Better Early Estimation of Human Systems Integration Effort as a Means of Reducing Life Cycle Cost

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What is HSI?

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History of HSI

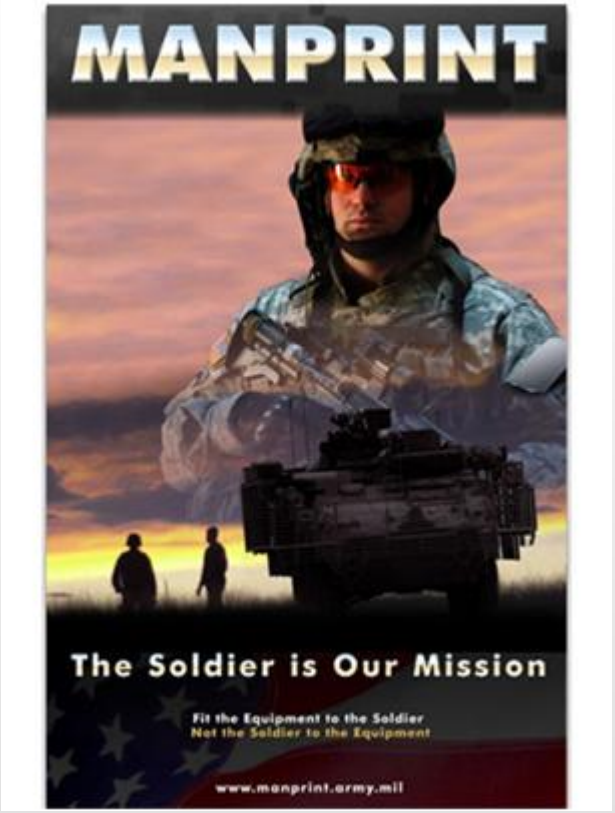
Industrial Revolution

Industrial Engineering
Human Factors Engineering (HFE)

Human Factors Societies

WWII

1980's- Present



Manpower

Personnel Capabilities

Training

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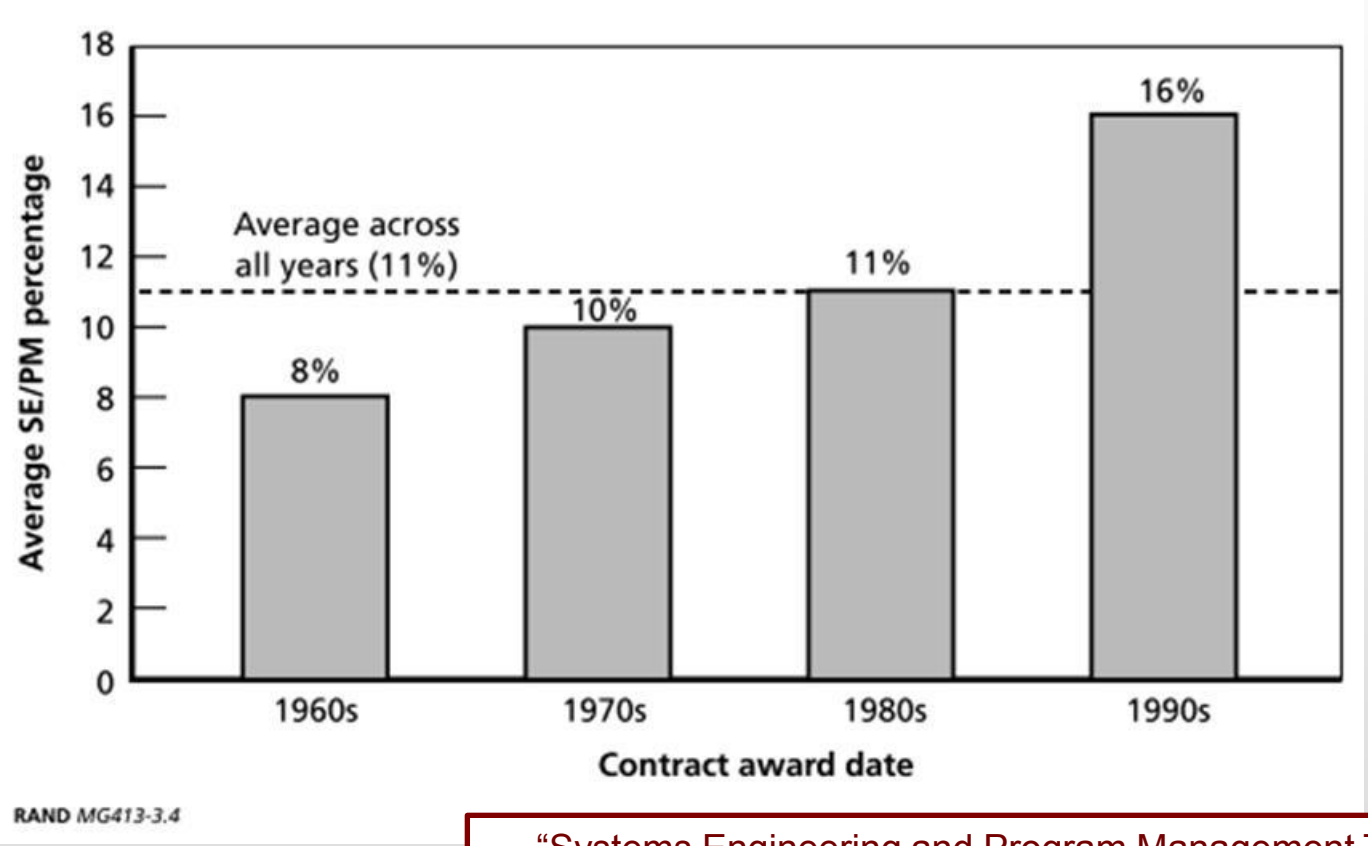
Why Measure SE/HSI Cost?

Aircraft SE/PM as a Percentage of Total Aircraft Development Cost Minus Outlier Development Programs, 1960s–1990s



"Systems Engineering and Program Management Trends and Costs for Aircraft and Guided Weapons Programs" – RAND Corp.

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Why Measure SE/HSI Cost?

Use #1: "Are my ballpark estimates of SE/PM and HSI reasonable?"

Use #2: "What is the *right* amount of SE/PM and HSI for my system?"

Required Inputs

Existing SE/PM Cost Estimate (rule-of-thumb, analogy, etc.)
Existing draft requirements document
Existing IPT or expert analysis

Calibration data from previous systems
Decomposition of requirements

Useful Outputs

Identify SE/PM and HSI cost drivers
Identify major issues/discrepancies
(risk, technology maturity, difficulty)

Improved cost estimate compared to existing methods

Plan for SE/PM and HSI work

Application

Pre-Milestone A

Whole life cycle: update as new info created

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Current Estimation Methods: Government

Data from Historical Systems

!

