Costing integrated with other model based engineering domains using open standards across the lifecycle

Charlie Stirk	CostVision	MBE
Harold P. Frisch	NASA GSFC emeritus	233
Thomas R. Thurman	Rockwell Collins	210
Keith A. Hunten	Lockheed Martin	209
Phil Spiby	Eurostep	233, 239

Outline

- Cost Modeling, Analysis, and Management
- Costing Using STEP Across the Product Development Lifecycle
- Lifecycle costing using STEP

Management Axiom

You Can't Manage What You Don't

Communicate

You Can't Communicate What you Don't

Measure

You Can't Measure What You Don't

Define

You Can't Define What You Don't

Understand

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Cost Modeling Principles

- There are valid alternative model assumptions that can change cost (inventory LIFO, FIFO, avg.)
- Historical costs are not valid for projection if business undergoing significant change
- Level of model detail varies
  - High level of aggregation – financial reports
  - Granular detail – managerial decisions
- Cost transfer is not cost reduction
- Cost avoidance is rarely measured (or incented)

Classification of Costs Depends on Analysis Purpose

- Behavior – fixed, variable, discretionary
- Relationship – direct, indirect
- Functional – G&A, M&S, IR&D, Mfg., Service
- Mfg – materials, labor, factory overhead
- Recognition – period expenses vs balance sheet
- Decision Analysis – incremental, sunk, opportunity, contingent

(Lianabel Oliver, The Cost Management Toolbox, American Management Association, 2000.)

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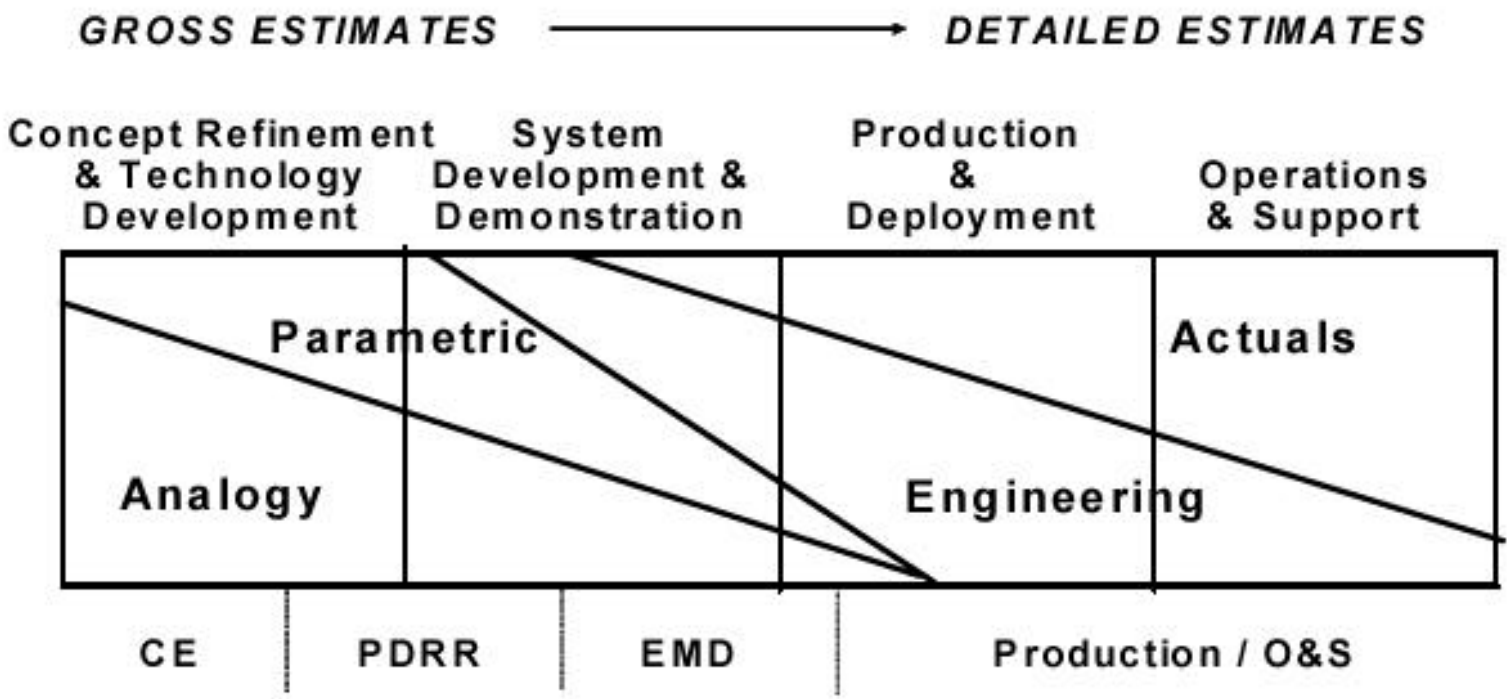
Fixed/Variable Depends on Context

- Variable with respect to what cost object or activity?
- All costs are variable in the long run
- Fixed vs Variable classification depends on
  - Time period of analysis
  - Range of activity or volume
- A series of decisions based on short term cost models does not optimize cost over the long term

Cost Analysis Method vs Lifecycle



(Jim Gates, Cost Estimating Methodologies, Defense Acquisition University, Teaching Note, April 2004.)

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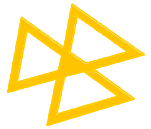
	Parametric Cost Estimating Relationships (CER)	Engineering Details Activity Based Costing (ABC)
Strengths	•Can be used for anything (system, part, schedule) •Useful where there are comprehensive historical cost databases •Fast evaluation •Very little inputs needed •Useful at very early program phases	•Insight to detailed trade-offs •Capability and resource constraints •New manufacturing technologies •High accuracy •Change inputs for new suppliers •Inter-relationships explicit (commonality) •Can integrate to other models like CAD and mfg. simulation
Weaknesses	•Correlation is not causation (weight) •Limited accuracy and insights •Results valid only within range of input data •Model independence makes integration unreliable •Deriving CER for rapidly changing mfg is time consuming •Requires expert developers	•Granularity and scope varies without standards •Detailed input data difficult to gather in early program phases •Building and maintaining a detailed model is time consuming •Information can be highly proprietary



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Estimating Best Practices

- Use more than one method as a sanity check
- Mix methods together in estimate as appropriate
  - Parametric for speed, detailed for critical insights
- Evolve methods and models through lifecycle
- Feedback from later methods for calibration
- Use consistent method for comparison
  - Make vs buy, benchmarking
- Inter-dependent models with constraints

What is Target Costing?

"The target costing process is a system of profit planning and cost management that is price led, customer focused, design centered and cross functional. Target costing initiates cost management at the earliest stages of product development and applies it throughout the product life cycle by actively involving the entire value chain."

CAM-I Target Costing Group (1996)

Why do Target Costing?

- Improve profit, market or cost position
- Produce the right product at the right time for the right price.

For many organizations this means reducing costs without sacrificing quality.

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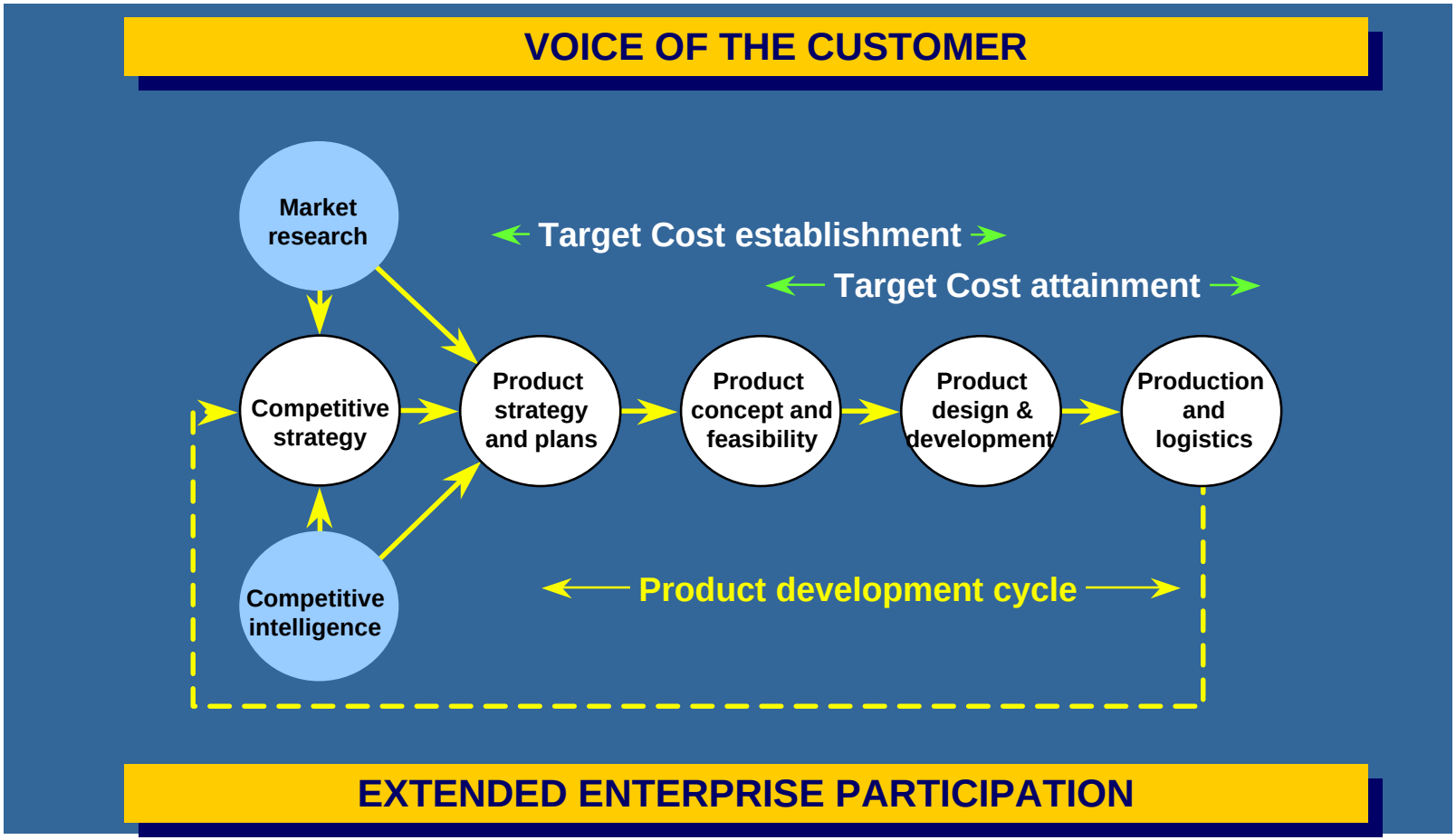
Target Costing Overview



