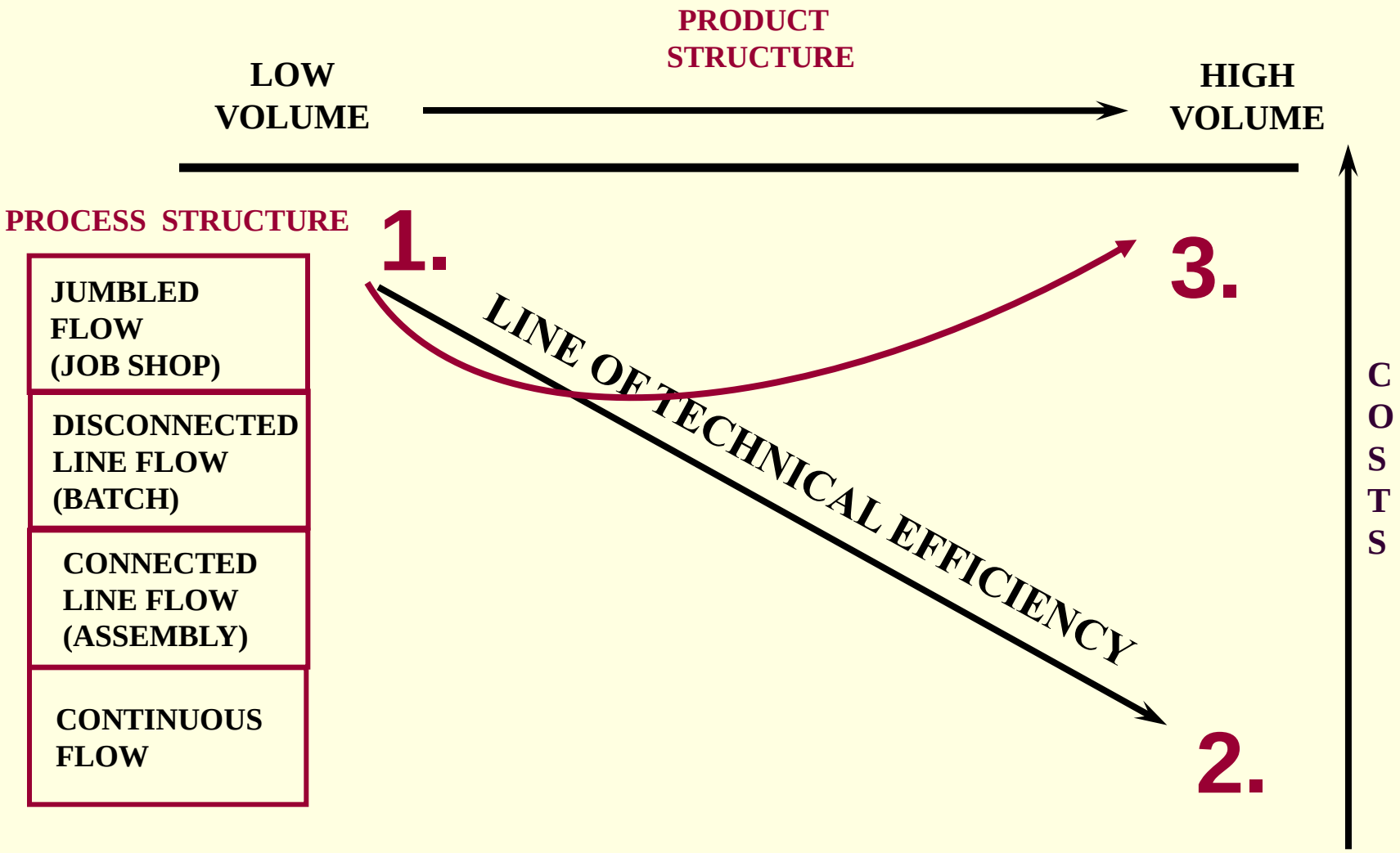
The Machine That Changed the World

George A. Noyes III

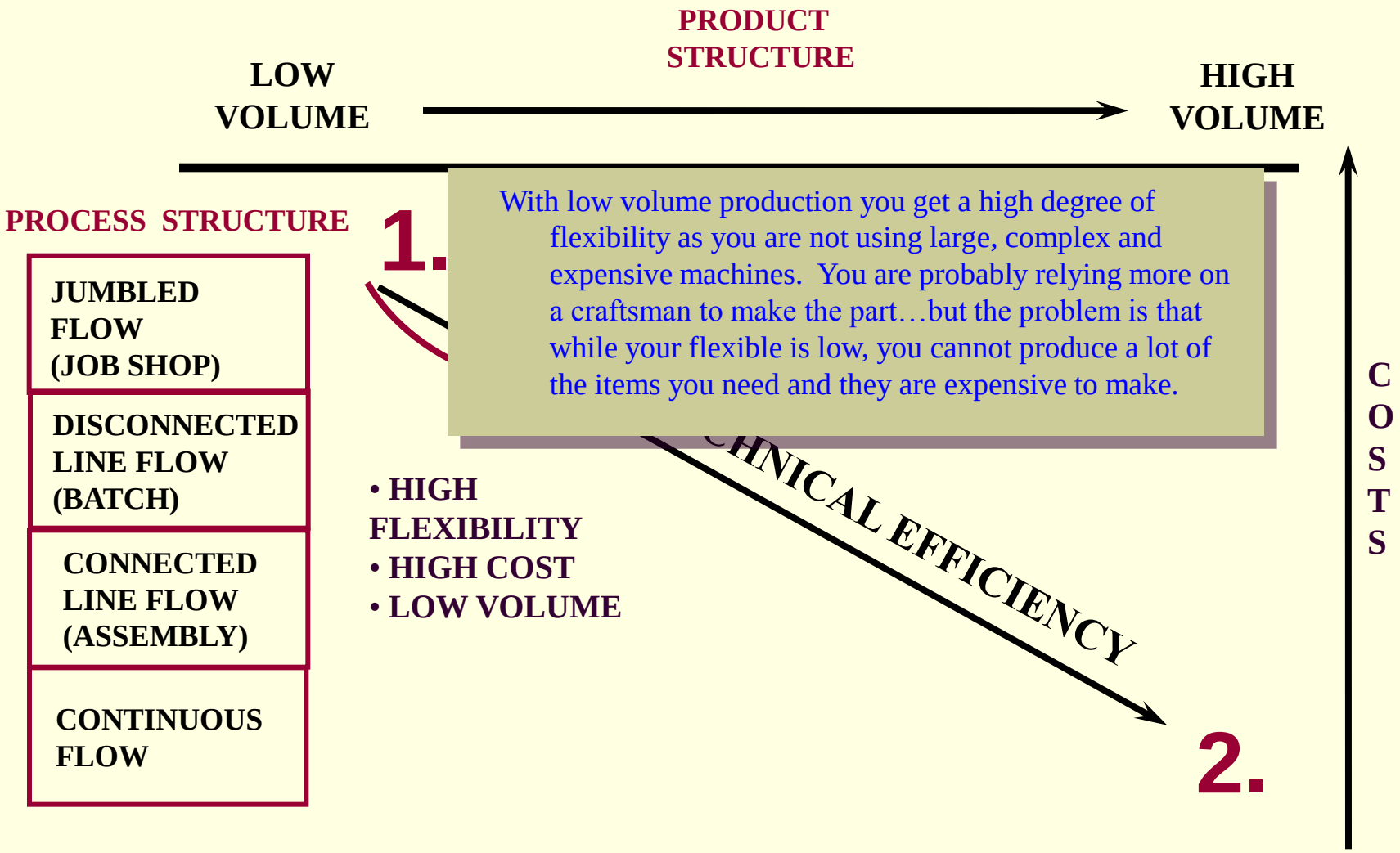
OUTLINE

- Background
- Parallels to the Auto Industry
- Craft Manufacturing
- Mass Production
- Ford's Contributions
- Sloan's Innovations
- United Auto Workers
- Line of Technical Efficiency
- Taiichi Ohno
- LEAN vs. Mass Design
- IPT Maturity Model
- Producibility
- LEAN vs. Mass Production
- LEAN vs. Mass Supply
- LEAN vs. Mass Distribution
- Lean Aerospace Initiative
- Next Steps

