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Systems Engineering of Deployed Systems

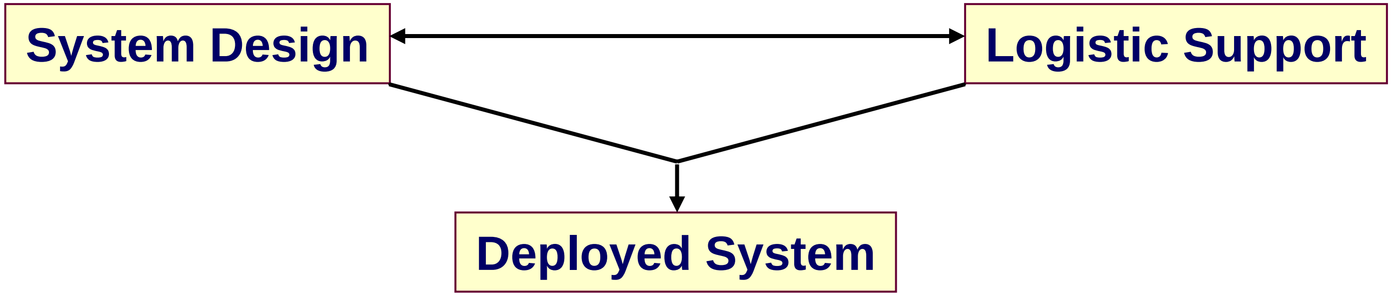
Bob Finlayson

Bryan Herdlick

The Johns Hopkins University, Whiting School of Engineering

Purpose

- Understand the role and function of the system engineer during the operations and support phase of a system
  - Understand logistic support considerations and how they influence design, manufacturing, production and operations decisions
  - Identify system supportability challenges and the means to address them
  - Develop deployed support resource requirements for system life
  - Master the ability to address system modifications in a dynamic environment



Challenge

- *"The operations and support phase of the system life cycle is the time during which the products of the system development and production phases perform the operational functions for which they were designed. In theory, the tasks of systems engineering have been completed. In practice, however, the operation of modern complex systems is never without incident."*

Kossiakoff, A., Sweet, W., *Systems Engineering Principles and Practice*

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Course Focus

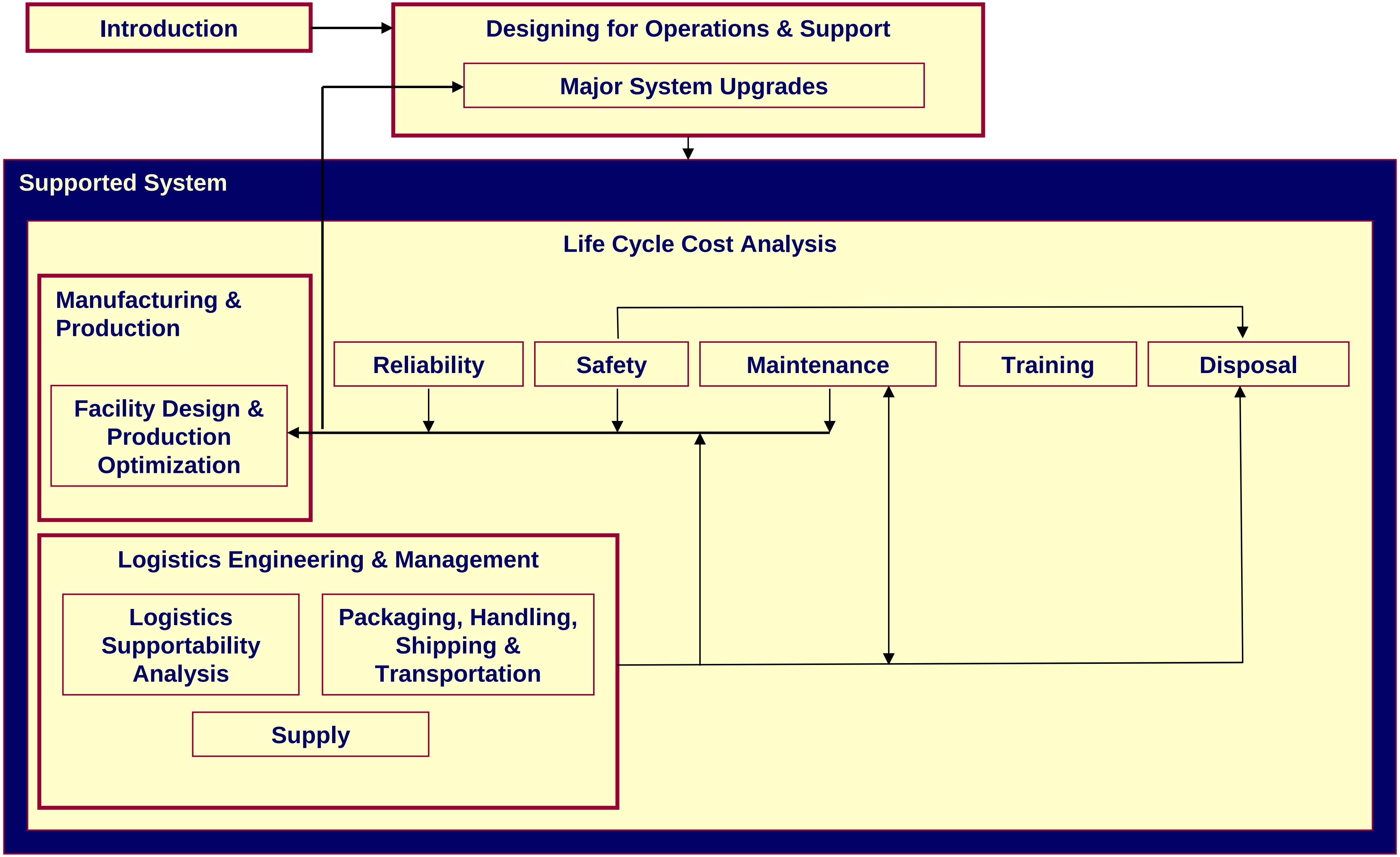
- What is peculiar about this aspect of the lifecycle & related SE topics in the context of mature / deployed / legacy systems?
- What lessons learned, best practices, tools should the systems engineer be familiar with?
- What are the risks that the SE should watch out for?
- Are there rules to live by?
- What is the role of the systems engineer in context of deployed / mature / legacy systems?