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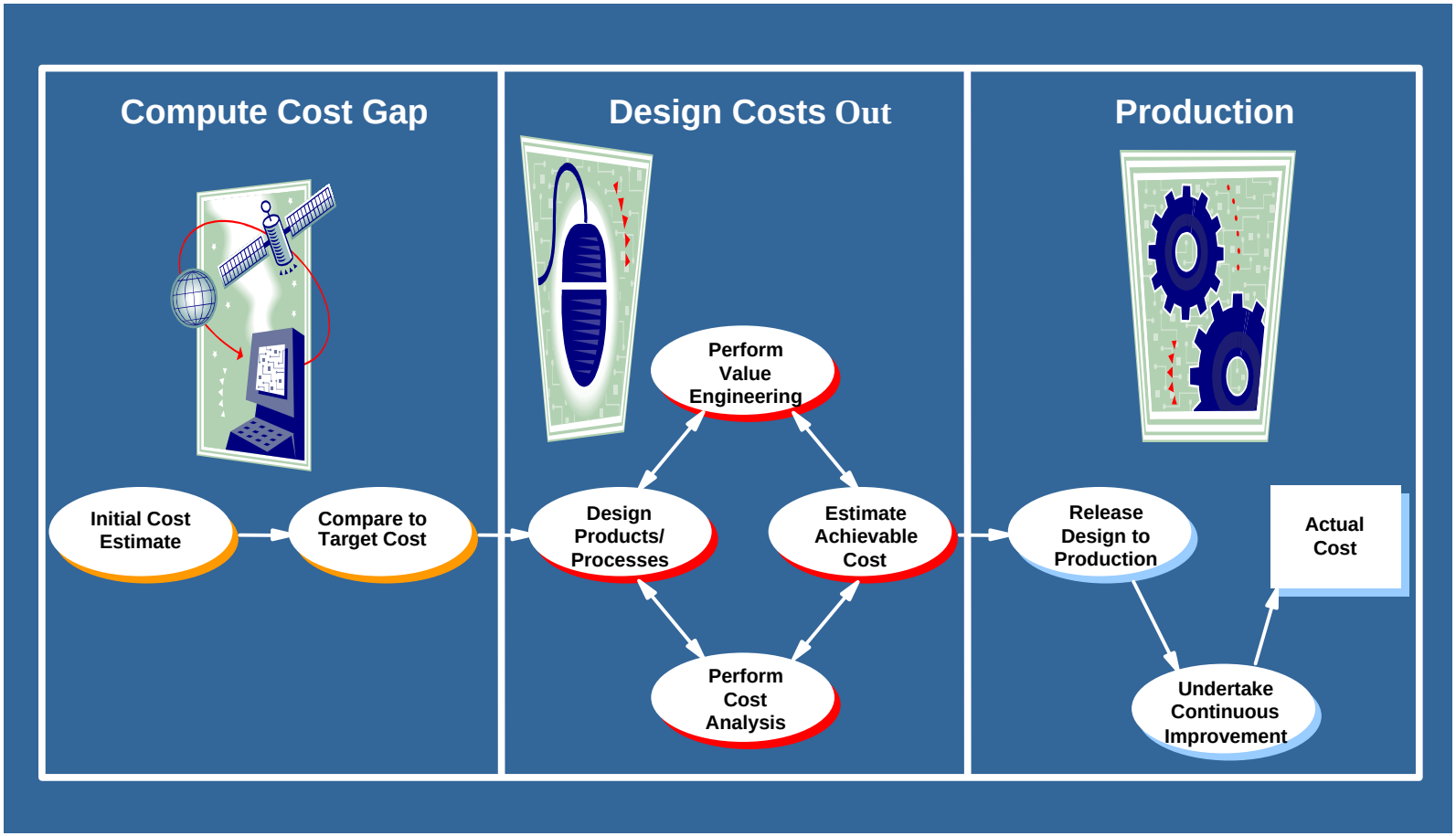
Process: Target Attainment



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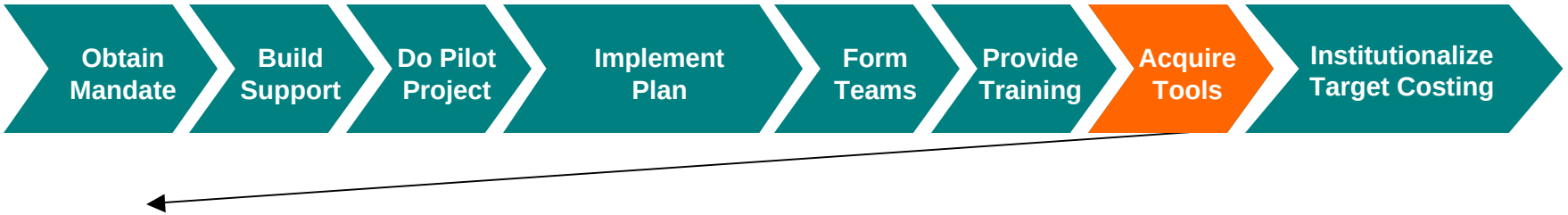
Target Costing Implementation



Acquire Core Tools

Acquire tools that support the following applications:

- **Customer Needs Analysis**
- **Target Decomposition**
- **Cost Estimation**
- **Value Engineering**
- **Target Cost Status Tracking**

Identify Support Tools

- **Identify general business support tools**
- **Identify the TC tools that align with the product and process development strategy**

Conduct a Tool Inventory & Gap Analysis

- **Identify data, process & tool gaps**
- **Conduct a company wide search**

Develop a Tool Acquisition Plan to Close Gap

- **Find a source for missing tools**
- **Match tool acquisition with Implementation Plan**
- **Evolve tool requirements**
- **Don't let the lack of tools be a show stopper**

(S.L. Ansari et al., Hitting the Target: CAM-I Target Costing Implementation Guide, 2005)

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Core Tools

TC Applications / Tool Name	Tool Type				Contact Info	Typical Home for Tool			
	Computerized	Paper Based	Custom	Packaged Application		Target-Costing Product Team	Marketing	Design and Manufacturing Engineering	Finance
Customer Requirements Analysis									
Conjoint Analysis							Primary		
Surveys							Primary		
Quality Function Deployment - House of Quality							Primary	Secondary	
Technology Roadmaps							Primary		
Target Cost Decomposition									
Value Index							Secondary		Primary
Product Feature Roadmapping						Primary			Secondary
Cost Estimation Tools									
Analogy Models								Secondary	Primary
Parametric Cost Estimation Database Models								Secondary	Primary
Engineering / Bottom Up Cost Models								Secondary	Primary
Cost trade-off Analysis									
Value Engineering						Secondary		Primary	
Functional Analysis System Technique (FAST Diagrams)						Secondary		Primary	
Competitive Benchmarking (Teardowns, Reverse Engineering)								Primary	Secondary
Target Cost Tracking									
Cost Target to Estimate/Forecast Performance Reporting								Secondary	Primary
Cost Roll-ups by Development Stage								Secondary	Primary

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General Business Support Tools

