1. Background and Motivation

Industrial Manufacturing Paradigms

a. Craft Production (< 1850)
b. American System of Manufacturing (1850 - 1900)
c. Mass Production (1900 - 1960)
d. Lean Manufacturing (1960 - 1990)
e. Mass Customization (> 1990)
f. Costs of Variety
What is Craft Production?

• Craft production is characterized by:
  - Highly skilled work force with detailed knowledge of design, machining, and fitting learned through apprenticeship

  - *Artisans* with the skills and know-how to turn raw materials into finished goods; not only an art, but a source of pride

  - Decentralized organizations where owner is in direct contact with everyone—customers, employers, and suppliers

  - General-purpose machine tools to drill, grind, cut, etc., both wood and metal

  - Lack of economies of scale: unit cost to make 200,000 cars only slightly less than unit cost to make 10 cars

  - Very low production volume: 1000 or fewer automobiles a year; maybe 50 of the same design, but no two exactly alike because of fitting process
Craft Production Firms Today

• Some craft production firms are still operating today
  ▪ Focus on tiny niches, usually upper, luxury end of market
  ▪ Buyers who want a unique image and opportunity to deal directly with factory
  ▪ Make agreements with larger firms to gain specialized expertise in areas of technological development

• Example: Aston Martin <http://www.astonmartin.com>

  • Aston Martin has made ~15,000 cars since its establishment in 1913
  • They average 1 automobile per day
  • Skilled panel beaters form body panels by pounding sheets of aluminum with wooden mallets

Aston Martin One-77 (limited to 77 examples)
The American System of Manufacturing

- ASM is the “factory system” that developed during the Industrial Revolution in the U.S. and later half of 1800s

- Eight (8) characteristics of ASM were:
  1. Interchangeable parts
  2. Specialized machines
  3. Reliance on suppliers
  4. Focus on process of production
  5. Division of labor
  6. Skills of American workers
  7. Flexibility
  8. Continuous technological improvement

- These factors were not enough to support growth of large industries in the early 1900s as they sought to meet the demands of an increasingly geographically dispersed economy
From ASM to Mass Production

- From ASM, mass production utilized these principles:
  1. Interchangeable parts
  2. Specialized machines
  4. Focus on production process
  5. Division of labor

- Additional principles needed for mass production were:
  1. Flow (i.e., assembly lines)
  2. Focus on low cost and low prices
  3. Economies of scale
  4. Product standardization
  5. Degree of specialization
  6. Focus on operational efficiency
  7. Hierarchical organization with professional managers
  8. Vertical integration
• In time, mass production became the paradigm for doing business

• What is a paradigm?
  - It is “an accepted model or pattern” that establishes an informational framework and set of rules by which its practitioners view the world (Kuhn, 1986)

• Paradigm of mass production has the shared goal of:

  Developing, producing, marketing, and delivering goods and services at prices low enough that nearly everyone can afford them

• More simply, mass production (MP) is efficiency through stability and control
Reinforcing Loops in Mass Production

- **Economies of Scale:**
  - *Beginnings of a reinforcing cycle:* As prices were lowered, people could buy more product, resulting in greater sales and greater production, even lower prices, and so on.

- **Production Standardization:**
  - *Reinforcing cycle:* Low costs of standardized products $\rightarrow$ low prices $\rightarrow$ maintained market homogeneity because the gap between the cost of MP goods and customized goods grew as prices fell $\rightarrow$ people clustered around homogeneous products.

- **Degree of Specialization and Professional Managers:**
  - Managers focused on planning the work of their workers, increasing their specialization, decreasing their skills, and *eventually replacing many of them with machinery.*
Mass Production’s Reinforcing Loop

- MP creates a feedback loop that reinforces standardized products, mass production techniques, and large homogeneous markets.

MP dictates the view of the world and *the decisions that must be made in order to achieve success*

- Company must make a profit to stay in business → the more profit, the more successful the business → selling lots of products at a low cost yields highest profit.