This is not a course in logistics management, but the systems engineer must have a thorough understanding of the logistics discipline if he or she hopes to address the engineering challenges of deployed systems

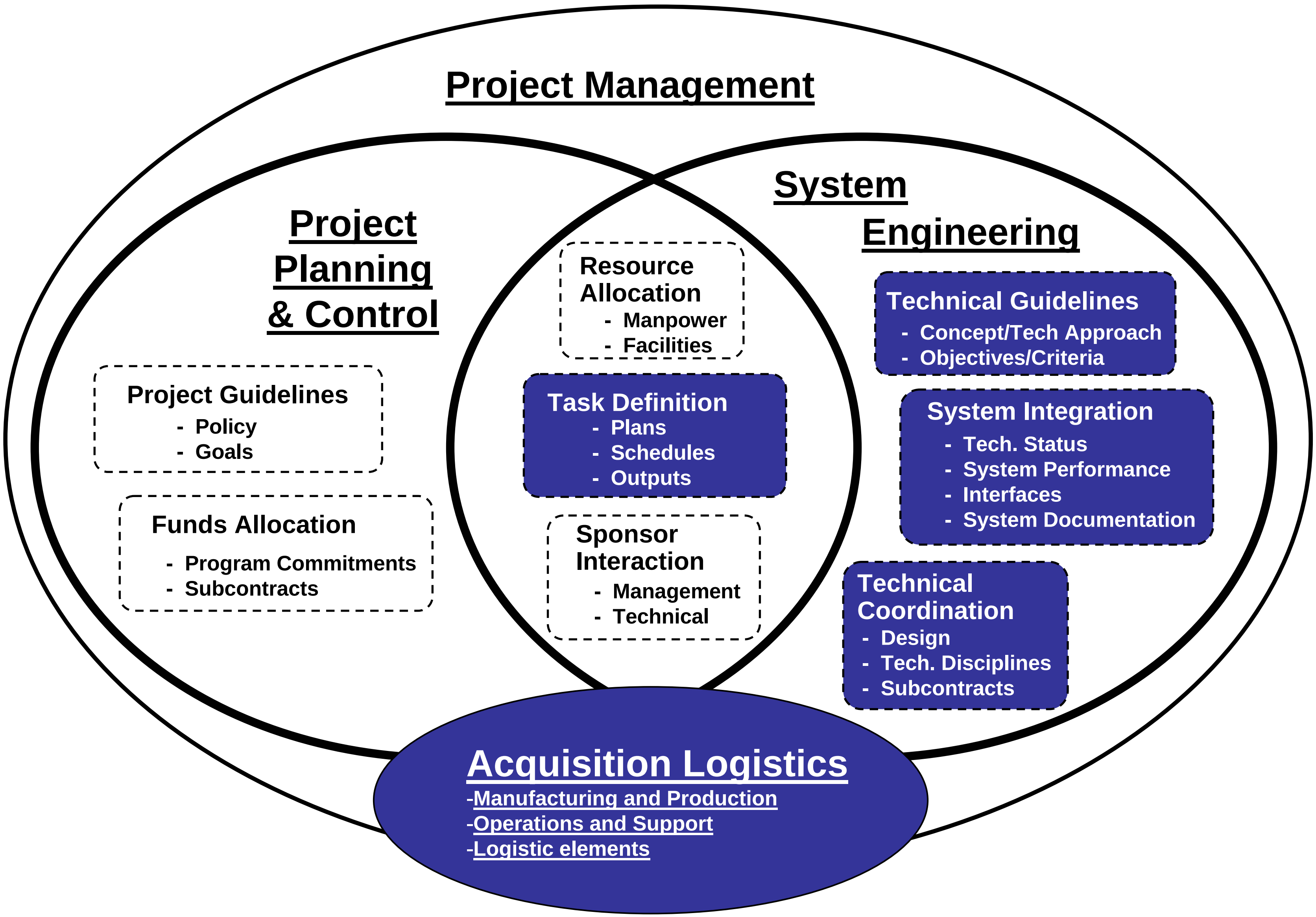
Scope

- System under design – usually in the early stages of initial design or during the design of deployed system upgrades
- Operating environment
- System developer and manufacturer
- Manufacturer’s supply chain
- Logistics elements and their impact on systems