GENERAL BUSINESS MANAGEMENT										
Budget Planning & Management										
Multiyear Product and Profit Plans										Primary
Product Portfolio Planning										Primary
Capital Budgeting										Primary
Program Management								Primary		
Capacity Analysis Tools								Primary		
Risk Analysis										
Monte Carlo Simulation and Sensitivity Analysis								Primary		
Decision Trees and Real Options								Primary		
DEPENDENT ON PRODUCT & PROCESS DEVELOPMENT STRATEGY										
Supply Chain Management										
Supplier Specific Cost Models						Primary				
Supply Chain Logistics Analysis						Primary				
Geographic Cost Models						Primary				
Make vs Buy Decision Support						Primary				
Hardware Estimating										
Circuit Boards								Primary		
Integrated Circuits								Primary		
Assemblies								Primary		
Mechanical Parts								Primary		
Design Integration Tools										
CAD feature extraction							Primary		Primary	
Extraction Transformation and Loading (ETL)							Primary		Primary	
Enterprise Application Integration							Primary		Primary	
Information Portals/Business Intelligence Reporting							Primary		Primary	
Process Planning										
Lean Manufacturing Modeling								Primary		
Design for Manufacturability										
Dynamic Production Simulation								Primary		
Software Estimating										
Function Point Analysis									Primary	Primary
Project Scheduling									Primary	Primary

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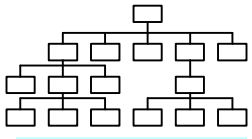
ISO 10303, STandard for the Exchange of Product model data (STEP)

STEP - http://www.tc184-sc4.org
USPRO – https://www.uspro.org

Aircraft Product Model Data Exchange Standards

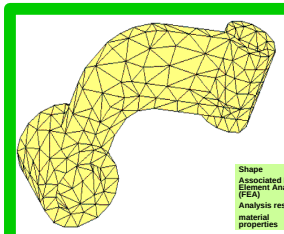
Requirements/Concept



Conformity to the concept of a system
System definition data and configuration control
Requirements, requirement analysis, and functional allocation
Functional, functional analysis, and functional behaviour
Physical architecture and synthesis
Trade studies for decision support

AP233, Systems engineering data representation

Analysis



Shape
Associated Finite Element Analysis (FEA)
Analysis results
material properties

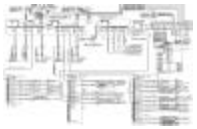
AP209:2001, Composite and metal structural analysis and related design

Detailed Design/BoM

Equipment Coverage
• Power-transmission
• Power-distribution
• Power-generation
• Electric Machinery
• Electric Light and Heat
• Control Systems

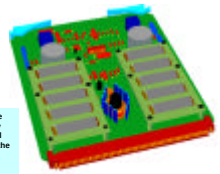
Electrotechnical Systems
• Buildings
• Plants
•
Transportation Systems

Data Supporting
• Terminals and Interfaces
• Functional Decomposition of Product
• 3D Cabling and Harnesses
• Cable Tracks and Mounting Instructions



Electrotechnical Plant
• Plant, e.g., Automobile
• Unit, e.g., Engine Control System
• Subunit, e.g., Ignition System

AP212:2001, Electrotechnical design and installation



Physical layout of the circuit card assembly
Description of logical connections among the functional objects
Packaged parts
Physical interconnections
Configuration management
Parameters for parts and functional objects

Edition 2 in process

AP210:2001, Electronic assembly, interconnect, and packaging

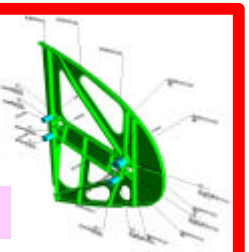
Configuration controlled exchanges between Product Data Management (PDM) systems
Links multiple formats

Design
Analysis
Manufacturing
Support

AP232:2002, Technical data packaging: core information and exchange

Manufacturing

Components
Assemblies

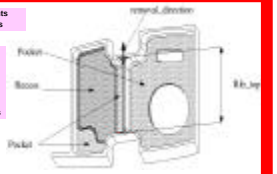


Administration
Planning
Execution
Archiving

Geometry
Dimensions
Tolerances
Inspection processes

AP219, Dimensional inspection

Components
Assemblies

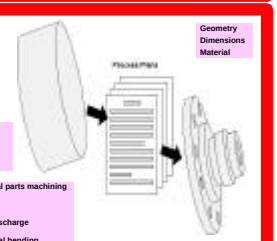


Machining features
Assembly information
Explicit geometry
Tolerances

Edition 3 in process to add gear features

Make or buy
Macro process planning

AP224:2001, Mechanical product definition data for process planning using machining features



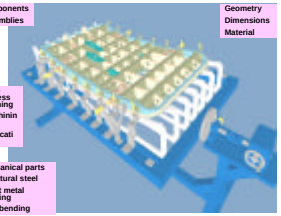
Geometry
Dimensions
Material

Mirco process planning
Automated NC generation

Mechanical parts machining
•milling
•turning
•electro discharge machining
Sheet metal bending
Pipe bending

AP238, Computer numerical controllers

Components
Assemblies



Geometry
Dimensions
Material

Maco process planning
•machining
•fabrication

Mechanical parts
Structural steel
Sheet metal bending
Pipe bending

AP240, Process plans for machined products

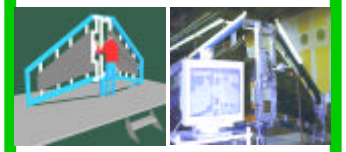
Lifecycle Support

Work activities and resources
•define
•justify
•approve
•schedule
•feedback

Configuration
•design requirements
•design configuration
•as-built
•as-maintained

Operating states
Behavior
Usage

Support
•facilities
•personnel
•equipment
•diagnostics



AP239, Product lifecycle support

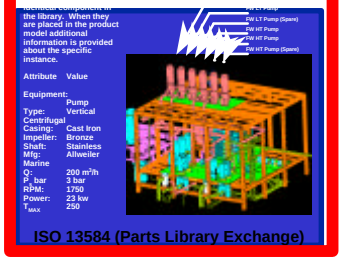
Cross Process Utility

Configuration Management of Product Structure
Versioning and Change Tracking
Bill of Materials

Edition 2
Tolerances
Construction history
Colors
Layers

AP203, Configuration Controlled 3D designs of mechanical parts and assemblies

Related Standards



Attribute Value

Equipment: Pump
Type: Vertical Centrifugal
Casing: Cast Iron
Impeller: Bronze
Shaft: Stainless
Mfg: Allweiler
Marine
Q: 200 m³/h
P_bar 3 bar
RPM: 1750
Power: 23 kw
T_MAX 250

ISO 13584 (Parts Library Exchange)

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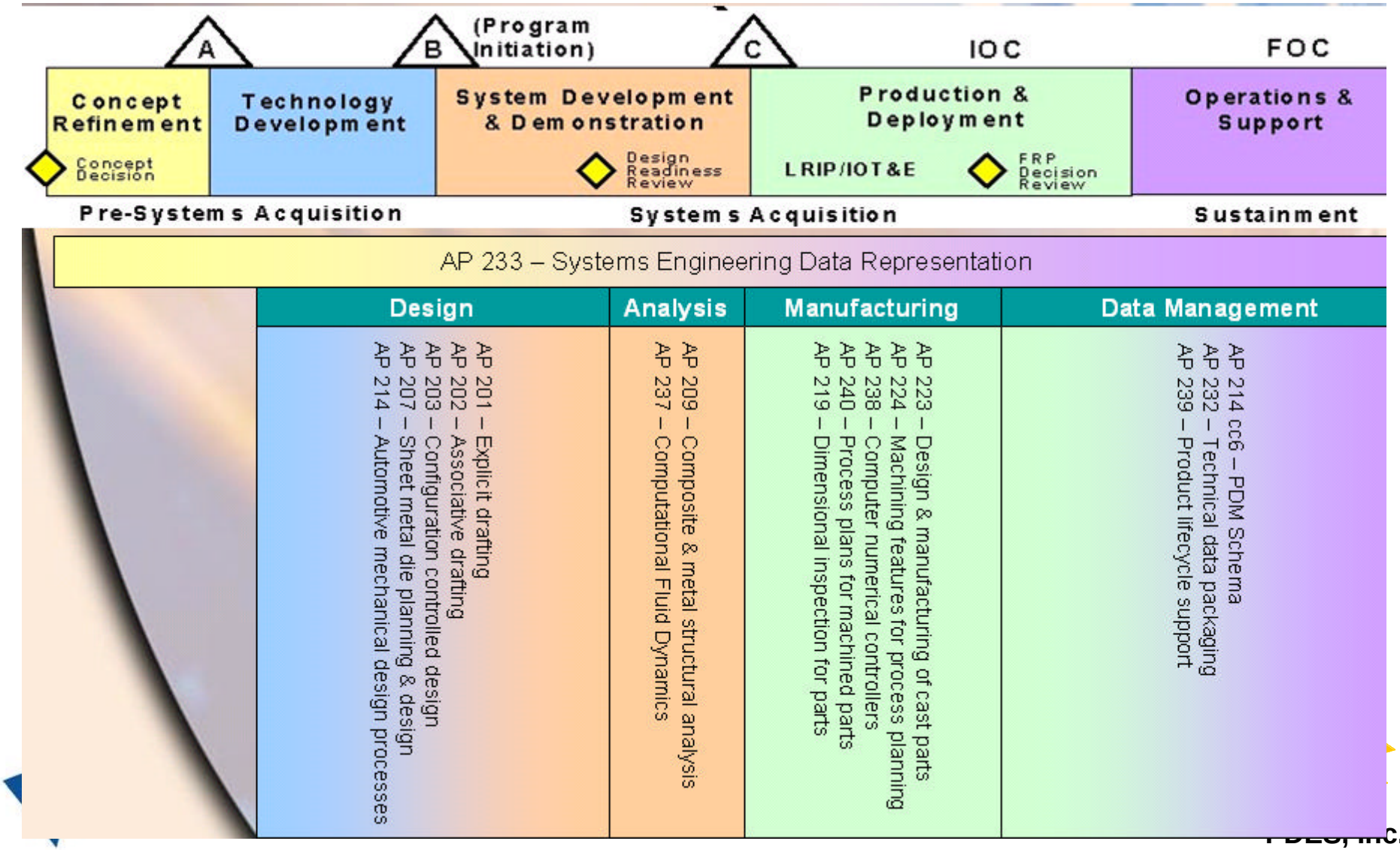
STEP for DOD Acquisition Cycle (Dr. Raj Iyer)



