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Systems Test & Evaluation

Engineering Successful Systems via Verification, Validation, and T & E

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Experiences with T& E

Overview

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- **What does a success look like?**
  - Who decides?
  - Law? Client? Etc.?
  - Score Cards
- **Problem Areas**
- **Acquisition Cycle and Where to Influence**
  - SE lifecycle…CD/ED/PD
- **T&E and V&V Contributions**
- **Execution**

DOD DOTE Score Cards

FY22 DOTE Effectiveness Results

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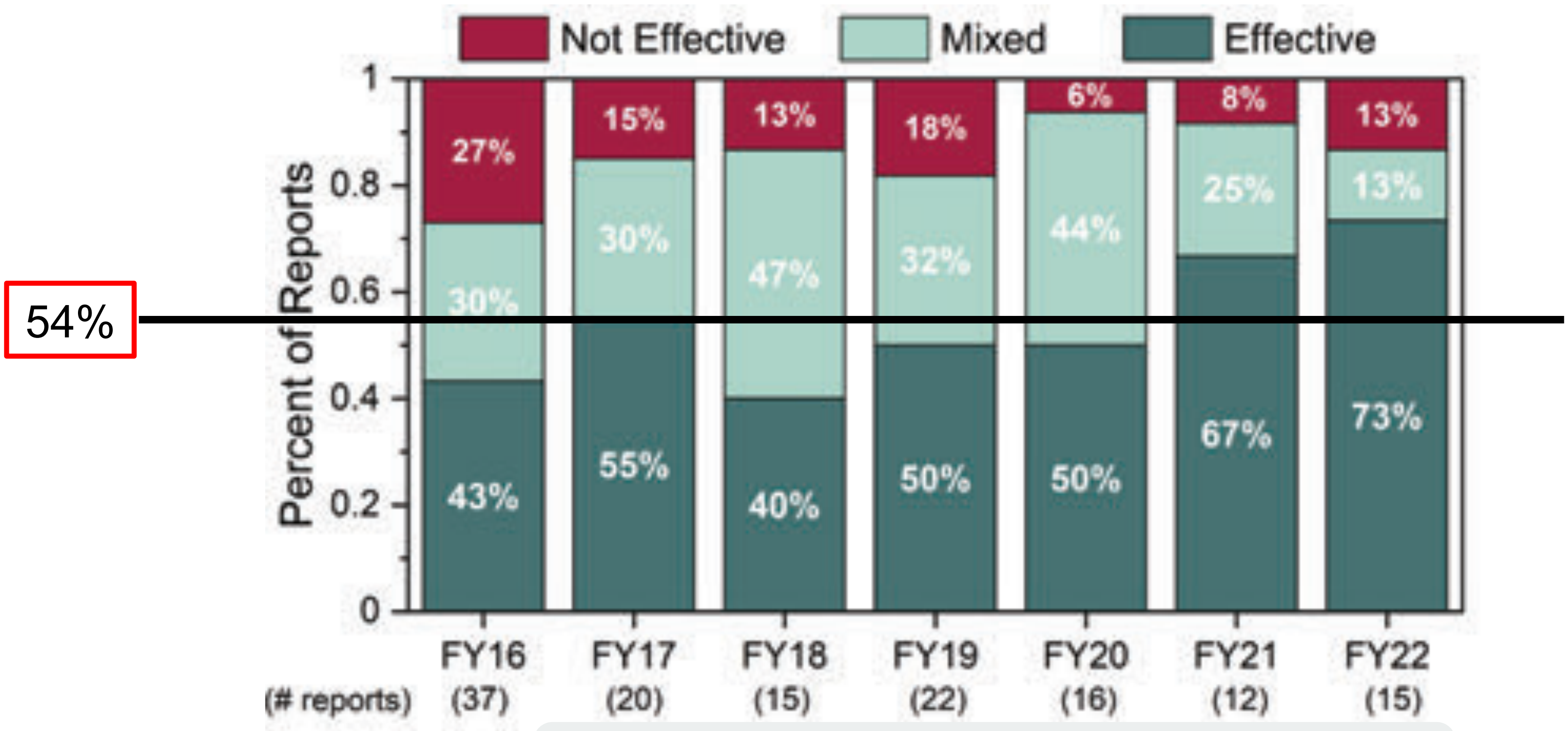


Figure 2. Operational Effectiveness Trends

FY22 DOTE Executive Summary, p. 10

FY22 DOTE Suitability Results

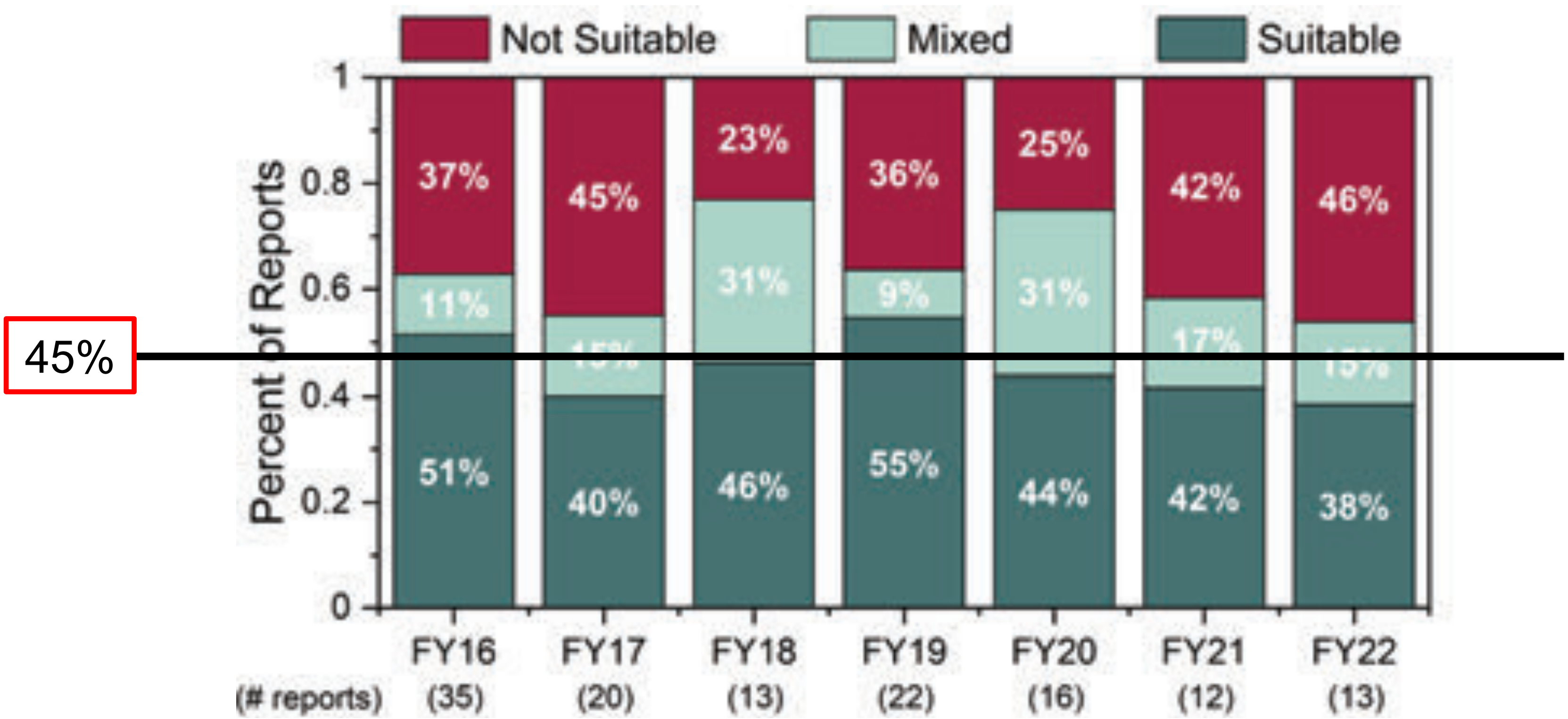


Figure 3. Operational Suitability Trends

FY22 DOTE Executive Summary, p. 11

FY22 DOTE Survivability Results

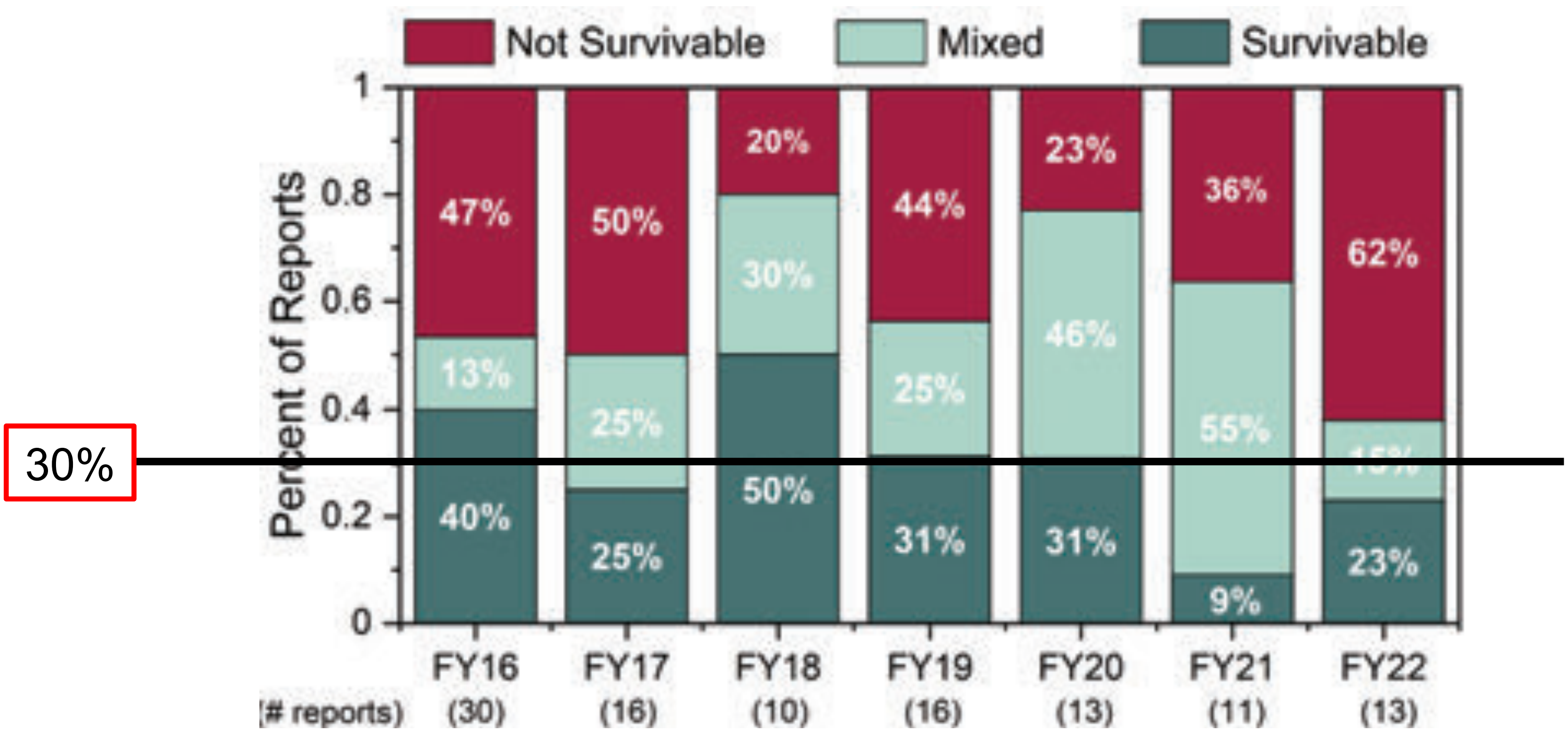
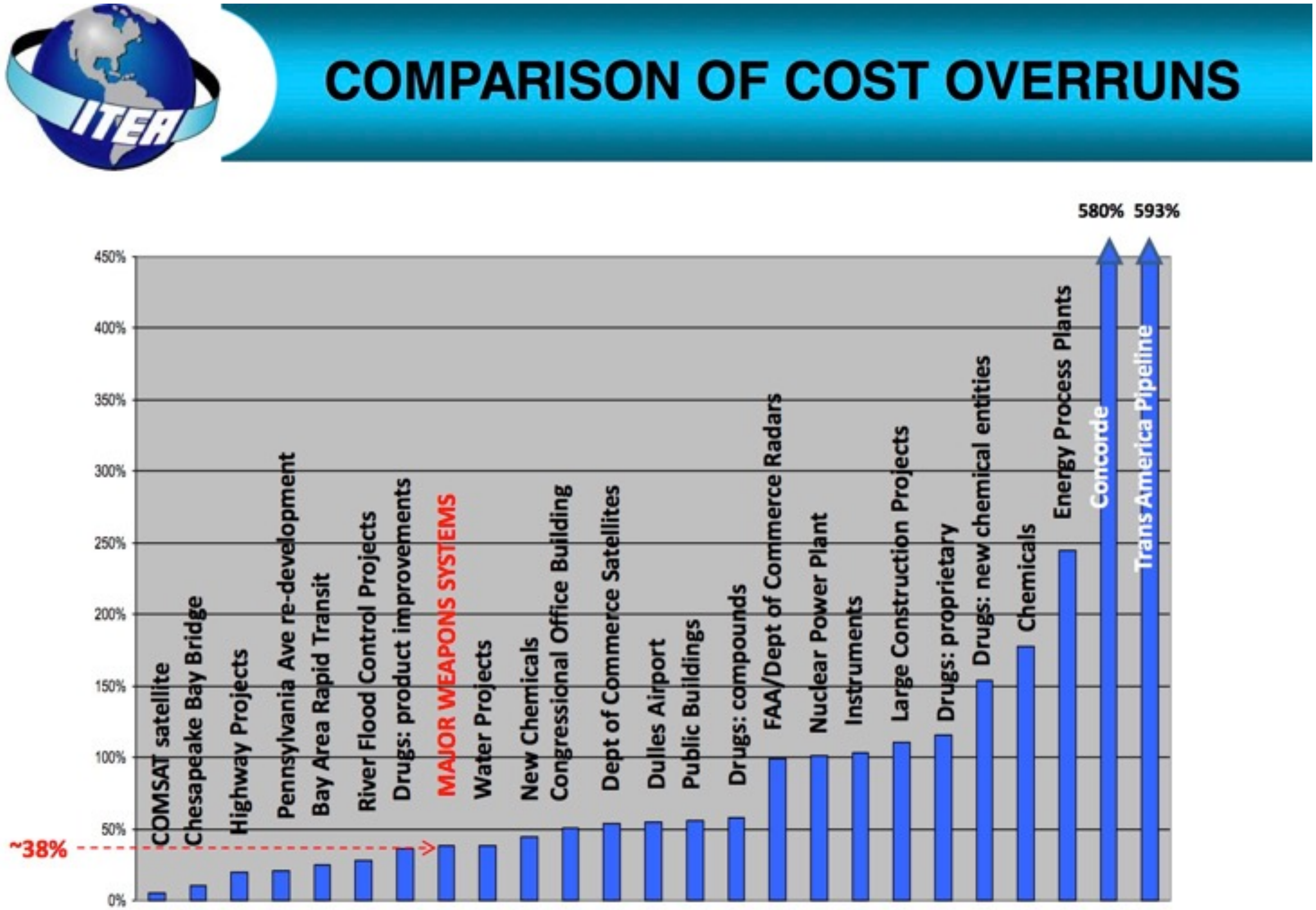


Figure 4. SurvivabilityTrends

FY22 DOTE Executive Summary, p. 11

Industry Score Card



Reynolds, Matt. Fundamentals of The Test & Evaluation Process. May 31, 2013. ITEA Webinar, available at http://itea.org.

The Idea...