Line of Technical Efficiency



Line of Technical Efficiency



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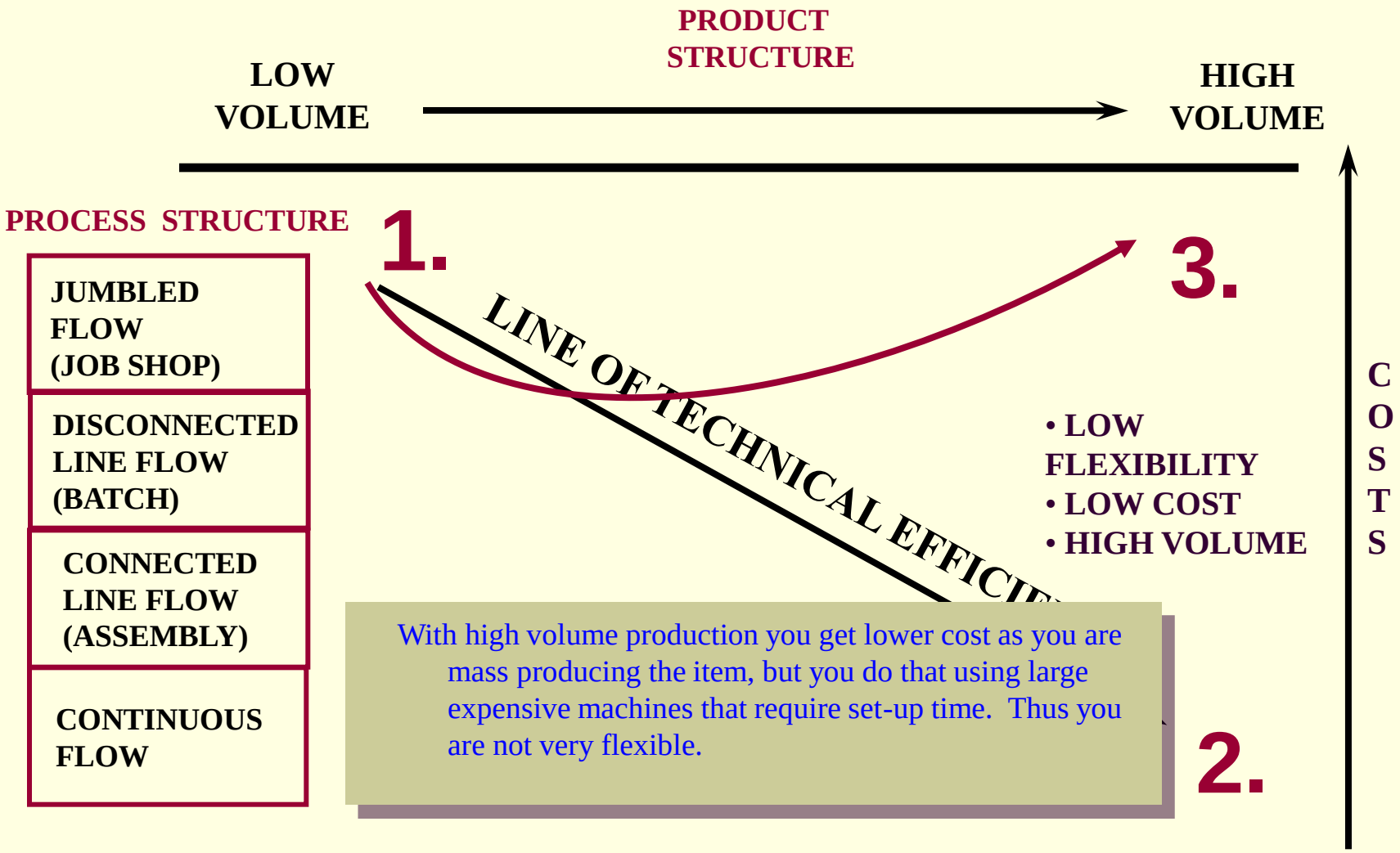

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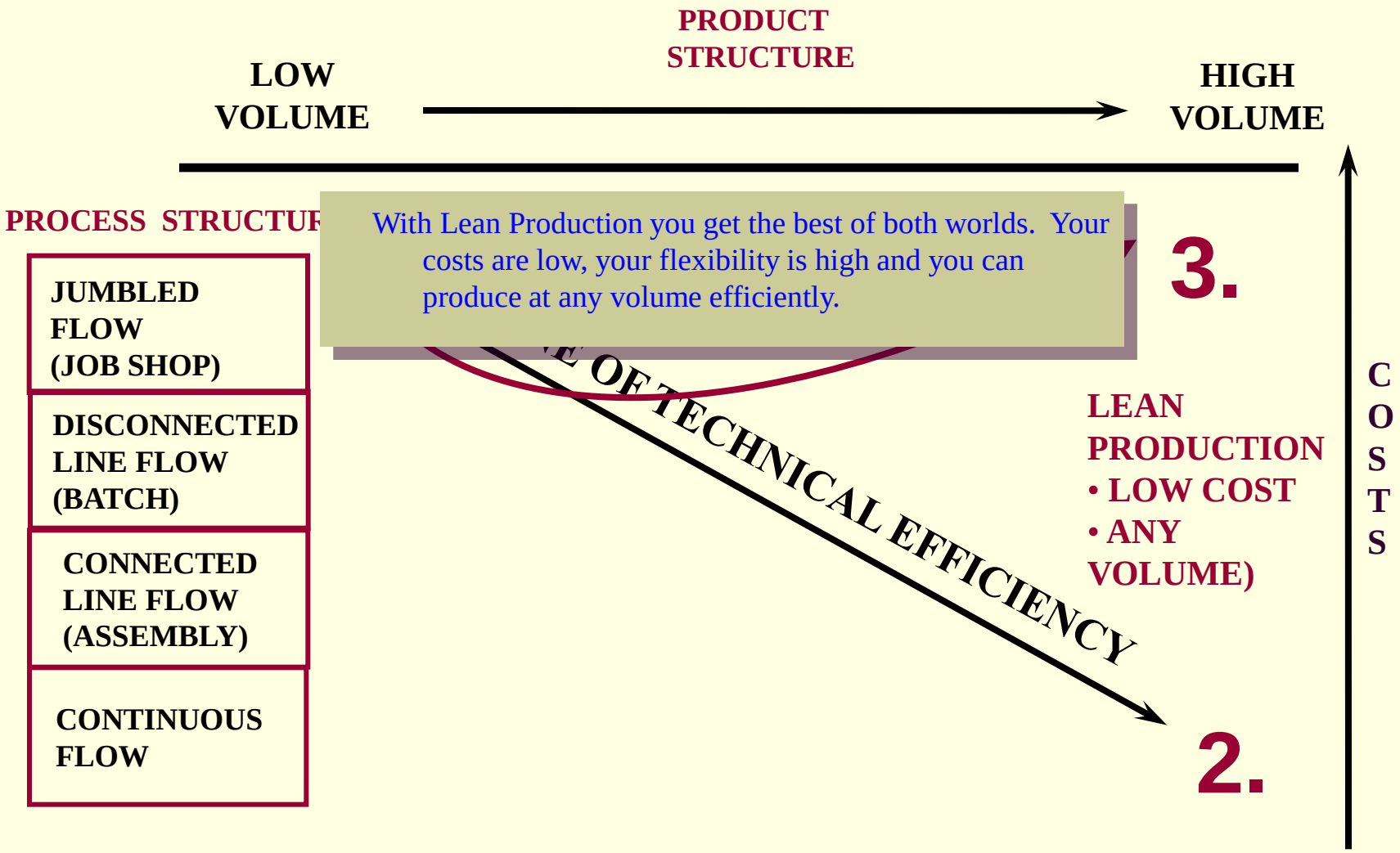


