th Conference on Systems Engineering Research, Hoboken, NJ, March 2007.



Madachy, R. & Valerdi, R., Knowledge-Based Risk Assessment for Systems Engineering: Expert COSYSMO, working paper, 2009.

Expert COSYSMO - Constructive Systems Engineering Cost Model Risk Advisor

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

Expert COSYSMO
Constructive Systems Engineering Cost Model Risk Advisor

System Size

	Easy	Nominal	Difficult
# of System Requirements	10	14	8
# of System Interfaces	4	11	3
# of Algorithms	10	23	16
# of Operational Scenarios	6	7	2

Cost Drivers

Requirements Understanding	Low	Documentation	Nominal	Personnel Experience/Continuity	Very 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	Low	Multisite Coordination	Nominal
Migration Complexity	Very High	Stakeholder Team Cohesion	Very Low	Tool Support	Very Low
Technology Risk	High	Personnel/Team Capability	Nominal		

Diagram: A flowchart showing inputs to the COSYSMO model. On the left, a dashed blue box labeled "Size Drivers" contains: # Requirements, # Interfaces, # Scenarios, # Algorithms, and 3 Adj. Factors. Below it, a dashed red box labeled "Effort Multipliers" contains: Application factors (8 factors) and Team factors (6 factors). Arrows from these boxes point to a central green box labeled "COSYSMO". A "Calibration" arrow also points to the COSYSMO box. The output of the COSYSMO box is labeled "Effort".

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




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

Product	60	
Process	2	
Personnel	20	

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

Outputs - Risk Mitigation Advice

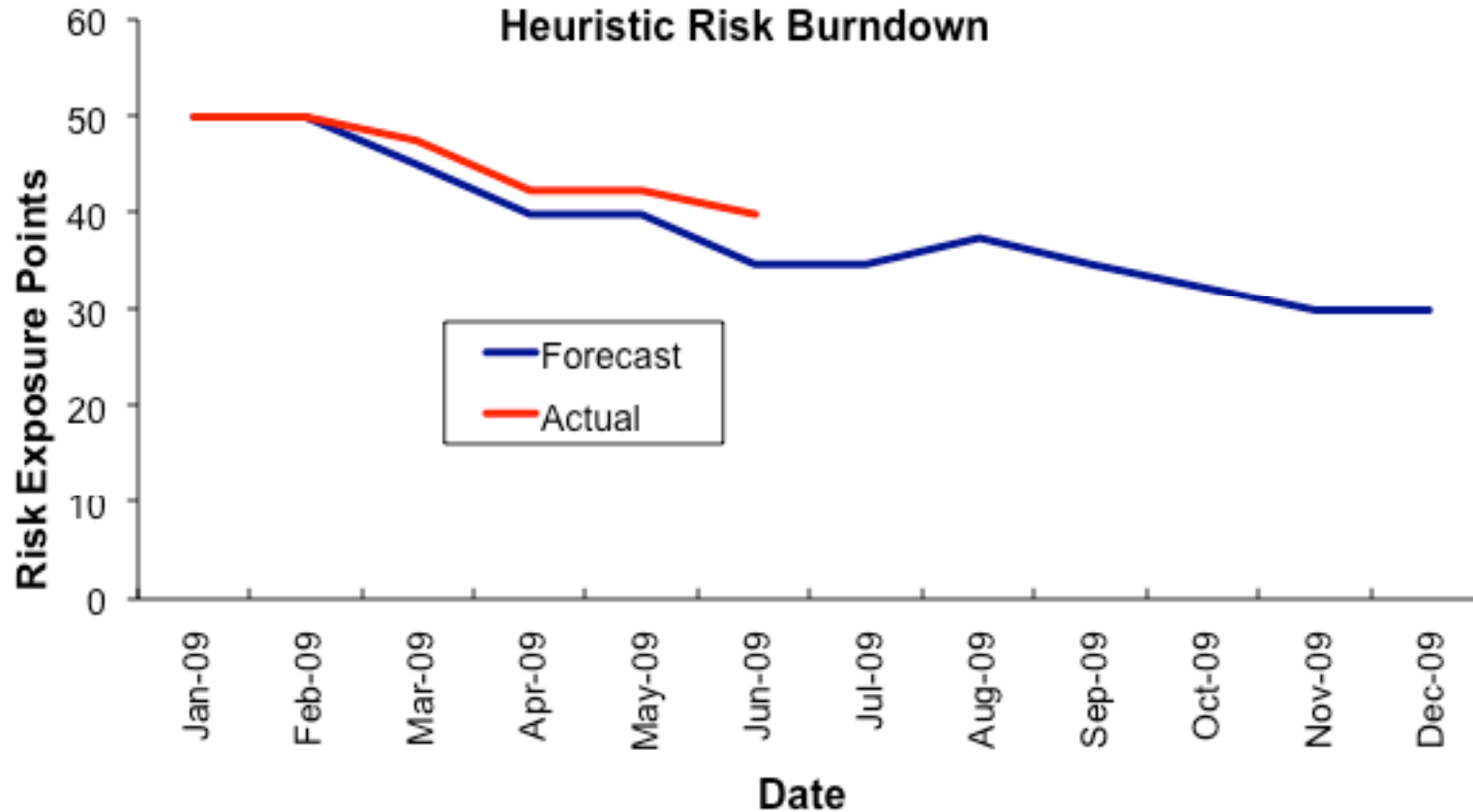
Risk Mitigation Guidance

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

Risk Severity	Description	Alternatives
High	Requirements Understanding = Very Low <i>and</i> Architecture Understanding = Very Low	Subcontract, prioritize requirements, cancel project
High	Architecture Understanding = Very Low <i>and</i> Technology Risk = Very High	Early prototyping, trade studies, negotiation on priorities
High	Architecture Understanding = Very Low <i>and</i> Personnel Experience/Continuity = Very Low	Hire experts, establish educational benefits, conduct training

Risk Exposure Trends as Leading Indicators

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





Publicly Available Resources

- U.S. General Accountability Office (<http://gao.gov/>)
 - Investigative arm of the U.S. Congress
- RAND Corporation (<http://rand.org/>)
 - Public think tank
 - “Managing Risk in USAF Force Planning”
- Defense Acquisition University (<https://acc.dau.mil>)
 - One of several U.S. Military Universities
 - “DoD Risk Management Guidebook “