Costing in the Product Lifecycle

Product Lifecycle	Complementary Software	STEP	Costing Framework
Business Strategy	Portfolio Management		Product Mix & Volume
Conceptual Design	Requirements	AP 233	Specification-Cost Map
Specification	Configurator	AP 203, 214, 210, 233/239	Bill of Materials
Functional Design	Product Data Management		
Detailed Design	MCAD, EDA	AP 203, 209, 210	CAD Adaptors
Process Planning	Simulation ECO, Sourcing	AP 214, 224, 240	Design-Process Map
Manufacturing	CAPP, CAM ERP, MES		Manufacturing Simulation Plant Utilities, Labor, Taxes
Service / Support	Supply Chain Asset Management	AP 239	Total Cost of Ownership
Disposal			

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Concept Phase Costing

- System Engineering and Design (STEP AP 233)
- Cost Drivers
  - Requirements specifications and constraints
  - Program/project (schedules, resources, tasks, risks)
  - Product structures
- Flow and state diagrams can be used for mfg. & support cost models
- Trade analysis can incorporate cost as a measure
  - shared base modules with AP 209 Engineering Analysis
- Target cost allocation and estimate roll-up
  - To specifications, functions, structure

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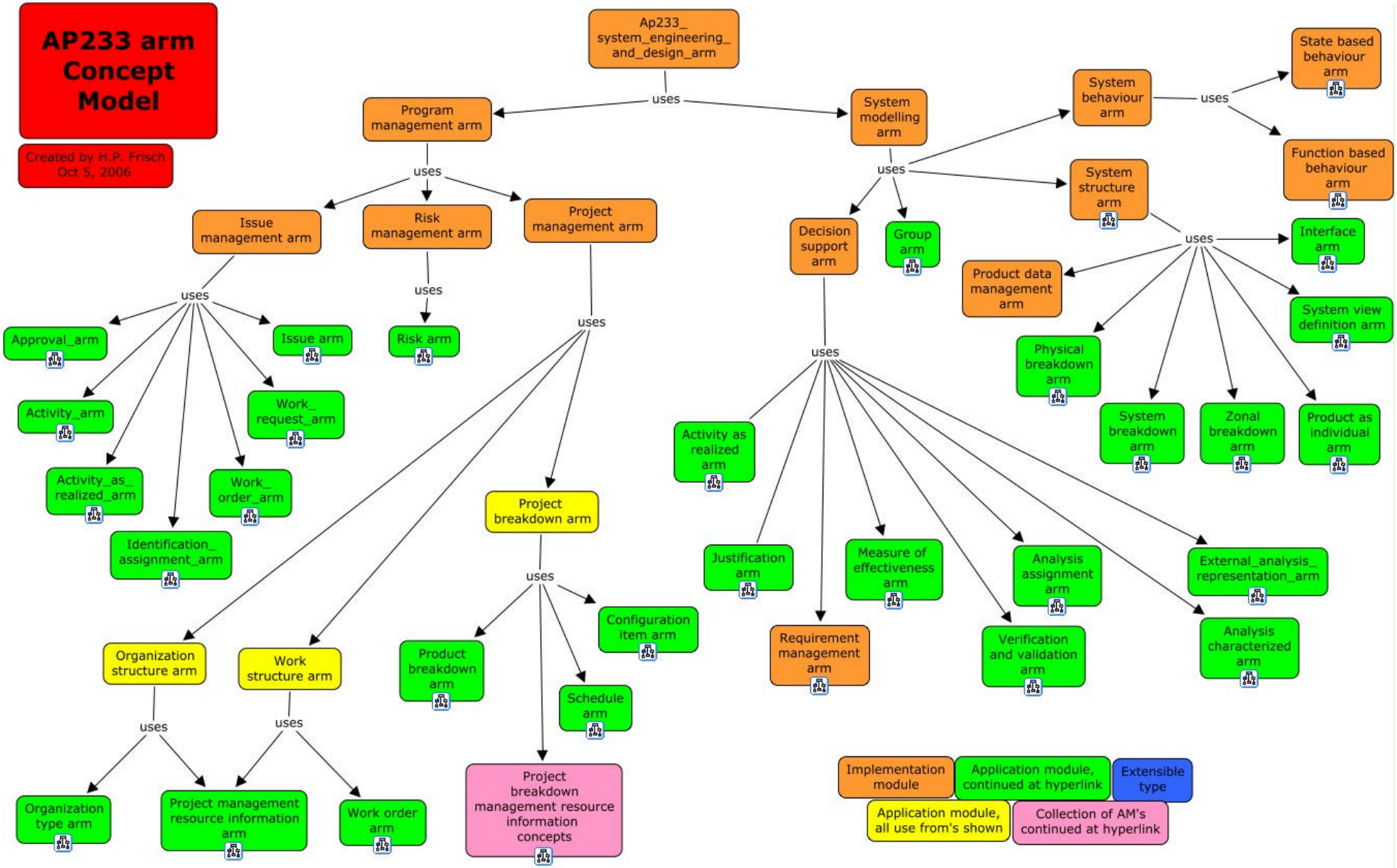
Ap233 Enabling Capability Breakdown



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What Does AP233 Enable?

- Program management
  - Issue
    - Activities
    - Approvals
  - Risk
    - Probability & Consequence
    - Source & Impact
    - Contingency plans
  - Project
    - Organizational structure
    - Project breakdown
    - Schedule
    - Work structure
    - Management information resources
- System modeling
  - Decision support
    - Requirements management
    - Measures of effectiveness
    - Analysis interface
    - Verification & Analysis
    - Justification
  - System structure
    - Product data management
    - Breakdown
    - Interface
  - System behavior
    - Function based behavior
    - State based behavior

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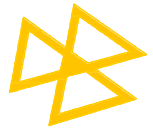
Trade Studies in AP233

- Measure of Effectiveness (MOE)
  - Has direction of optimization (min or max)
  - Has weight
- Cost, performance and reliability can be MOE
- Regularization functions use weights & MOE to optimize solutions
- Derived requirements for particular design solution trace to MOE's and trade study



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Electrical Design Costing

- AP 210 Electronic Assembly, Interconnect and Packaging Design
  - Many Domain Specific Predefined properties can
    - Be Explicitly driven by requirements
    - Be Cost Drivers
    - Be Constraints
  - Predefined support for Electrical, Thermal, Magnetic, Optical Material Property Classification
  - Production Rules can
    - Be cost rules
  - Supply Chain Support
    - OEM Model
    - Interconnect Substrate Fabricator Model
    - Sub Assembly Supplier Model
    - Component Supplier Model
    - Intellectual Property Protection
- AP 220
  - Not completed
  - Factory Models