"Rule of Thumb"

Hours, total engineering development

Estimate of SE/PM as Ratio of Total

Factors influencing Estimate

Expert opinion
Technology Changes
Aircraft Weight
Units
Material Complexity

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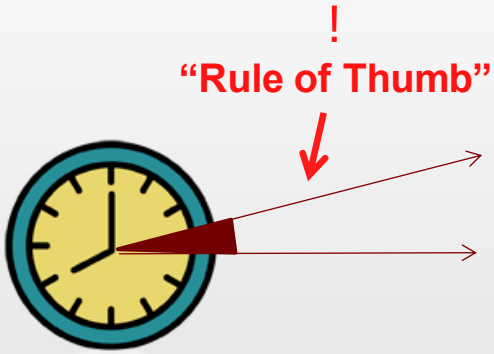
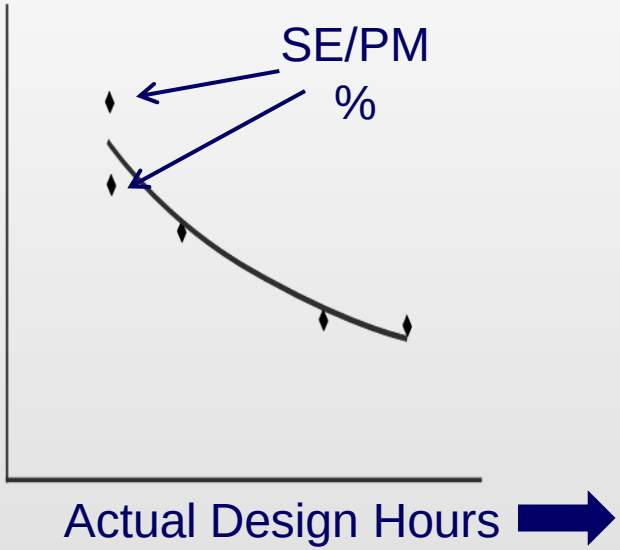
Current Estimation Methods: Industry





People/Task

X

=

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Downsides of Current Methods

1. Disconnect between Top-Down "Rough Estimate" and SE/PM in WBS

   MIL-HDBK-881: "the overall planning, directing, and controlling of the definition, development, and production of a system or program... **[It] excludes systems engineering/program management effort that can be associated specifically with the equipment (hardware/software) element**.

2. Existing approaches do not help *plan* SE/PM and HSI

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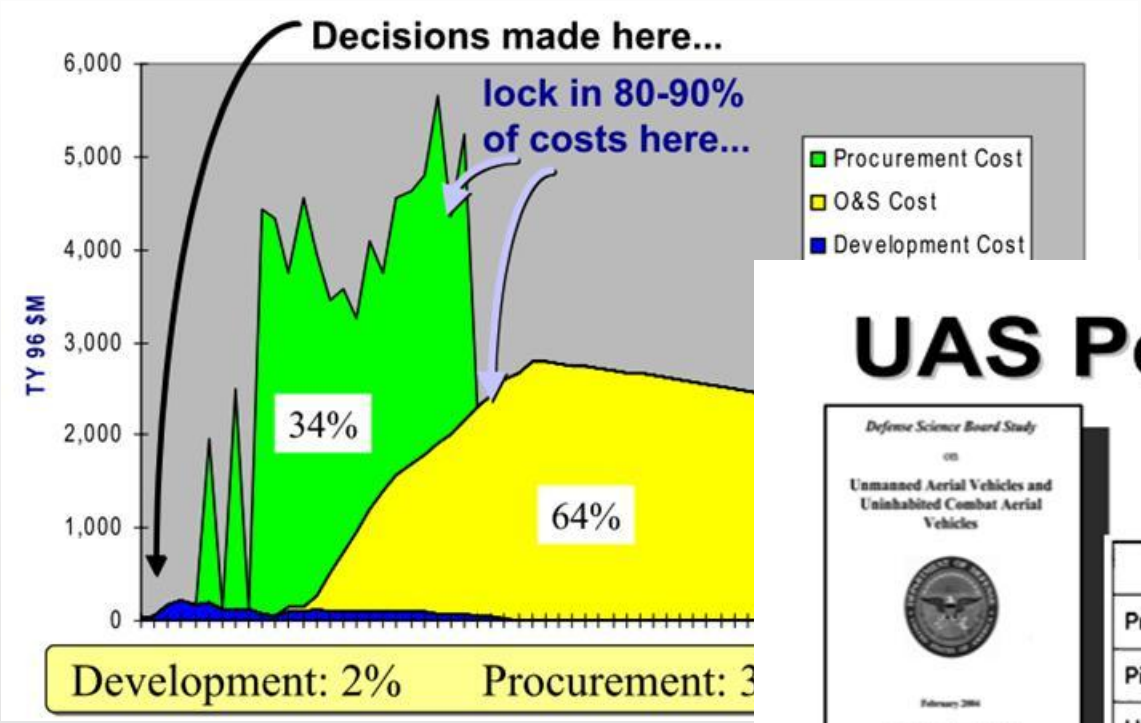
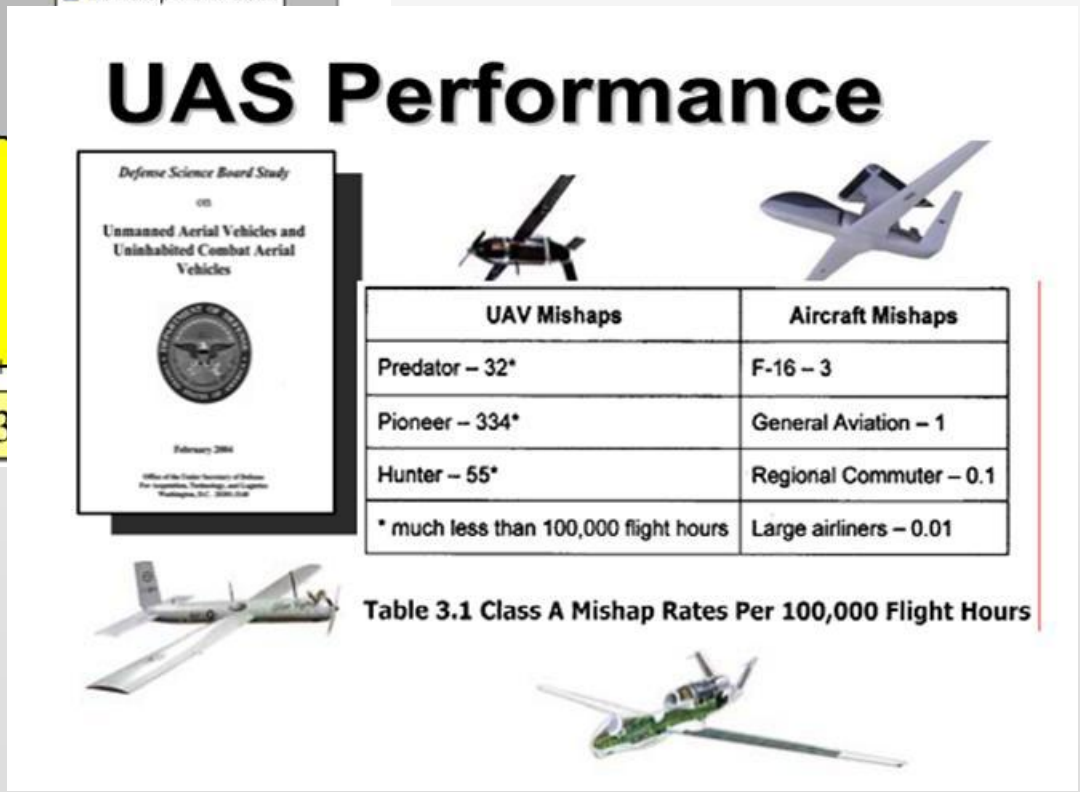
Disconnect Between SE/PM Estimate and Life Cycle Cost





"Life Cycle Cost of Surface Combatants." Graph from Mr. Joe Louden NAVSEA TOC Deputy May 24, 2000.