Course Flow

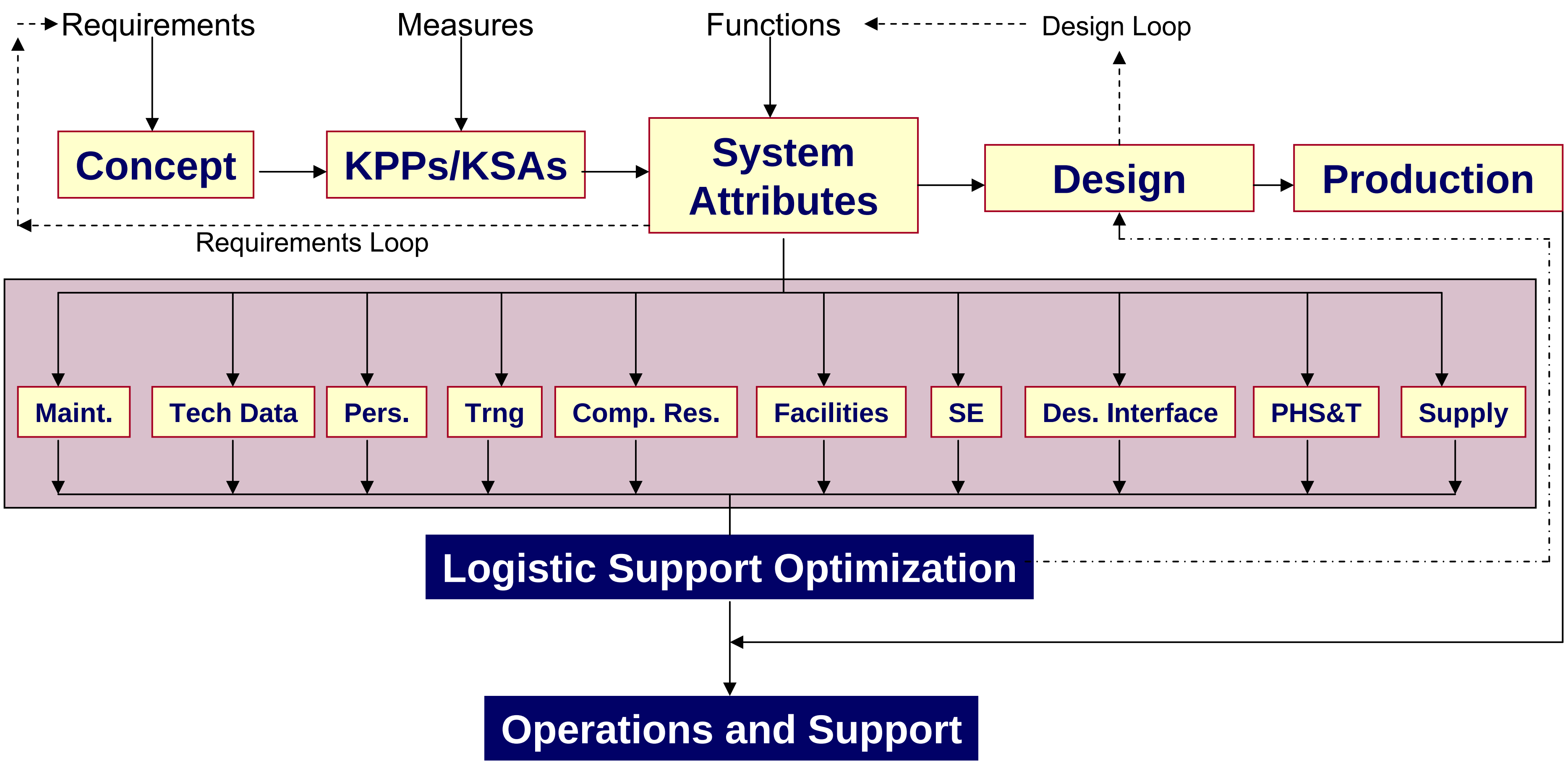

Introduction
Designing for Operations & Support
Major System Upgrades
Supported System
Life Cycle Cost Analysis
Manufacturing & Production
Facility Design & Production Optimization
Reliability
Safety
Maintenance
Training
Disposal
Logistics Engineering & Management
Logistics Supportability Analysis
Packaging, Handling, Shipping & Transportation
Supply

System Engineering is Part of Project Management



Logistics Management:

A systems approach



KPP – Key Performance Parameter
KSA – Key System Attribute
SE – Support Equipment

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Deployed System Design

- What aspects or attributes of deployed systems do we typically worry about?
  - Reliability
  - Maintainability
  - Training
  - Supply support
  - Health and status
  - Safety (Operational Risk)
  - Adaptability
  - Upgradeable
  - Disposability
  - Cost

How do we account for these in the design phases, during production and then again, once the system is deployed?

Limitations/Constraints

- Analyses limitations
  - Availability of data to conduct
  - Time to complete
  - Resources
- Funding
  - Deployed phase often relegated to second tier status
    - “Worry about it later” mentality
    - Change in funding source
    - Lack of R&D funds in deployed phase
- System design
  - May be “frozen”
- Concept of operations (CONOPS) and the associated tempo are already established
  - Reluctance to alter CONOPS based on new capability

Manufacturing & Production

Lecture Topics

- **Production as a system**
- **Producibility**
- **Designing for Manufacture**
- **Analysis & Metrics**
  - **Facility / Utility**
  - **Operational Equipment Effectiveness**
  - **FMECA**
- **Depot Maintenance & Warranty Repair**
- **Test**
- **Upgrades**
- **Foreign Military Sales**
- **Engineering Disciplines and the Systems Engineer**

Admin

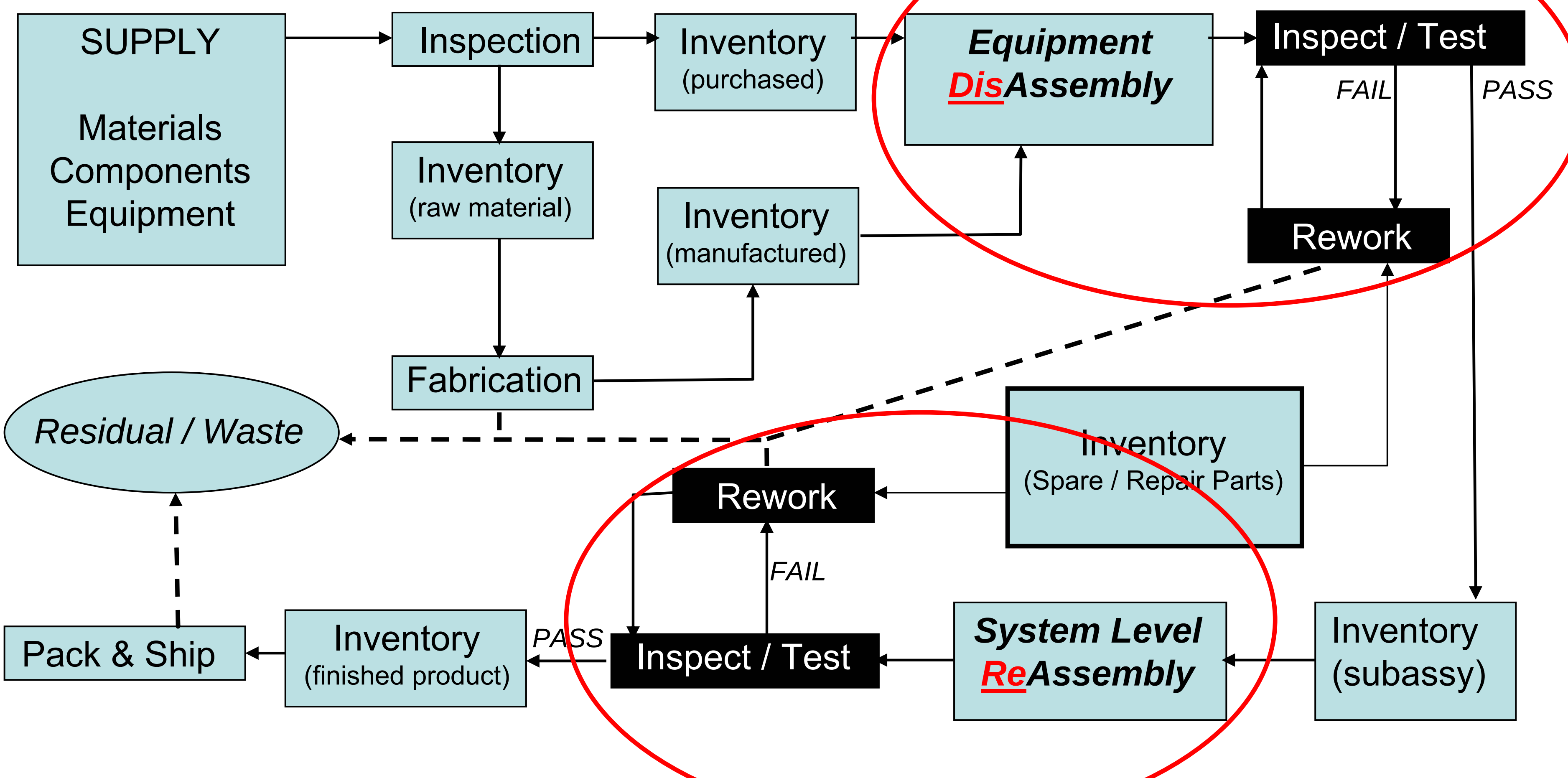
- **Instructor** – Bryan Herdlick
- **Learning Objectives**
  - Establish an understanding of fundamental manufacturing & production processes
  - Identify SE principles and activities that influence effectiveness of manufacturing and production
  - Understand the responsibility of the systems engineer relative to manufacturing & production
- **Preparation**
  - 3.1, 4.4(c), 5.2.2, 6.2.4 / Chapter 7 / TBD
- **Homework Problems**
  - 3.1, 3.4, TBD