- More products can be sold in a large homogeneous market.

Note: MP loop and its derivation is adapted from (Pine, 1993)
High production volumes reduce manufacturing costs through economies of scale

Lowering prices increases demand and therefore volume, yielding higher profits

As prices drop, markets expand; customers in niche market on the “fringe” of an MP market are lured in by lower prices
Efficiency of production must be maintained at all times - stability, no delays, no interruptions, and no surprises!

→ How is stability ensured?
How is stability ensured?

1. Inputs must be stabilized (wages and supplier prices):
   - fight Unions which cannot be allowed to control labor market
   - play suppliers off one another to reduce their prices
   - vertically integrate as much as possible to ensure stability of material inputs

2. Stabilize production process:
   - introduce buffers and queues
   - standardize as much as possible
   - break down manufacturing into small specified tasks
   - specialize workers also

3. Outputs must be stabilized (control demand levels):
   - ignore niche markets, leaving them for the “little guys”
   - adjust inventory levels to respond to changes in demand
   - if demand falls below a level that adversely affects profits, lay off workers
For even better stability → lengthen product life cycle

– This reduces per unit development costs and investments in product and process technology and allows experience (learning) curve to operate at its fullest

– Minor changes only add cost and should be avoided
Long product life cycles enable long product development cycles to develop product extensions and new products for the masses.
R&D should only focus on product developments that can be easily mass produced.
“New products manufactured by a mass production process yield low-cost, consistent quality, standardized goods for large, homogenous markets; this results in stable demand, causing long product life cycles, which allows for long product development cycles from which new products are created”
Automate the process as much as possible to realize lowest costs and largest volumes (high fixed costs, but low unit costs)
Pursue new process technology to improve throughput further and reduce prices further through added volume
R&D should focus on product developments that can be mass produced; marketing should push current product out the door
A steady stream of products can provide stable base of products needed to maintain profits over the long run
Recall that outputs must be stabilized (control demand levels):
  - ignore niche markets, leaving them for the “little guys”
  - adjust inventory levels to respond to changes in demand
The Paradigm of Mass Production

- Long Product Life Cycles
- New Products
- Mass Production Processes
- Low-cost, Consistent Quality, Standardized Products
- Homogeneous Market
- Stable Demand
- Ignore Niches
- Inventory Adjustments

Product Technology
Process Technology

R R
Limits to Mass Production

• By 1950s, MP was commonplace around the world

• Peak in automobile industry was in 1955
  - First year in which 7 million cars were sold in U.S.
  - Ford, GM, and Chrysler had 95% of all sales
  - Six (6) models accounted for 80% of all cars sold

• A more complete picture of the MP paradigm includes balancing loops which shed light on why shift to mass customization has occurred.
Input Stability and Market Homogeneity

• MP requires input stability
  - E.g., labor costs must keep falling in order for MP loop to keep reinforcing itself or productivity must continue to increase

• MP requires homogenous markets; as we neared the end of the 20th century, we found:
  - American society is much less homogeneous with regard to class, race, gender, lifestyles, national origin
  - Income distribution is less equal, creating differences in disposable income and disparities in needs and wants
  - American market is no longer new and is not growing much faster than the rest of the industrialized world
    → Demand for new products frequently has to be diverted from older ones; therefore, new products must meet the needs of customers more completely, be of higher quality, and simply be different from what is already available
Demand Stability and Growth

- Demand must be stable and grow steadily, which was the case until 1970s, but since then:
  - *Seller’s market has become a buyer’s market*
  - Many industries have matured, been saturated, and buffeted by recessions (e.g., oil crises)
  - Forecasting and production planning is problematic making it difficult to justify production of high volume, low cost products when markets are unpredictable
  - Technological shocks such as digital equipment
  - Process technology shocks, e.g.,
    - Lean Production and JIT in automobile industry was designed to compete against MP, allowing Japanese to produce smaller volumes at lower cost with higher quality
    - CIM, FMS, etc. have made it economically viable to produce greater variety of high quality products
Balancing Loops in Mass Production