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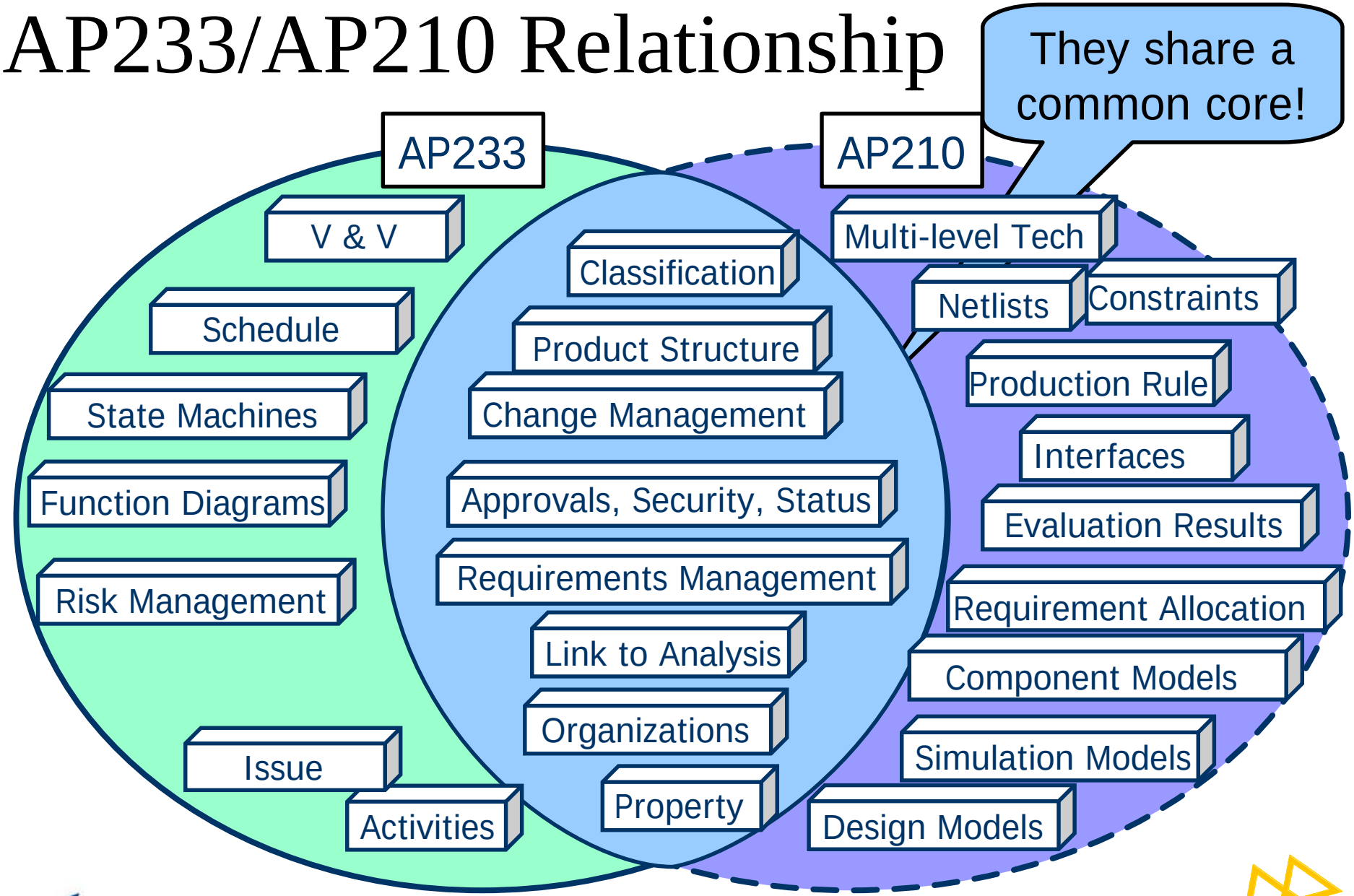
AP233/AP210 Relationship



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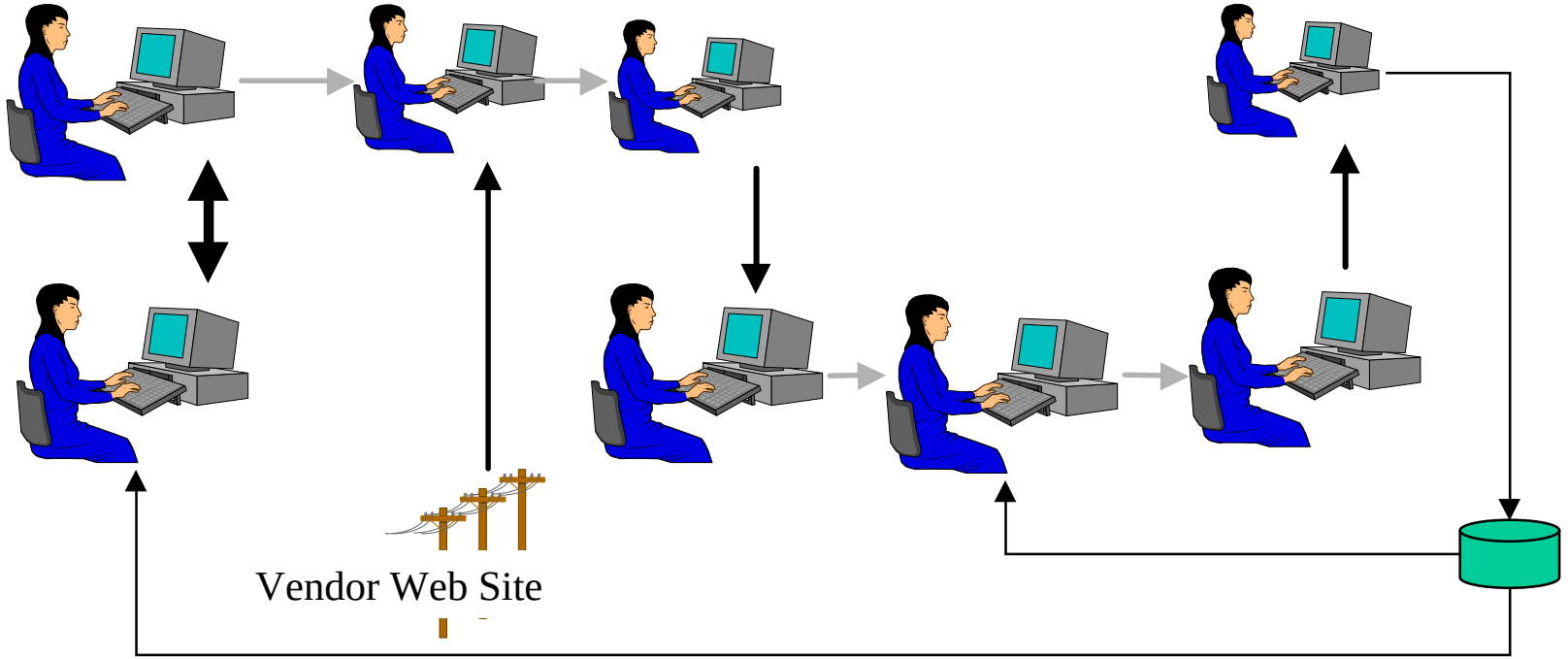
AP210 Usage
Engineering Interaction

System Engineer

EE



Initial Task Negotiation and data dump to EE

Sys Eng Gets More Data

Sys Eng sends data to EE

EE Performs Task

EE Transmits Data to Sys Eng

Final Data Package Stored in Repository

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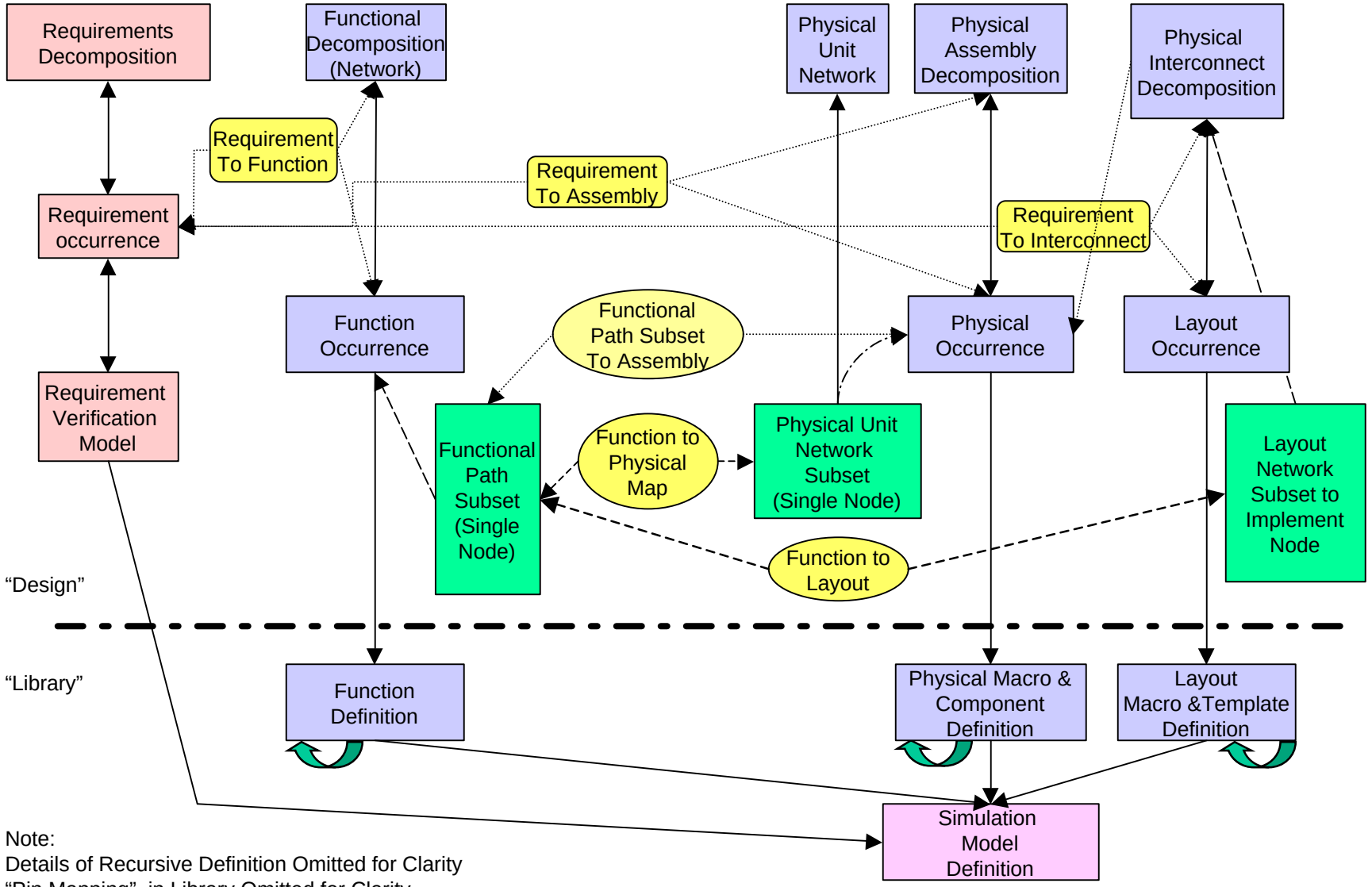
AP 210 Requirements Traceability