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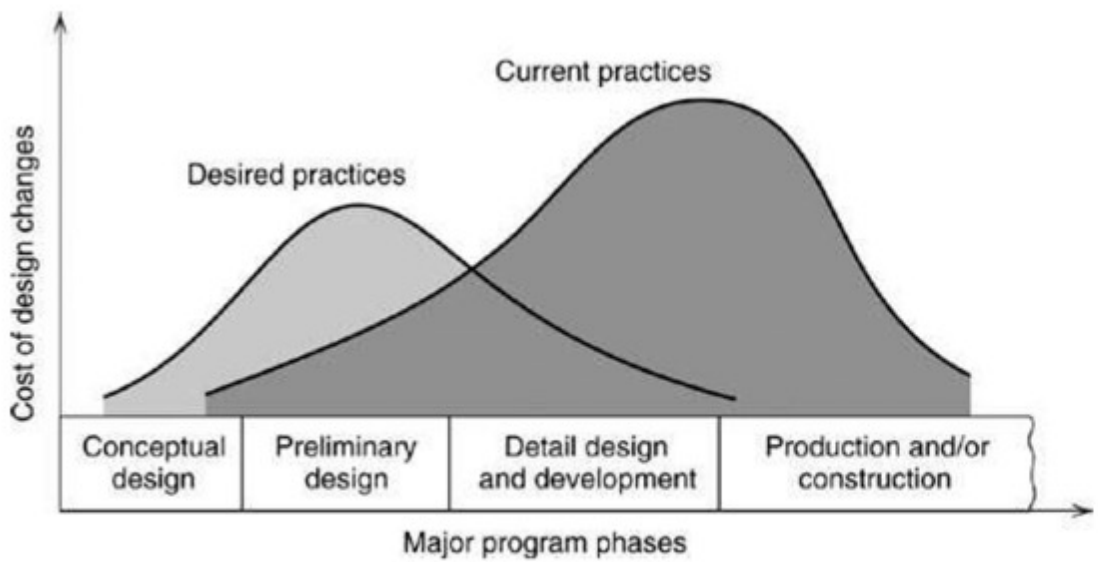
Motivation for Better Systems Management

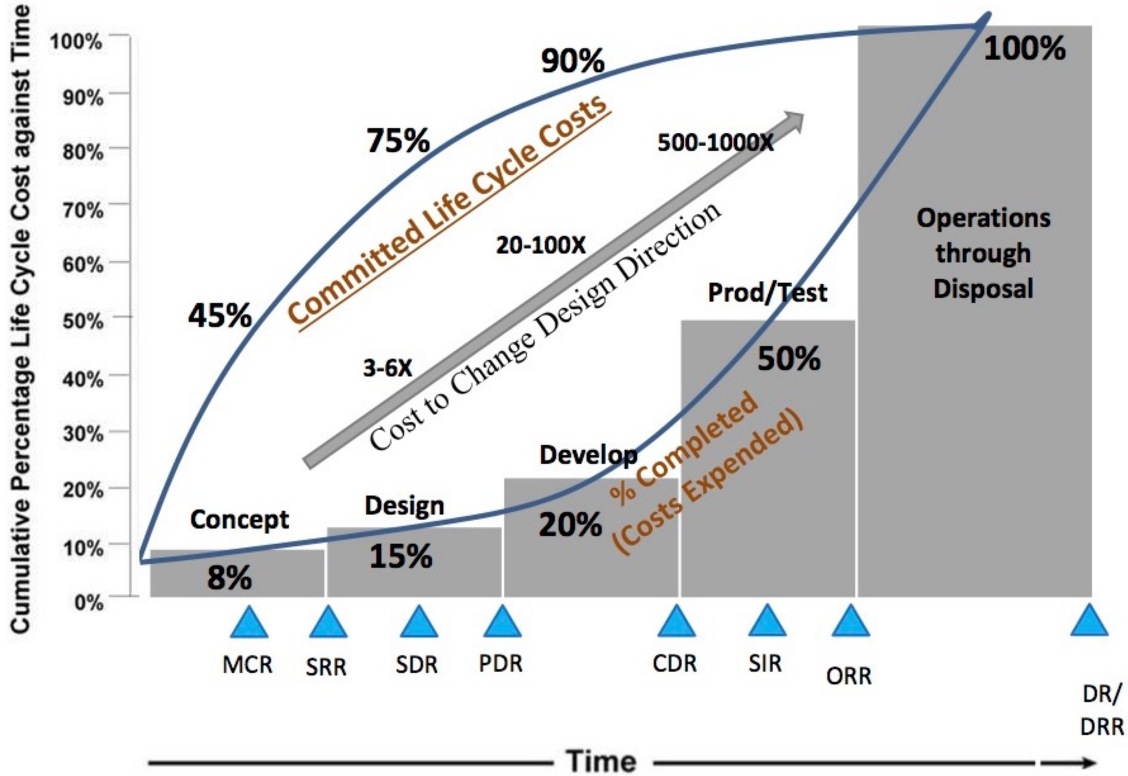


Benjamin S. Blanchard, *System Engineering Management*

31 May 2013, 2100

28

Bell, David W. and C. David Brown. "What T&E's Need to Know about Systems Engineering and Program Management." n.d. ITEA Webinar, available at http://itea.org.



MCR	Mission Concept Review	CDR	Critical Design Review
SRR	System Requirements Review	SIR	System Integration Review
SDR	System Definition Review	ORR	Operational Readiness Review
PDR	Preliminary Design Review	DR/DRR	Decommissioning/Disposal Readiness Review

Adapted from INCOSE-TP-2003-002-04, 2015

- Available at: NASA. Systems Engineering Handbook, Revision 2. https://www.nasa.gov/feature/release-of-revision-to-the-nasa-systems-engineering-handbook-sp-2016-6105-rev-2

Success

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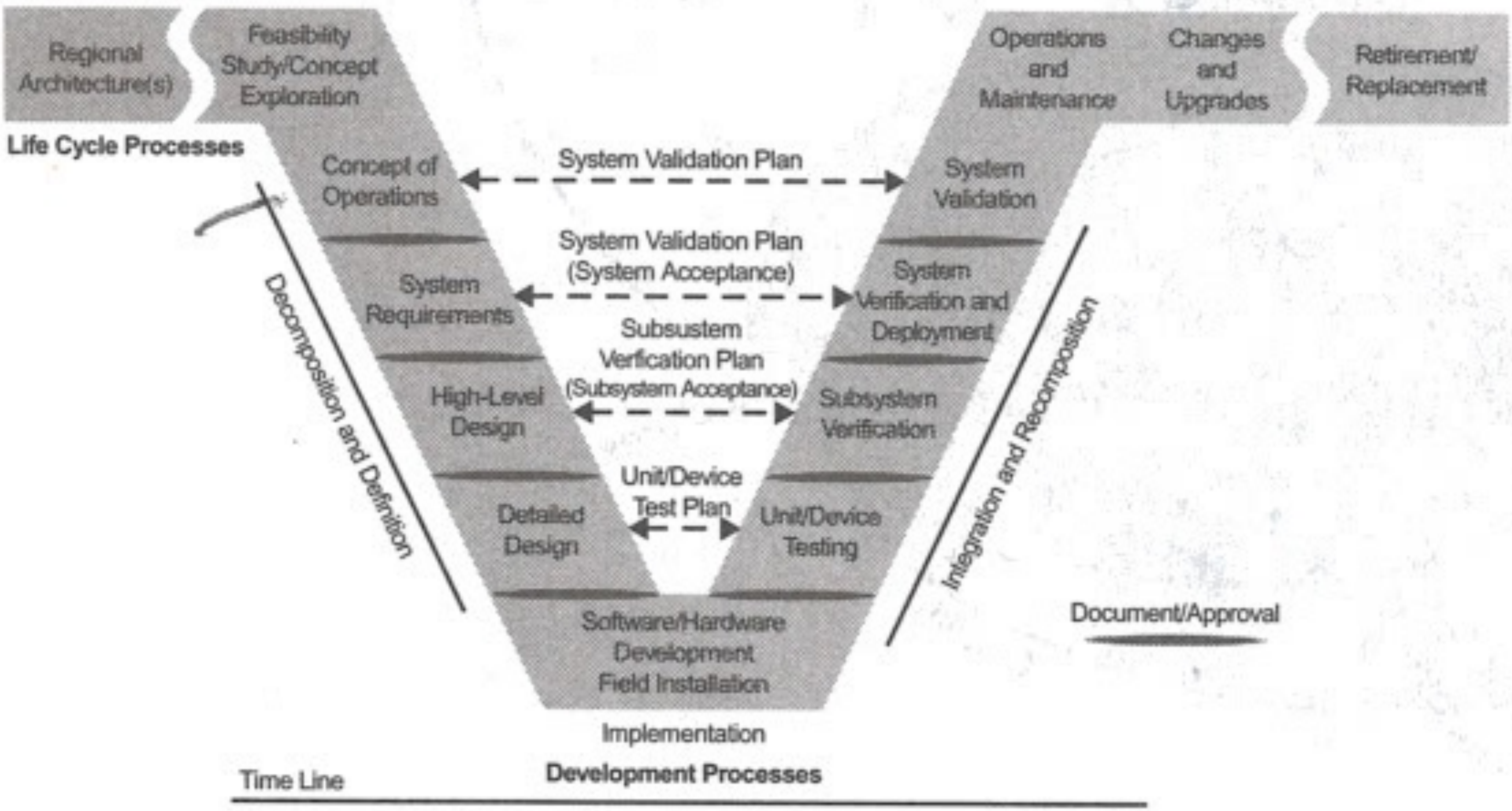
- **Meet requirements and development objectives**
- **Successful operation in the field**
- **Long useful operating life**
- **On/within budget & On schedule**

- **SE – "To guide the engineering and development of complex systems." (Kossiakoff, 2020, p. 3)**
- **Choose the "correct" path from among many**
- **Uncertainties → Test & Eval → Knowledge**

Decompose – Build – integrate/Test – Validate



Kossiakoff, Alexander, William N. Sweet, Samuel J. Seymour, and Steven M. Biemer. Systems Engineering-- Principles and Practice. 2d ed. Wiley and Sons. Hoboken, N.J., 2011

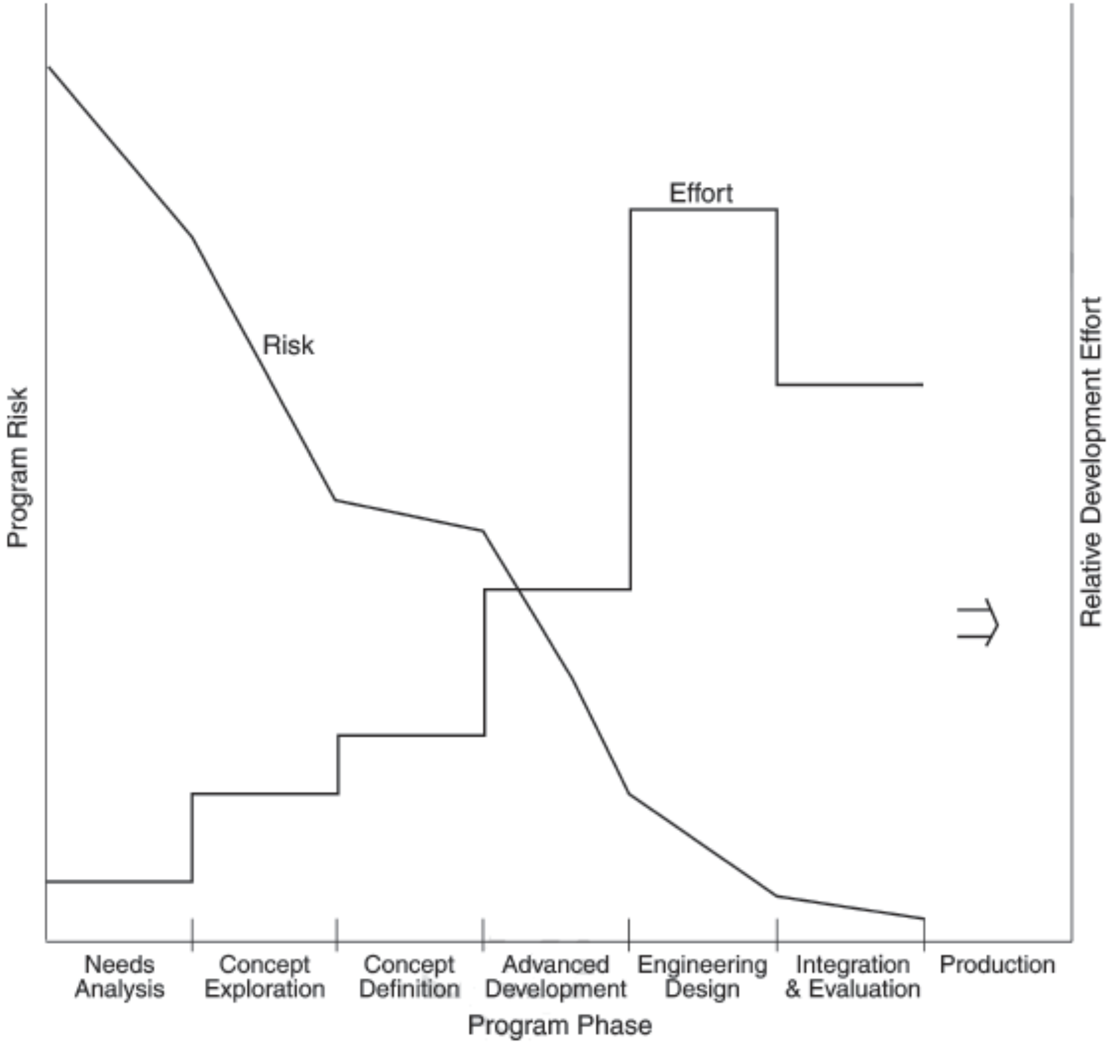


Fig. 5.3 Variation of program risk and effort throughout system development.

Uncertainties (risks) are systematically reduced by

- analysis,

- experiment,

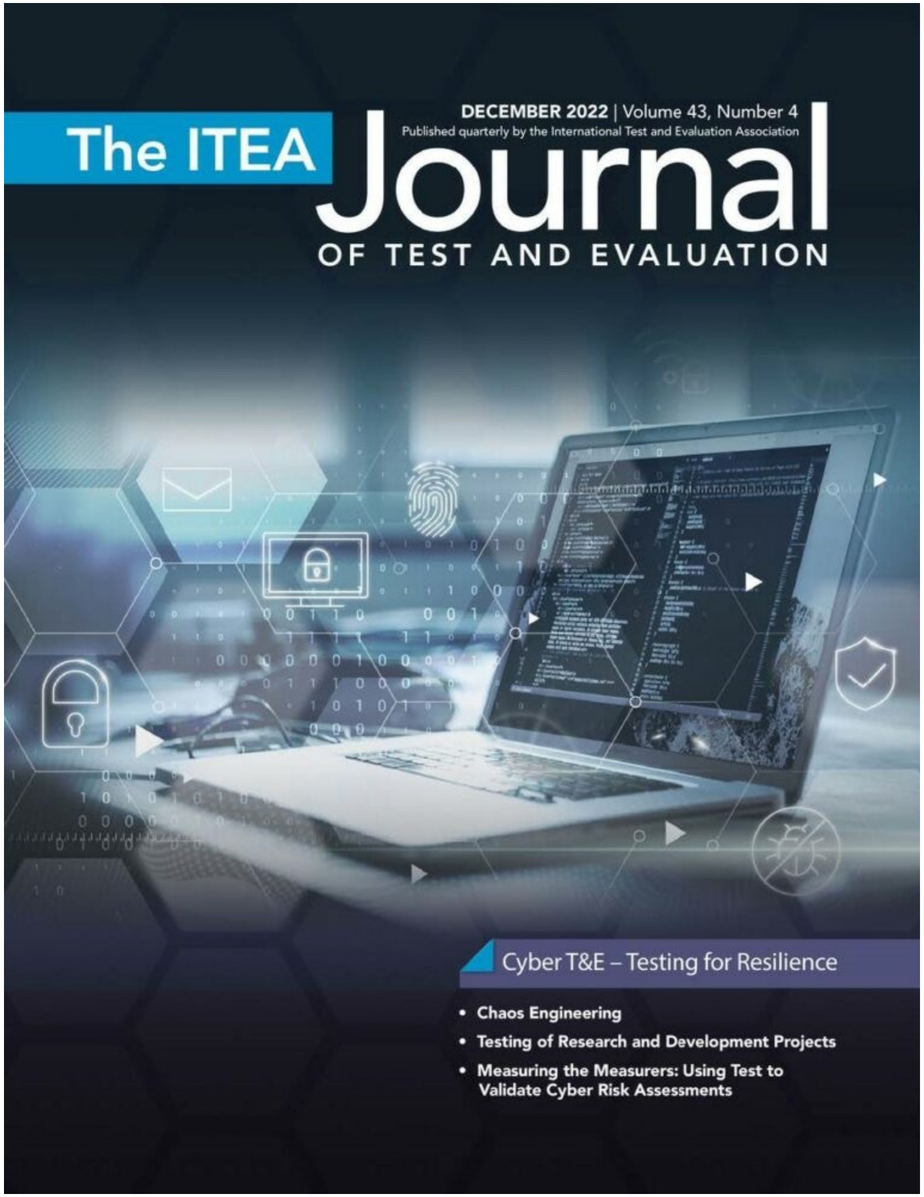
- test, or

- change in course

Source: Kossiakoff, A., & Sweet, W. (2011). *Systems engineering : principles and practice*. Hoboken, N.J. : Wiley-Interscience.