- **New Products**
  - **Mass Production Processes**
  - **Low-cost, Consistent Quality, Standardized Products**
- **Process Technology**
  - **Input Stability**
- **Changing Demographics**
- **Changing needs**
- **Economic cycles/uncertainties**
- **Homogeneous Market**
- **Ignore Niches**
- **Inventory Adjustments**
- **Stable Demand**
- **Market Saturation**
- **Product/process technology shocks**
- **Long Product Life Cycles**
- **Long Product Development Cycles**
- **Ignore Niches**
- **Stable Demand**

**Product Technology**
As a result, **efficiency**, **stability**, and **control** are lost

Many other factors have contributed to the “downfall” of mass production and the rise of mass customization

- Shortening of product life cycles and development times
- Customer expectations: if Company X can’t satisfy my every need, I know someone else can
- Globalization of markets: companies compete globally and must satisfy wider variety of customers than ever before
- Pervasiveness of computers in design and manufacturing process, e.g., CAD, CAM, CIM, along with:
  - **Digital** - fax it, print it, copy it, beam it, email it ... digital makes it easy
  - **Internet** - ease of acquiring and disseminating information
  - **Databases** - it is cheap and easy to store individual customer information
Paradigm Shift Away From MP

• The breakdown of MP began in the 1960s, accelerated in the 1970s, and finally burst fully into management consciousness in the 1980s

• The competitive landscape changed in the 1990s:
  - Time-based competition
  - Proliferation of variety
  - JIT production
  - Lean production
  - Continual improvement
  - Cycle time reduction
  - Shortening product life cycles
  - Market driven quality
  - Globalization
  - Increased customization
  - Total quality management
  - Flattened hierarchies
  - Computer-integrated manufacturing
  - Process re-engineering
  - Heightened importance of service
  - Fragmented markets
  - Quick response
  - Flexible manufacturing systems
Lean Manufacturing

• Lean principles can be applied to all areas within a company (e.g., manufacturing, assembly, operations)

1. Elimination of Waste
   - Quick changeover (single-minute die exchanges), standard work, just-in-time supply, inventory reduction, workspace layout, error-proofing

2. Continuous, One-Piece Product Flow
   - Incremental inventory reduction, root-cause analysis, 5 Why’s, Kaizen blitz, error-proofing, just-in-time supply of materials

3. Customer Pull
   - Kanban production scheduling, just-in-time manufacturing, supply chain management, system-wide inventory reduction
Shift to Mass Customization

• Smaller, more flexible (and usually foreign) companies have exploited opportunities created by the inability of mass producers to adapt to market turbulence by providing more variety and customization

→ This fuels market turbulence which makes mass customization firms even more competitive

• Companies are undergoing a paradigm shift, i.e., “a change to a new game, a new set of rules”
  □ The old paradigm of MP can no longer explain anomalies or provide solutions for new problems
  □ Cannot ignore the changes that have occurred over the past decades and no hope of a return of the good old days
The Paradigm of Mass Customization

“A new paradigm of management is emerging, one in which variety and customization supplant standardized products, heterogeneous and fragmented markets spring from once homogeneous markets, and product life cycles and development times spiral downward” (Pine, 1993)

• The new paradigm of MC is variety and customization through flexibility and quick responsiveness.