UAS Performance graph from Defense Science Board Study, "Unmanned Aerial Vehicles and Uninhabited Combat Aerial Vehicles." February 2004.

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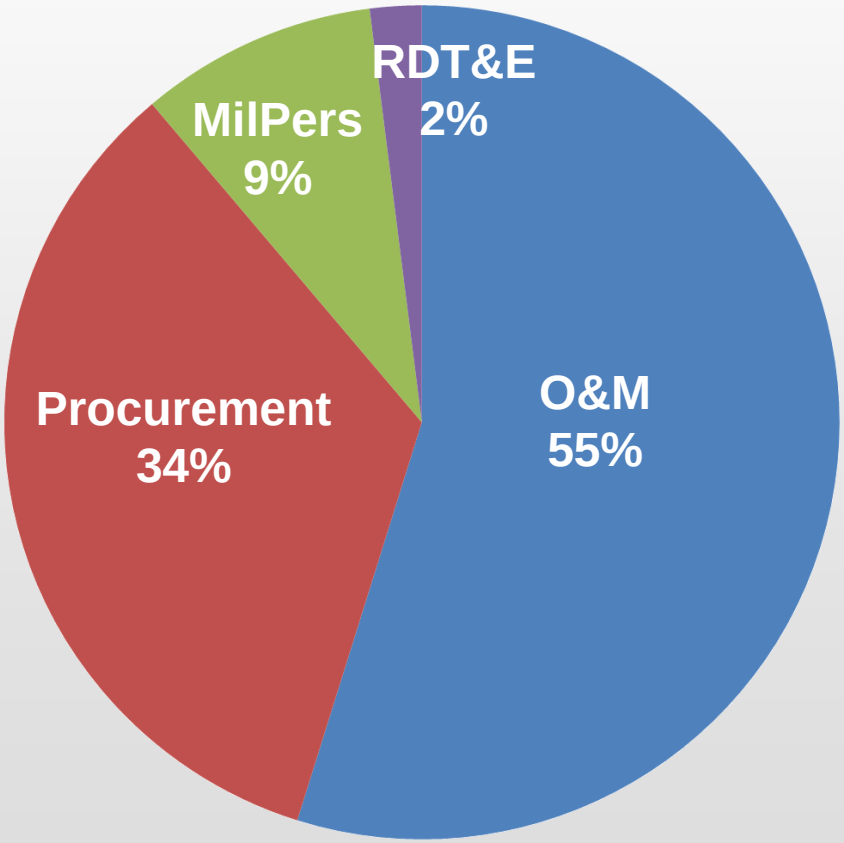
Comparison of System Life Cycle Costs



Surface Combatants Life Cycle Costs (from 2000 NAVSEA TOC)

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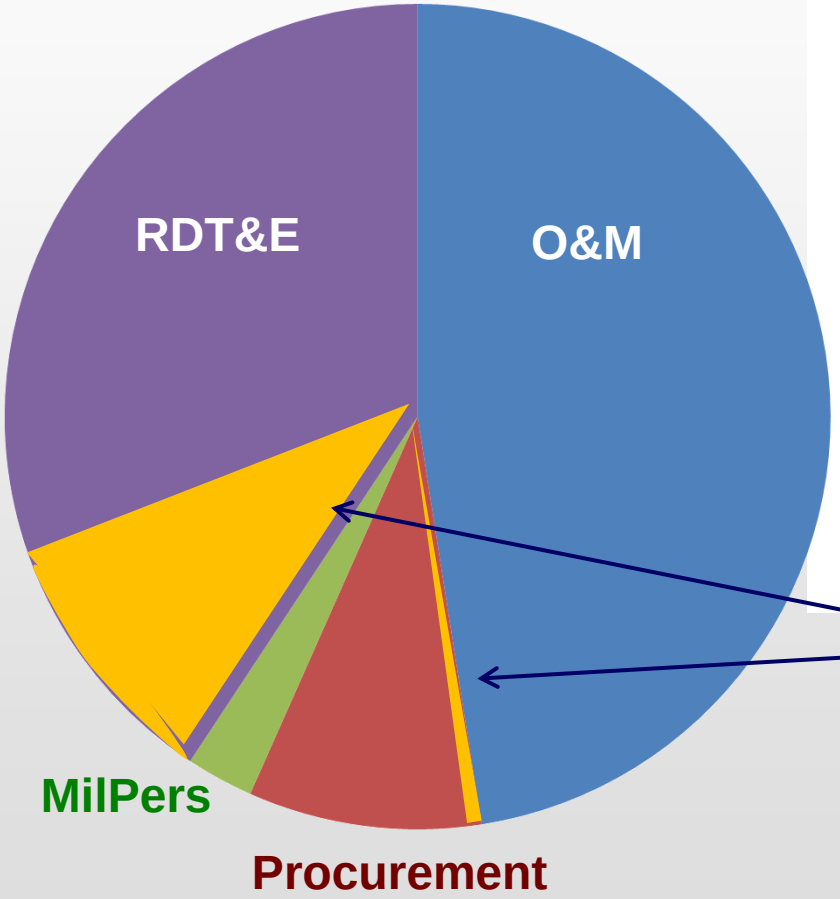
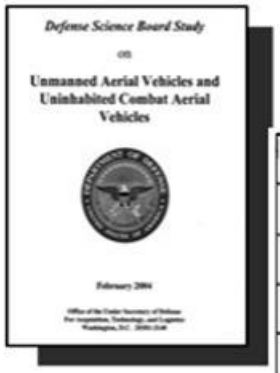
Comparison of System Life Cycle Costs

Major Recent UAS



= SE/PM Costs

UAS Performance



UAV Mishaps	Aircraft Mishaps
Predator – 32*	F-16 – 3
Pioneer – 334*	General Aviation – 1
Hunter – 55*	Regional Commuter – 0.1
* much less than 100,000 flight hours	Large airliners – 0.01