Take Aways

- A stable process, with quantifiable & meaningful metrics, active monitoring and control programs, and characteristic workforce 'ownership' is a prerequisite for any successful improvement efforts.
- TBD
- TBD

- **Example :** JSF Airframe Affordability Demonstration

Depot / Warranty Repair



Maintenance concept & contractual stipulations for warranty repair may direct return of entire system or sub-assemblies for depot level repair

Facility Design & Production Optimization

Lecture Topics

- **Goals & Benefits**
- **Cost of Quality**
- **Tools**
  - **FMECA**
  - **Six Sigma**
  - **Lean Manufacturing**
- **Industrial Engineering**
  - **Facility design**
  - **Manufacturing process**
- **Role of SE and the systems engineer**

Admin

- **Instructor** – Bryan Herdlick
- **Learning Objectives**
  - Identify aspects of facility design and the production process that can influence efficiency
  - Establish a basic understanding of the tools available to monitor and optimize production activities
  - Understand the responsibility of the systems engineer relative to improving manufacturing & production efficiency
- **Preparation**
  - 5.2.2, 6.2.4, Chapter 7
- **Homework Problems**
  - 6.10(a&c), 6.18, Chapter 7: 1, 3, 5, 8, 11, 12, 27, 30, 32

Take Aways

- The production process, including the associated facilities, is a system unto itself and is well suited to the application of basic systems engineering principles.
- Each production "batch" or "lot" is an iteration in the collection of reliability data and insight into opportunities for enhanced efficiency, with recommendations for improvement becoming more accurate and actionable
- The systems engineer serves a vital role in the planning and conduct of successful production activities by bridging multiple engineering disciplines and facilitating cooperative process & design improvement efforts

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Production Optimization
(CONTINUOUS PROCESS)

- Achieving peak effectiveness through continuous efficiency enhancement
  - ***Production line <u>reliability</u> is key***
  - Minimize down-time
    - Preventative Maintenance (PM)
      - Reliability Centered Maintenance (RCM) approach
        - » PM only when justified (***reliability data***, physics-of-failure, etc.)
    - Continuous production (i.e. no "breaks" in production runs)
    - Maintainability features
  - ***Involve operators in ongoing process analysis and improvement***
    - *Responsibility* for process "escapes"
    - *Responsibility* for initial troubleshooting
    - Understanding of cause-effect relationships = *"ownership"*

Each production "batch" or "lot" is an iteration in the collection of reliability data and insight into opportunities for enhanced efficiency, with recommendations for improvement becoming more accurate and actionable as each cycle is completed.

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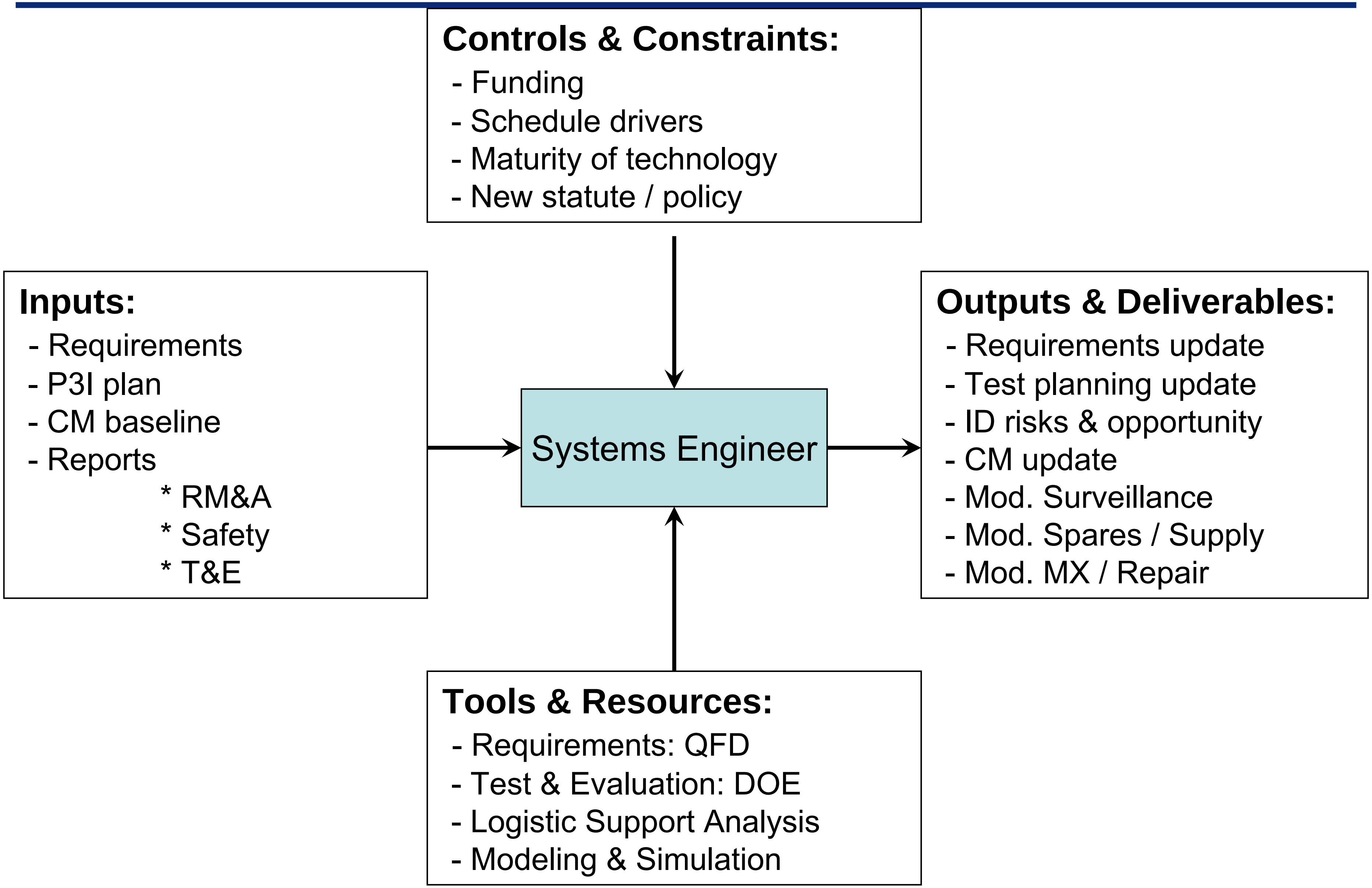
Major System Upgrade Challenges