Let's Talk Test and Eval

ITEA & The CTEP Certification



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Things to Remember

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SUCCESS IN T&E =

- ✓ Testing that is rigorous +
- ✓ Evaluations that are unbiased +
- ✓ Conclusions that can be supported by objective evidence to the maximum extent possible +
- ✓ Procedures and results that are repeatable +
- ✓ Recommendations that can be relied upon +
- ✓ Managed, conducted and overseen by organizations whose organizational placement will not allow their reports to be stifled +
- ✓ Technical integrity (e.g. requisite accurate, statistically significant sample sizes, realism appropriate for the test objectives, end-to-end functional testing as applicable, etc.) should be a high priority so the results and recommendations can be relied upon +
- ✓ T&Eers who are qualified +
- ✓ T&Eers who have high ethical principles.

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The Conundrums

- **What to test?**
- **When to test?**
- **Where to test?**
- **How to test?**
- **When to stop?**

Test Happens...Regardless.

- **Any deficiencies I don't find, the end user will likely find**

- **Aircraft: cost of finding a deficiency during…**
  - Development test $1
  - Operational test $10
  - In the field $100

- **Consider product life cycle duration**
  - WWI aircraft: 1 year design to obsolescence
  - Cell phone 1 year between releases
  - F-22: 14 years, requirement to operational capability
    37 years since requirement drafted
  - B-52: 55 years flying

Product Development...The Reality.

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Product is perfect	**Testing: no deficiencies**	**Not realistic**
Product is imperfect	**Testing: no deficiencies**	**Testers failed**
Product is imperfect	**Test: deficiencies found**	**Testers succeeded**

Goal: Find deficiencies that matter, quickly and affordably

(Some of) The Things That Matter…

Identify Areas Early – Choose the Correct Path

RISK AS OF **NOV 2010**

PROBABILITY OF OCCURRENCE		1 LOW	2 MINOR	3 MODERATE	4 SIGNIFICANT	5 HIGH
81% to 99%	5	26			1	
61% to 80%	4	16, 17, 20	24	5, 9, 23		6
41% to 60%	3				8, 10, 11	
21% to 40%	2		18	15		7
1% to 20%	1	4, 12, 14, 19	2, 3, 13, 21, 22			

CONSEQUENCE

Risk #	Risk Nomenclature
1	HMD Integration
2	Thermal Management
3	Mission Systems Fusion
4	Safe Escape
5	Airworthiness Process Execution
6	Maturity
7	Lightning
8	Joint Technical Data (Flight Series Data)
9	JTD Maintenance
10	Flight Test Schedule
11	Aircraft Delivery
12	Steps/Gaps
13	Lab Capacity to support field problems
14	Aircraft Exterior Lighting
15	ICAWS
16	Forward Signature
17	Aft Signature
18	Interoperability
19	EO DAS Algorithms
20	Edge/Aperature Integration
21	S/W Block Integration
22	PVI
23	Enhanced Diagnostics
24	Cockpit Cooling
25	Classified
26	Propulsion

Finding a balance...

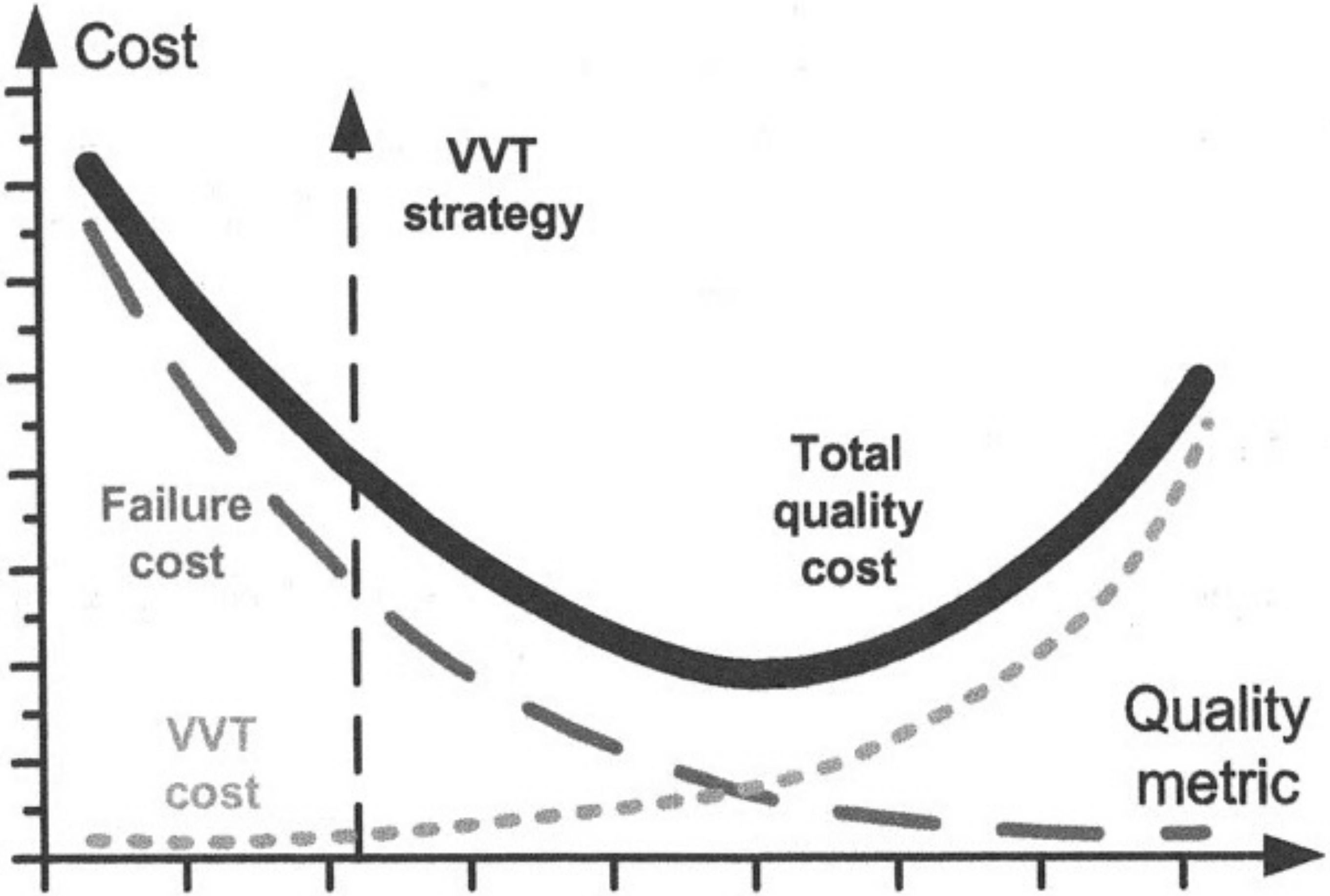


Figure 2.5 Juran's quality cost model.

Engel, Avner. Verification, Validation, and Testing of Engineered Systems. Wiley and Sons. Hoboken, N.J., 2010.

Getting the Wrong Balance…Drives Cost/Sched

- **Optimize the risk balance between too much/little test**
  - **Commercial context**
    - **Goal: profit (near-term and long-term)**
    - **Balance cost/time of development, production, testing, marketing, recalling, warranty service**
    - **Test too much:**
      - **Product release is delayed, decreasing profit**
      - **Funding for other needs is unnecessarily consumed**
    - **Test too little**
      - **Customers dissatisfied, reputation poor, decreasing profit**
  - **Military context**
    - **Goal: field sufficient capability quickly**
    - **Balance cost/time of development, production, testing, recalling, losing battle**
    - **Test too little**
      - **Product recalled for fixes, lose the war**
    - **Test too much**
      - **Product roll-out is delayed, lose the war**
      - **Funding for other needs is unnecessarily consumed**

Magnitude and Rigor

Who are my stakeholders?
What do they value?

What is the right mix of Test cost, Test schedule, and Test rigor?

Characterize
Determine
Demonstrate
Evaluate
…

Prgm Mgt	Test
Cost	Cost
Schedule	Schedule
Performance	Rigor

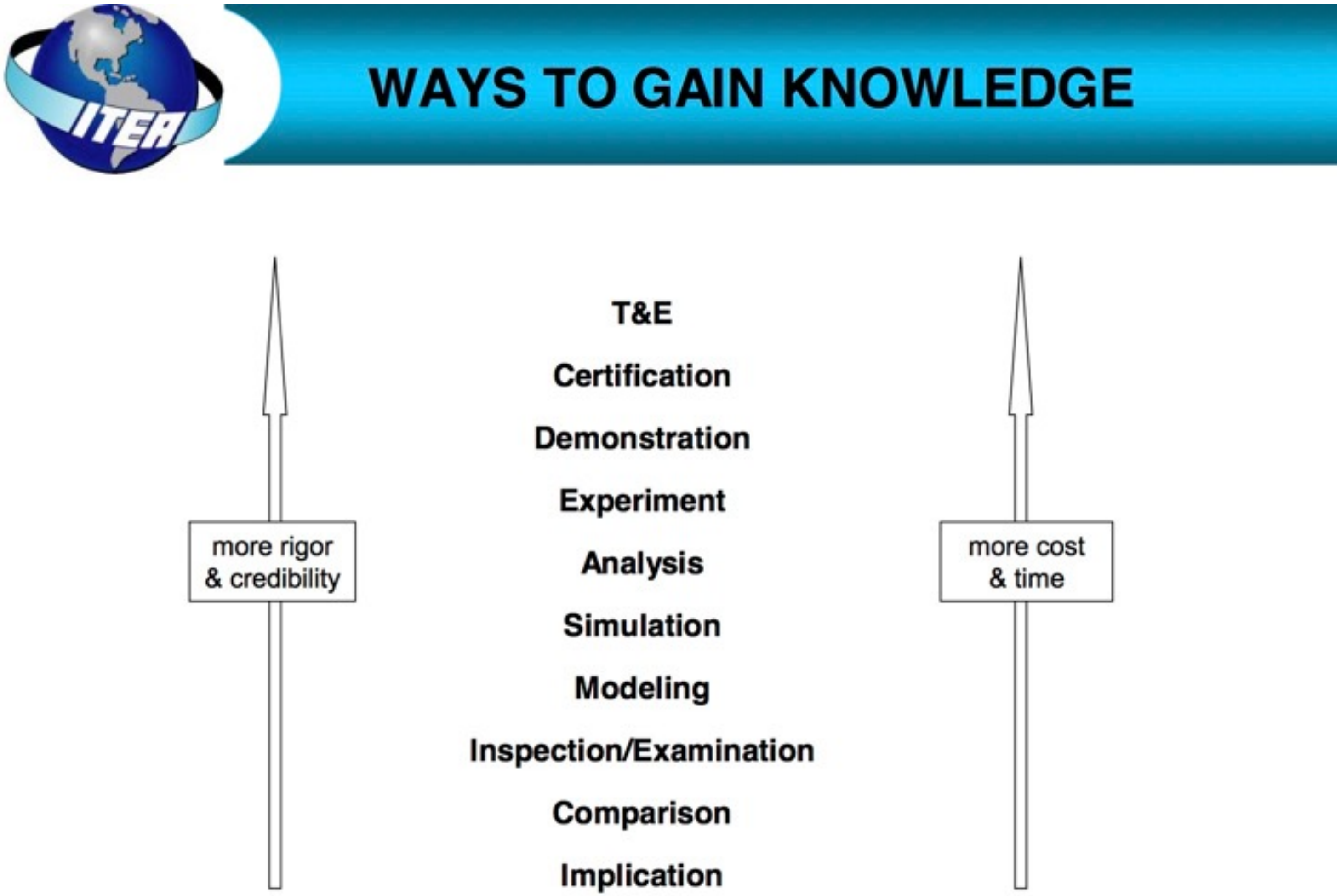
Define Test Objectives

“E<T”

What data do I need to satisfy the objectives?

	DT	OT
H0	System bad	System good
H1	System good	System bad

Balance Rigor to Amount of Needed Confidence



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VERB DEFINITION

Verb	Action	Typical Use	Level of Evaluation
Observe	To watch carefully, especially with attention to detail or behavior for the purpose of arriving at a judgement.	Observe the radar altimeter display over nonlevel terrain while maneuvering.	Low because no measure of the overall worth is made. Typically used when the AFFTC is hired to gather data for an external Government agency or contractor. Pilot and engineer observations are delivered to the customer along with the data at the end of the test.
Compare	To examine in detail the likenesses and differences in the quality or performance of the test items.	Compare the detection range of the APG-66 versus the APG-70.	Low because no measure of overall worth is made.
Demonstrate	To reveal something qualitative or quantitative which is not otherwise obvious.	Demonstrate that the C-17 can back up a 2-percent grade using thrust reverser.	Low because no measure of the overall worth of this function is made. Little or no relevance is made as to whether the test subject accomplishes the test with ease or its last breath. It either passes the test or it does not.
Determine	To discover certain measurable or observable characteristics of a test item.	Determine the maximum grade a C-17 can back up.	Some engineering expertise might be required to interpolate test results if all we had was a 2-percent ramp and a 5-percent ramp. The test article did fine on the 2-percent ramp but did not make it up the 5-percent ramp. The engineer would then have to use engineering expertise to determine what grade the C-17 could make it up.
Evaluate	To establish overall worth (effectiveness, adequacy, usefulness, capability) of a test item.	Evaluate the APG-66 radar maximum detection range.	High. This is the favorite AFFTC verb. Requires test expertise, corporate knowledge, and operational sense in order to perform the evaluation. Requires the maximum range to be determined, then an evaluation of the worth of that much range (e.g., offensive capability, weapons deployment advantage, etc.).
Verify	To confirm a suspected, hypothesized, or partly established contention. Implies use of a statistical evaluation.	Verify the APG-32 radar reboots less than once in 10,000 target acquisitions.	High. Requires concise knowledge of statistics in order to determine the number of acquisitions to perform in order to have a given level of confidence that the reboot rate has been determined.

	of the test items.		
Demonstrate	To reveal something qualitative or quantitative which is not otherwise obvious.	Demonstrate that the C-17 can back up a 2-percent grade using thrust reverser.	Low because no measure of the overall worth of this function is made. Little or no relevance is made as to whether the test subject accomplishes the test with ease or its last breath. It either passes the test or it does not.
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Test and Evaluation Master Plan (TEMP)

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System Introduction:
- Mission description
- Operational environment
- Measures of effectiveness and suitability
- System description
- Critical technical parameters

Integrated Test Program Summary:
- Test program schedule
- Management
- Participating organization