Table 3.1 Class A Mishap Rates Per 100,000 Flight Hours

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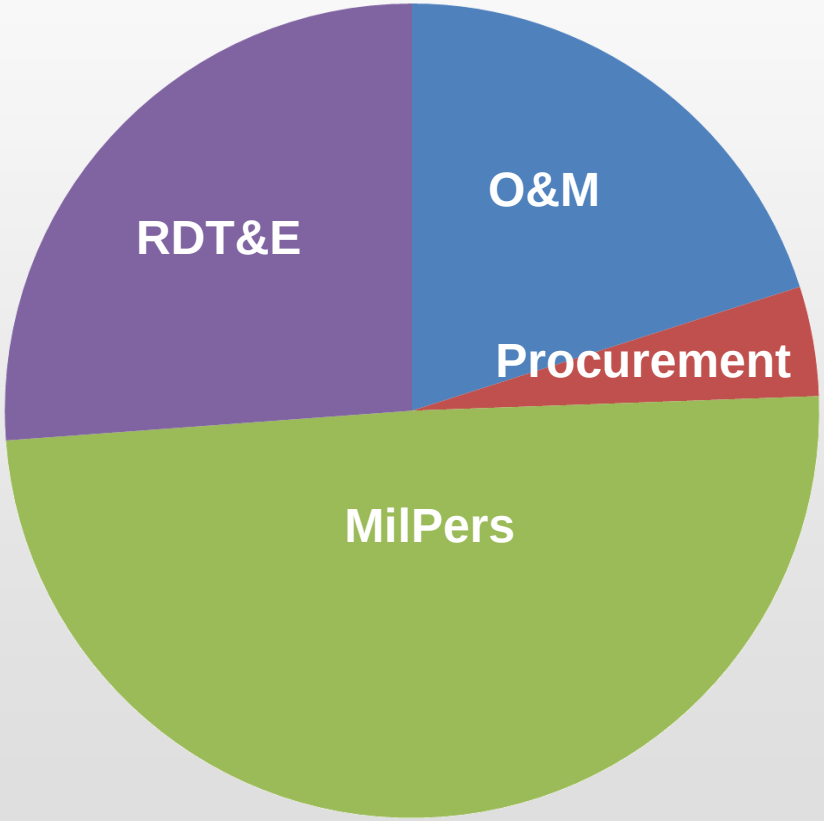
Comparison of System Life Cycle Costs

Cargo Plane



Averaged over
5 years

Total Budget
> $20B

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“Essentially, all models are wrong, but some are useful”

George E. P. Box, statistician

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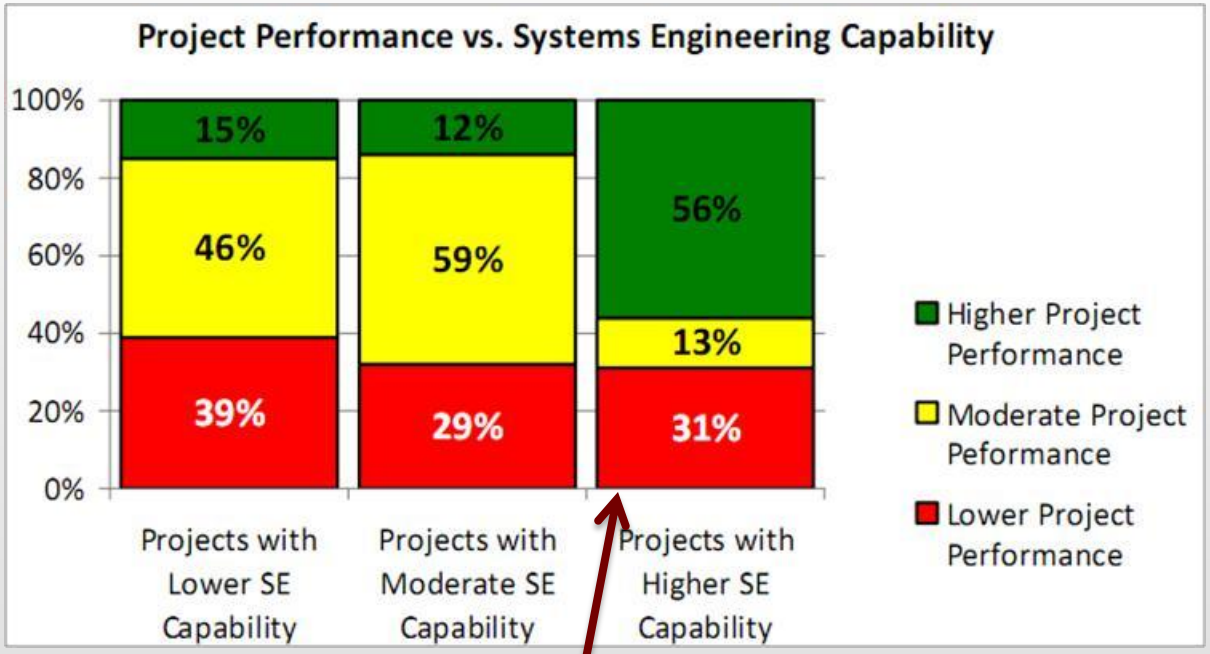
Existing approaches do not help plan SE/PM and HSI

NDIA Survey of SE Effectiveness



SE/HSI is not the answer alone

Methodology:
Surveys assessing awareness/strength in various SE processes

Identified practices and products from CMMI

MULTI-YEAR EFFORT

Parametric Estimation of SE: COSYSMO

Size Drivers

Requirements
Interfaces
Scenarios
Algorithms
+
3 Volatility Factors

Effort Multipliers

- Application factors
  - -8 factors
- Team factors
  - -6 factors
- Schedule driver

CO SYS MO
CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL

COSYSMO

SE Effort

Calibration

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Inputs Needed to Implement COSYSMO

Effort Multipliers

Requirements understanding
Architecture understanding
Level of service requirements
Migration complexity
Technology risk
Documentation to match life cycle
Tool support

and Diversity of installations/platforms
of Recursive levels in the design
Stakeholder team cohesion
Personnel/team capability
Personnel experience/continuity
Process capability
Multisite coordination needs

Data source: input from high-level IPT.

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Application of COSYSMO to HSI

HSI requirements include, but are not limited to, any requirement pertaining to one or more domains of HSI, or the integration of those domains. Broadly, the term encompasses any requirement that contributes to the integration of human considerations into the system being developed.

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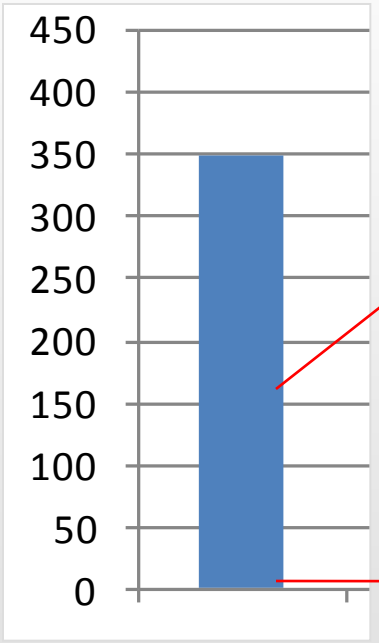
Application of COSYSMO to HSI Notional Example

Shall's + Will's + Must's



Human factors. Human factors engineering principles such as specified in **MIL-STD-1472** shall be employed in each XXX system solution **(Threshold = Objective).**

H
S
I

<-"hard"

