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Quantifying Systems Engineering Reuse

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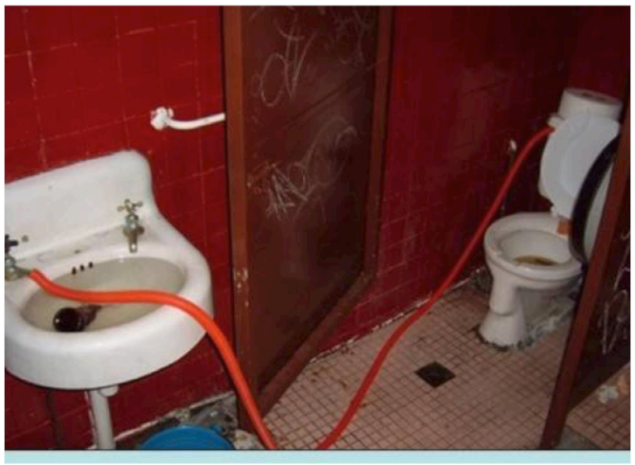
A Jolly Old (INCOSE) Fellow
Congratulations, Garry!

Discussion Points

- Problem and motivations
- Generalized Reuse Framework
  - *Design **With** Reuse*
  - *Design **For** Reuse*
- Quantifying the Reuse Framework in COSYSMO
- Calibrating the model
- Conclusion and future work

Contrastable Manners of Reuse

- Ad Hoc / Opportunistic Reuse
  - Search & discover reusable resources
  - Adapt to current application
  - Deal with problems
  - E.g., “Code scavenging”
- Planned / Systematic Reuse
  - Strategy, portfolio and roadmap
  - Explicit processes and standards
  - Investment in reusable resources



Problem & Motivations

- Reuse has been focusing on leveraging previous artifacts in order to save labor, with an inherent *assumption* that there's something there to reuse in the first place
- However, product line decision makers today need to consider:
  - Cost to develop artifacts
  - How to materialize the artifacts in future products
  - Modifications or additional costs required
  - Cost vs. benefit
- We want to be able to assess not only the effort to *leverage* but also the effort to *invest*
- The goal is an effective tool for design sensitivity analysis and product line investment decisions

Two Fundamental Reuse Processes

Development For Reuse (DFR)

- Producer's View
- Production of reusable resources

Development With Reuse (DWR)

- Consumer's View
- Consumption of reusable resources

Key is How to Plan and Balance Both in a Development Project

Contrasting DWR and DFR

	Development with Reuse (DWR)	Development for Reuse (DFR)
Role	Consumer	Producer
Purpose	Consumption of reusable resources	Production of reusable resources
Goal	• Improving product quality • Cost savings • Time to market	• Investment for future benefits • Product line, lifecycle strategies
Challenges	• Discovery of what to reuse • Decisions on how to tailor and integrate	• Plans for how to reuse • Design for reusability • Means to verify
Reusability	• If ad hoc, then generally low • If planned, then generally high	• Generally high, if done right

Developing for Product Line In a Project

- Project activities in two-fold:
  - Develop & deploy target system
  - Invest in product line (for future target systems)