Developmental Test and Evaluation:
- Method of approach
- Configuration description
- Test objectives
- Events and scenarios

Operational Test and Evaluation:
- Purpose
- Configuration description
- Test objectives
- Events and scenarios

Test and Evaluation Resource Summary:
- Test articles
- Test sites
- Test instrumentation
- Test environment and sites
- Test support operations
- Computer simulations and models
- Special requirements

“Talk the Talk”

Established ways that T&E Informs

Test & Eval Contributions

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❖ **Development Test:** ***Exploratory / Seek Understanding / Inform / Verify***

- Gain knowledge – Discover failure modes / problems
- Increase robustness of design / gain confidence
- Confirm what you ”think” you know / Verify
- Find / Choose the “Correct Path”
- Subsystems and Components

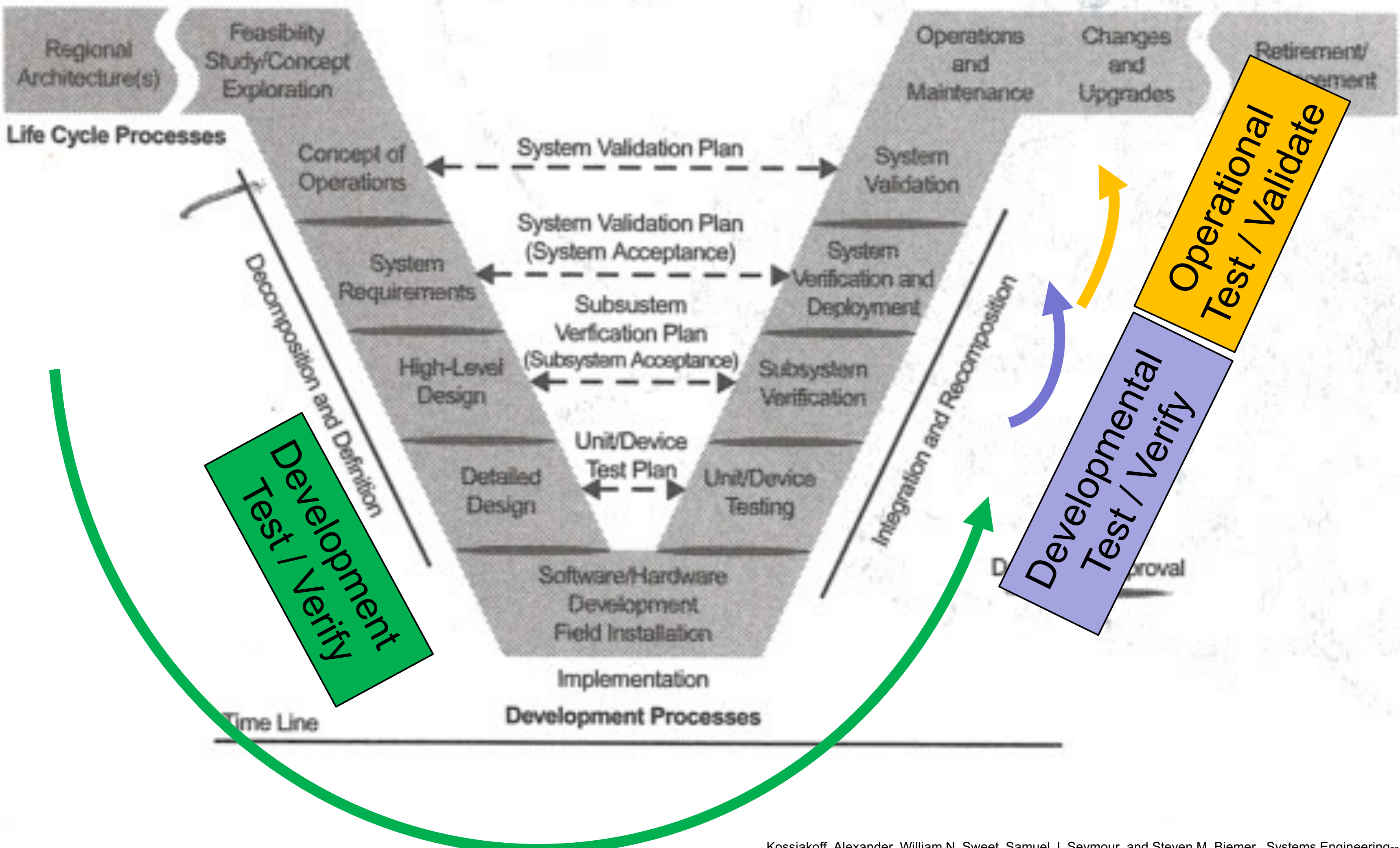
❖ **Developmental Test / Verification:** ***Did we build it (i.e., the system) right?***

- Full System Integration and Test / Aggregation
- Compliance with standards / regulatory agencies
- Verification of specifications and requirements
- System-level → Gain confidence for Operational Test

❖ **Operational Test / Validate:** ***Did we build the right thing?***

- Does the system “do” what the stakeholders intend it to “do?”

Develop – Build – Integrate/Test – Validate/OT



Kossiakoff, Alexander, William N. Sweet, Samuel J. Seymour, and Steven M. Biemer. Systems Engineering--Principles and Practice. 2d ed. Wiley and Sons. Hoboken, N.J., 2011

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Verification

- Confirmation and provision of objective evidence that an *engineering element*:
- 1.has been produced by an acceptable transformation.
- 2.*meets its requirements* (context dependent)
- 3.meets the rules and characteristics defined for the organization's best practices and guidelines in creating the element.

Validation

- Confirmation and provision of objective evidence that an *engineering element* will *result or has resulted in a system* that meets its intended use in its *intended operational environment*.

INCOSE-TP-2021-004-01 | VERS/REV:1.0 |May 2022, p. 15

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System Verification

- Confirmation that the designed and *built/coded system or system element*:
- 1.has been produced by an acceptable transformation of design inputs into design outputs (*designed correctly*)
- 2.meets its *design input requirements and design output specifications*.
- 3.no error/defect/fault has been introduced at the time of any transformation
- 4.meets the requirements, rules, and characteristics defined by the organization's best practices and guidelines in system development.

System Validation

- Confirmation that the designed, built, and verified system or system element:
- Will result or has resulted in a *SOI that meets its intended purpose* in its *operational environment* when operated by its *intended users* and *does not enable unintended users to negatively impact the intended use of the system* as defined by its integrated set of needs.

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Key Differences

DT*

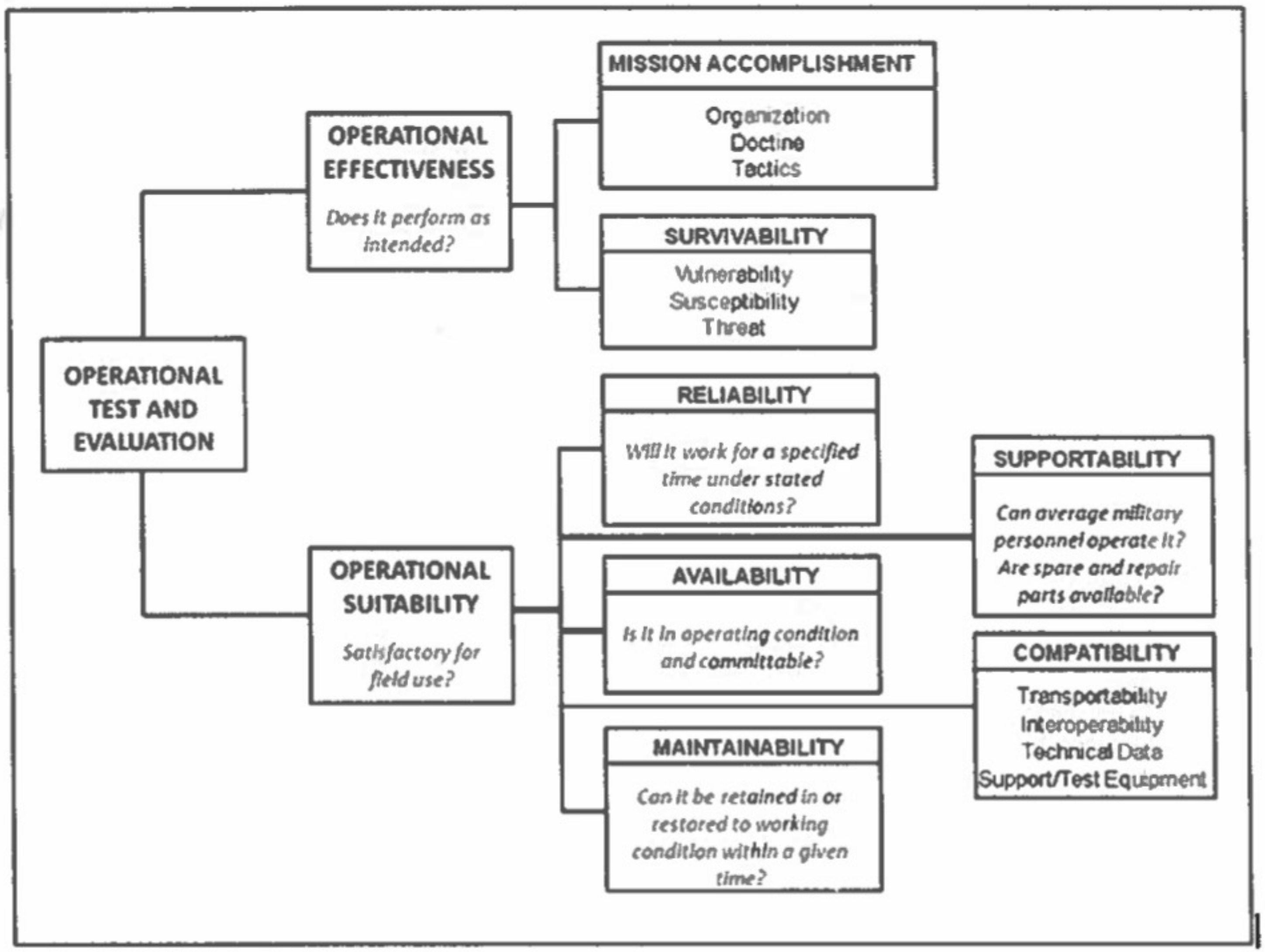
- Controlled by PM
- One-on-one tests
- Controlled environment
- Contractors involved
- Trained, experienced operators
- Precise performance objectives and thresholds
- Test to specification
- Developmental, engineering, or production test article

OT*

- Controlled by independent agency
- Many-on-many tests
- Realistic operational environment
- No system contractors
- Use normalized operators
- Performance measures are effectiveness and suitability
- Test to operational requirements
- Production representative test article

*Department of Defense. DOD System Engineering Fundamentals, 71.

Operational Test / Validation



Department of Defense. DOD Test & Evaluation Management Guide.

The DT/OT and RMA Complication

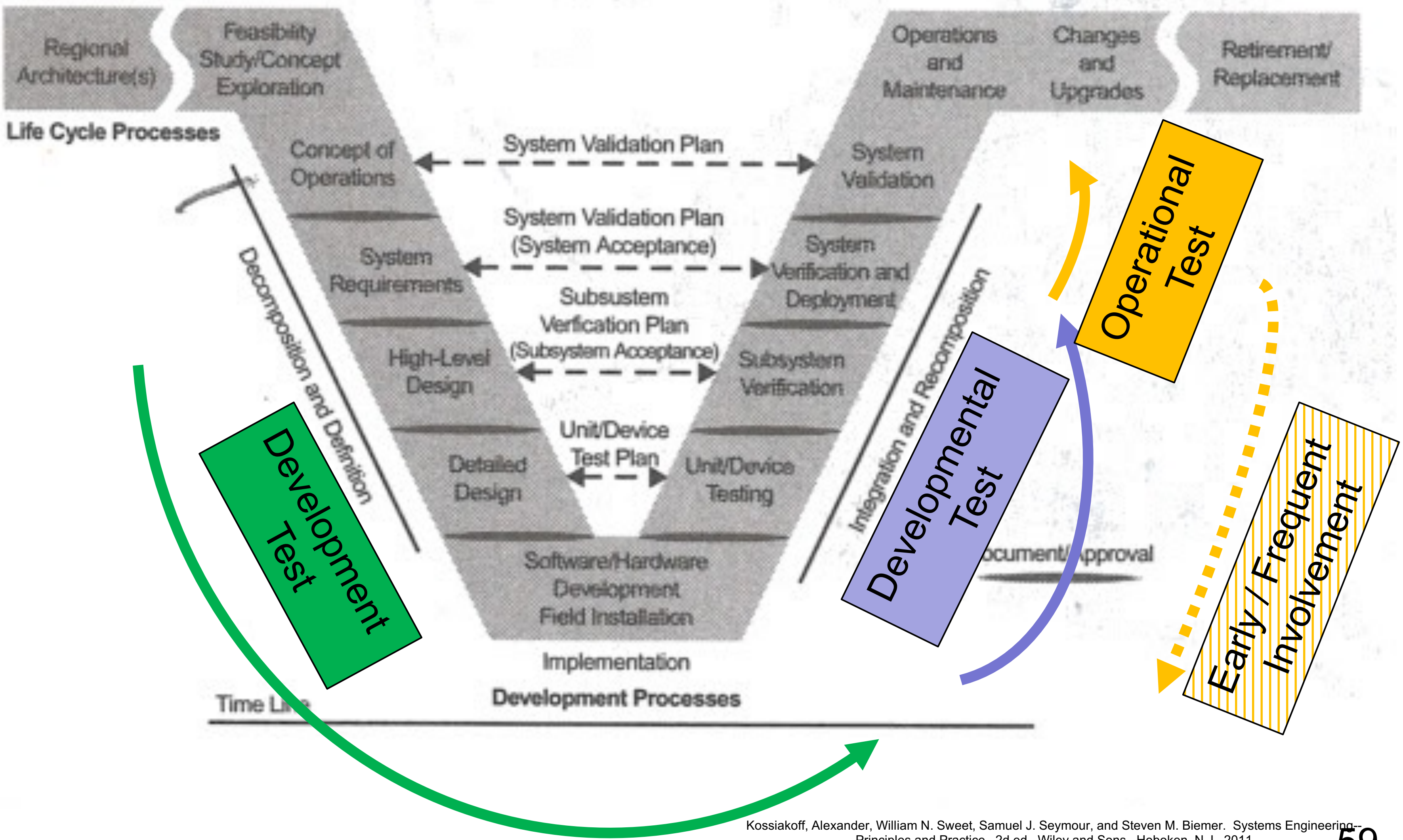
- **OT&E**
  - Short duration – reliability problems are often found much later
  - Material fatigue, cracks, aging/wear-out, corrosion, etc.
  - Time constraints push system into OT, and suitability is left hanging
  - LRIP/prototype articles are not used for long durations

  - Solutions to Consider:
    - Engineer reliability into the design
    - Increase reliability emphasis during development
    - Conduct OAs – enhance DT to include relevant environments
    - Lengthen OT timeline to gain increased understanding
    - Consider OT degradation—and predict/model outcomes
    - Plan a FOT&E to more fully address the issue

"Reliability Growth: Enhancing Defense System Reliability (2015)." The National Academies Press Book. Available at http://www.NAP.edu/10766, accessed April 1, 2018

Optimizing Your Build
Via
Test & Eval

"Shift Left"