<-"nominal"

<-"easy"

"hard"

"nominal"

"easy"

Human Interfaces

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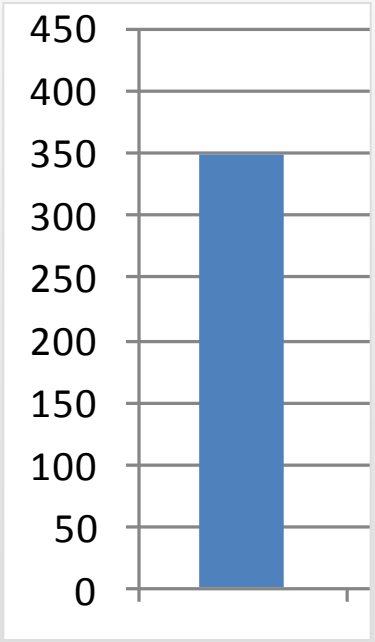
Application of COSYSMO to HSI Notional Example

Shall's + Will's + Must's



COSYSMO 1.1

CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL

© 2007 Ricardo Valerdi

5-Mar-07

ENTER SIZE PARAMETERS FOR SYSTEM OF INTEREST

	Easy	Nominal	Difficult
# of System Requirements	100	200	50
# of System Interfaces			
# of Algorithms			
# of Operational Scenarios			

500
0
0
0
500 equivalent size

SELECT COST PARAMETERS FOR SYSTEM OF INTEREST

Requirements Understanding	N	1.00
Architecture Understanding	N	1.00
Level of Service Requirements	H	1.32
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	H	0.81
Personnel experience/continuity	L	1.21
Process capability	N	1.00
Multisite coordination	N	1.00
Tool support	N	1.00
		1.29 composite effort multiplier

SYSTEMS ENGINEERING PERSON MON **238 Person-Months**

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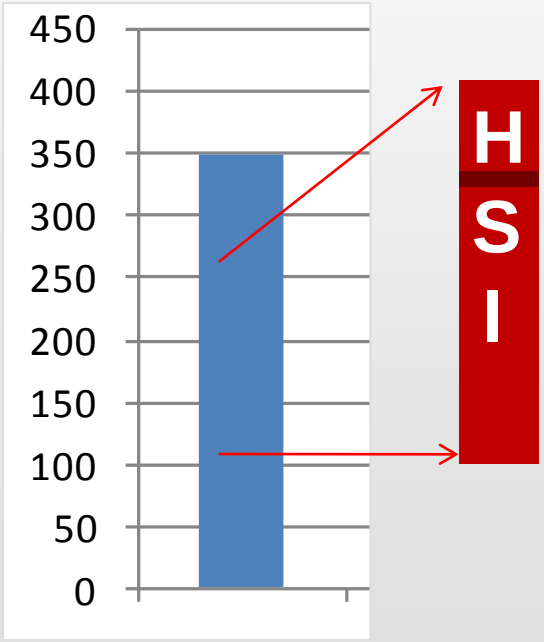
Application of COSYSMO to HSI Notional Example



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CO SYS MO — CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL — 1.1 — 5-Mar-07

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ENTER SIZE PARAMETERS FOR SYSTEM OF INTEREST

	Easy	Nominal	Difficult	
# of System Requirements	50	35	25	185
# of System Interfaces				0
# of Algorithms				0
# of Operational Scenarios				0
				185

equivalent size

SELECT COST PARAMETERS FOR SYSTEM OF INTEREST

Requirements Understanding	N	1.00
Architecture Understanding	N	1.00
Level of Service Requirements	H	1.32
Migration Complexity	N	1.00
Technology Risk	H	1.32
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	L	1.21
Process capability	N	1.00
Multisite coordination	N	1.00
Tool support	L	1.16
		2.43

composite effort multiplier

SYSTEMS ENGINEERING PERSON MONTHS **156 Person-Months**

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Addressing Downsides of Current Estimation Methods

Disconnect between Top-Down "Rough Estimate" and SE/PM in WBS

- COSYSMO defines SE cost/size drivers
- Allows analysis at different level-of-interest or HSI Domains
- More work needed to incorporate O&S into early planning

Existing approaches do not help *plan* SE/PM and HSI

- Decomposition of Requirements, interfaces
- IPT involvement in assigning complexity, cost drivers
- Early SE/HSI analysis (AoA) copy-pasted into SEP/HSIP

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HSI Already Integrated Into Systems Engineering

F119 Engine

On time
Within Cost
Superior Performance

Types of studies
- Technology assessment
- Engine size and cycle
- Design life optimization
- Stage count, configuration, rotor speeds
- Evolution from demonstrator to prototype

Tradeoff alternatives
Design and programmatic alternatives based on cost, schedule, and performance requirements

Evaluation criteria
- Safety
- Weapon system life cycle cost
- Supportability
- Reliability/maintainability
- Weight
- Operability/stability
- Manpower, personnel, and training

Planned trade studies
- Affordability
- Design refinement
- Pre-planned product improvement
- Materials and manufacturing technology

Balanced design

- Low-risk
- Affordable
- Achieves all ATF / NATF requirements

Yankel, J., & Deskin, W. (2002). "Development of the F-22 propulsion system."

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Future Work

Recently Developed Resources Useful for Implementation of COSYSMO for HSI

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Acknowledgments

Systems Engineering Advancement Research Initiative

Pratt & Whitney
A United Technologies Company

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Back-Up Slides

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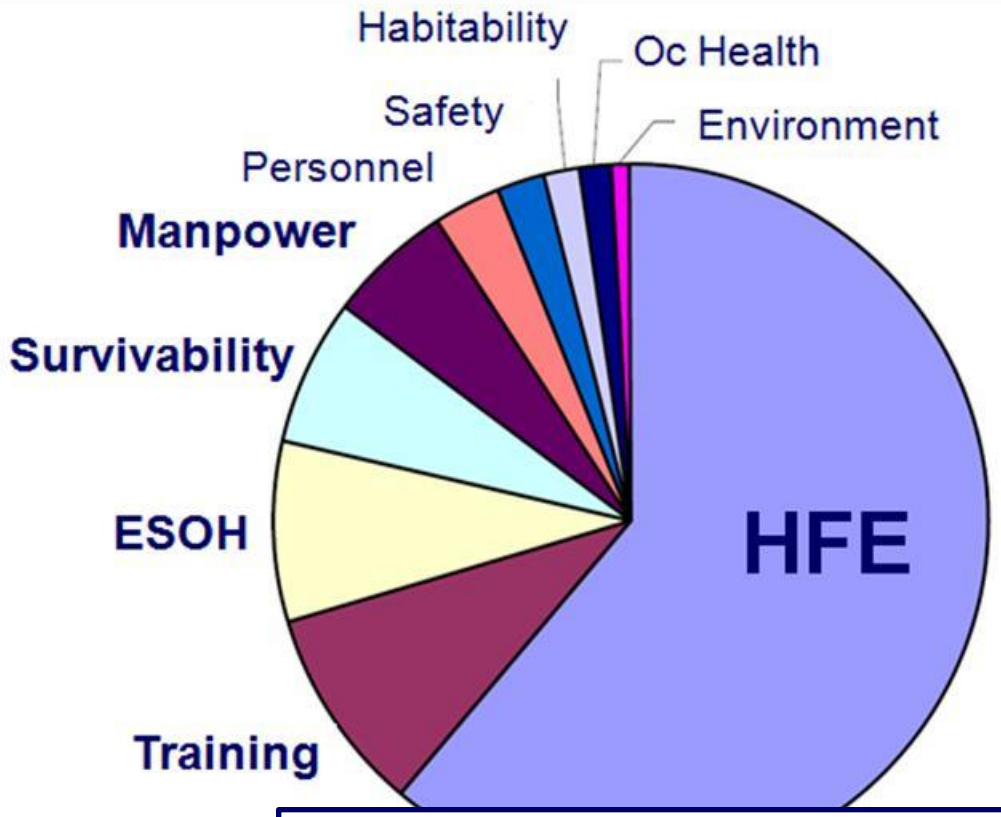
Application of COSYSMO to HSI
Application to HSI Domains