Total Project Effort

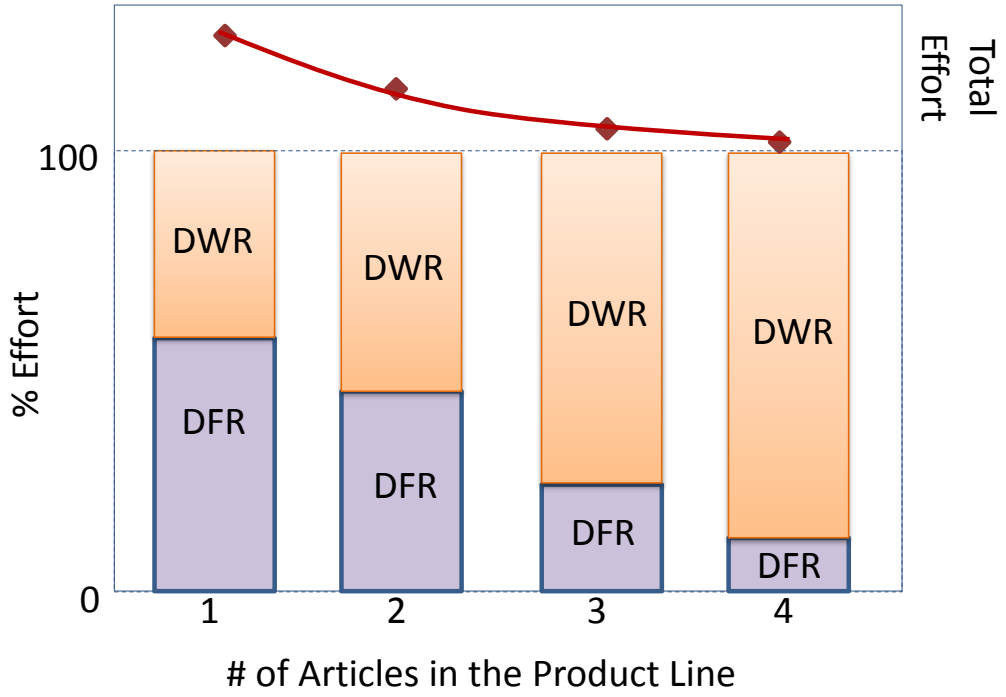
=

DWR Effort

+

DFR Effort

Product Line Benefits of Reuse

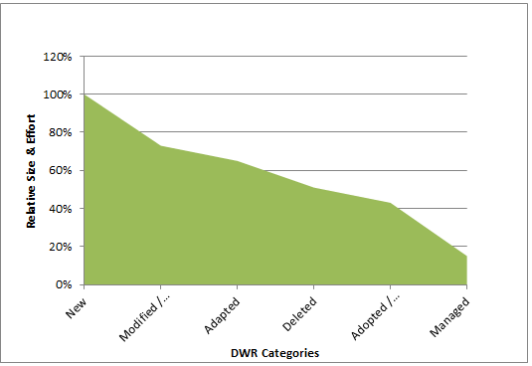


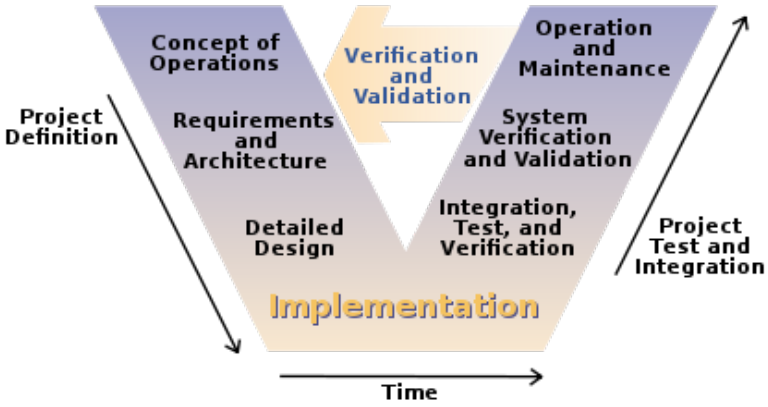
Investments in Development for Reuse (DFR) are leveraged to reduce Product Line Cost

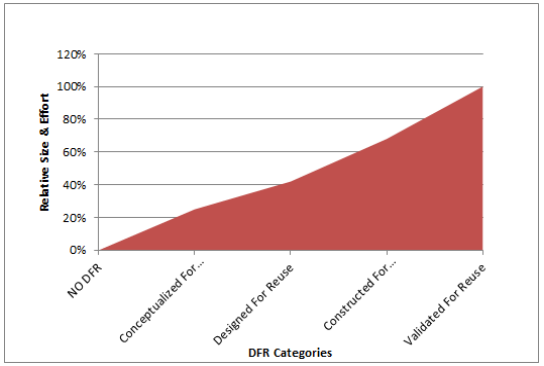
Reuse Framework - Definitions

- **DWR Categories**:
  - New
  - Modified / Implemented
  - Adapted
  - Deleted
  - Adopted / Integrated
  - Managed