• At its limit, mass customization is mass production of individually customized goods and services.
“Mass customization is best defined as a delivery process through which mass-market goods and services are individualized to satisfy a very specific customer need, at an affordable price. Based on the public's growing desire for product personalization, it serves as the ultimate combination of ‘custom-made’ and ‘mass production.’ And it is rapidly emerging as the organizing business principle of the 21st century”

http://www.mass-customization.com
# Comparison of MP and MC Paradigms

<table>
<thead>
<tr>
<th>Focus</th>
<th>Mass Production</th>
<th>Mass Customization</th>
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<tbody>
<tr>
<td></td>
<td><strong>Efficiency through stability</strong></td>
<td>Variety and customization through flexibility</td>
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<td></td>
<td><strong>and control</strong></td>
<td>and quick responsiveness</td>
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<tr>
<td>Goal</td>
<td>Developing, producing, marketing,</td>
<td>Developing, producing, marketing, and delivering</td>
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<tr>
<td></td>
<td>and delivering goods and services</td>
<td>affordable goods and services with enough</td>
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<td></td>
<td>at prices low enough that nearly</td>
<td>variety and customization that nearly everyone</td>
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<tr>
<td></td>
<td>everyone can afford them</td>
<td>finds what they want</td>
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<tr>
<td>Key Features</td>
<td>• Stable demand</td>
<td>• Fragmented demand</td>
</tr>
<tr>
<td></td>
<td>• Large, homogenous markets</td>
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<td>services</td>
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<td></td>
<td>• Long product development cycles</td>
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</tr>
<tr>
<td></td>
<td>• Long product life cycles</td>
<td>• Short product life cycles</td>
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</table>
Mass Customization

• Mass customizers seek to:
  - Provide personalized, custom-designed products at prices so close to those traditionally offered only for mass-produced merchandise
  - Give customers exactly what they want, at the price they want, and at the time they want it
  - Provide sufficient variety in products and services so that virtually every customer is able to purchase a customized product for a price near the mass-produced item

• Customization ≠ product variety

• Customized products are uniquely produced for each customer; therefore, customers must be involved in the process at some point!
**Point of Customer Involvement**

Unique design or features

Where is customer involved?

Unique configurations or options

Customer’s voice (product specifications)

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**Stages of Product Realization**

Suppliers → Design → Fabrication → Assembly → Delivery → Customers

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Adapted from:
Begin ordering process **Seat tube length sizing process** (step 1 of 5)

- **47.0 cm**

Selecting the proper seat tube length is the first step in the design process. Seat tube length and seat post height work together to establish one of the more critical dimensions on your bicycle: the distance between the top of your saddle and your pedals. Seat tube length also has some effect on the "feel" of a...
http://www.dell.com/

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### Results of Customer Involvement

<table>
<thead>
<tr>
<th>Customer Involvement</th>
<th>Design</th>
<th>Fabrication</th>
<th>Assembly</th>
<th>Delivery</th>
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<tbody>
<tr>
<td>Product Variety</td>
<td>All unique</td>
<td>Unique fit</td>
<td>Combinatorial</td>
<td>Combinatorial</td>
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<tr>
<td>Production Planning</td>
<td>Made-to-order</td>
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<td>Assembled-to-order</td>
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<tr>
<td>Information Technology</td>
<td>Design-oriented</td>
<td>Order processing</td>
<td>Order processing, scheduling</td>
<td>Point-of-sale Inventory</td>
</tr>
</tbody>
</table>

Adapted from:
Pine’s Five Steps to Mass Customization

1. Customize Services
2. Embed Customizability
3. Create Point-of-Delivery Customization
4. Provide Quick Response
5. Modularize

Degree of Market Turbulence vs. Degree of Organizational Turbulence

Sources:
Step 1: Customize Services

1. Customize Services:
   - Customize services around standardized products
   - Higher value than MP but added value typically allows a premium price

Notes:
- Requires minimal change(s) within organization (i.e., service dept.)
- Realize that customers are buying service, not technology
- Customers are looking for value; if customized service does not add value to product, customers are not going to pay for it
- Be open to integrating services with other services and products as well (often an easy first step to look for customized service)

Warning: The competitive advantage through customized service is not sustainable. Anyone can do it, and you must be ready to adapt/move
Step 2: Embed Customizability

2. Embed Customizability
   - MP goods or services that people can adapt to their individual needs

Notes:
   - Requires minimal changes within organization, but creativity and innovation on designers’ part
   - Starts pushing company into MC since designers must embed customizability

Warning: Can over-design a product, and it becomes difficult to charge a premium since someone else can provide precisely what user wants for less cost
• Lutron makes customizable lighting control systems for commercial and residential applications including hotel lobbies, ballrooms, conference rooms, and exec offices.