BACKGROUND

- **5-YEAR, $5M STUDY**
- **WORLD-WIDE AUTO INDUSTRY**
  - **Europe, North America and Asia**
  - **Very Little Change From the Days of Henry Ford**
  - **Turned into a study of Toyota's Production System**
  - **20 year journey (continues today)**
- **5-M's (Manpower, Machines, Methods, Material, Measurement)**

Parallels to the Auto Industry

- The U.S. automotive industry had their significant emotional experience over 10 years ago, including:
  - Rapidly declining market share
  - Overcapacity in capital and labor
  - Lengthening design times
- They have improved, and their improvement is directly and proportionally traceable to the adoption of “Lean Production Techniques.”
- Today the defense industry is facing very similar “significant emotional events.”

CRAFT

- Highly Skilled Workers
- Flexible Machines & Tools
- Quality = Craftsmanship
- Decentralized Organizations (Guild System)
- Low Volume/High Cost
- Great Amount of Variety
- 1-1 Customer Relationships
- Today: Luxury/Image Cars (Aston Martin)

MASS

- Professionals with Narrow Skills
  - Mfg., Tooling, Inspection, Design, etc.
- Semi or Unskilled Workers
  - Variable Cost, Work was Cyclical and Boring
- Expensive, Single Purpose Machines & Tools
  - Intolerant of Disruption
  - Low Flexibility
- Economies of Scale
- Keep Standard Designs a Long Time
  - Low Variety

MASS
(Continued)

- Centralized Organizations
- Reward Individuals
- High Volume, Low Cost
- Quality = AQL

Henry Ford 1900-1920

- Interchangeable Parts
  - Single Gaging System
- Simplicity of Design & Ease of Assembly
  - Easy to Maintain
  - 1908 Model T (514/minutes cycle time)
  - 1913 Model T (2.3/min.)
- Moving Assembly Line
  - Single Task per Assembler (1.19/min.)
- Vertical Integration
  - Tolerances & Scheduling
- Lots of Support Workers
  - Tooling, Quality, Foreman, Expediters, etc.

SLOAN
1920-30's

- 12 Car Companies
  - Managed Separately
  - High Degree of Product Overlap
- Decentralized
  - 5 Car Companies, One for every pocketbook
- New Breed of Professionals
  - Finance & Marketing
  - Management By-the-Numbers
  - Stovepiped Top-to-Bottom
- Standard Mechanical Parts for all Cars
- Endless Series of Add-On Features
  - Internal Self-Starter, Radio, Heater, Roll-Up Windows, etc.

UNITED AUTO WORKERS
1930's

- Big "3" Agreement
  - Based on Seniority & Job Rights
  - Attempt to Dampen Impact of Cyclical Layoffs
  - Final Wedge Between Management & Worker
  - Final Stovepiping in Factory Operations
- Mass Production in it's Final Mature Form

Factories of the Future

- **1900-1970: Mass production used 150 machine tools to create 10-15 products, with 25% or more of the products requiring rework because of poor quality.**
- **1971-2000: Flexible production uses 30-50 machine tools to create 100-1,000 products, with 0.02% of the products requiring rework because of poor quality.**
- **2001-2020: Mass customization will use only 20-25 machine tools to create an unlimited number of products, with less than 0.0005% or the products requiring rework due to poor quality.**

SOUREC: Business Week, "21st Century Capitalism" special issue, 1994

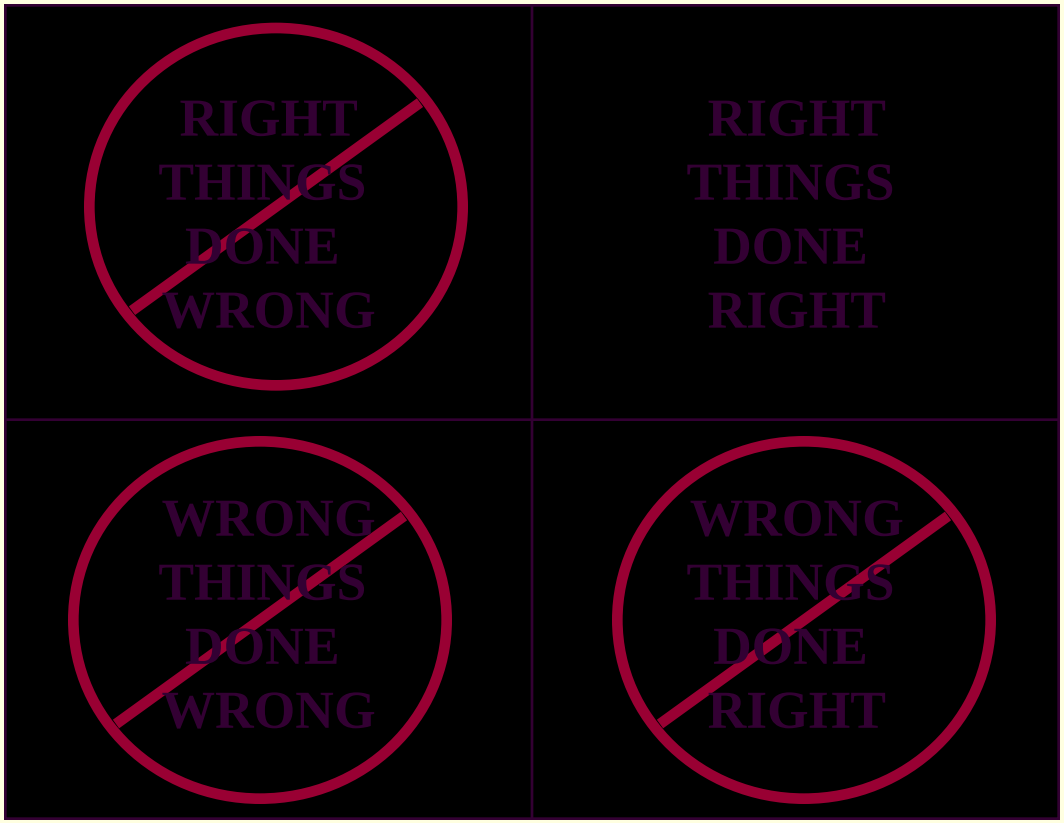
Taiichi Ohno

- Ford's System Rife with Muda (Waste)
  - 20% of Floor Space Dedicated to Rework
  - 25% of Total Hours Involved in Fixing Mistakes
- Only the Assembly Worker "Adds Value" - Value Stream
- Workers Given Additional Jobs
  - QC, Housekeeping, Minor Tool Repair, etc.
  - Time Set Aside for Continuous Improvement (Kaizen)
- No Rework
  - Cord to Stop the Line - Five Why's
  - Poka-Yoke (Foolproofing)
- Group Works in Teams with a Leader
  - Accomplishes Groups of Tasks
  - Leader is also a Worker