- **DFR Categories**:
  - No DFR
  - Conceptualized For Reuse
  - Designed For Reuse
  - Constructed For Reuse
  - Validated For Reuse





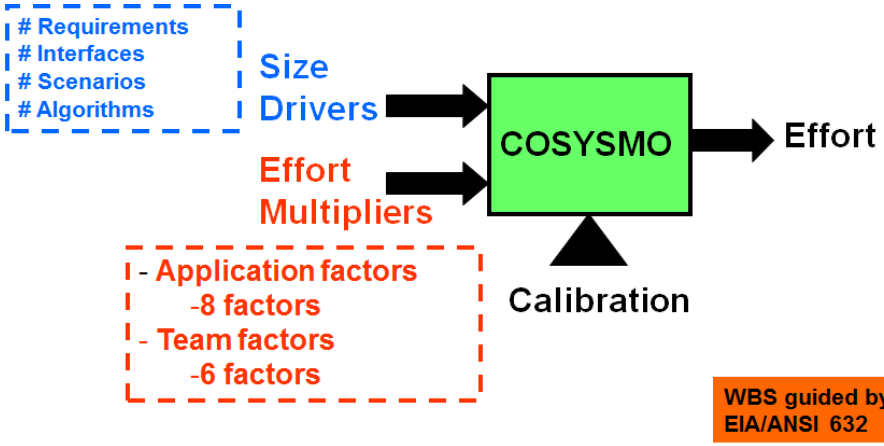


e: the weights shown are notional

Interfacing DWR and DFR

Reusability from DFR Produces	Reusable Resources	Reused by DWR with Effort
Conceptualized for Reuse	System Concept Definition	• ***New***
Conceptualized for Reuse	Logical Architecture	• ***New***
Designed for Reuse	Physical Architecture (intended for built to print)	• ***New***, if architectural modification required • ***Implemented***, if no modification required
Constructed for Reuse	Constructed Product/Component	• ***Modified***, if architectural modification required • ***Adapted***, if tailoring needed for integration • ***Adopted***, if only integration and testing required
Validated for Reuse	Validated Product/Component	• ***Modified***, if architectural modification required • ***Adapted***, if tailoring needed for integration • ***Adopted***, if only integration and testing required • ***Managed***, if limited testing required

COSYSMO



- COSYSMO
  - COnstructive SYStems Engineering Cost MOdel
  - Parametric Estimate of the Systems Engineering Effort
  - Covers full systems engineering lifecycle
  - Originally developed by Dr. Ricardo Valerdi and Dr. Barry Boehm at USC

- Inception of COSYSMO 1.0
  - Valerdi, R., The Constructive Systems Engineering Cost Model (COSYSMO), PhD Dissertation, University of Southern California, May 2005.
- Introduced the Reuse Model Extension to COSYSMO 2.0
  - Wang, G., Valerdi, R., Ankrum, A., Millar, C., and Roedler, G., "COSYSMO Reuse Extension," Proceedings of the 18th INCOSE International Symposium, June 2008.
  - Fortune, J. Estimating Systems Engineering Reuse with the Constructive Systems Engineering Cost Model (COSYSMO 2.0). Ph.D. Dissertation. University of Southern California. December 2009
  - Wang, G., Valerdi, R., Fortune, J., "Reuse in Systems Engineering," IEEE System Journal, v4, No.3, 2010.
- Marching to COSYSMO 3.0 (work in progress…)
  - Fortune, J. and Valerdi, R., "Considerations for Successful Reuse in Systems Engineering," AIAA Space 2008, San Diego, CA, September 2008.
  - Wang, G. and Rice, J., "Considerations for a Generalized Reuse Framework for System Development," Proceedings of the 21st INCOSE International Symposium, June 2011.
  - Peña, M. Quantifying the Impact of Requirements Volatility on Systems Engineering Effort. Ph.D. Dissertation. University of Southern California. August 2012.
  - Fortune, J. and Valerdi, R., "A Framework for Systems Engineering Reuse," Systems Engineering, 16(2), 2013.