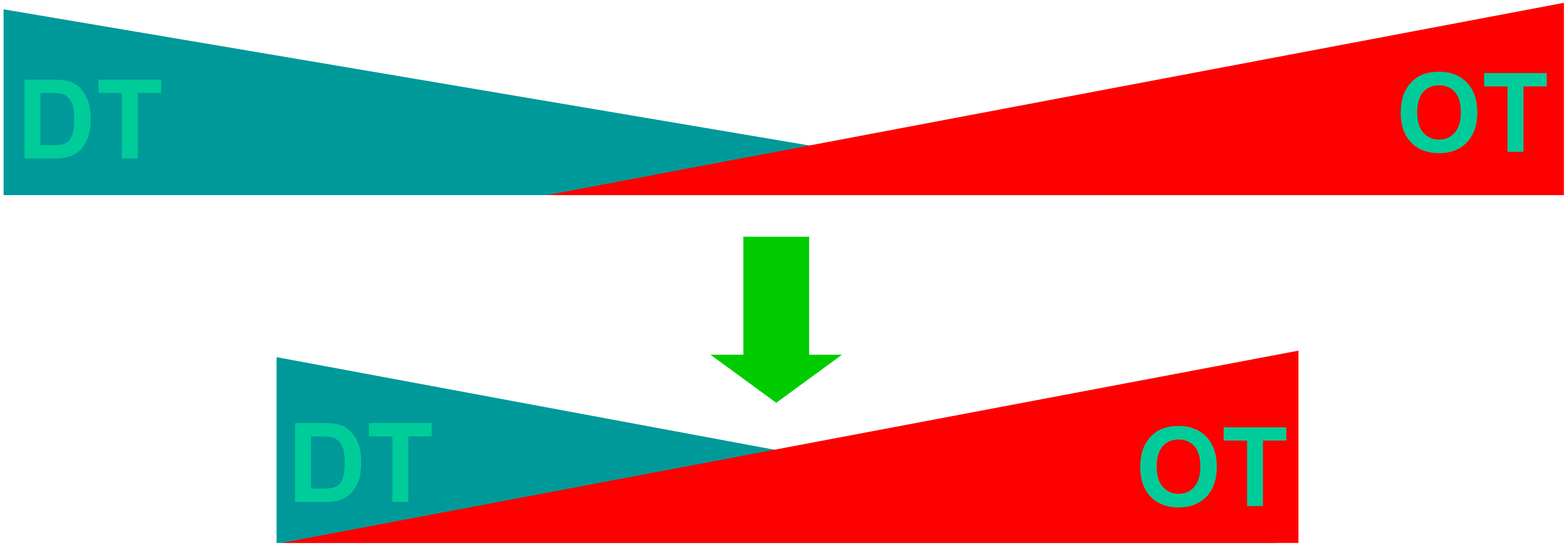


Kossiakoff, Alexander, William N. Sweet, Samuel J. Seymour, and Steven M. Biemer. Systems Engineering--Principles and Practice. 2d ed. Wiley and Sons. Hoboken, N.J., 2011

Shift Left / Combined Test

"**Seamless verification** minimizes the seams between contractor, developmental, and operational testing by implementing **integrated testing** techniques and procedures"

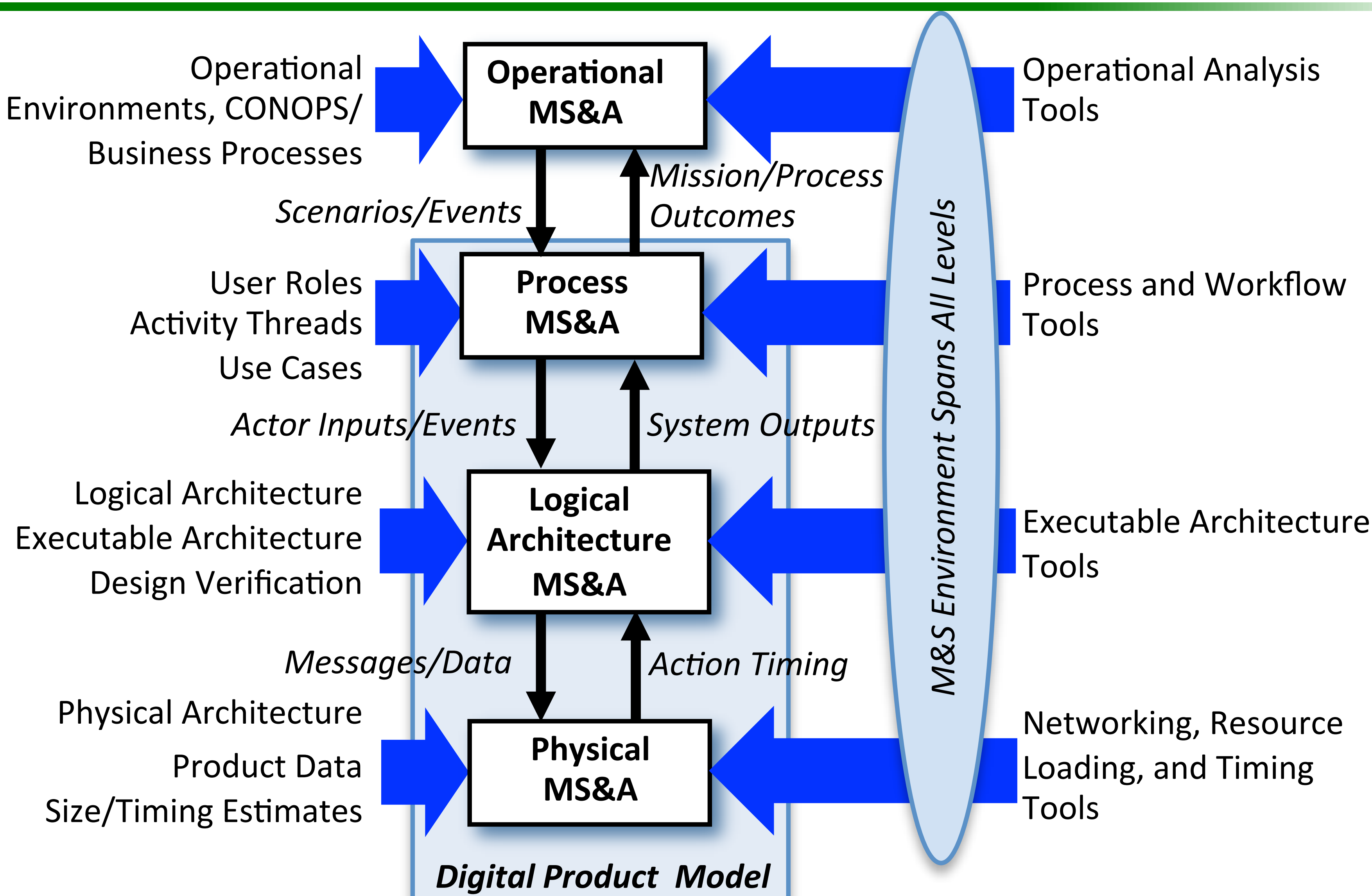
AFI 99-103, 2008



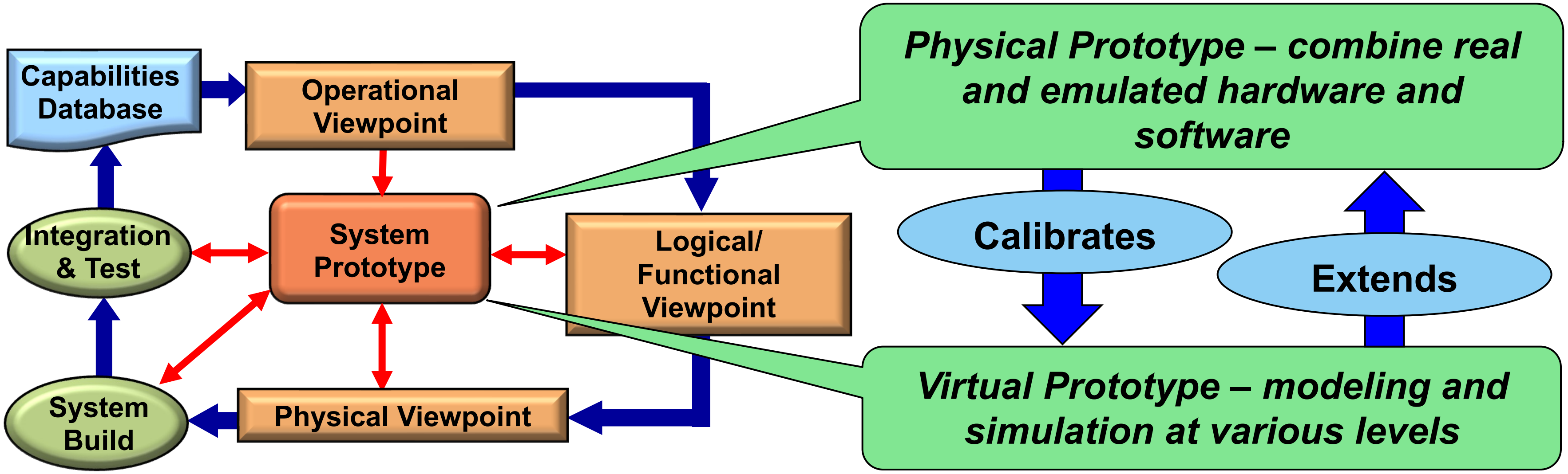
Modeling and Simulation

Digital Twin
Digital Thread
MBSE – Virtual Prototyping

Integrated Simulation Environment



The Role of Prototyping



- Validate the architecture before the risk and expense of implementation
- Find design errors, improper operating conditions, and other problems as early as possible
- Support affordable exploration design excursions ("what ifs")
- Support early and continuing customer interaction to ensure the design meets needs and expectations
- Get an early start on integration and test

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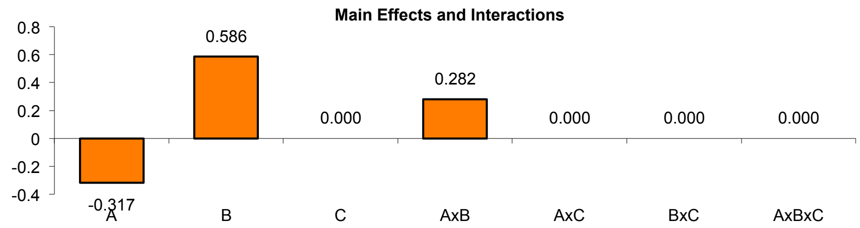
Screening / Sensitivity Analysis

Design of Experiments

	Run Order	flow	dec time	na	AxB	AxC	BxC	AxBxC	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1	6	55	s	0	1	1	1	-1	14.037	16.165	13.972	13.907	
2	8	55	s	0	1	-1	-1	1	14.037	16.165	13.972	13.907	
3	1	55	l	0	-1	1	-1	1	14.821	14.757	14.843	14.878	
4	4	55	l	0	-1	-1	1	-1	14.821	14.757	14.843	14.878	
5	2	59	s	0	-1	-1	1	1	13.88	13.86	14.032	13.914	
6	5	59	s	0	-1	1	-1	-1	13.88	13.86	14.032	13.914	
7	3	59	l	0	1	-1	-1	-1	14.888	14.921	14.415	14.932	
8	7	59	l	0	1	1	1	1	14.888	14.921	14.415	14.932	



Select Factor or Interaction for Calculation Details:

- ◯ A
- ◯ B
- ◯ C
- ◉ A x B
- ◯ A x C
- ◯ B x C
- ◯ A x B x C

High (+1) settings:

average (14.5203 14.5203 14.789 14.789) = 14.6546

Low (-1) settings:

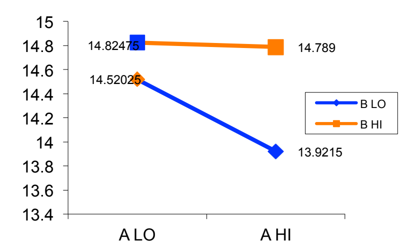
average (14.8248 14.8248 13.9215 13.9215) = 14.3731

Effect:

14.6546
- 14.3731
0.2815

A x B Interaction

		B LO	B HI
A LO	1	14.5203	14.8248
	2	14.5203	14.8248
	Avg	14.5203	14.8248
A HI	1	13.9215	14.789
	2	13.9215	14.789
	Avg	13.9215	14.789



Let's Break It!

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- **HALT – Highly Accelerated Life Testing**
- **(H)AST – Highly Accelerated Stress Testing**

- **Good to use if:**
  - **Mechanisms of failure not fully understood (fatigue, etc.)**
  - **Tests are planned to specifically provide information on what failures might occur**
  - **Determine application / environment that might cause failure**
  - **Set up item in test chamber / facility**
  - **Break – Fix – Break – Fix**
  - **Does not help determine MTBF – <u>used primarily to increase reliability and durability</u>**

- **Environmental Stress Screening – subjecting systems to <u>stressors higher than specifications</u>.**

ITEA Industry Trends

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- Digital Engineering → Digital Test / Eval
- Digital Twin
- Test Driven Development
- Systems Engineering and T&E Synchronization
- MBSE to Support Test-Driven Development
- Using LVC in Test Design
- How to Gain Timely Info and Knowledge from Data

Things to Remember

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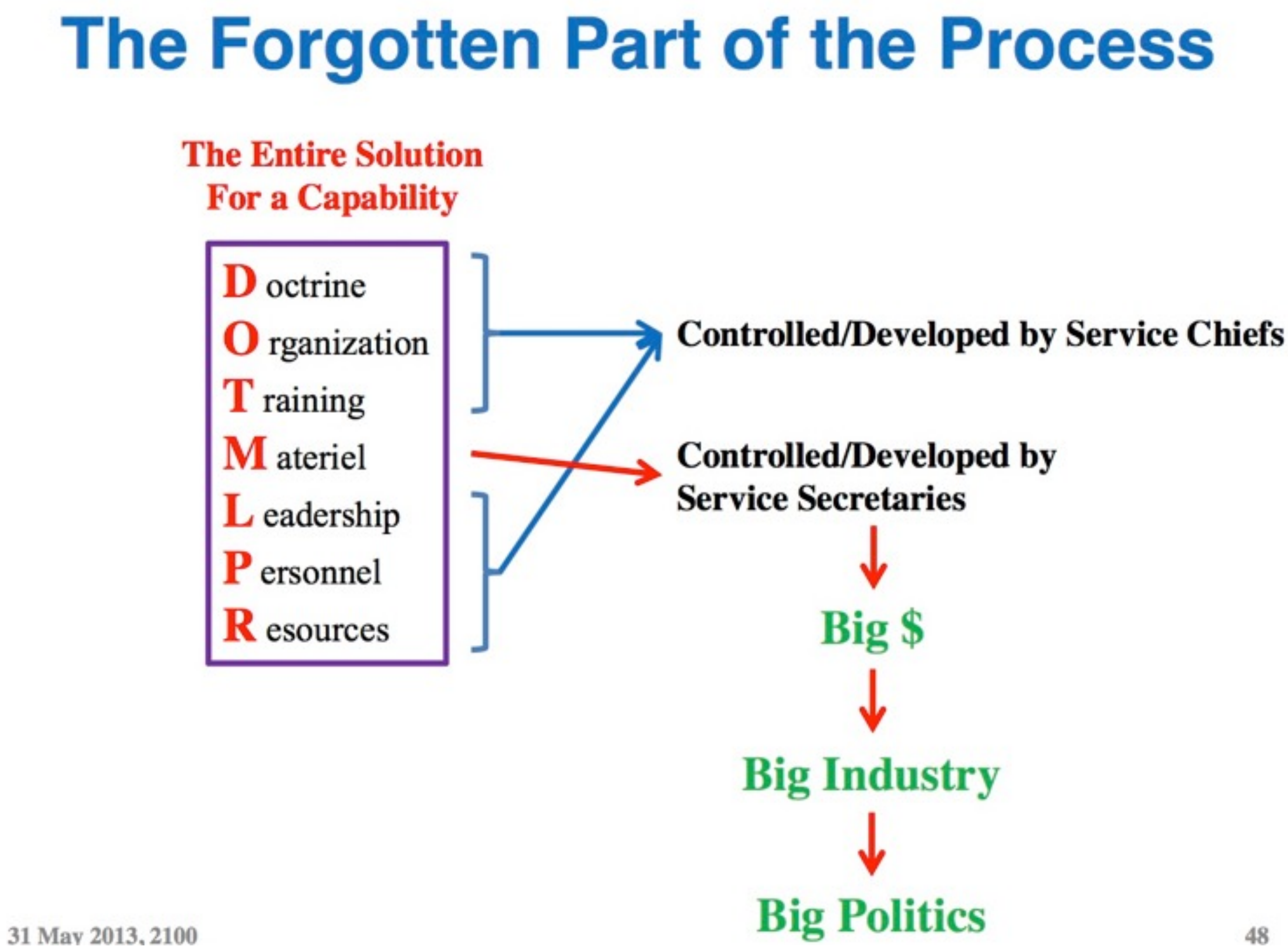
Questions

Back Up Slides

Oftentimes the Best…and Fastest



Bell, David W. and C. David Brown. "What T&E's Need to Know about Systems Engineering and Program Management." n.d. ITEA Webinar, available at http://itea.org.