- Upgrades are often pursued without due diligence in one or more of the following areas:
  - Requirements refinement & validation
  - Supportability Analysis
  - Configuration Management
  - Accurate assessment of
    - Design / integration challenges
    - Technology maturity

In addition to ensuring that a system upgrade satisfies *requirements* for corrective action or performance enhancement, the systems engineer is also responsible for maintaining or improving the suitability of the fielded system – including both supportability and lifecycle affordability

The Systems Engineer

(In the context of system upgrades)



Conducting a Logistics Supportability Analysis

- An LSA can aid in:
  - Initial establishment of supportability requirements during conceptual design
  - Early establishment of supportability design-to criteria
    - Definition of system operational requirements
    - Maintenance and support concept
    - Identification and prioritization of technical performance measures
    - Performance of functional analysis
    - Allocation of requirements
  - Synthesis, analysis and design optimization effort through trade studies
    - Alternative repair policies
    - Reliability and maintainability characteristics
    - Commercial-off-the-shelf implementation
  - Evaluation of a given design configuration
  - Assessment of an operating system's effectiveness and supportability in its intended environment

LSA Tools

- Life Cycle Cost Analysis (LCCA) (Session 13)
  - Total cost of the system and its supporting activities throughout the life of the system
- Failure Mode, Effects and Criticality Analysis (FMECA) (Session 6)
  - Identification of potential system and/or process failures, the expected mode of failure and causes, failure effects and mechanisms, anticipated frequency, criticality and the steps required for compensation
- Fault Tree Analysis (FTA)
  - Deductive approach involving graphical enumeration of different ways a failure can occur and its probability of occurrence
- Maintenance Task Analysis (MTA) (Session 7)
  - Maintenance functions to be allocated to a human
- Reliability Centered Maintenance (RCM) (Session 3)
  - Best overall approach for preventative maintenance
- Level-of-Repair Analysis (LORA) (Session 7)
  - Maintenance policies in terms of level of repair
- Evaluation of Design Alternatives (Analysis of Alternatives (AoA))
  - Assess design configurations using multiple criteria

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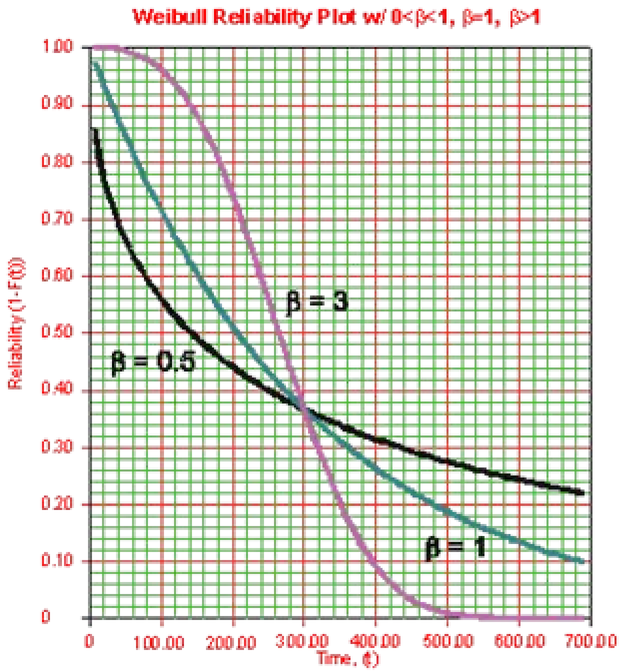
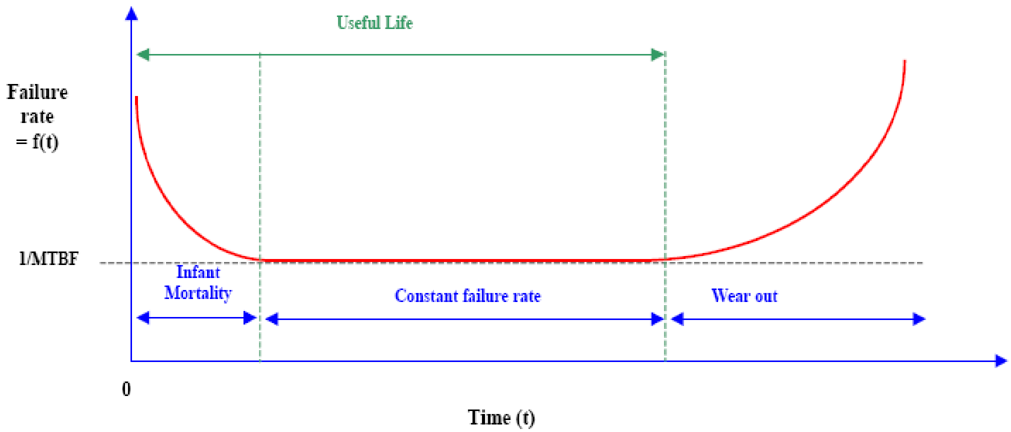
Addressing Reliability

- It's one thing to teach reliability theory, it is another to apply it in the proper manner

- Do you truly understand the problem at hand?
  - Environment, requirements, CONOPS
- Have you set the boundary conditions?
  - Assumptions, limitations
- Have you correctly assumed equilibrium?
  - Modeling
- Can you solve for the unknowns?
  - Design and verification





This is a typical behavioral model for an organic and inorganic system – looks fairly benign, but there is much more to the curve than depicted here – randomness, environmental effects, catastrophic events, etc.