How complex are the safety requirements?

What tools are available for survivability analyses?

How verifiable are the environmental requirements?

How do these factors affect level of effort?

HSI-related requirements found in Government-furnished requirements documents.

Adapted from "Airman Performance Integration Capability Document Analysis", 311th Human Systems Wing, September 2007

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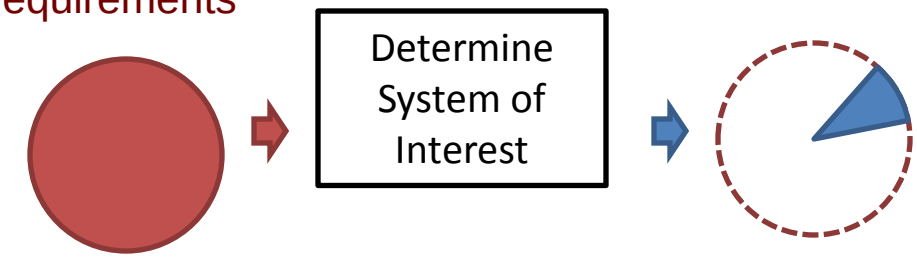
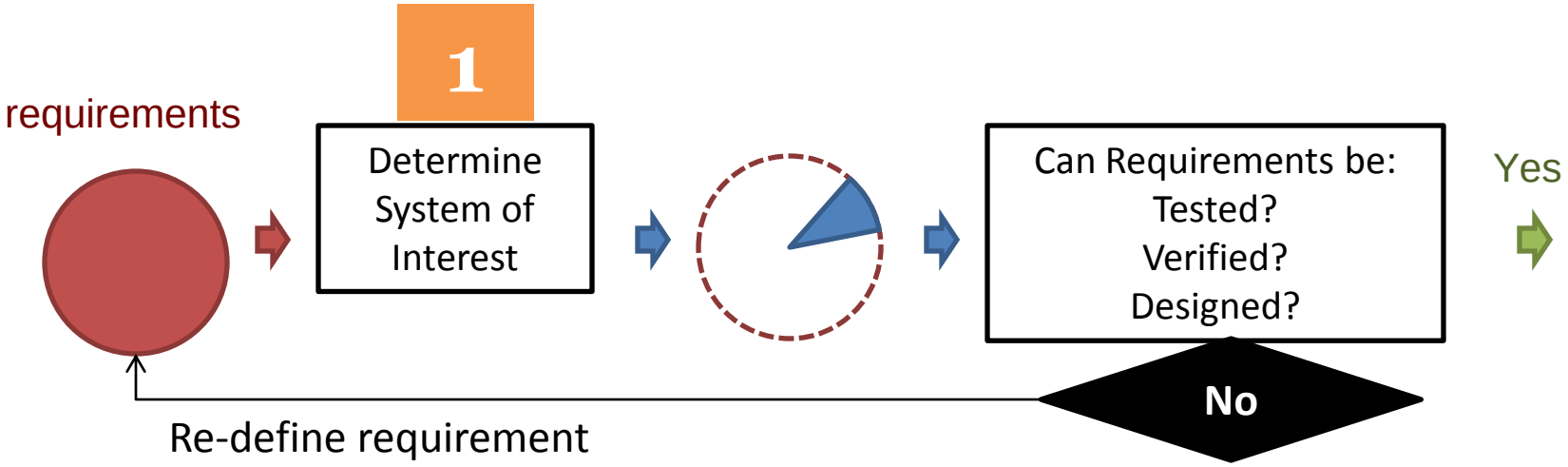
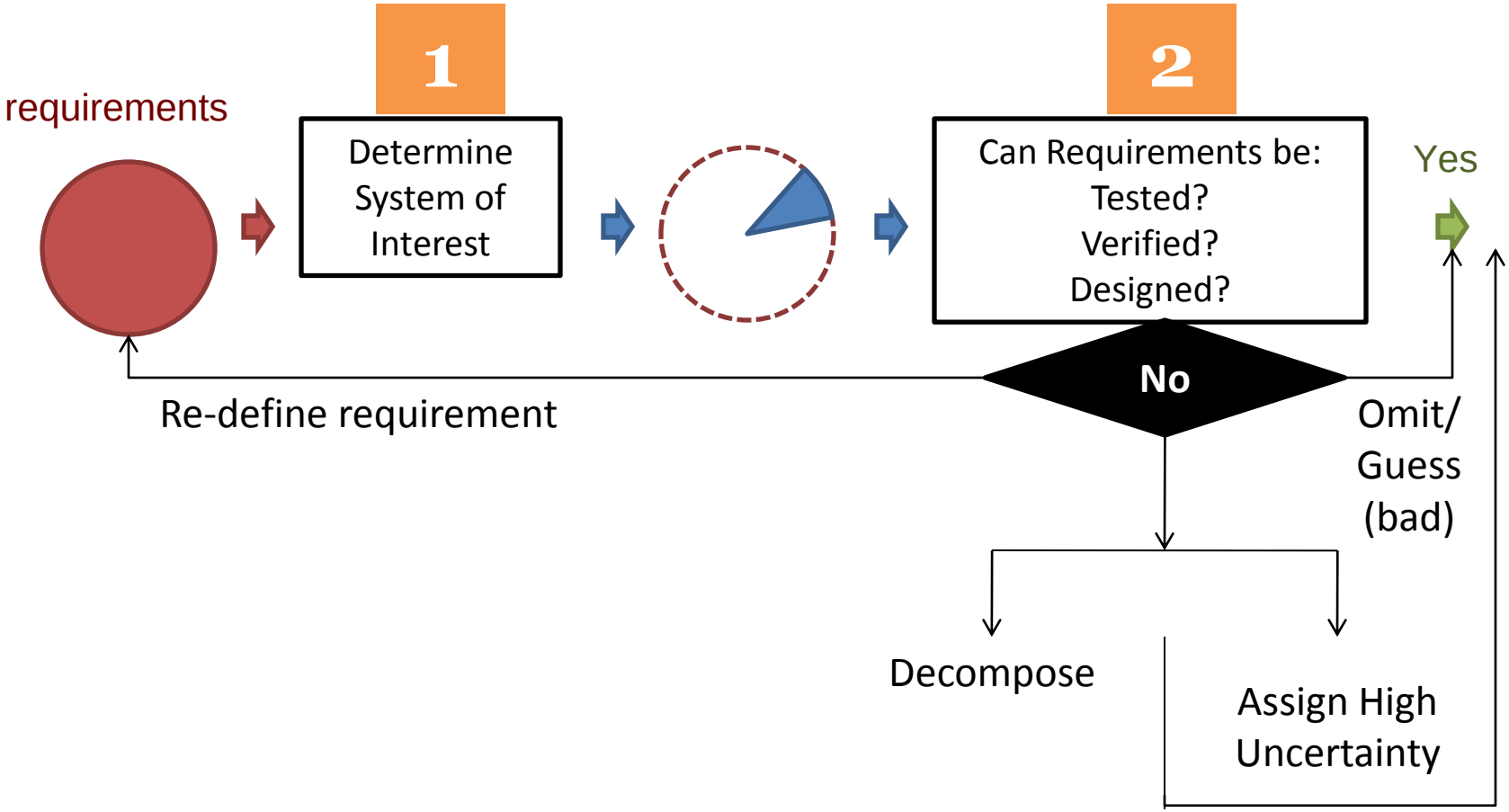
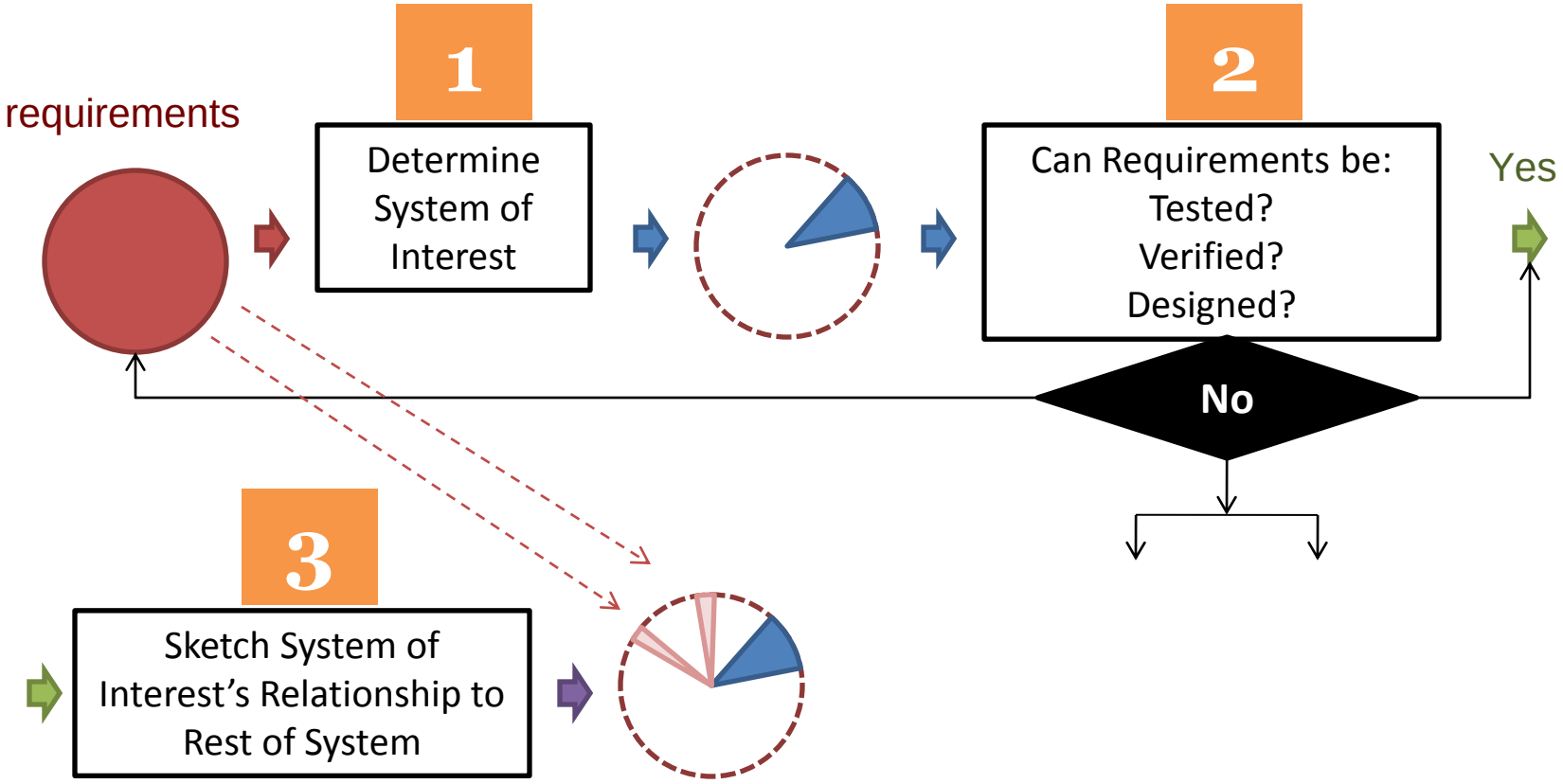
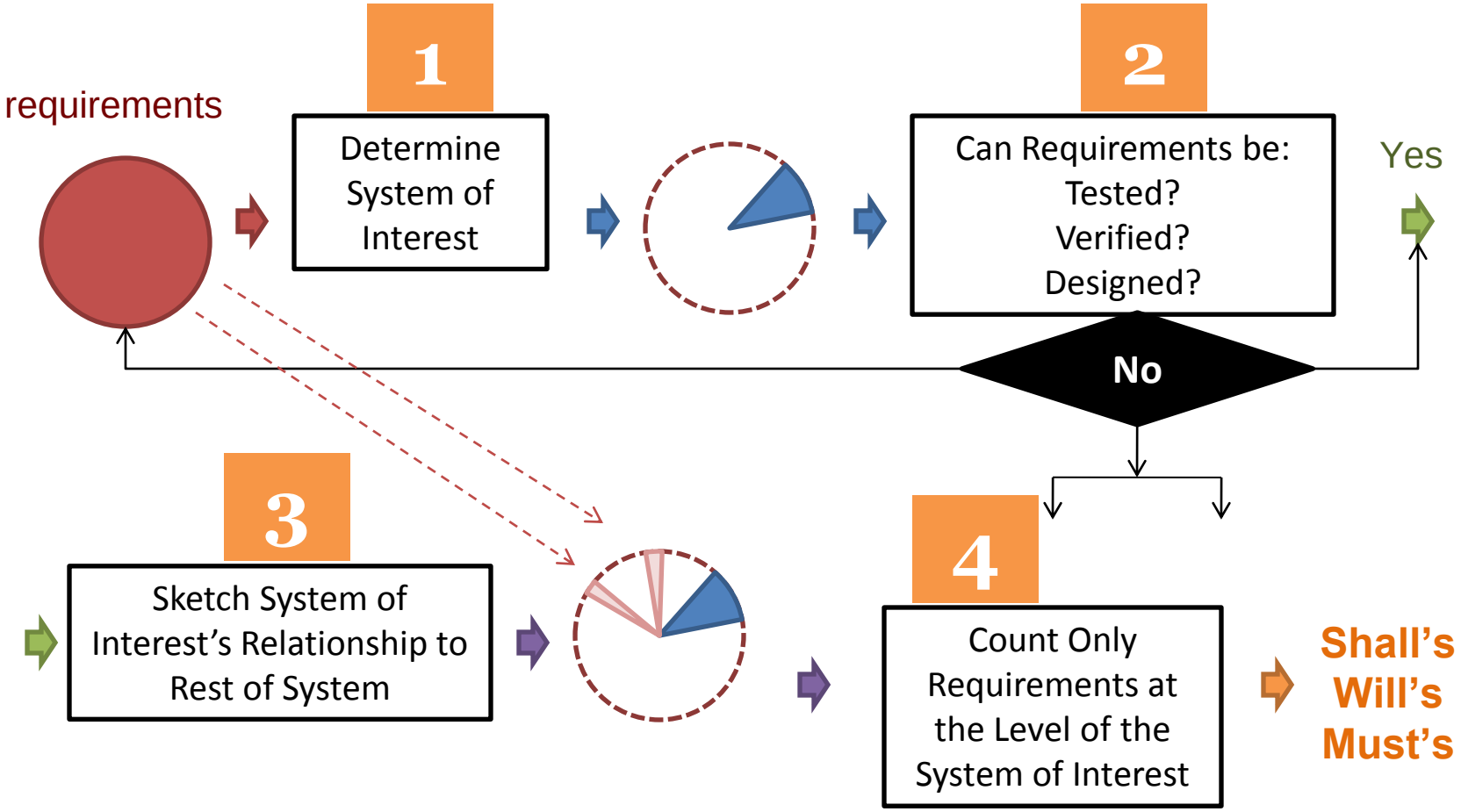
requirements