Test Beds and/or Prototypes = Big $$

- **Increasing Complexity**
  - **Flying Test Beds**
    - **F-35 / Lockheed-Martin CATB**

http://www.edwards.af.mil/News/Article/396409/f-35-jsf-avionics-test-bed-arrives-at-edwards/

Boeing 787

- **Three years behind schedule**
- **Estimated cost-to-build $5 billion**
- **Actual cost 17 to 23 billion from 2003 to 2013**
- **Motivation for outsourcing was to decrease cost but end up cost more**

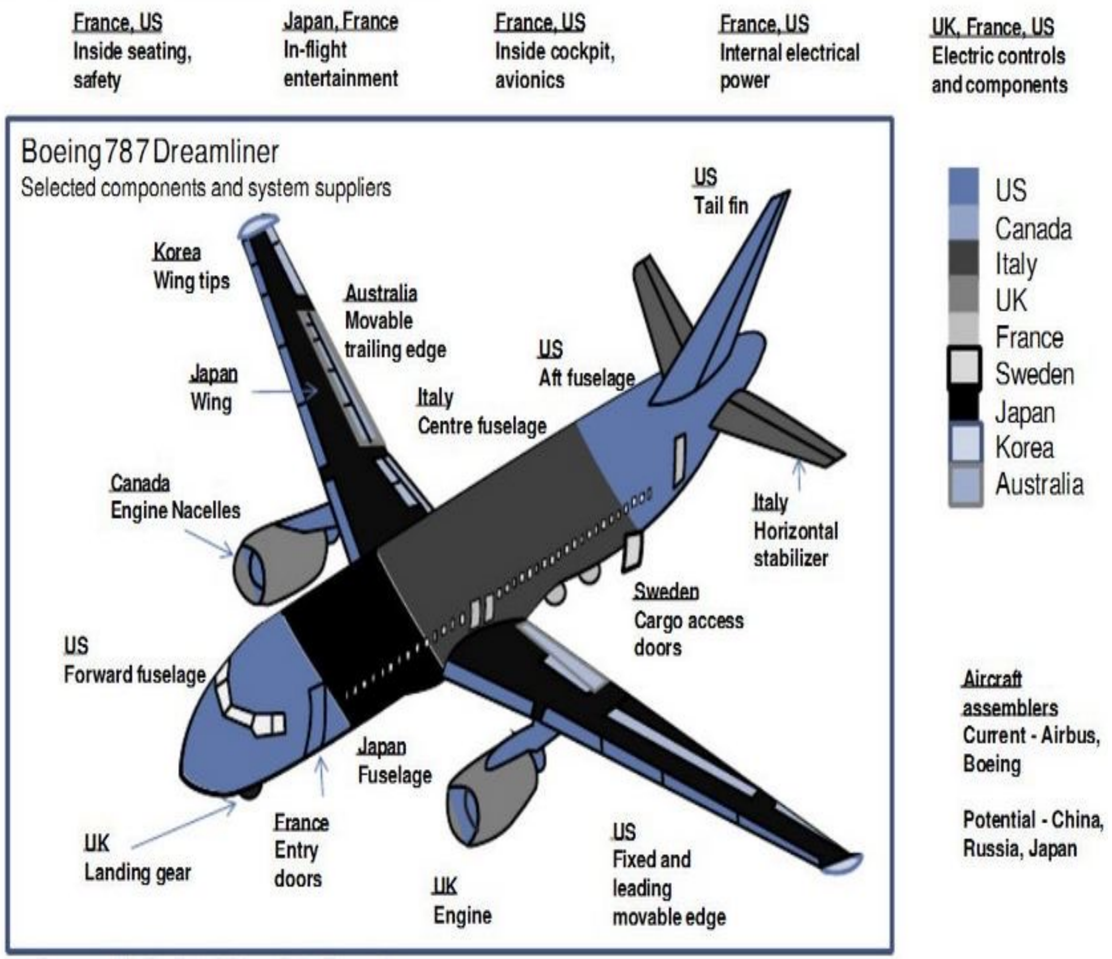


Image taken from:
https://www.consultancy.uk/news/297/outsourcing-main-cause-for-boeing-787-dreamliner-problems

- **January 2013, first reported <u>fuel leak incident</u> by Japan Airlines**
- **July 2013, first reported <u>fire incident</u> by Ethiopian Airlines associated with <u>Lithium-ion batteries</u>**
- **July 2013, first reported <u>wiring damage</u> on two 787 locator beacons by All Nippon Airways**
- **September 2013, Norwegian Long Haul reported two 787 <u>broke down</u> on six occasions**
- **January 2014, Norwegian Air Shuttle experienced <u>fuel leak</u>**
- **March 2016, Ethiopian Airline reported 787 had its <u>nose gear collapse</u> before flight ready to depart**
- **December 2017, <u>turbine blades in the engines reported wear out</u> much quicker than expected**

Definitions

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- **Reliability**
  - **"probability the system will perform its intended function under appropriate operating conditions for a specified period of time."**
  - **System operating modes can drive reliability**
    - **i.e., how the system is used…difference in DT vs. OT**
  - ***R = Probability of completing msn (10 hrs) without a critical failure***
  - **Must be defined early in the program**
  - **Requires longer test periods to evaluate…Hence, the DT / OT Gap**
  - **Reliability Growth Models can be useful in predicting future**

USAF DATA

Department of Defense. "DOD Guide for Achieving Reliability, Availability, and Maintainability." August 3, 2005.

System Design for Reliability

- **785B Methodology – 30% design / 70% figured out later**
- **Test-Analyze-And-Fix (TAAF)**
  - **Inefficient and Ineffective in comparison to designing for reliability**
- **MIL-HDBK-217 – produces misleading predictions**
  - **Predict via "stress" method**
  - **Predict via "parts count" method**
  - **→ Poor designs and logistics decisions**
- **Better to follow Petroski – Anticipate – Use FRACAS**
  - **Physics-of-Failure method (failure modes/mech/sites) w/ damage models**
  - **Design-for-reliability method (FMEA, Robustness, root-cause, etc)**
  - **Life-Cycle Loads / Field Trials / M&S / HALT / Quality of parts / Etc.**

"Reliability Growth: Enhancing Defense System Reliability (2015)." The National Academies Press Book. Available at http://www.NAP.edu/10766, accessed April 1, 2018

Early Reliability Growth Development

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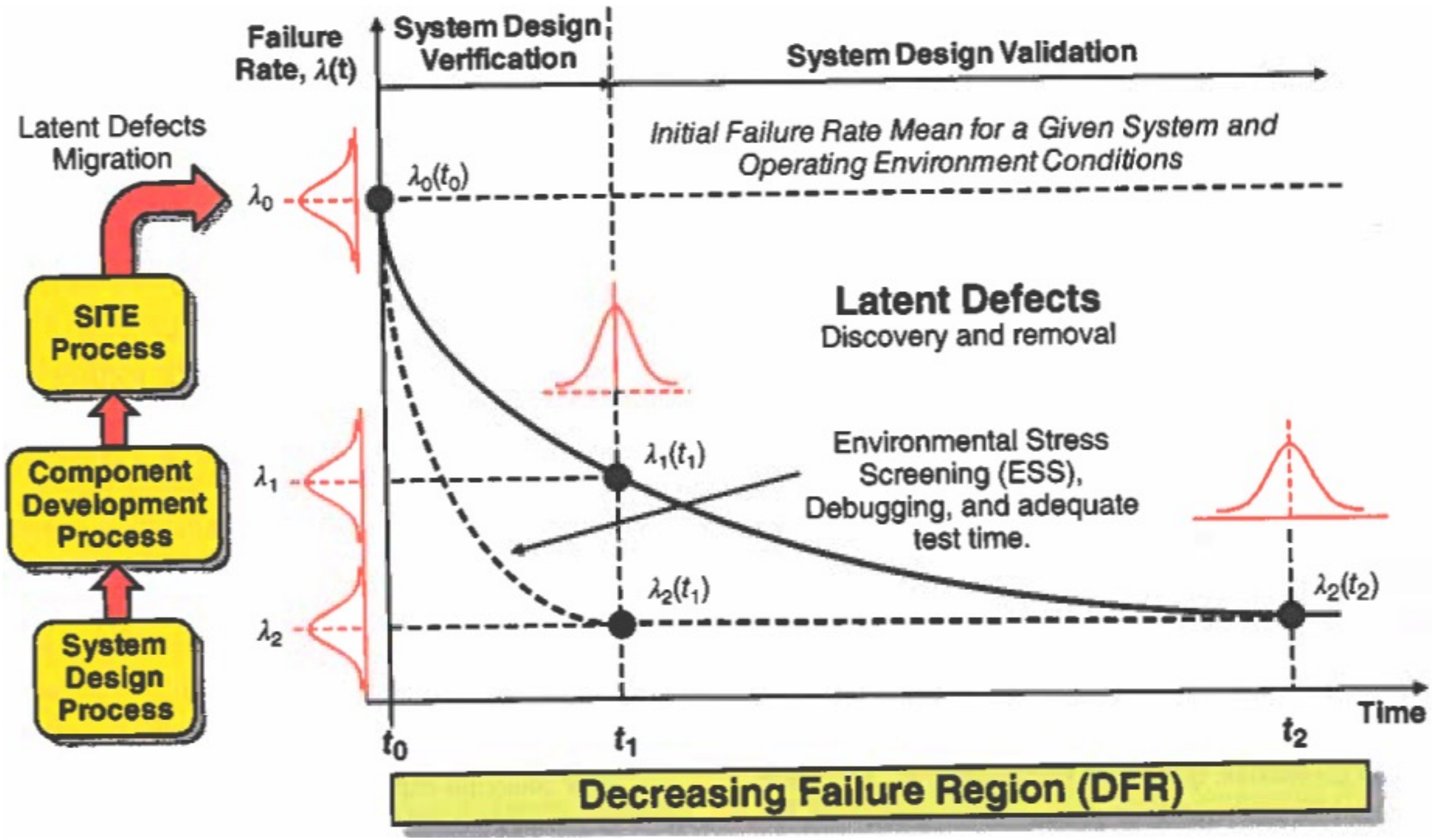
- **Used to identify failure modes**
- **Assess how "reliable" is the system**

- **Test – as the system gets built / produced (short-term)**
  - **Use TAAF to eliminate design weakness**
  - **HALT to discover weakness / redesign for improvement**
  - **Accelerated degradation tests (springs, corrosion, etc.)**
  - **Drift…degrade…then failure predictions**
  - **Actual condition testing– but test 24/7 (ex. tires, engines, etc)**

  - **Use STAT / DoE to inform the process**
  - **Save (and pass) data to users to inform future use**

"Reliability Growth: Enhancing Defense System Reliability (2015)." The National Academies Press Book. Available at http://www.NAP.edu/10766, accessed April 1, 2018

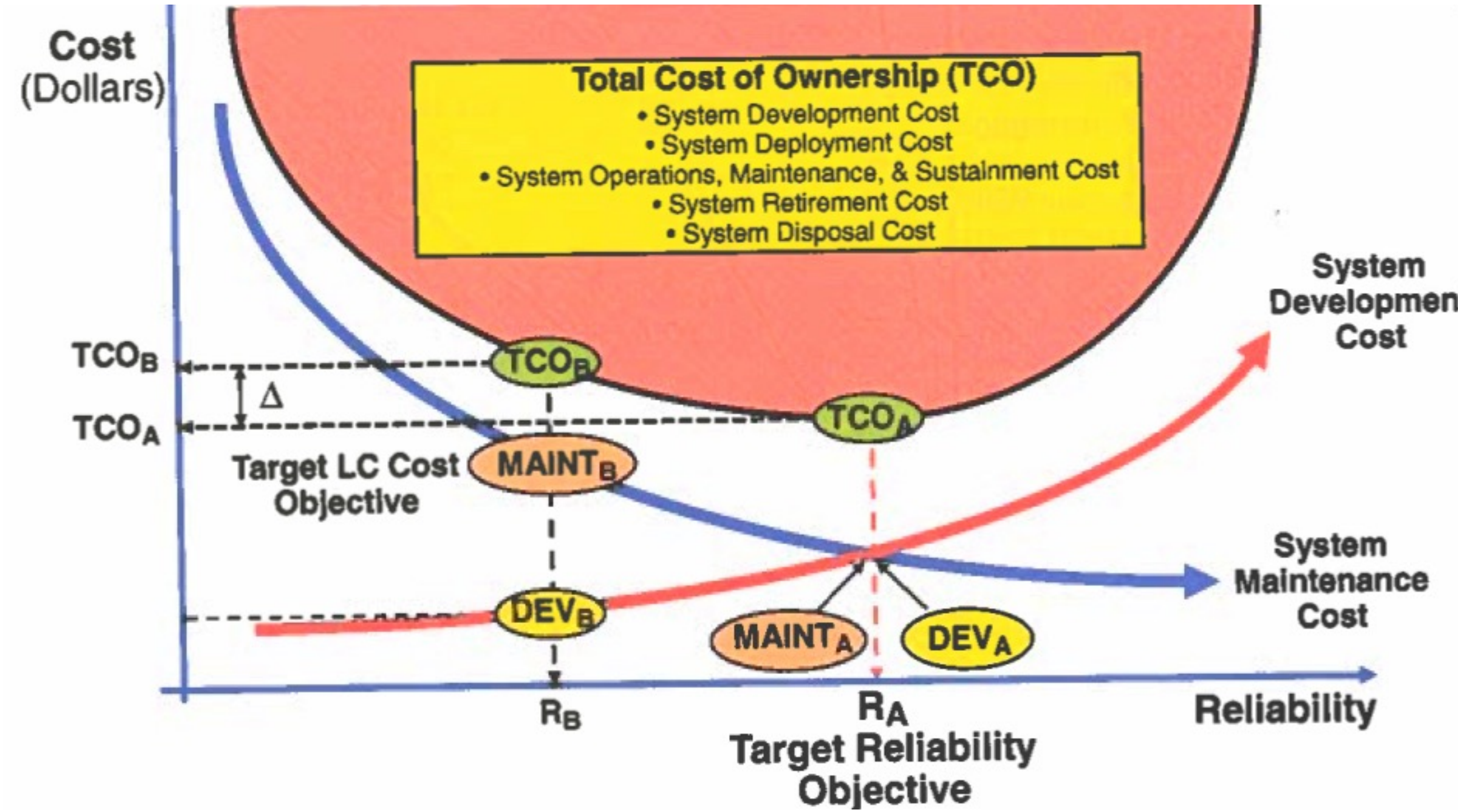
Wassen 775-776



Wasson, Charles. System Engineering. Analysis, Design, and Development. 2d ed. Wiley, Hoboken N.J. 2016.