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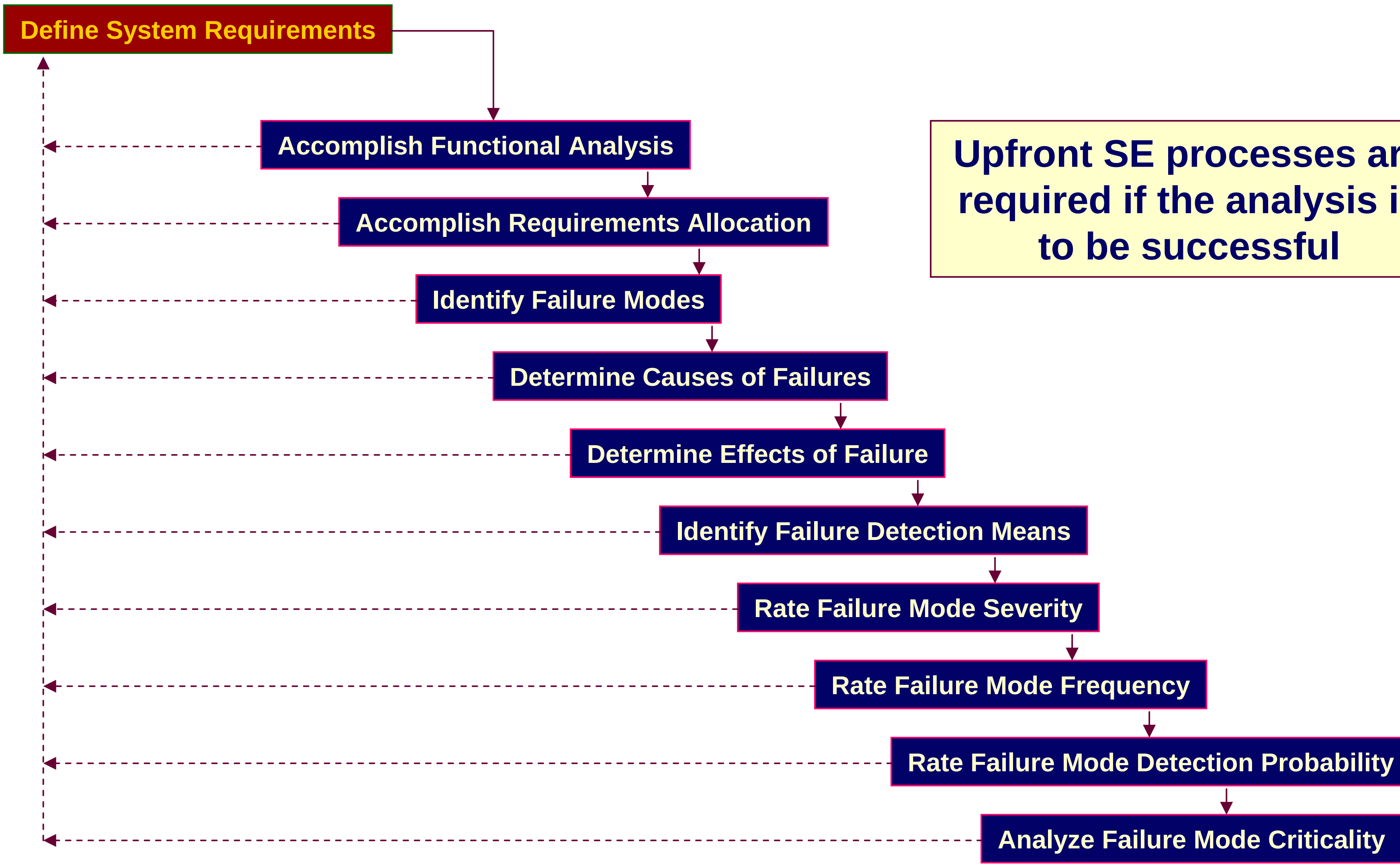
FMECA Approach



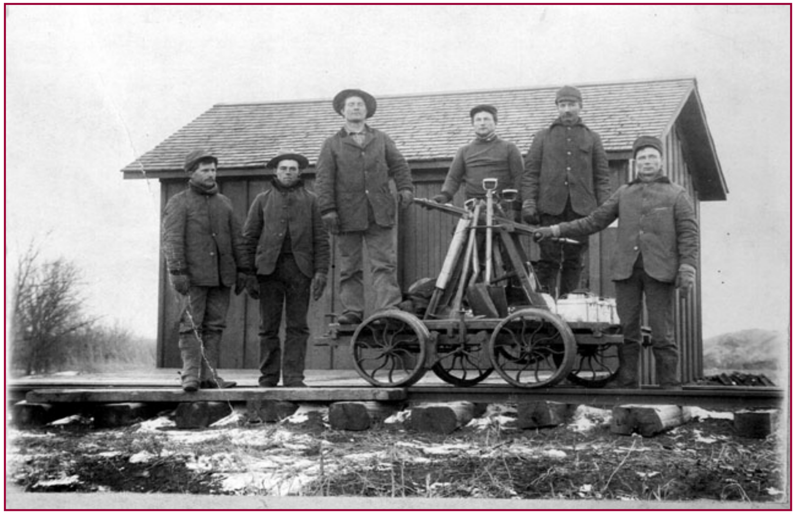
Upfront SE processes are required if the analysis is to be successful

Overall Maintenance Conceptualization

- Why – reusable or disposable
- Who – personnel requirements and limitations
- What – type of maintenance to be performed (electronic, software, structural, mechanical)
- Where – field environment or designated repair facility
- When – Planned versus unscheduled
- How – appropriate level of maintenance

Maintenance Planning: Environmental

- Location
  - Constraints
    - Space, accessibility to the system
  - External factors
    - Weather, contaminants
- Supply chain
  - Provide the necessary support infrastructure to conduct maintenance actions
- Number of personnel available
  - Limited detachment
  - Provisioning
- Support equipment
  - Weight, volume, fragility



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Spares Hypothesis Testing

- *Following deployment of a system (and throughout the lifecycle) the requirements for spares and parts must be reevaluated based on…*
  - *Actual system performance / reliability / availability*
  - *Changes in the operating and programmatic environments*
  - *Changes in the maintenance concept or production*

Planning for adequate spares and repair parts (including subassemblies) is based upon assumptions and predictions that must be continuously reviewed in light of post-deployment system performance and maintenance / repair activities

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Spares Calculation

- What goes into predicting spares requirements?
  - Failure rates
    - Individual parts
    - Subassemblies
    - Composite system
  - Spares procurement & stock intervals
    - Predicated on one-for-one replacement maintenance concept
  - Mission duration
  - Number of systems in service (available to satisfy mission)

- K λT = Translation factor
  - K = Number of Parts (per assembly under consideration)
  - λ = Part failure rate
  - T = Interval for procurement of stock / spares