Note:
Details of Recursive Definition Omitted for Clarity
"Pin Mapping" in Library Omitted for Clarity

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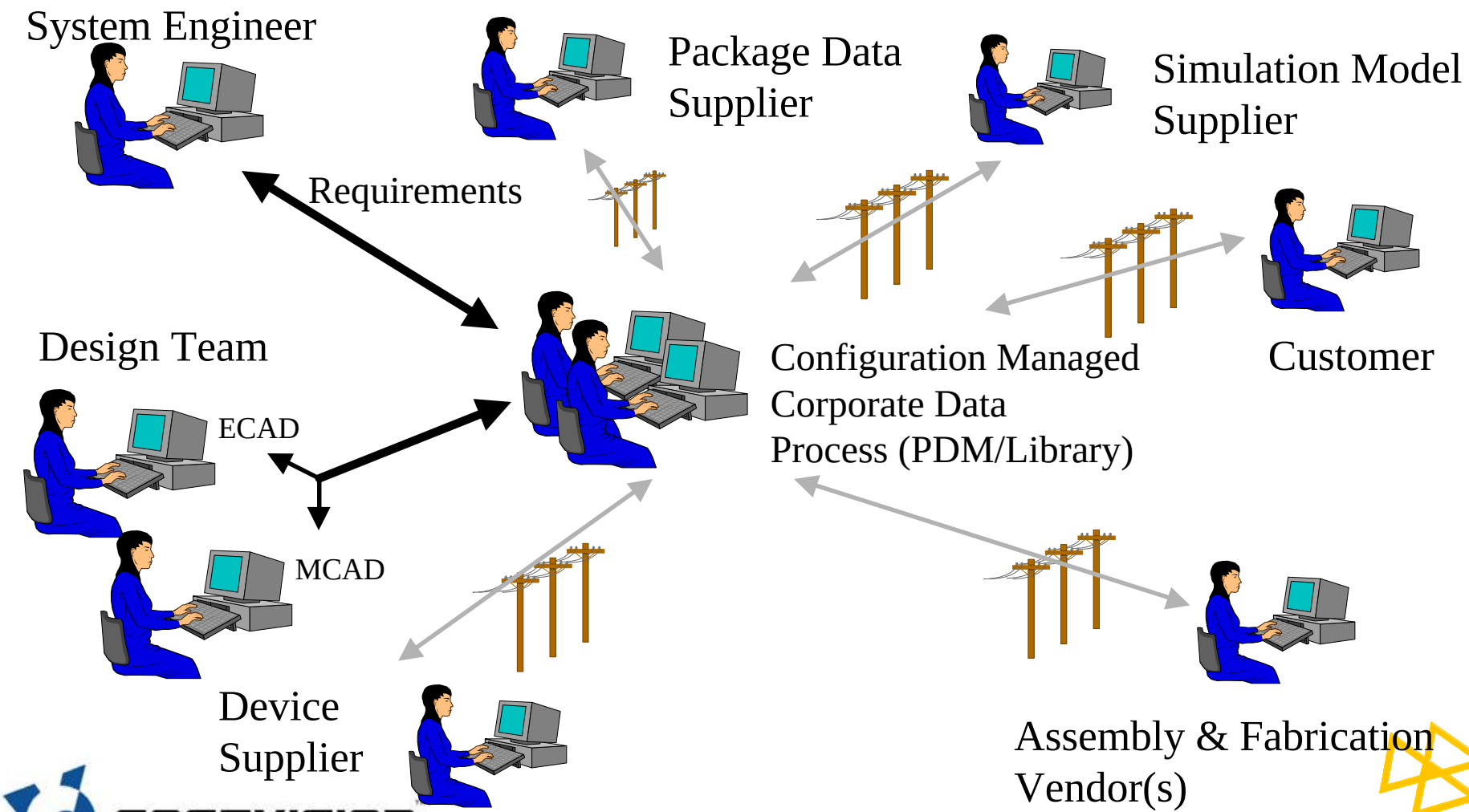
AP210 Usage
Supply Chain



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Mechanical Design Costing

- AP203 Ed. 2
  - Config. Controlled 3D Design of Mech. Parts
  - Cost driver data
    - Assembly structure (quantity, effectivity)
    - Geometric dimensions and tolerances (GD&T)
    - Future – parametrics/constraints from construction history
- AP 214 Ed. 3 draft
  - Core Data for Automotive Design Processes
  - Cost drivers same as AP 203
  - Mfg. process plans
  - Application Programming Interface (API)
    - OMG PLM Web Services 2.0

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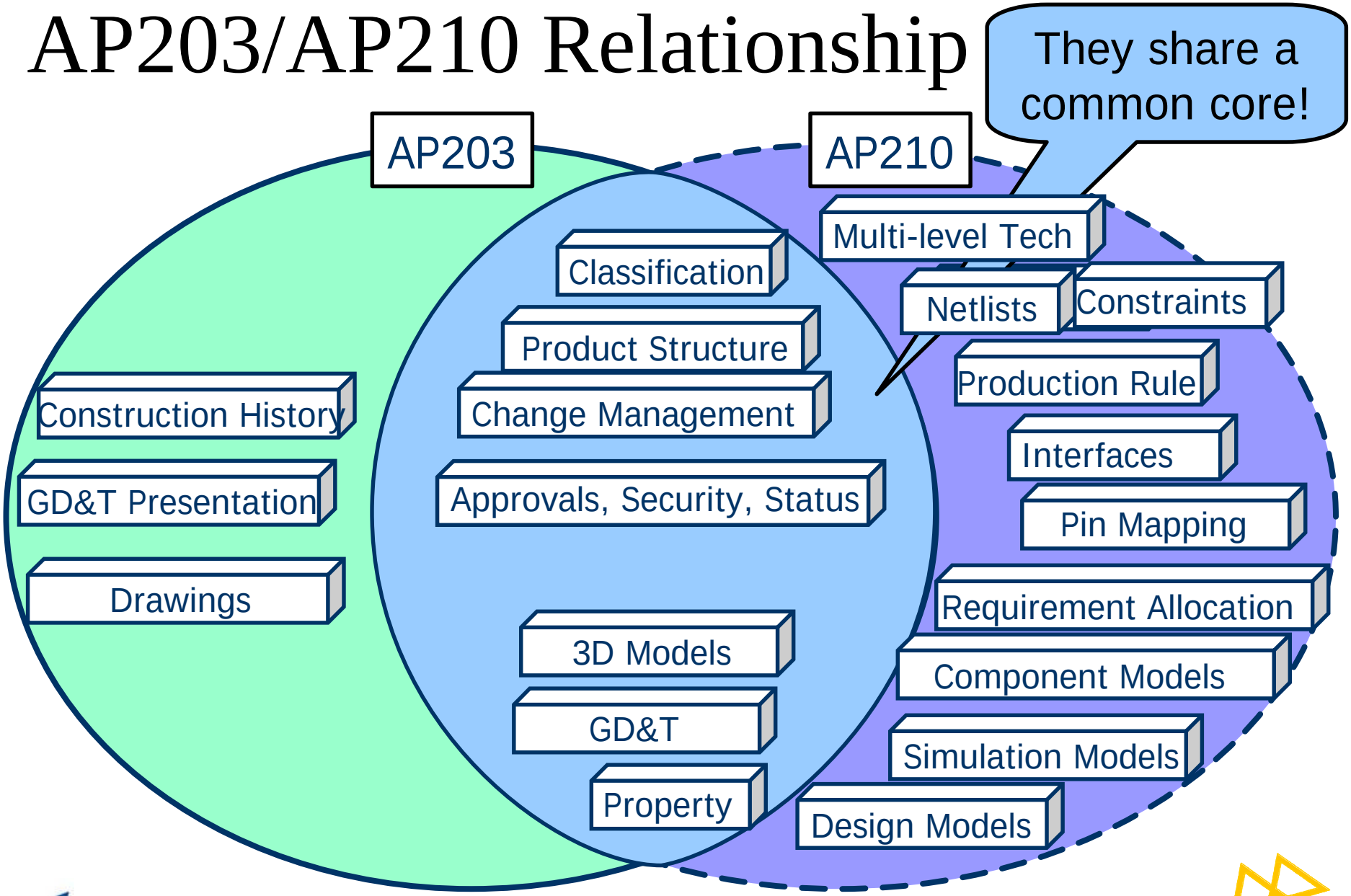
AP203/AP210 Relationship