Quality Grid
(Phillip Crosby)

RIGHT THINGS

WRONG THINGS



DONE WRONG

DONE RIGHT

LEAN DESIGN ELEMENTS

- Integrated Product/Process Development
  - Multifunctional Teams
  - Well-Defined Development Processes
  - Design for Manufacturing & Assembly
  - Supplier Participation
  - Cycle-Times Reduced
  - Funding Profiles Changes
  - More Designs for the same Development Budget
- Prototypes with Production Processes & Workers
- Production Experienced Design Teams

LEAN DESIGN ELEMENTS
(Continued)

- **Project Team Leader Carries Great Power and Prestige (Shusa)**
  - **Assigned for the duration of the Project**
- **Teams are Small Tightly Knit Groups**
  - **Get Report Card from the Team Leader**
  - **Advancement is Through Performance on the Team**
  - **Groups Forced to Confront all Difficult Trade-Offs Early**
  - **Team Starts-Off Large and Gradually Shrinks**

MASS DESIGN ELEMENTS

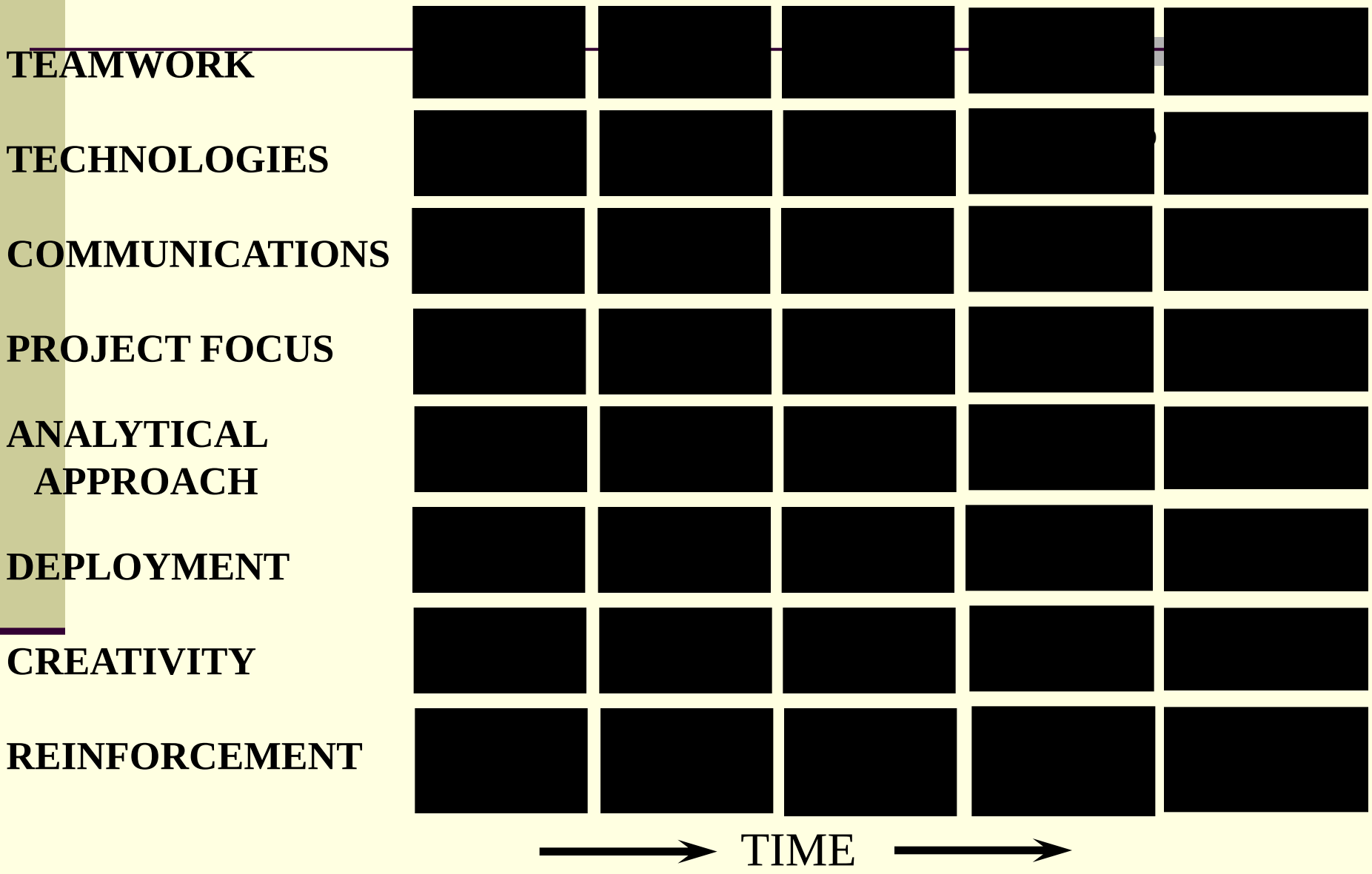
- Classic Design Methodology
  - Throw Over the Wall to Manufacturing
  - No Supplier Participation
  - Design Stays Fixed for a Long Production Run
- Design Requires Extensive Collaboration, but the Process is Fractured
  - Stovepiping Between Divisions and Functions
  - Designers have no Factory Floor Experience
  - Design Keeps Changing, even through Production
- The PM is a Coordinator not a Manager
  - PM given a Budget, but no Home
  - PM Changes Several Times before Production

MASS DESIGN ELEMENTS

(Continued)

- Teams are Large and Loosely Connected
  - Assigned for Limited Period of Time
  - May get Report Card from PM, but Future Success is Through Functional Boss
  - Groups Avoid Early Decisions, no Process to Force Decisions
  - Teams Start-Off Small and Grow as Problems Mount
- Products Developed 1st, then the Processes to Make Them
  - Product Development Cycle Time is High
  - Developing a New Product is Very Expensive
  - Funding Profile Does Not Support Teaming