• Lutron has rarely shipped the same lighting system twice.
  - Work with individual customers to extend the product line until they have 100+ models from which to choose.
  - Engineering and production redesign the product line with 15-20 standardized components that can be configured into the same 100+ models.
Step 3: Point-of-Delivery Customization

3. Create Point-of-Delivery Customization
   - Customize product at point of sale

Notes:
- Requires small changes within organization:
  - Marketing: must focus on personalization and convenience
  - Designers: creative and innovative solutions
  - Delivery: must have capability to perform last MC operations
  - Production: not affected, still MP
  - Sustainability of competitive advantage depends on degree of successful transformation within organization

Warning: (1) Production and delivery must be integrated and well coordinated, and designer must consider impact of point-of-delivery on product
(2) requires lots of IT to speed response and know/understand customers

Create Point-of-Delivery Customization

Customize Services

Degree of Organizational Turbulence

Degree of Market Turbulence
Product Postponement at HP

Distribution Problem:
- Printers are manufactured for countries with varying voltages
- Elapsed time between distributor’s order entry and receipt: ~1 month
- Demands often changed during transit
- Factory shipped to three distinctly different markets

Distribution Solution:
- Customization shifted to distribution centers
- Power supply was modularized to allow for postponement
- Resulted in reduction of transportation lead time and unit costs
- Backorders and excess inventory were virtually eliminated
4. Provide Quick Response

- Provide quick, instant responses to changing customer demands, a.k.a. time-based competition

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**Step 4: Provide Quick Response**

1. Customize Services
2. Embed Customizability
3. Create Point-of-Delivery Customization
4. Provide Quick Response
Step 4: Provide Quick Response (cont.)

Notes:
- Must shorten product development process
- Reduce tool set-up times in manufacturing
- Shorten order-to-delivery cycle
- Sustainability of competitive advantage depends on degree of successful transformation within organization

Warnings:
- Lots of organization changes are required for success
- Large capital investments for Computer Aided Manufacturing (CAM), Flexible Manufacturing Systems (FMS), Agile Manufacturing Systems (AMS), or Reconfigurable Manufacturing Systems (RMS)
- Large inventories may be needed in order to respond quickly
- Requires lots of IT to speed response and understand customers
National Bicycle Industrial Company (NBIC)

• Kotha (1995) examines three key issues in MC firms:
  - Are mass production and mass customization strategies really as incompatible as suggested by Pine and his co-authors?
  - How does a firm that derives a major portion of its revenues from mass production implement mass customization?
  - How does knowledge creation enable strategic flexibility in the context of mass customization?

• Kotha examines National Bicycle Industrial Company:
  - NBIC is Japan’s second largest manufacturer of bicycles and one of Japan’s premier MC firms
  - NBIC is also a mass producer of bicycles, deriving over 90% of its sales revenues from mass production
• Produces bicycles under three different brand names:
  - *Panasonic* - high quality, high-priced sports and fashion bicycles (top of the line)
  - *National*
  - *Hikari* - basic transportation bicycles from home to work

• NBIC has two factories located next to each other:
  - mass production
  - mass customization

• High-end Panasonic bicycles are produced in *both* the MP and MC factories
  - MP factory employs more line workers
  - MC factory employs best skilled workers
NBIC’s Shift to MC

- MC idea originated after NBIC’s president visited a famous department store in Osaka and noticed that women could custom order dresses which were delivered in 2 weeks

- Despite opposition, MC factory was fully operational 7 months after department store visit

- Panasonic Ordering System (POS)
  - choose from over 8 million possible variations based on model types, color, frame size, and other features
  - production begins after arrival of customer order and specs delivered in 2 weeks, not a day more or a day less
  - priced only 20-30% higher
Interaction Between MP and MC Factories