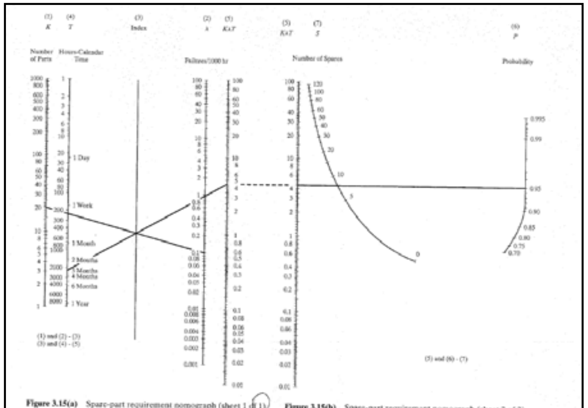
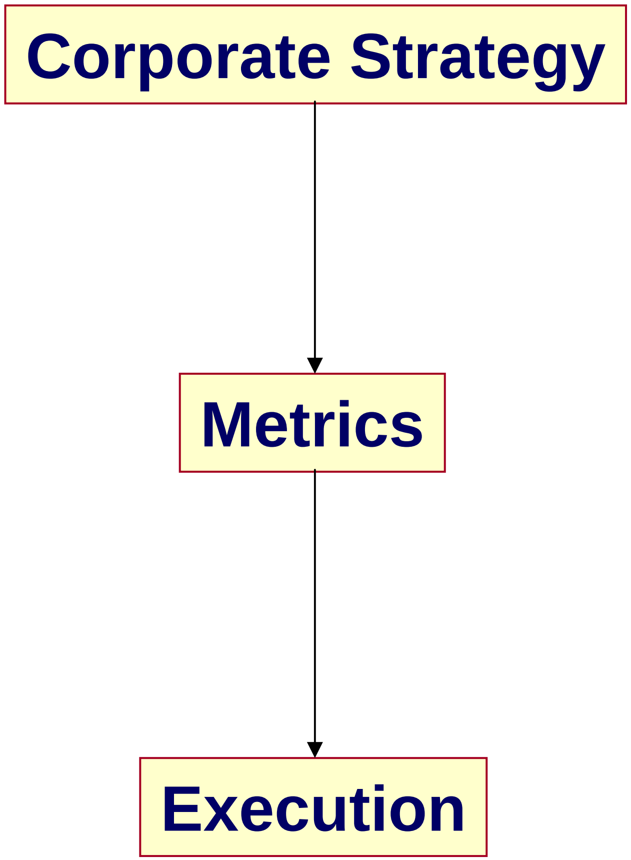


Figure 3.15(a) Spare-part requirement nomograph (sheet 1 of 1).
Figure 3.15(b) Spare-part requirement nomograph (sheet 2 of 2).

PHS&T: Implementing a Supply Chain



- What are the strategic objectives with regard to logistics?
  - In-house transportation management
  - Investment in automated systems
  - Customer liaison policy
  - Warehousing and inventory management
  - Corporate reach (global?)
- Are adequate measures in place to assess progress?
  - Requirements articulated
  - Supply chain modeling
  - Design in place
  - Functional flows understood
  - Trades analyses identified
- Is the infrastructure in place to execute, monitor and control the process?
  - Personnel
  - Tools
  - Visibility
  - Quality Management
  - Risk forecasting

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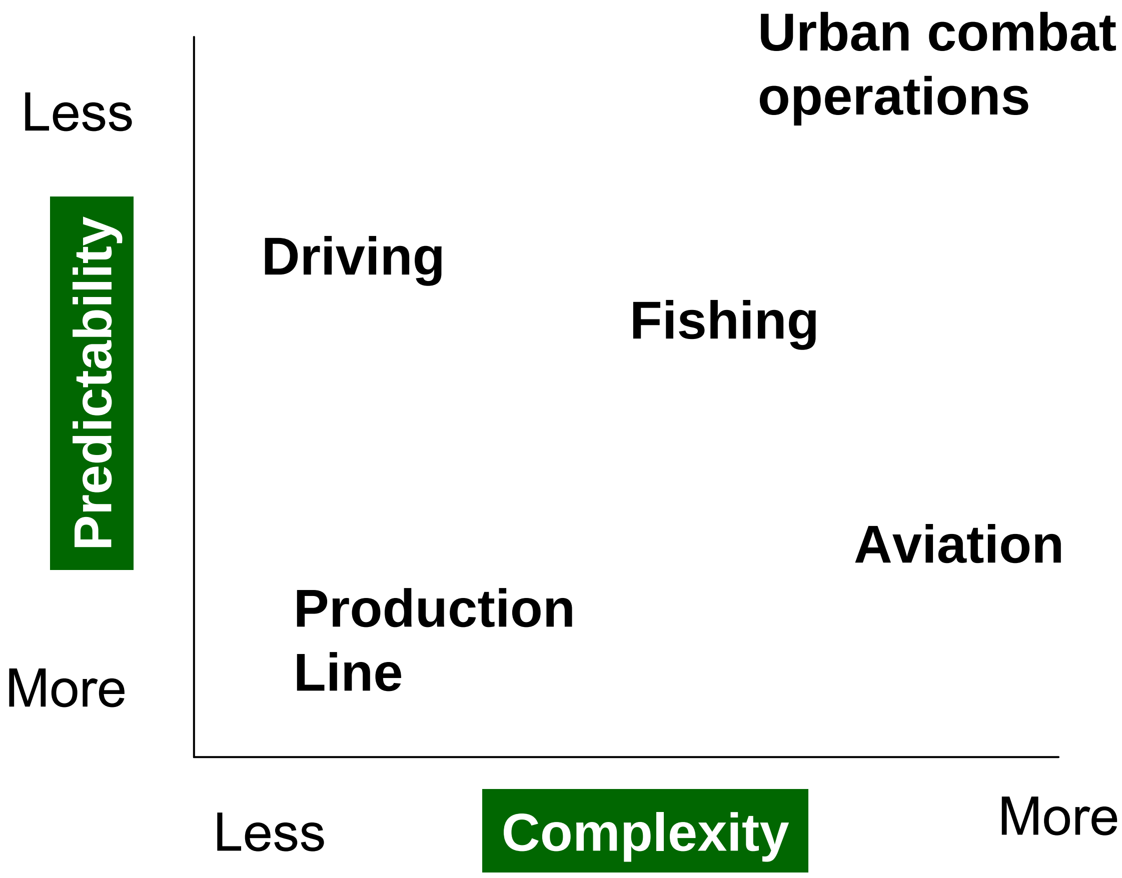
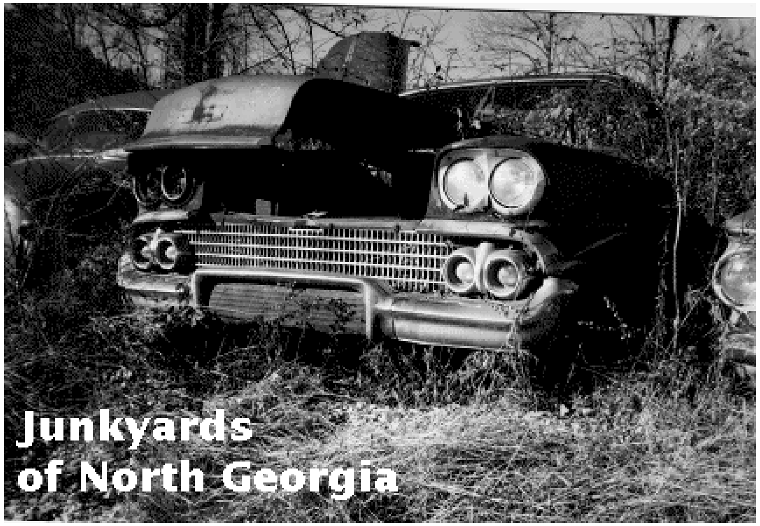
Typical Training Requirements