Quantifying Reuse Framework in Extended COSYSMO (3.0)

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$$Project\ Effort = DWR\ Effort\ +\ DFR\ Effort$$

$$PM_{DWR+DFR} = A_1 \cdot \left[\sum_k \left(\sum_r w_r \left(w_{e,k} \Phi_{e,k} + w_{n,k} \Phi_{n,k} + w_{d,k} \Phi_{d,k} \right) \right) \right]^{E_1} \cdot CEM_1$$

$$+ A_2 \cdot \left[\sum_k \left(\sum_q w_q \left(w_{e,k} \Psi_{e,k} + w_{n,k} \Psi_{n,k} + w_{d,k} \Psi_{d,k} \right) \right) \right]^{E_2} \cdot CEM_2$$

Where:
PM_{DWR} = effort in Person Hours/Months (Nominal Schedule)
A_1 = DWR constant derived from historical project data
k = {REQ, IF, ALG, SCN}
r = {New, Implemented, Modified, Deleted, Adopted, Managed}
w_r = weight for defined levels of size driver reuse
w_x = weight for "easy", "nominal", or "difficult" size driver
Φ_x = quantity of "k" size driver
E_1 = represents diseconomy of scale in DWR
CEM_1= composite effort multiplier for DWR

Where:
PM_{DFR} = effort in Person Hours/Months (Nominal Schedule)
A_2 = DFR constant derived from historical project data
k = {REQ, IF, ALG, SCN}
q = {Conceptualized, Designed, Built, Validated}
w_r = weight for defined levels of size driver reuse
w_x = weight for "easy", "nominal", or "difficult" size driver
Φ_x = quantity of "k" size driver
E_2 = represents diseconomy of scale in DFR
CEM_2 = composite effort multiplier for DFR

Example Scenario #1 – Modification of Fielded System

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Modification of Fielded System:

- *There are 20 heritage requirements that were previously Designed for Reuse and are satisfied through the existing physical architecture*
- *The customer has decided to delete 10 requirements and levy 5 requirements that have not been previously analyzed*
- *The deletion of the requirements results in the modification of 3 of the 5 heritage interfaces*
- *There are no changes to the 3 heritage algorithms.*

DWR

COSYSMO System-level Cost Drivers:

- *New* system requirements:5
- *Modified* system requirements: 20
- *Deleted* system requirements: 10
- *New* system interfaces: 3
- *Modified* system interfaces: 2
- *Adopted* algorithms: 3

Example Scenario #2 – Refactoring For Reuse

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Standard API Development:

- *Generalize existing functionalities and services into reusable libraries with standardized APIs during the development of the current system, encapsulating*
  - *25 system requirements*
  - *7 system interfaces*
  - *2 system critical algorithms*
  - *And can potentially impact one operational sequence*

DFR

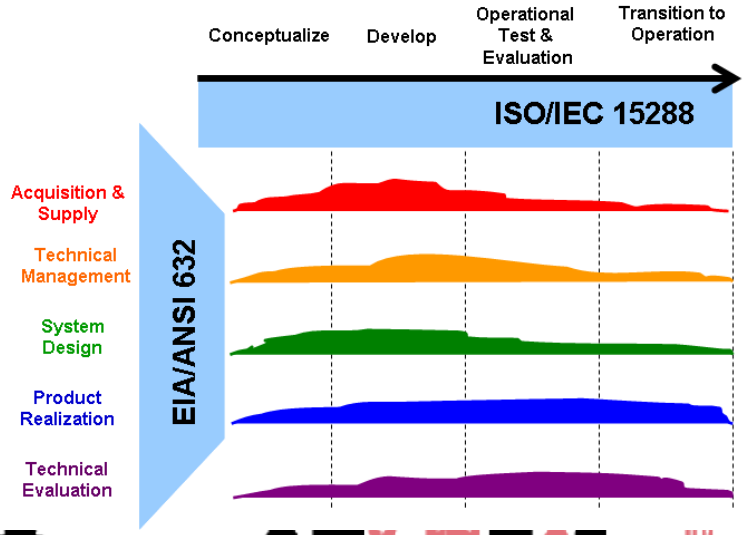
COSYSMO System-level Cost Drivers:

- *Validated for Reuse* Requirements: 25
- *Validated for Reuse* Interfaces: 7
- *Validated for Reuse* Algorithms: 2
- Adopted Op. Scenario: 1

Determining the Coefficients

$$PM_{DWR+DFR} = A_1 \cdot \left[\sum_k \left(\sum_r w_r \left(w_{e,k} \Phi_{e,k} + w_{n,k} \Phi_{n,k} + w_{d,k} \Phi_{d,k} \right) \right) \right]^{E_1} \cdot CEM_1$$

$$+ A_2 \cdot \left[\sum_k \left(\sum_q w_q \left(w_{e,k} \Psi_{e,k} + w_{n,k} \Psi_{n,k} + w_{d,k} \Psi_{d,k} \right) \right) \right]^{E_2} \cdot CEM_2$$



EIA 632 Fundamental Process	Phases			
	Conceptualize	Develop	Operational Test & Eval.	Transition To Operation
Acquisition & Supply	μ_{11}	μ_{12}	μ_{13}	μ_{14}
	1.96%	3.57%	0.91%	0.56%
Technical Management	μ_{21}	μ_{22}	μ_{23}	μ_{24}
	3.74%	6.46%	4.25%	2.55%
System Design	μ_{31}	μ_{32}	μ_{33}	μ_{34}
	10.20%	12.00%	5.10%	2.70%
Product Realization	μ_{41}	μ_{42}	μ_{43}	μ_{44}
	1.95%	4.50%	4.80%	3.75%
Technical Evaluation	μ_{51}	μ_{52}	μ_{53}	μ_{54}
	5.58%	8.37%	12.40%	4.65%