IPT Maturity Model



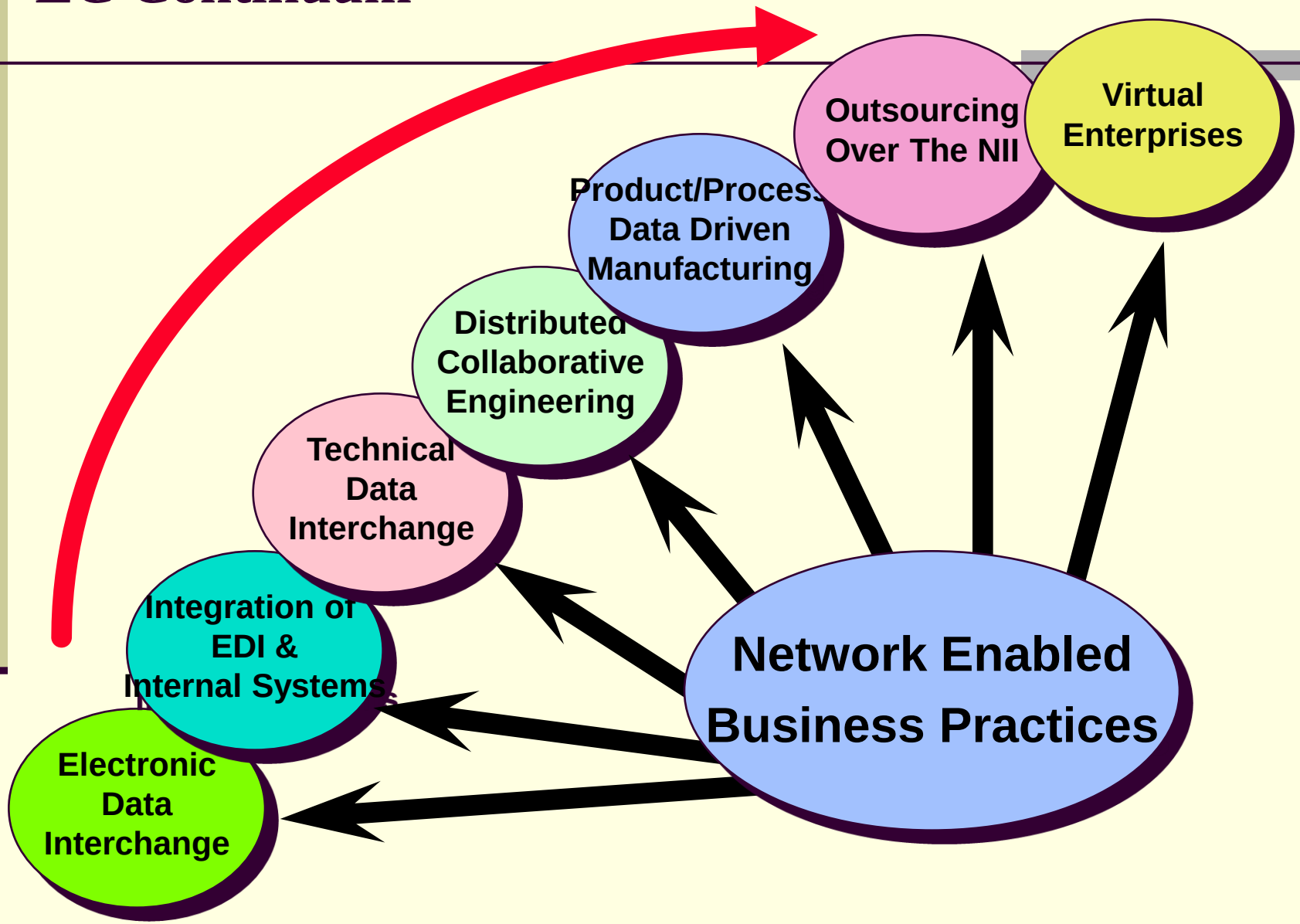
KOLBE CONCEPT

- Individuals have three mental faculties:
  - Cognitive (intellectual) controls thought
  - Affective (emotional) controls feelings
  - Conative (functional) controls actions
- The conative faculty translates instinct into acts & deeds
- Individuals have four instincts:
  - Instinct to Probe
  - Instinct to Pattern
  - Instinct to Innovate
  - Instinct to Demonstrate
- The Power of the Will propels people to act on their creative instincts

KOLBE
BALANCED TEAMS

- **Increase team productivity by identifying and harnessing an individual's natural striving pattern**
  - **the instinct to Probe deals with detail, complexity and provides the perspective of experience, FACT FINDER Mode**
  - **the instinct to Pattern deals with structure, order, and provides focus and continuity, FOLLOW THRU Mode**
  - **the instinct to Innovate deals with originality, risk-taking, and provides intuition & a sense of vision, QUICK START Mode**
  - **the instinct to Demonstrate deals with physical space and the ability to operate manually, and provides durability and a sense of the tangible, IMPLEMENTOR Mode**
- **GOAL: Put the right people into the right jobs, balance the team**

EC Continuum



Analytical Approach

- **LEAN (Uses tools to help solve problems)**
  - **Fix the Problem**
  - **7 Quality Tools**
  - **Cause & Effect Diagrams**
  - **Structured Brainstorming**
  - **5 Whys**
  - **7 Management Tools**
  - **QFD, DOE, SPC**
  - **Key Characteristics**
  - **Real Integration**
- **MASS (Limited tool use)**
  - **Fix the Blame**
  - **SPC used by QA only**

Key Characteristics

- **Features or characteristics whose variability has the greatest impact on fit, performance, or service life**
  - **Key characteristics provide a focus for product improvement**
  - **Quality if conformance to nominal on all key characteristics**
  - **Quality improvement comes from reducing variation by:**

    -- Eliminating special causes

    -- Improving consistency of measurement systems

    -- Controlling the product by controlling the processes

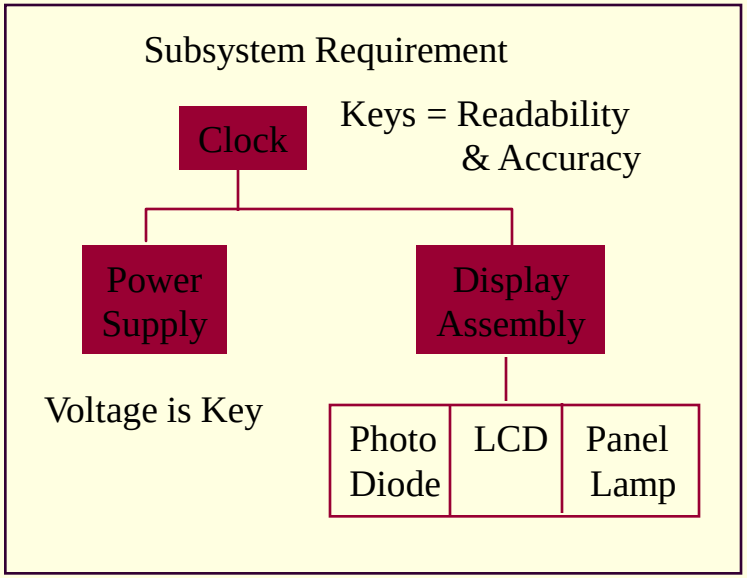
    -- Reducing losses and eliminating waste