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Engineering Analysis & Cost

- AP 209 Composite and Metallic Structural Analysis and Related Design
- Base analysis shared with AP 233 SE
- Developing a binary, open API
- Cost Drivers
  - Composite: ply boundaries, laminate stacking tables
  - Material specifications and properties

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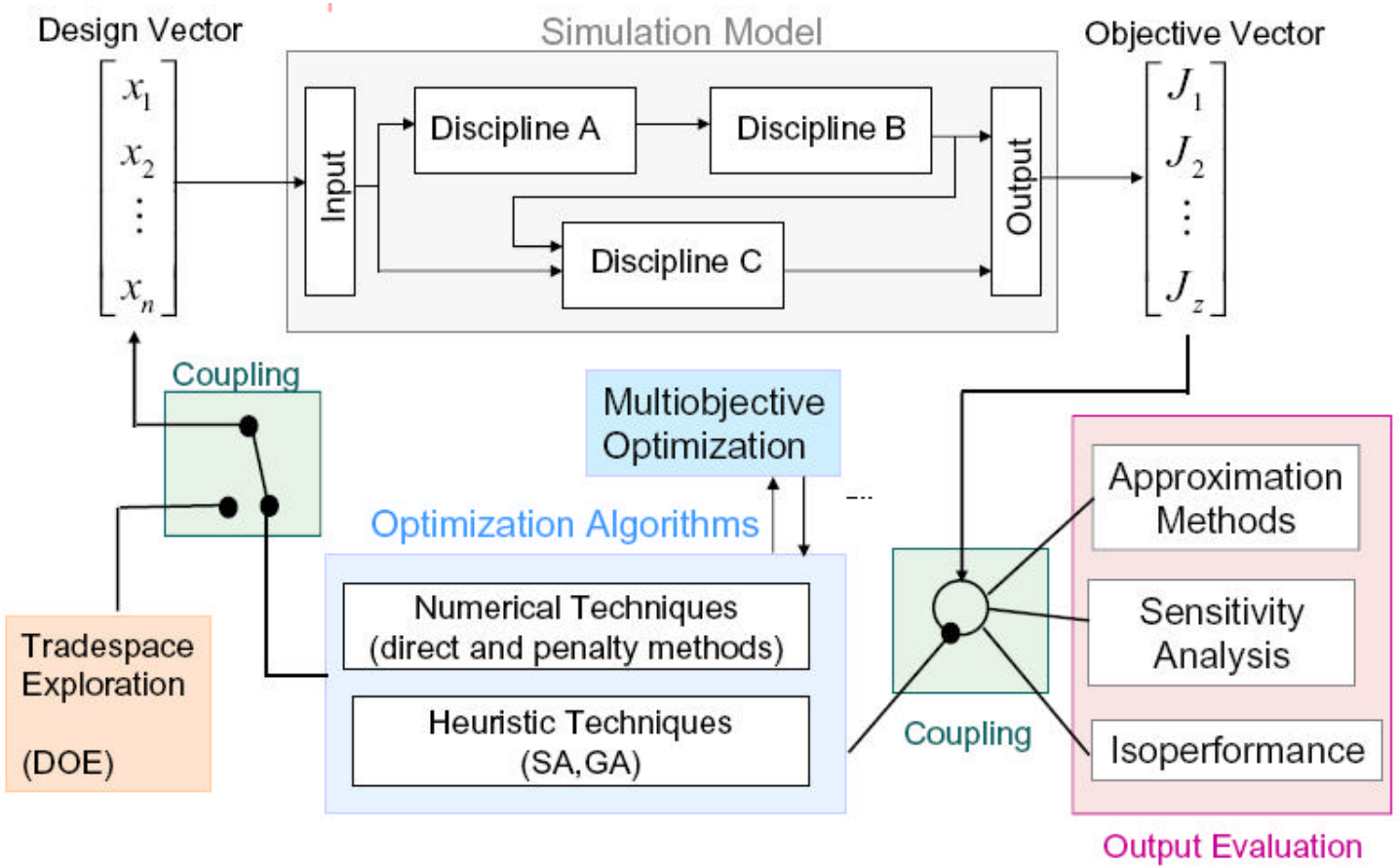
Multi-Domain Optimization

- FEA, CFD, mass properties & cost are objectives



(O. De Werk & K. Wilcox, Multidisciplinary System Design Optimization, MIT Course 16.888)

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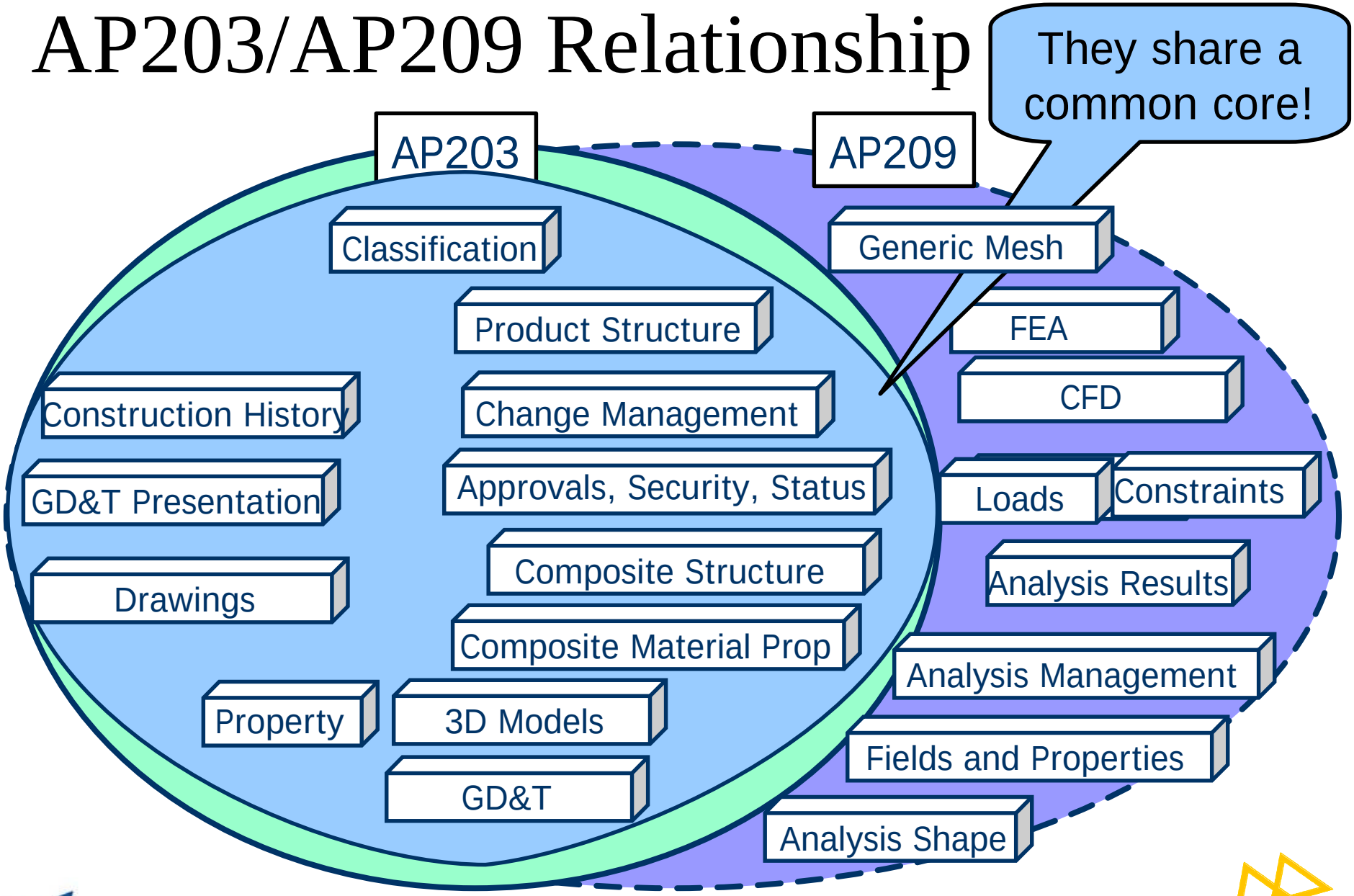
AP203/AP209 Relationship