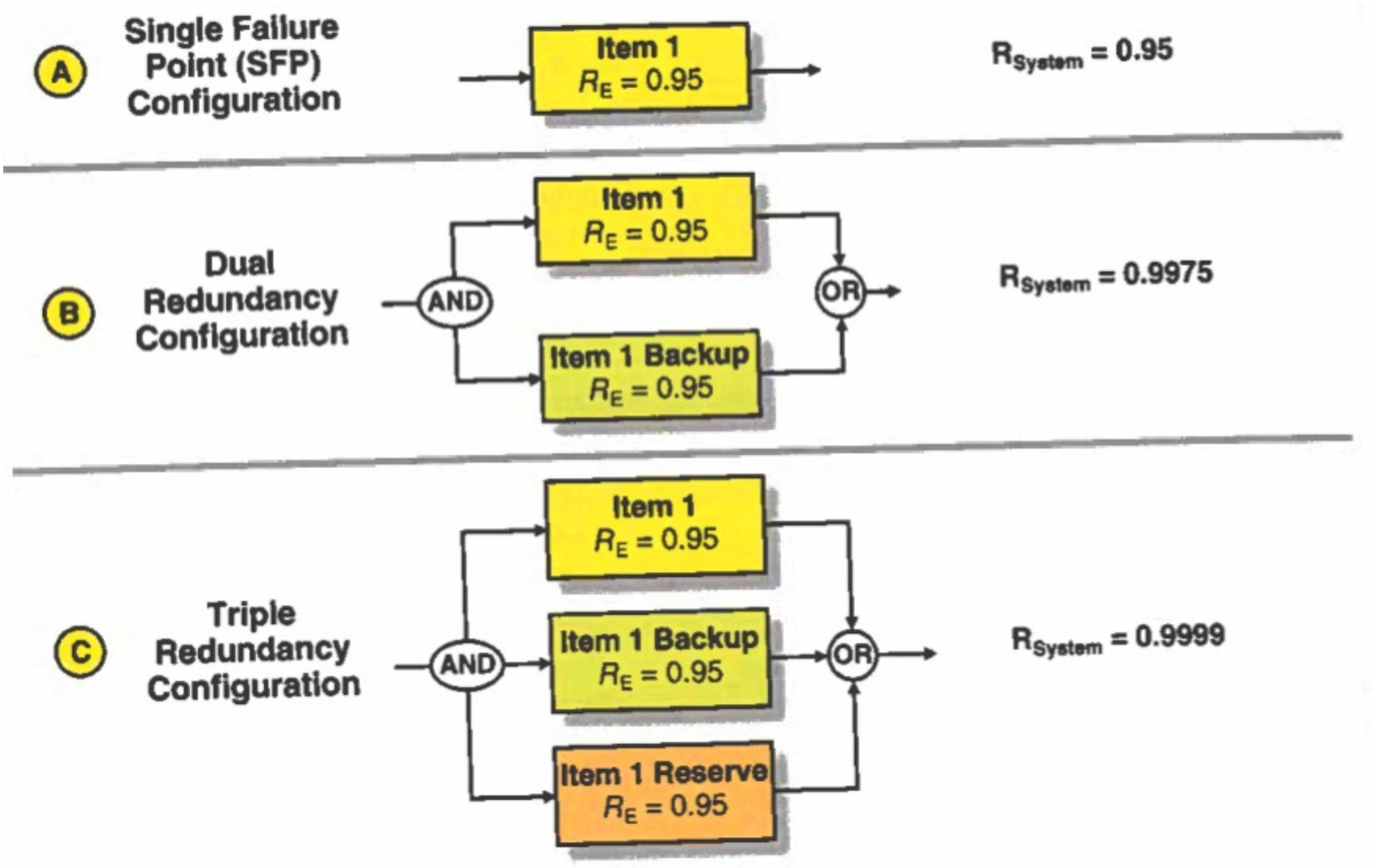
Wassen 782-789

- **Total Cost of Ownership (TCO) – Fig. 34.24**



Wasson, Charles. System Engineering. Analysis, Design, and Development. 2d ed. Wiley, Hoboken N.J. 2016.

Simple Engineering Approaches



Wasson, Charles. System Engineering. Analysis, Design, and Development. 2d ed. Wiley, Hoboken N.J. 2016.

More Comprehensive Bake-In's

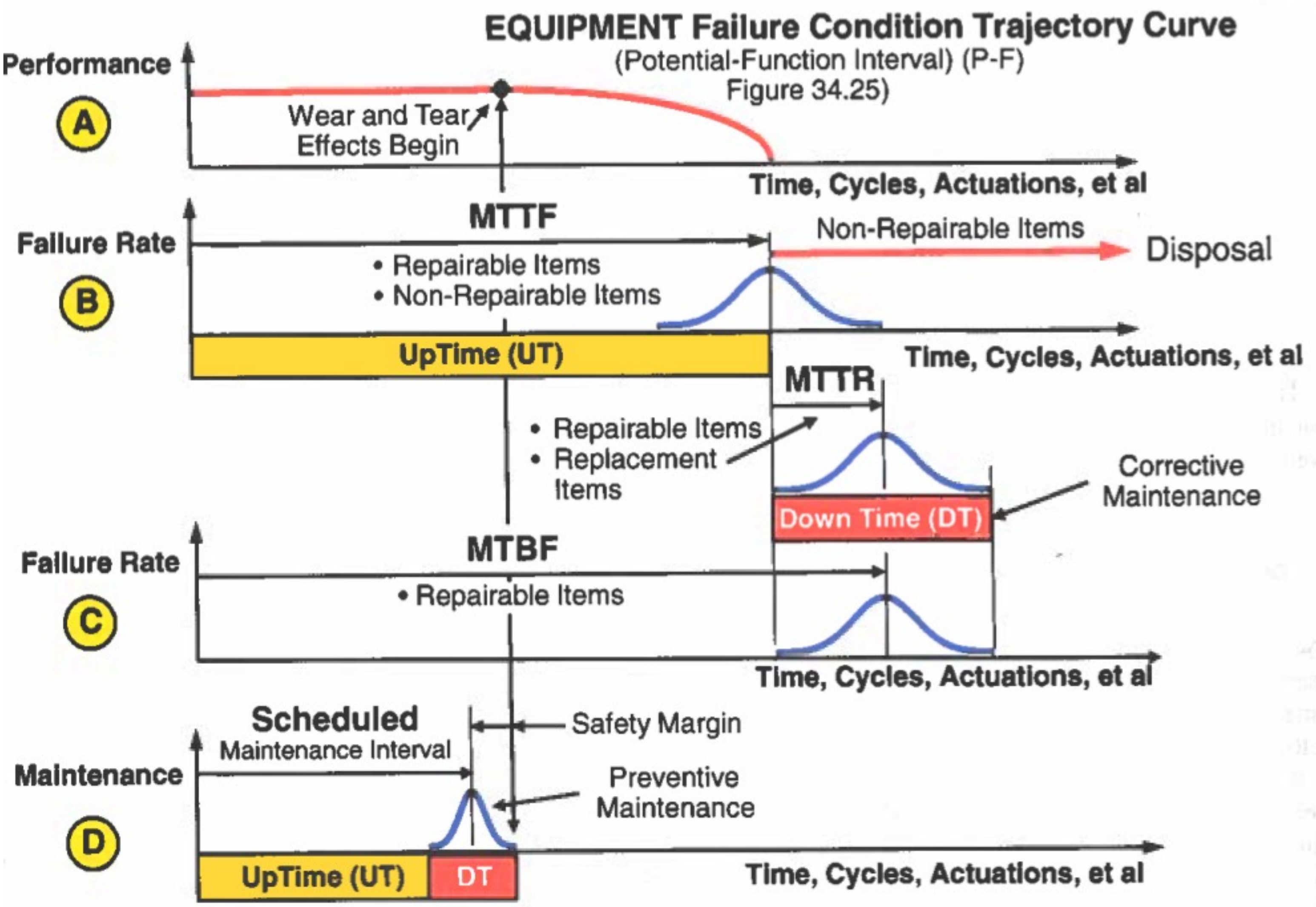
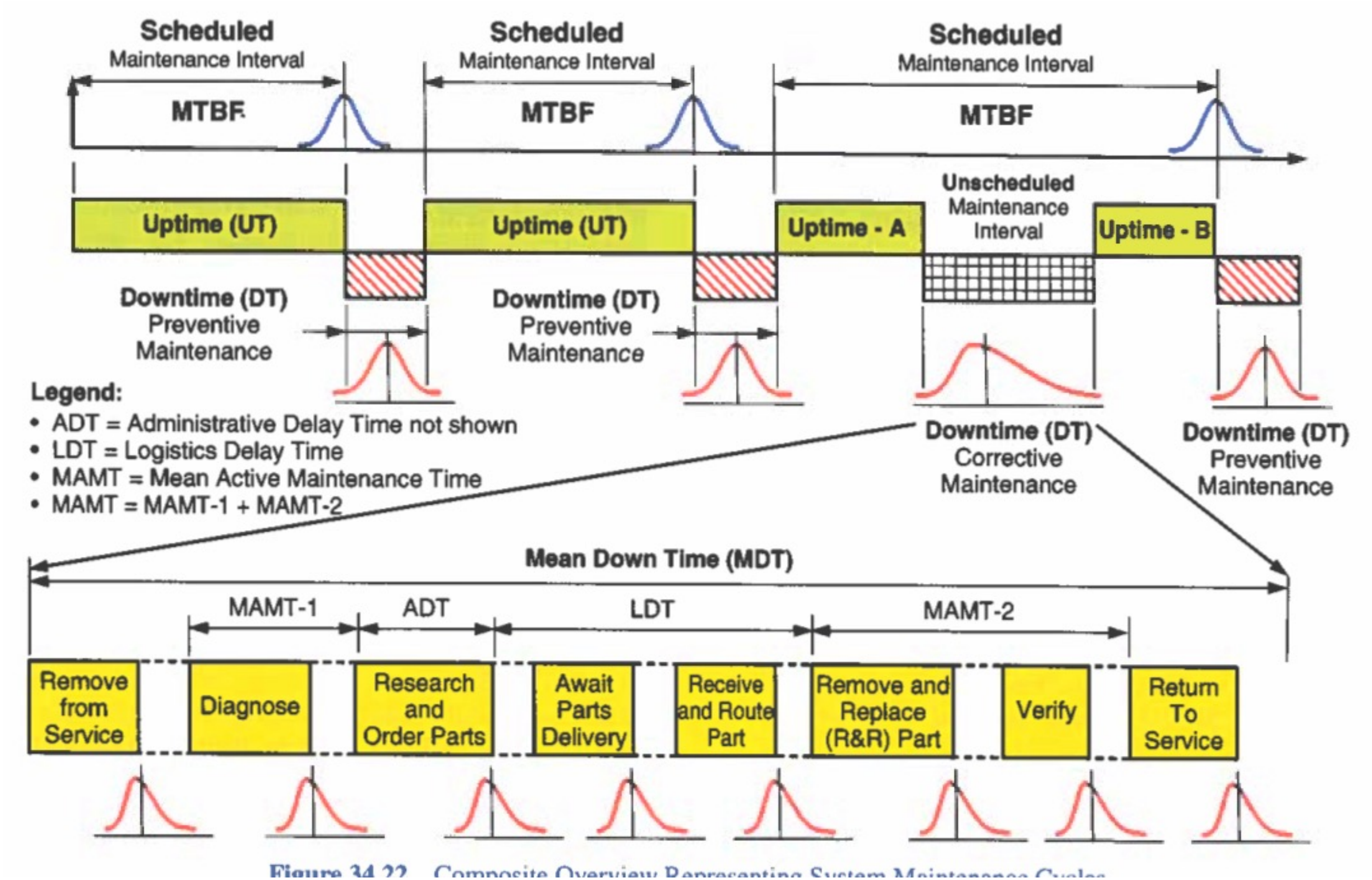


Figure 34.21 Underlying Concepts of Maintainability

Wasson, Charles. System Engineering. Analysis, Design, and Development. 2d ed. Wiley, Hoboken N.J. 2016.

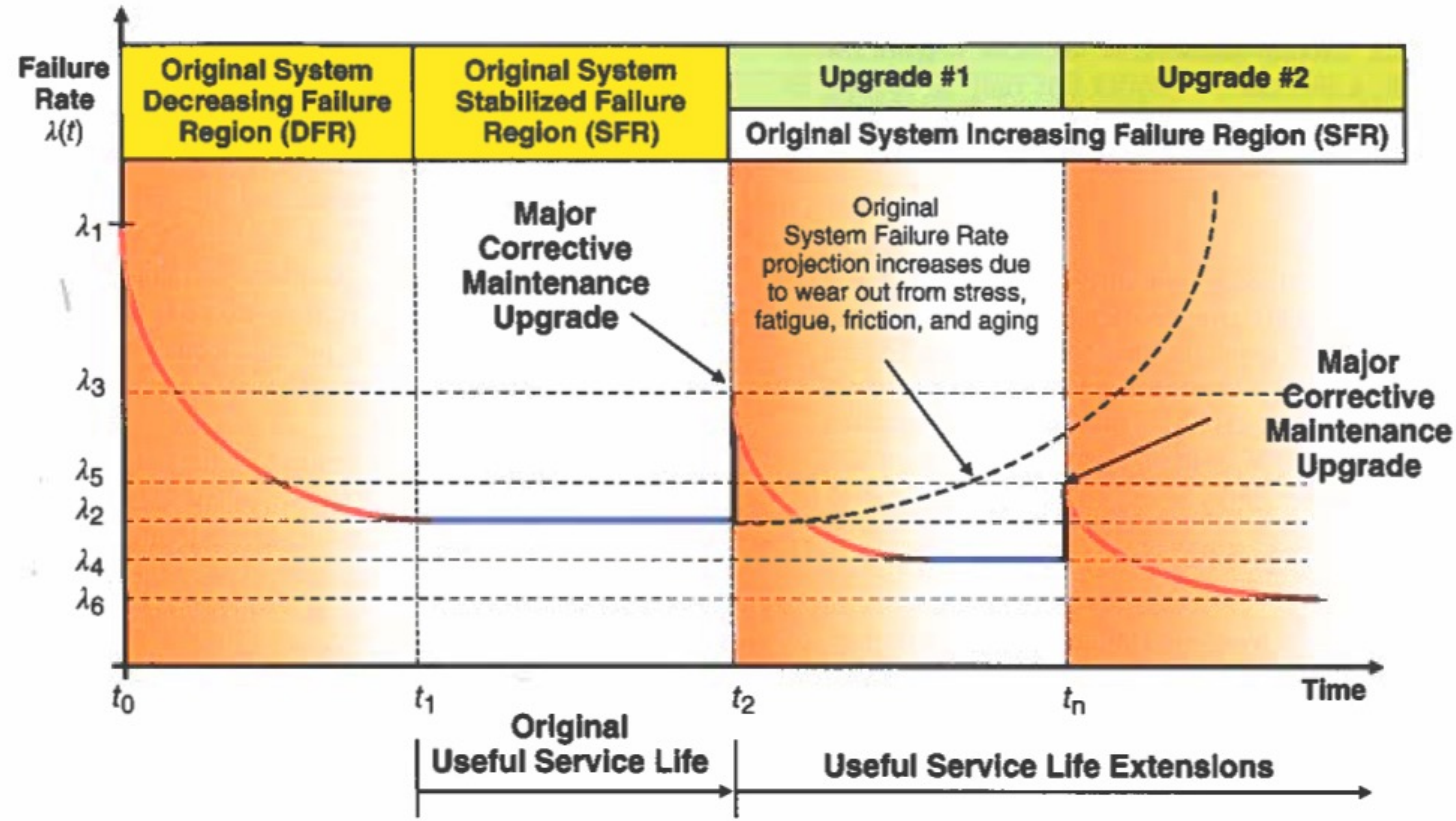
Techniques of Old

- **Time-based or Event-driven**



Wasson, Charles. System Engineering. Analysis, Design, and Development. 2d ed. Wiley, Hoboken N.J. 2016.

Wassen 775-776



Wasson, Charles. System Engineering. Analysis, Design, and Development. 2d ed. Wiley, Hoboken N.J. 2016.