- **But - How do you identify the features that are the most vital?**

Transformation Methodology

From Customer Requirements to Material & Manufacturing Processes

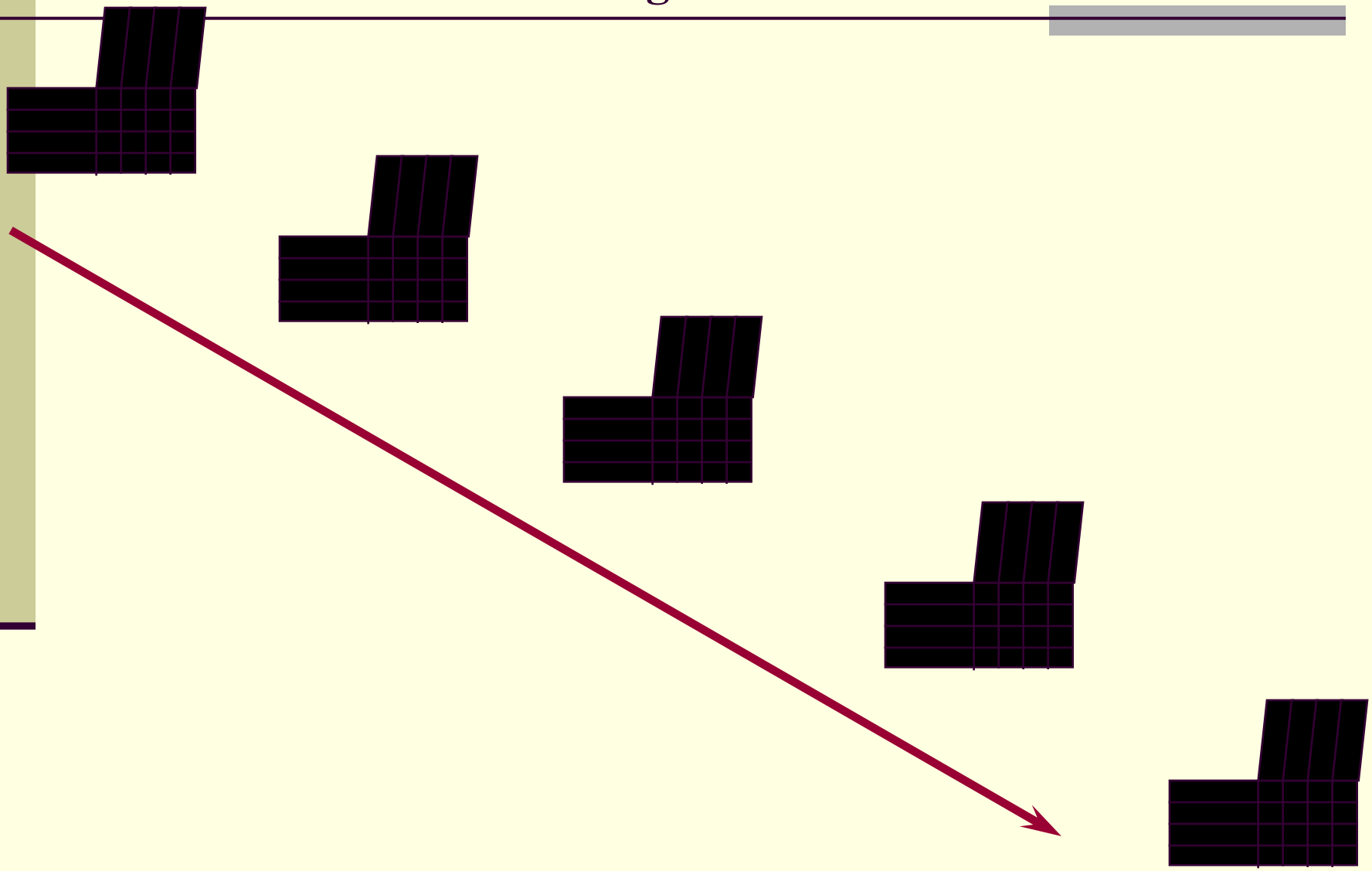
Customer Requirement
- Support the SIOP
  (Be on time is a Key Reqmt)



Manufacturing Requirements
- Hardware Requirements
  -- MIL-SPEC Diode
  -- Good Solder Joints
- Process Requirements
  -- MIL-STD 2000
  -- Wave Solder Machine
- Verification Requirements
  -- DOE to Identify Key Characteristics
  -- SPC to control key process factors

Quality Function Deployment

"The Start of Lean Thinking"



Maturity Models (Deployment)

SCORE	APPROACH/DEPLOYMENT	RESULTS
Failed	Failed to meet SOW requirements Early systematic approach evident to meeting the requirements Major shortcomings in understanding the requirements Early stages of transition from reacting to problems to problem prevention Major gaps in deployment exists	Major shortcomings in execution or understanding No results or poor results in most areas In the early stages of developing trends Some improvements in or good performance in a few areas results are not reported for most areas of importance or for key requirements
Meets Standard	Meets the SOW requirements Have a sound & systematic approach to the primary purpose Uses fact-based improvement process in key areas More emphasis is placed on improvement than on reacting to problems No major gaps exist in deployment	Improvements required in some areas Good performance or improvement trends in many areas There is no pattern of adverse trends or poor performance Some trends or performance levels are benchmarked and show they are areas of strength
Exceeds Standard	Exceeds the requirements in most areas A sound & systematic approach to most purposes Fact-based improvement is a key management tool Clear evidence of the use of improvement cycles & analysis Approach is well deployed in most areas	Clearly above the standard Current performance is good to excellent in most areas Sustained performance levels in some areas Most trends or performance levels are benchmarked and show areas of leadership
Best of Breed	Best of the Breed in some areas A sound & systematic approach to all requirements Very strong fact-based improvement process with excellent analysis Approach is fully deployed with no (even minor) gaps	Clearly above the standard in most areas Best throughout the ECRC system Current performance is excellent in most areas Excellent improvement trends or sustained excellence in most areas Strong evidence of benchmark leadership in most areas

PRODUCIBILITY

- **A design accomplishment resulting from a coordinated effort by all engineering functions to create a functional hardware design that optimizes ease and economy of fabrication, assembly, inspection, test, and acceptance without sacrificing desired function, performance, or quality.**

PRODUCIBILITY
(Continued)

- **MAXIMIZE**
  - **Modularity**
  - **Use of Standard Components**
  - **Design of Parts for Multi-use**
  - **Design for Ease of Assembly**
  - **Design for Ease of Fabrication**

- **MIMIMIZE**
  - **Total Number of Parts**
  - **Use of Separate Fasteners**
  - **Need for Assembly Directions**
  - **Handling (Time and Distance)**

Producibility Assessments

MANAGEMENT

FUNDING

.9 FUNDING MATCHES PROJECTED BUDGET
.7 FUNDING ADEQUATE, DOES NOT EXCEES 5% OVER
.5 FUNDING MINIMAL, OVERRUNS OF 15% LIKELY
.3 FUNDING SKETCHY, HIGH OVERRUNS LIKELY
.1 FUNDING IS TOTALLY INADEQUATE

PRODUCIBILITY

.9 PRODUCIBILITY ASSESSMENT DONE BEFORE AWARD
.7 PRODUCIBILITY IMPLEMENTED AFTER PDR
.5 PRODUCIBILITY IMPLEMENTED AFTER CDR
.3 PRODUCIBILITY IMPLEMENTED AFTER EMD
.1 PRODUCIBILITY NOT CONSIDERED

RISK ASSESSMENT

.9 RISK IS MANAGEABLE/PREDICTABLE - PLAN IS IN PLACE
.7 RISK IS LOW
.5 RISK IS MEDIUM
.3 RISK IS HIGH
.1 NO RISK PLAN OR POLICY CONSIDERED