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Production & Supply Chain

- AP 233 Functional Flow Block Diagrams
  - Input to Discrete Event Simulation
  - Can do both mfg. and supply chain planning
- Machining
  - AP 224 – **feature** based process planning
  - AP 240 – micro process planning
  - AP 238 – CNC
- Casting and Forging in development
- AP 214 Process planning for design phase
  - Sequence, tools, enumerated activity/work types

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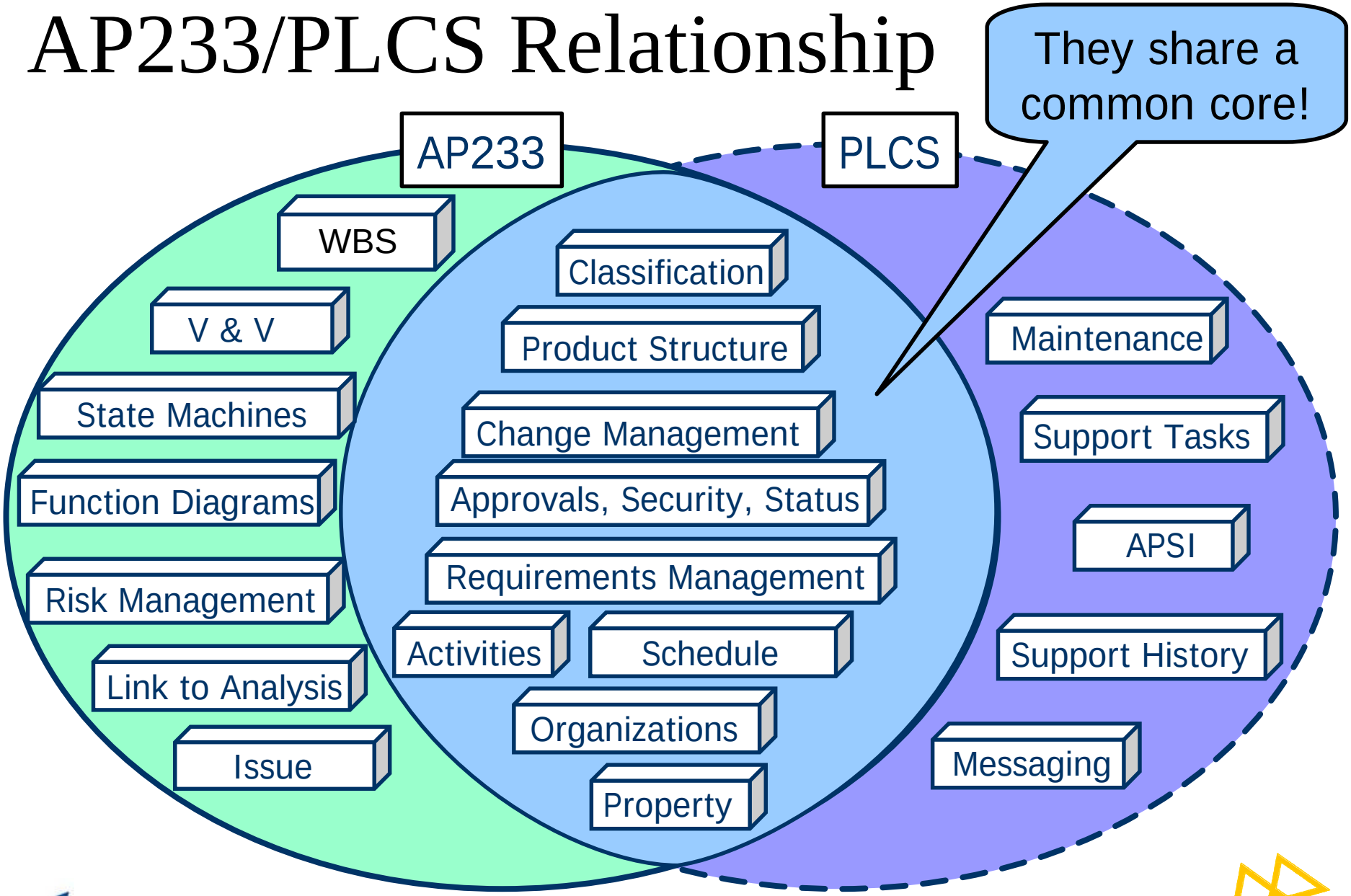
AP233/PLCS Relationship



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Product Breakdown for Support DEX

- Data Exchange Set (DEX) Contents
  - documentation of the performance, interface and other attributes of a product
  - any part of the operational product needing support
  - any related item that requires support
  - **predicted failures**
  - **diagnostic data**
  - **product characteristics of relevance to support**
- **Latter can be cost drivers**

PLCS for Lifecycle Costing

- PLCS potential uses
  - Data format for collecting cost driver info
  - Transfer mechanism between suppliers
  - Input to cost estimating and cost management tools
- Need to extend data models and API
  - Standard definition for cost characteristics
  - OASIS Capabilities Templates

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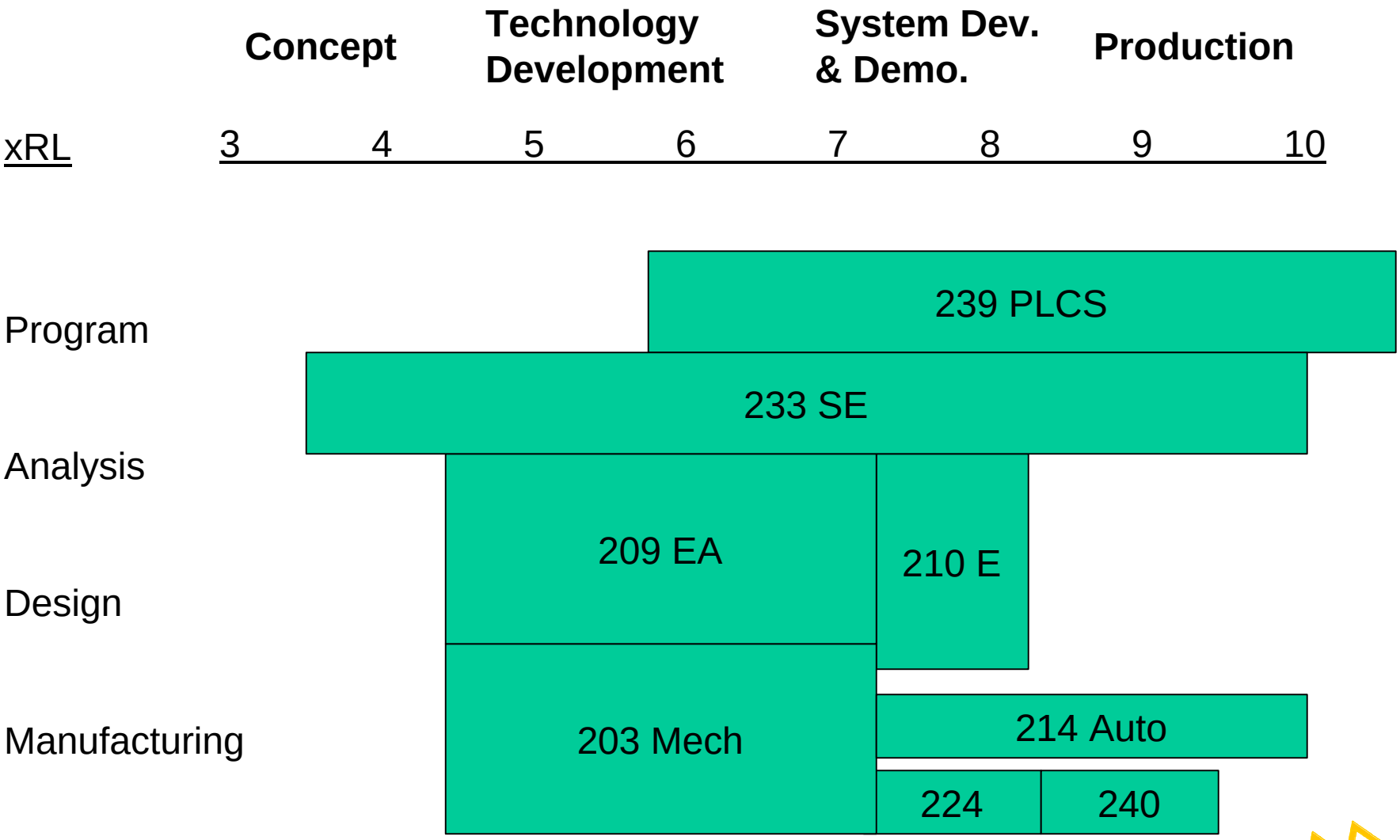
Tech. & Mfg. Readiness Levels (xRL)



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Summary

- Activity models in STEP are the foundation of activity based costing
  - Need to attach cost information
- Cost drivers in STEP
  - Requirements, property, failures, plans, GD&T
- Cost objects to trace costs to
  - Structure, organization, product, project, contract, requirements