O'Connor Chapter 6

- **DoE or HALT?**
  - Complimentary
  - No clear cut approach

Table 6.1 DoE/HALT selection

Important variables, effects, etc.	DoE/HALT?
Parameters: electrical, dimensions, etc.	DoE
Effects on measured performance parameters, yields	DoE
Stress: temperature, vibration, etc.	HALT
Effects on reliability/durability	HALT
Several uncertain variables	DoE
Not enough items available for DoE	HALT
Not enough time available for DoE	HALT

SEM-4 Development Testing

1. Determine what data must be collected
2. Consider methods to obtain data
3. Define how data will be processed, analyzed, and presented

Consider:

- Volume of data in dynamic performance tests
- Required analysis software
- Test points and auxiliary sensors
- Relationship between test configuration, test scenarios, test analysis, and design criteria

Evaluation of User Interfaces

<u>Especially important in decision support systems</u>, e.g., air traffic controllers

<u>Difficult to objectively quantify</u> – variations in individual user experience, visual/logical skills, preferences

<u>Consider:</u>

1. <u>Ease</u> of learning operational controls
2. <u>Clarity</u> of visual situational displays
3. <u>Usefulness</u> of information content to system operation
4. On-line <u>user assistance</u>

Analysis and Evaluation of Test Results

Test discrepancy – first check test equipment

Analysis:

- Depends on:
  (1) high quality data (2) correct interpretation

- Requires: team of analysts, test engineers, and system engineers

- Includes tracing performance deficiencies to system requirements – especially when significant redesign required

Test Planning Methodology

1. Review operational requirements, determine features to be evaluated
2. Determine test conditions, upper and lower limits
3. Review component selection process and related design issues
4. Identify interfaces between test component and system/environment.
5. Define configurations for testing selected components
6. Identify test inputs to components and outputs that measure response
7. Define requirements for test equipment and facilities
8. Determine costs to conduct tests
9. Develop test schedules
10. Prepare test plans

Creating the Test Environment

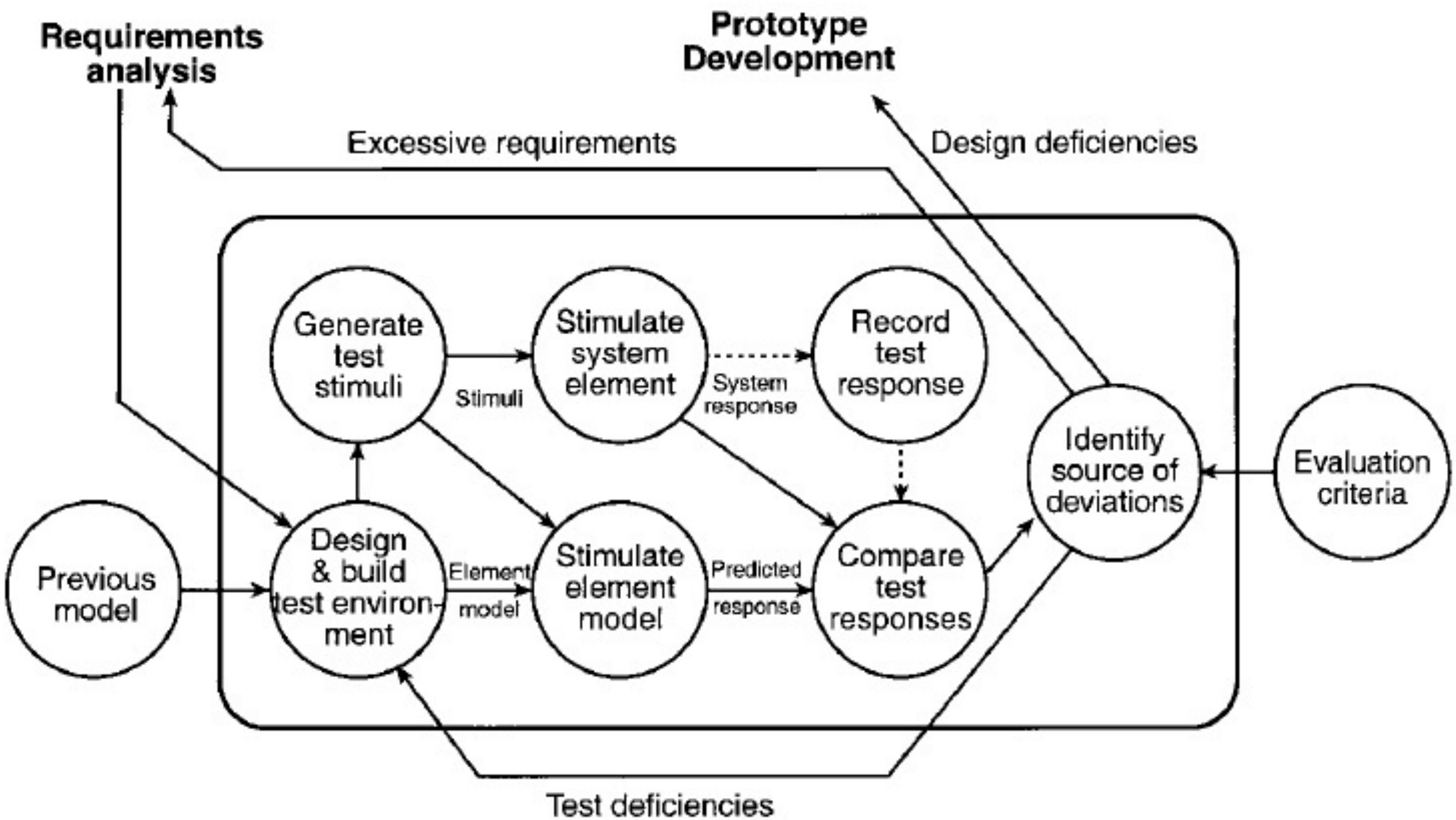


Fig. 13.3 Test and evaluation process of a system element.

Source: Kossiakoff, A., & Sweet, W. (2020). *Systems engineering: principles and practice*. Hoboken, N.J. : Wiley-Interscience.

Compare model outputs to test component

Systems Engineering Life Cycle Evolution

Level \ Phase	Needs Analysis	Concept Exploration	Concept Definition	Advanced Development	Engineering Design	Integration & Evaluation
System	Define operational objectives	Explore concepts	Define selected concept	Validate concept		Test and evaluate
Subsystem	Visualize	Define functions	Define configuration	Validate selected subsystems		Integrate, test
Component		Visualize	Select, define functions	Validate, specify construction	Design, test	Integrate
Sub-component			Visualize	Define functions	Design	
Part				Visualize	Select or adapt	

Visualization and Development Early in Design

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Materialization Process

TABLE 4.1 Evolution of System Materialization Through System Life Cycle

Level \ Phase	Needs Analysis	Concept Exploration	Concept Definition	Advanced Development	Engineering Design	Integration & Evaluation
System	Define operational objectives	Explore concepts	Define selected concept	Validate concept		Test and evaluate
Subsystem	Visualize	Define functions	Define configuration	Validate selected subsystems		Integrate, test
Component		Visualize	Select, define functions	Validate, specify construction	Design, test	Integrate
Sub-component			Visualize	Define functions	Design	
Part				Visualize	Select or adapt	

Iteration -- X^7

Systems Engineer

Discipline Specific Engineer

Information Flow

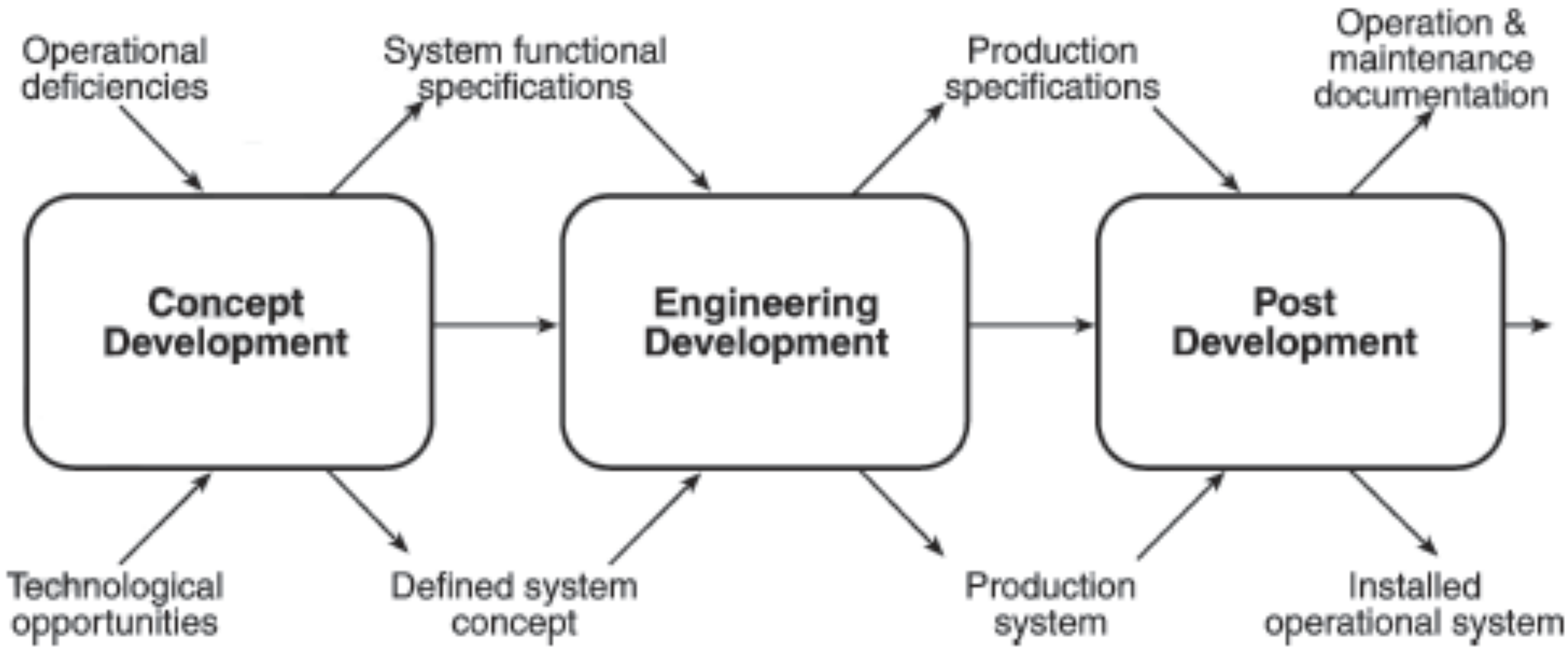

Fig. 4.3 Principal stages in system life cycle.

Design Representation

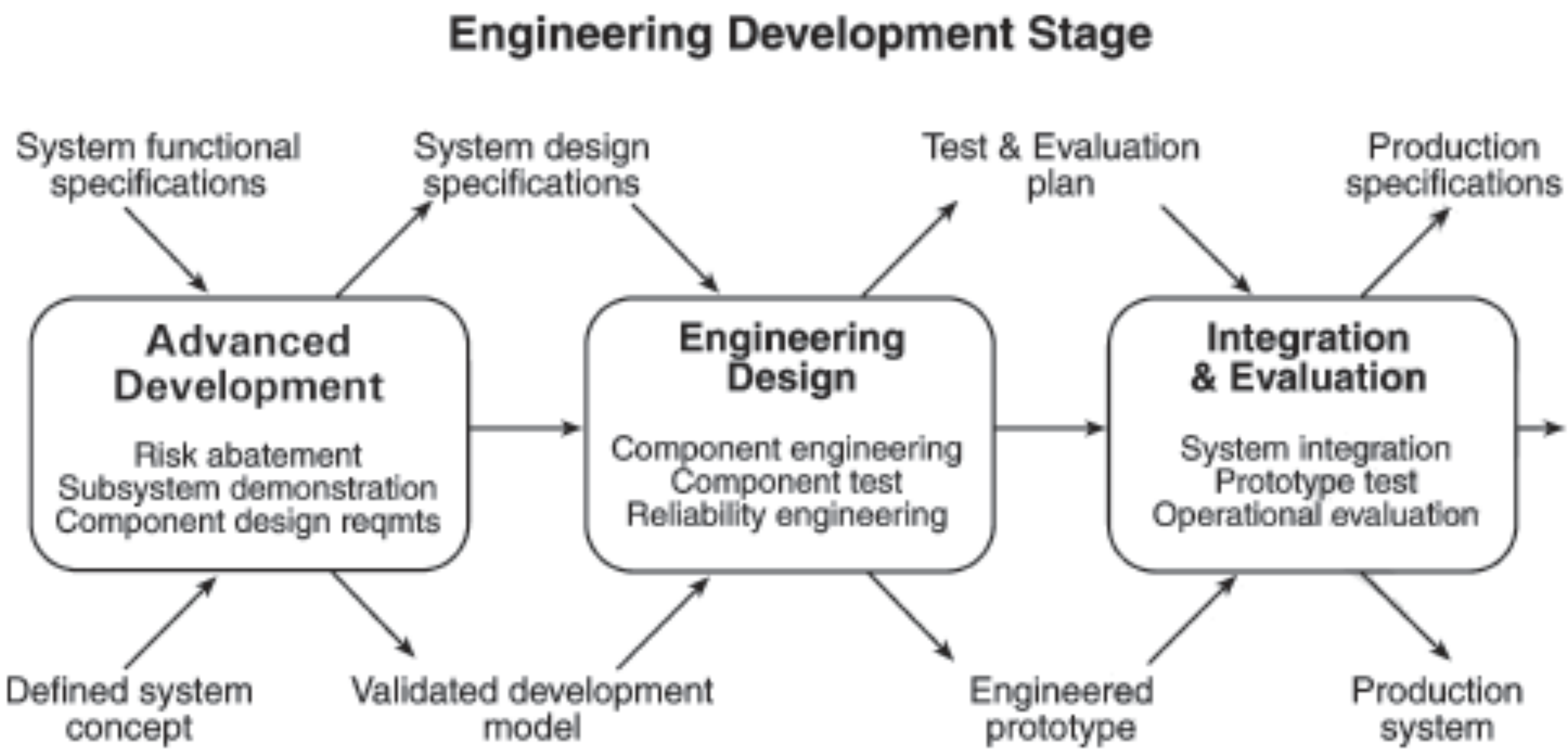

Fig. 3-4 Engineering development phases in system life cycle.

Testing

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1. **Some critical system characteristics stressed beyond their specified limits…which ones?**
2. **Some key elements need to be instrumented. The instruments must exceed the test articles in precision and reliability.**
3. **A test plan and an associated test data analysis plan must be prepared to assure that the requisite data are properly collected. Stakeholders and interested parties must be informed beforehand.**
4. **All limitations in the tests need to be explicitly recognized, and their effects overcome.**
5. **A formal test report is the first consideration in test evaluation**

Unknowns

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- Project cost depends on a host of factors; some are known to be “not known.”
- “Known unknowns” are identified early and singled out for resolution.
- Unanticipated problems are “unknown unknowns” and are addressed when identified / experienced.
  - BUT, must have margin to address planned in!

Transforming the Unknown into the Known

- “What if...? attitude.
- Risk assessment is identifying unknowns/uncertainties and resolving them to an adequate level of confidence.
- Tools: analysis, simulation and test, throughout the entire development.
- New design approach: testing is usually done first on a theoretical or experimental model of the design element—done for less cost– and to gain necessary confidence.

Risk Assessment

- **Used to *eliminate alternative concepts* that are overly dependent on immature technologies, unproven technical approaches, etc. (CE phase)**
- **Used to *identify* proposed design features that warrant *special analysis, development and test* (Advanced Development phase)**
- **Provides a (*on-going*) mechanism to *allocate resources* among the identified risks**
- **Comparison of two risk components primarily based on:**
  - **likelihood that component will not meet its goals**
  - **impact or criticality of such a failure to program success**

Risk Likelihood: Probability of Failure

CSU

- **Rough measure to determine relative priorities**
- **Rank order based on high, medium, and low risk**
- **Key Sources:**
  - **<u>Unproven technology</u>: identify similar cases where the technology is used and determine its level of development (e.g., laboratory design, prototype, production component)**
  - **<u>Highly complex components and interfaces</u> are more difficult (*especially human–machine interactions*) and always warrant early prototyping**
  - **<u>High software risks</u>: real-time programs, new operating systems, programs with high logic content**