DATA REQUIREMENTS

.9 ALL SPECs/CDRLs ARE ON CONTRACT
.7 TAILORING OF ALL SPECs/CDRLs IS ACCOMPLISHED
.5 ALL SPEC/CDRL COST DRIVERS IDENTIFIED
.3 A FEW SPEC/CDRL COST DRIVERS IDENTIFIED
.1 NONE IDENTIFIED

EMD

DESIGN

.9 EXISTING/SIMPLE DESIGN
.7 MINOR REDESIGN OR INCREASE IN COMPLEXITY
.5 MAJOR REDESIGN OR MODERATE INCREASE
.3 COMPLEX REDESIGN OR MAJOR INCREASE
.1 STATE OF THE ART RESEARCH REQUIRED

PROCESS/METHOD

.9 PROVEN PROCESSES & TECHNOLOGIES
.7 PREVIOUS EXPERIENCE WITH PROCESSES
.5 PROCESS EXPERIENCE IS AVAILABLE
.3 PORCESS AVAILABLE BUT NOT PROVEN
.1 NO EXPERIENCE, PROCESS NEEDS R&D

MATERIALS

.9 READILYAVAILABLY
.7 1-3 MONTH LEAD TIMES
.5 3-9 MONTH LEAD TIMES
.3 9-18 MONTH LEAD TIMES
.1 18= MONTH LEAD TIMES OR NEEDS R&D

DESIGN TO COST

.9 BUDGET NOT EXCEEDED
.7 EXCEEDS BUDGET BY LESS THAN 5%
.5 EXCEEDS BUDGET BY 5-20%
.3 EXCEEDS BUDGET BY 20-50%
.1 EXCEEDS BUDGET BY MORE THAN 50%

DFMA

Design for Manufacturing/Assembly

- A part is a candidate for redesign if you can answer no to the following three questions:
  - During operation, does this part move relative to the part to which it is attached?
  - Does this part need to be made of a different material that the part to which it is attached?
  - Does this part need to be removable?

* Source: Boothroyd & Doohurst

Producers Rank Other Producers

"Manufacturability of Products in Assembly Plant"

	RANK
Toyota	2.2
Honda	3.9
Mazda	4.8
Fiat	5.3
Nissan	5.4
Ford	5.6
Volkswagen	6.4
Mitsubishi	6.6
Suzuki	8.7
General Motors	10.2
Chrysler	13.5
Jaguar	18.6

SOURCE: 1990 IMVP MANUFACTURABILITY SURVEY

“”Contributions to Quality Improvement at Toyota”

QFD helps to identify what is important
Taguchi, FTA/RFTA and FMEA are used to make the continuous improvements (breakthroughs)
SPC is used to hold the gains and monitor the process
FTA = Fault Tree Analysis
RFTA = Reverse Fault Tree Analysis
FMEA = Failure Mode and Effect Analysis

TAGUCHI

Statistical Process Control

LEAN PRODUCTION

- Transfers Maximum Number of Tasks and Responsibilities to the Worker
- Only Workers Add Value
  - Indirect Specialists Go Away or Reduce in Numbers
- Develops and Advanced Quality System
  - Root Cause Corrective Action (5-Whys)
- Workers have Multiple Stills
  - Invest Heavily in Training (TI, Motorola)
- Use Highly Flexible Machines
- Produce a Great Variety of Products

MASS PRODUCTION

- Work Arranged for the Worker
  - Only a Few Well Defined Tasks, Requiring Little Training
  - Work Brought to the Worker
  - Relentlessly Disciplined by the Pace of the Line
- Many Indirect Specialists
  - Industrial & Mfg. Eng.., QA, Housekeeping, Tooling, etc.
- Equipment
  - Very Accurate, Specialized & Expensive
  - Designed for High Volume (Set-Up Times Minimized)
- Limited Number of Products (High Volume)
- Buffers Between Production Steps
  - Excess Capacity, Excess People, and Large WIPs

Theory of Constraints

"Eli Goldratt"

- **Inventory is the Root of All Evil**

(Ohno and Goldratt)

- **The action you are proposing:**
  - **Will it increase throughput?**
  - **Will it decrease inventory?**
  - **Will it decrease operating expenses?**

  (Where is Muda in all this?)
- **Conventional cost accounting systems make machine & employee utilization a key performance measure and treat inventory as an asset!**

Theory of Constraints
(Continued)

- Making Product does not equal Making Money
- People Working does not equal Making Money
- Manufacturing Goals (Simultaneously):

Throughput (Sales)	
Inventory & WIP	↑
Operating Expense	↓
Net Profit	↓
ROI	↑
Cash Flow	↑
	↑

Theory of Constraints
(Bottlenecks Pace the Plant)

- The output of upstream operations control the output of downstream operations
- Cycle times of all work centers vary - this variability spreads throughout all downstream operations
- The maximum deviation of a preceding operation will become the starting point of the next operation, therefore:
  - Work centers with excess capacity cannot work on parts they cannot get
  - Bottlenecks cannot work on additional parts when they are at 100% capacity
  - Fluctuations in bottleneck operations only make things worse

Theory of Constraints
(Continued)

- **Sum of the Local Optimums ≠ Global Optimum**
  - **Balance Flow not Capacity**
  - **Bottlenecks Govern Both Throughput & Inventory**
  - **An Hour Lost at a Bottleneck is an Hour Lost for the Entire System**
  - **An Hour Saved at a non-Bottleneck is is Mirage**

    (The potential of a non-bottleneck is not determined by itself but by the bottleneck)
  - **If You Don't Need a Part Don't Make It**
    - **It is OK to let a non-bottleneck sit idle**
    - **It's Never OK to let Bottlenecks sit idle**

Theory of Constraints
(Continued)

- **Drum - Buffer - Rope**
  - **Drum: Paces the Plant (Bottleneck)**
    (Takt Time)
  - **Buffer: Inventory to Protect the Bottleneck**
    (ensures there are no work stoppages)
  - **Rope: Ties Everything Together: material releases and assembly schedules (Kanban)**
    (reflects the bottleneck constraints)

Theory of Constraints
(The Process)

- Identify the bottlenecks (capacity constraints)
- Protect the bottlenecks
- Use non-bottlenecks only to keep pace with bottleneck flows
- Only improve capacity & variability at existing bottlenecks & capacity constrained resources
- Reduce:
  - Set-up Times
  - Cycle Times & its Variability
  - Vendor Variability (Quality, Quantity & Times)

LEAN SUPPLY CHAIN

- **Designing the Parts:**
  - **Fewer Suppliers**
  - **Suppliers Selected on Basis of Past Relationships vice Cost**
  - **Suppliers Design and Build Entire Components**
  - **Suppliers Work with Assemblers Early in the PD Cycle**
  - **Assemblers Work with Suppliers and Provide Help**
  - **There is a Framework and Process for Exchanging Information**

LEAN SUPPLY CHAIN
(Continued)

- **Supplying the Parts:**
  - System for Establishing Price & Cost (Market Price Minus vs. Supplier Cost Plus)
  - Continually Reduce Cost while Improving Quality
  - Quality: Work with the Suppliers
  - Share Proprietary Information
  - Heijunka - Production Smoothing (Assembler & Supplier
  - Daily (52%) and Hourly (31%) Deliveries
  - Use of VE and Kaizen

MASS SUPPLY CHAIN

- **Designing the Parts:**
  - **Design Process is Sequential, One-Step at at Time**
  - **Suppliers Given Drawings and Asked for Bids**
  - **Given Quality Targets and Delivery Schedule**
  - **Contract Key Elements (Price, Quality, Reliability, and Contract Length)**
  - **Supplier Buys-In and Makes Up on the Next Contract**
  - **Suppliers Have No Contract with One Another**