- System design
  - Human system interface, operational environment
- Training facilities
  - Location, size
- Throughput
  - Number of training events per day
- Data capture and recording – feedback
- Task Complexity
- SS environmental predictability
  - Numerically controlled machine maintenance
  - Driver's education

Training System Interaction



Disposal



Lecture Topics

- Disposal at retirement
- Disposal during the lifecycle
- Environmental considerations / impact statements
- Designing for disposal
  - Disposal considerations during mod / upgrades
  - Ties to maintenance plan decision tree
- The “Zero Waste” ideal
  - Reuse / reclaim options
  - Salvage operations
  - Cost, benefits and examples

Admin

- **Instructor** – Bryan Herdlick
- **Learning Objectives**
  - Discuss disposal considerations associated with each phase of a system’s lifecycle
  - Identify SE principles and activities that can assist in avoiding or managing disposal risks and cost
  - Understand the role and responsibilities of the systems engineer relative to system disposal
- **Preparation**
  - See text reference list
- **Homework Problems**
  - Problems: 8.23, 8.27, 8.28, 8.29, 8.30, 8.31

Take-Aways

- Disposal, as an activity, is not relegated to system retirement and the end of the lifecycle
- Disposal, as commonly defined (e.g. dumping, discarding, throwing away), should be considered the least efficient and least desirable alternative for the processing of residual / waste materials
- A system successfully “designed for disposal” would incorporate extensive use of alternatives to disposal such as salvage, recycling, reuse
- Exceptionally high quality products / systems evidence longevity that can reduce retirement waste (but mid-life maintenance waste still exists)

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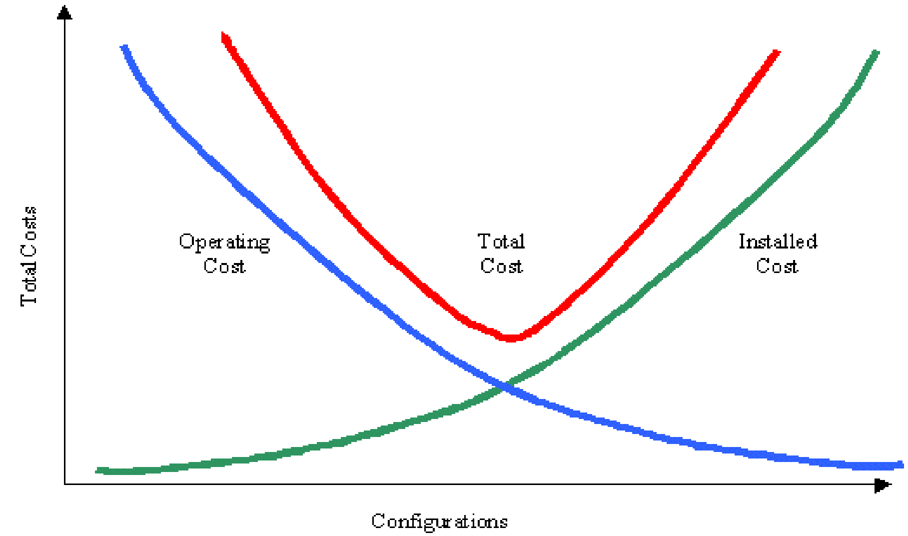
"Disposal" in the Design Checklist

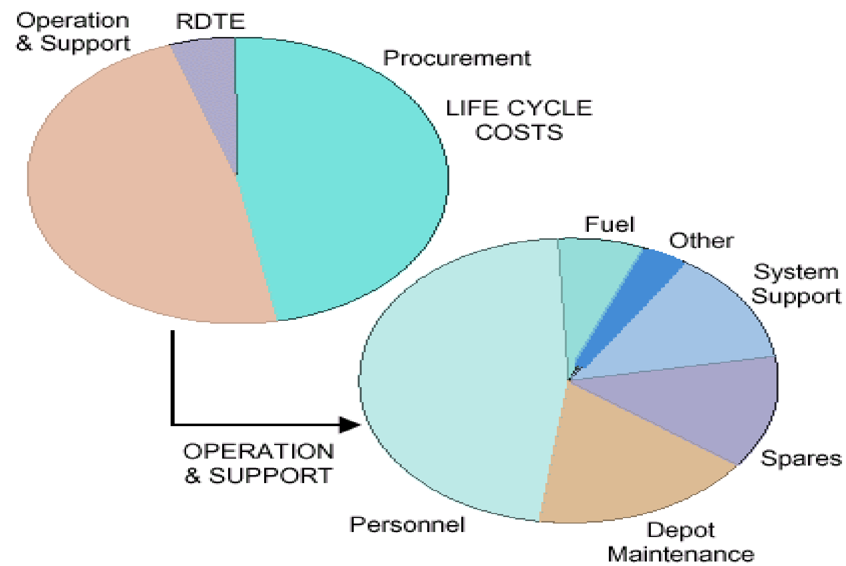
- Has disposability been evaluated during design?
  - Is recycling or re-use of components an alternative?
  - Is decomposition / disassembly an alternative (requirement)?
  - Are additional logistic support resources required?

- Have disposal procedures been identified / prepared?
  - Are methods & results consistent with environmental, safety, political and social requirements
  - Are the methods economically feasible?

Life Cycle Cost Analysis

- LCCA is presented at the end of the course
  - Necessary to understand the other elements in order to conduct a LCCA
  - Serves as a review of the material
- Can only address certain aspects of the LCCA
  - Too encompassing to cover it completely
  - SE contributes, but typically does not conduct the LCCA itself
- However, a primary driver not only for decision making, but for keeping O&S activities under control





Deployed Systems Engineering Risks

- Confusing performance requirements with supportability requirements
  - Can't have one without the other, but there is a tension between them in many cases
- Incomplete understanding of requirements and their allocation to system functions
- Assigning the wrong measures (and the respective values) to the system evaluation process
- Addressing 3 or 4 of the primary logistic elements (e.g., maintenance, personnel), while ignoring the rest
- Designing for O&S at the component level without regard for the system and its internal and external interactions

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Deployed Systems Opportunities

- Good systems engineering is necessary in the O&S phases
  - Success is not in deploying a system, but in the system performing its intended role effectively and efficiently for its entire duration
- A good SE approach will reveal risks and challenges that often go unseen until a system is too far along in the design process
  - Costly upgrades
  - Performance degradation
  - Excessive schedule delays
- Understanding and applying a disciplined technical approach is necessary for all phases of the life cycle
  - Computers can crunch numbers, but they cannot build a credible model
    - Intuition, discipline, accurate assumptions
  - Technical leadership that encompasses many disciplines