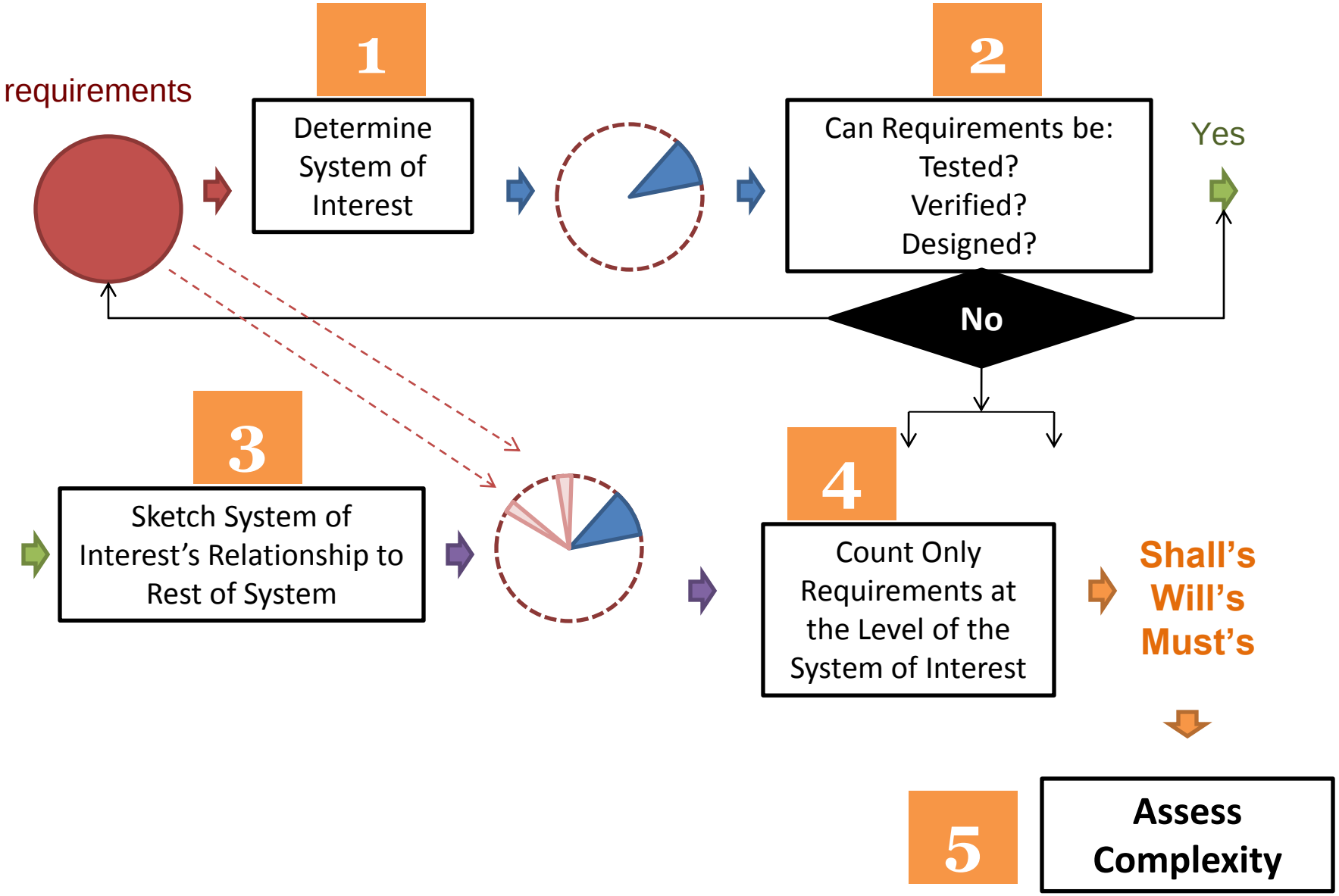



requirements
1
Determine System of Interest
Can Requirements be:
Tested?
Verified?
Designed?
Yes
No
Re-define requirement


requirements
1
Determine System of Interest
2
Can Requirements be:
Tested?
Verified?
Designed?
Yes
No
Re-define requirement
Omit/ Guess (bad)
Decompose
Assign High Uncertainty


requirements
1
Determine System of Interest
2
Can Requirements be:
Tested?
Verified?
Designed?
Yes
No
3
Sketch System of Interest's Relationship to Rest of System


requirements
1
Determine System of Interest
2
Can Requirements be:
Tested?
Verified?
Designed?
Yes
No
3
Sketch System of Interest's Relationship to Rest of System
4
Count Only Requirements at the Level of the System of Interest
Shall's
Will's
Must's


requirements
1
Determine System of Interest
2
Can Requirements be:
Tested?
Verified?
Designed?
Yes
No
3
Sketch System of Interest's Relationship to Rest of System
4
Count Only Requirements at the Level of the System of Interest
Shall's
Will's
Must's
5
Assess Complexity