MASS SUPPLY CHAIN
(Continued)

- **Supplying the Parts:**
  - **Purchasing Worries About Cost not Production**
  - **Many Suppliers**
  - **Debugging Process After Production (Running Changes)**
  - **Often Don’t Meet Quality Targets (Ignore or Cancel)**
  - **Fluctuating Markets (Keep Buffers)**
  - **Cost Estimating Difficult**
  - **Effort to Keep Supplier Profits Low**
    - **Cost Continue to Rise**

LEAN DISTRIBUTION

- Distribution Channels for Specific Models
- Established Link Between Customer and Assembler
- Use of Fully Trained Teams
  - Sell Door-to-Door
  - Daily Meetings to Solve Problems and Improve
- Custom Orders with Delivery within 10 Days
  - Very Accurate Build Schedule
  - Closer Handle on Trends with Flexibility to Change
- Production Smoothing
  - Done by Aggressive Selling
- Success: Market Share
  - Don’t Ever Loose a Customer

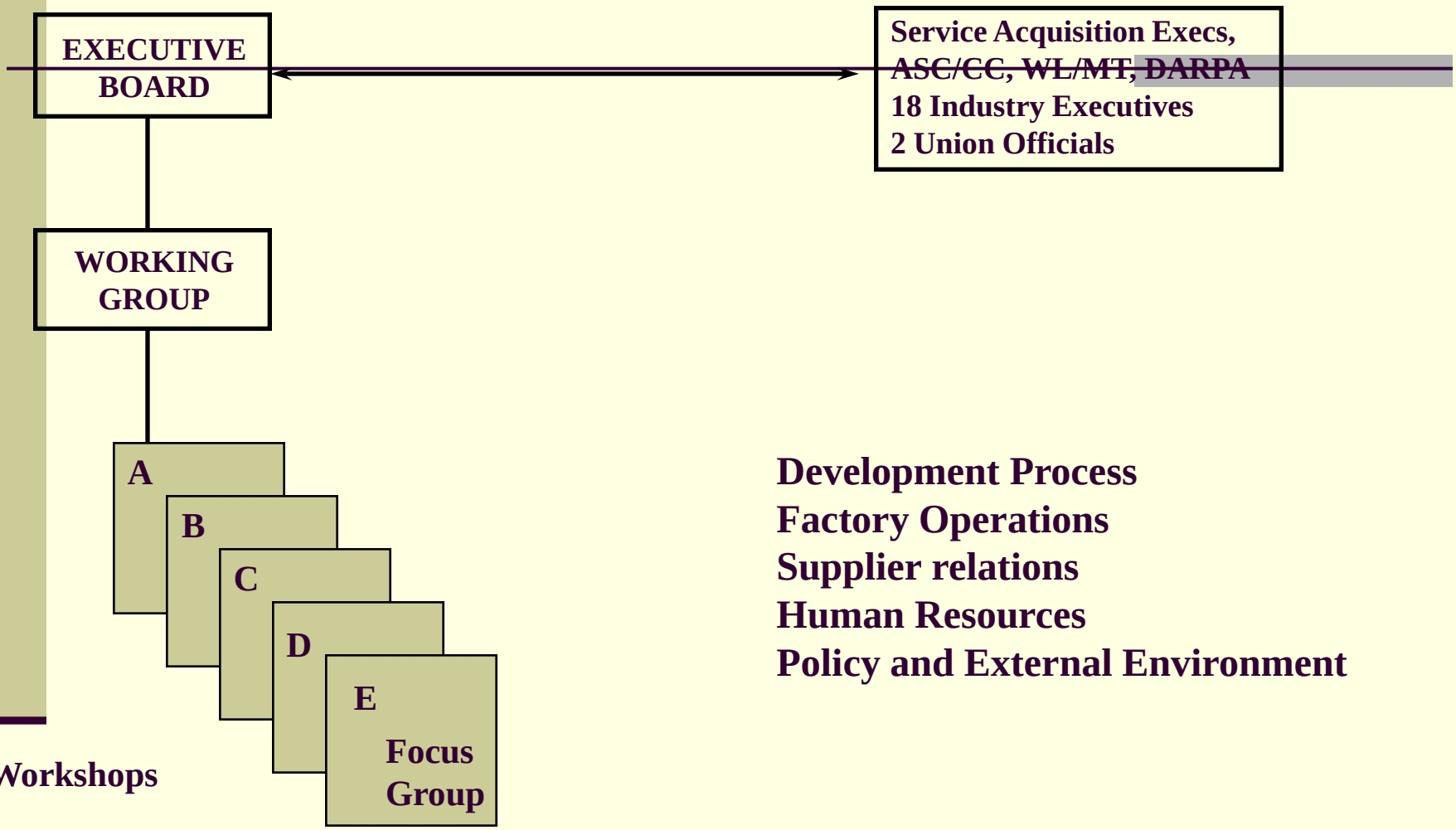
MASS DISTRIBUTION

- Geared to the Needs of Production
  - The Customer Comes Last
- Established Barriers Between Customer, Dealer and Assembler
  - Little Feedback on Design from the Customer
- Dealer Used to Buffer Production
  - Large Inventories and Inventory Cost
  - Models Customers do not Want
  - Goal: Outwit the Customer
- Salespeople Have Limited Focus
  - They Don’t Know Cars, Just Know How to Close a Deal
- Success = Number of Sales per Month per Salesman

LEAN AIRCRAFT INITIATIVE

- 3-Year Research at MIT Based on “The Machine That Changed The World”
- Uses Lean Production Principles as a Starting Point
- Aimed at Substantial Improvements in Industrial Performance
- Sponsored by 21 Companies and ASC
- All Aircraft Industry Sectors (Airframe, Engine, Avionics and Equipment)

STRUCTURE and PROCESS



Development Process
Factory Operations
Supplier relations
Human Resources
Policy and External Environment

LEAN THINKING

"Value Stream"

- **Value is defined by the Customer**

- **Start with the Customer's Key Characteristics**

- **Value is created by the Producer**

- **Often hears "the Voice of the Engineer"not the customer**

- **Value Stream : the set of all actions required to bring a product through three critical management tasks:**

- **Problem Solving:**
- **Information Management:**
- **Physical Transformation:**

LEAN THINKING
(Five Principles)

- Organizations accurately specify value
- The entire value stream is identified
- Make value creating steps flow continuously
- Let customers pull value from the enterprise
- Perfection….becomes possible

(Hoshin Planning)

Hoshin Planning Tools

STEPS	1	2	3		4	5	6
QC Tools	**Aim**	**Plan**	**Do**	**Do**	**Do**	**Check/Act**	**Check/Act**
Fishbone	●		●			●	●
Pareto	●			●			
Line	●				●	●	●
Flow	●		●			●	●
Check Sheet	●					●	
Histogram	●					●	
Control	●				●	●	
Mgmt Tools							
KJ	●	●					
ID	●	●					●
Tree	●	●	●				
Matrix	●	●					●
PDPC					●		
Arrow					●		
Alignment Tools							
Flag		●		●		●	●
Target/Means				●			
Cascading				●			
T/M Tree							
QFD		●		●			

NEXT STEPS