Delphi in Progress

- To correlate the reuse categories to SE activities

Categories of Reusable Artifacts Feeding into the DWR Process	==>	Concept / CONOPS	Logical Architecture	Physical Architecture	Developed Product Component	Deployed in End System	Physical Architecture	Developed Product Component	Deployed in End System	Developed Product Component	Deployed in End System	Product Component	Deployed in End System	Developed Product Component	Deployed in End System	Deployed in End System
EIA/ANSI 632 Process	*EIA/ANSI 632 Task*	*New*					*Modified / Implemented*			*Adapted*		*Deleted*		*Adopted*		*Managed*
Acquisition and Supply	1. Product Supply	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	2. Product Acquisition	x	x	x	x	x	x	x	x							
	3. Supplier Performance	x	x	x	x	x	x	x	x	x	x			x	x	x
Technical Management	4. Process Implementation Strategy	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	5. Technical Effort Definition	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	6. Schedule and Organization	x	x	x	x	x	x	x	x	x	x	x				
	7. Technical Plans	x	x	x	x	x	x	x	x	x	x	x				
	8. Work Directives	x	x	x	x	x	x	x	x	x	x	x				
	9. Progress Against Plans and Schedules	x	x	x	x	x	x	x	x	x	x	x				
	10. Progress Against Requirements	x	x	x	x	x	x	x	x	x	x	x				
	11. Technical Reviews	x	x	x	x	x	x	x	x	x	x	x				
	12. Outcomes Management	x	x	x	x	x	x	x	x	x	x	x				
	13. Information Dissemination	x	x	x	x	x	x	x	x	x	x	x				
System Design	14. Acquirer Requirements	x	x	x	x	x	x	x	x	x	x	x				
	15. Other Stakeholder Requirements	x	x	x	x	x	x	x	x	x	x	x				
	16. System Technical Requirements	x	x	x	x	x	x	x	x	x	x	x				
	17. Logical Solution Representations	x	x	x	x	x										
	18. Physical Solution Representations	x	x	x	x	x	x	x	x	x	x	x				
	19. Specified Requirements	x	x	x	x	x	x	x	x	x	x	x				
Product Realization	20. Implementation	x	x	x	x	x	x	x	x							
	20.a Integration	x	x	x	x	x	x	x	x	x	x	x				
	21. Transition to Use	x	x	x	x	x	x	x	x	x	x					
Technical Evaluation	22. Effectiveness Analysis	x	x	x	x	x	x	x	x							
	23. Tradeoff Analysis	x	x	x	x	x	x	x	x							
	24. Risk Analysis	x	x	x	x	x	x	x	x	x	x	x				
	25. Requirements Statements Validation	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
	26. Acquirer Requirements Validation	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
	27. Other Stakeholder Requirements Validation	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
	28. System Technical Requirements Validation	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
	29. Logical Solution Representations Validation	x	x	x	x	x										
	30. Design Solution Verification	x	x	x	x	x	x	x	x	x	x	x	x			
	31. End Product Verification	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
	32. Enabling Product Readiness	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
	33. End Products Validation	x	x	x	x	x	x	x	x	x	x	x	x	x	x	

Participants Needed!

Categories of Reusable Artifacts Coming Out of the DFR Process	==>	N/A	Concept / CONOPS	Logical Architecture	Physical Architecture	Developed Product Component	Deployed in End System
EIA/ANSI 632 Process	*EIA/ANSI 632 Task*	*No DFR*	*Conceptualized For Reuse*		*Designed For Reuse*	*Constructed For Reuse*	*Validated For Reuse*
Acquisition and Supply	1. Product Supply					x	x
	2. Product Acquisition					x	x
	3. Supplier Performance					x	x
	4. Process Implementation Strategy		x	x	x	x	x
	5. Technical Effort Definition		x	x	x	x	x
	dule and Organization		x	x	x	x	x
	ical Plans		x	x	x	x	x
	Directives		x	x	x	x	x
	ess Against Plans and Schedules		x	x	x	x	x
	gress Against Requirements		x	x	x	x	x
	hnical Reviews		x	x	x	x	x
	comes Management		x	x	x	x	x
	mation Dissemination		x	x	x	x	x
	uirer Requirements		x	x	x	x	x
	er Stakeholder Requirements		x	x	x	x	x
	tem Technical Requirements		x	x	x	x	x
	cal Solution Representations		x	x	x	x	x
	sical Solution Representations				x	x	x
	cified Requirements				x	x	x
	ementation					x	x
	sition to Use						x
Technical Evaluation	ctiveness Analysis		x	x	x	x	x
	leoff Analysis		x	x	x	x	x
	Analysis		x	x	x	x	x
	25. Requirements Statements Validation		x	x	x	x	x
	26. Acquirer Requirements Validation		x	x	x	x	x
	27. Other Stakeholder Requirements Validation		x	x	x	x	x
	28. System Technical Requirements Validation		x	x	x	x	x
	29. Logical Solution Representations Validation		x	x	x	x	x
	30. Design Solution Verification				x	x	x
	31. End Product Verification					x	x
	32. Enabling Product Readiness						x
	33. End Products Validation						x

Conclusion

- Described a generalized Reuse Framework with two complementary processes – DFR and DWR
- Defined a quantitative cost estimating relationship in extended COSYSMO
- Improved ability to conduct comprehensive cost trades for investment decisions and product line management
- Work in progress in calibrating the model
- Please join us by participating the Delphi
  - If interested, leave your business card with us at the end of this presentation!

Questions and Comments

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