Source:
Advantages of MC Factory at NBIC

• MC workers train MP workers, improving MP processes
• Innovation at MC firm adopted by MP firm
  □ 3-D automated measuring machine
  □ software for CAM systems
  □ robots for painting
• Lot sizes in MP factory have decreased from 50 units to 20 units
• Customer feedback through MC process used by MP factory to create new and innovative designs (i.e., “fringe awareness”)
• Enjoy first mover advantage: MC = Panasonic
• Since Panasonic = MC, Panasonic MP enjoys premium pricing due to brand “image”
Step 5: Modularize

5. Modularize
- Design modular components that can be configured into a wide variety of end products and services

Diagram:
- Degree of Organizational Turbulence
- Degree of Market Turbulence
- Modularize
- Customize Services
- Embed Customizability
- Create Point-of-Delivery Customization
- Provide Quick Response
Step 5: Modularize (cont.)

Notes:
- Economies of scale maintained at component level
- Economies of scope at module level since they are used over and over again in different products
- Organization changes:
  - Marketing must figure out how to sell products without overwhelming customers with choices
  - Designers must modularize designs
  - Production must provide low cost manufacturing

Warnings:
- Modular products are much easier to reverse engineer
- Product is not optimized since competitor can lower cost by reducing modularity, but this is only for a single product/service
- Modular designs can lead to less innovative solutions over time
Modularity Allows Combinatorial Variety

- Nippondenso can make 288 different panel meters from variations of 8 modules (17 different parts)
Modularity in Automobiles

Different Modules in an Automobile

Source:
Rolling Chassis Module

• Consists of brake, fuel, steering, and exhaust systems, suspension, and driveline assembled to the frame

• Largest and most complex module provided by suppliers

• Used in both truck and SUV manufacturing, accounting for 25% of vehicle content

• Dana’s rolling chassis saved DaimlerChrysler $700 million at the Dodge Dakota facility

Source:
“Any color you want as long as it’s black.” – H. Ford

Example Customization of the Model T

For sources and more info:
Shifting Paradigms (Manufacturer’s View)

• From Craft Manufacturing → AMS → Mass Production → Lean → Mass Customization → ?

Product Variety

Total # of products manufactured

Total # of variants

Craft (<1850)

AMS (1850-1900)

Mass Production (1900-1960)

Mass Customization (>1990)

Lean (1960-1990)

Reconfigurable Products (2010 - ? )

Hyper-Differentiation (2010 - ? )

Production Rate

Unit time period (e.g. 1 year)
Future Trend: Reconfigurability?

- Customer buys one product; however, the product can easily be reconfigured by the customer or service agent during its useful life: PC’s, phones, cars, furniture, …
- Can increase product variety index >1
- Product evolves with user needs and creates secondary markets for add-on products & accessories
- Cautions: ensure quality/testability of all configurations, avoid cannibalization of future sales

Smart Cars: Exterior Body Panels

Nokia: Mobile Phones Reconfiguration (1xxx, 2xxx…series)

Face Plates

Ring Tones etc…
Future Trend: Hyper-Differentiation?

• Hyper-Differentiation is MC pushed to its extreme limit

• Perfectly informed consumers pay less for commodities, since search and comparison are easy and competition reduces the prices of interchangeable products to their production costs

• Hyper-differentiated products have no direct competitors – if these products resonate with consumers then their willingness to pay for these products is determined by the value the place on them rather than by the price of competitors’ offerings

• While this degree of HyperDifferentiation may appear to be an unreachable goal, IT helps producers determine what consumers want and what desires are currently unmet; more importantly, it allows producers to communicate their precise value proposition easily and accurately

Ref: Prof. Eric K. Clemons, The Wharton School, University of Pennsylvania
Types and Costs of Variety

• **External Variety**
  - Useful variety is appreciated by the customer: useful options, stylistic differences
  - Useless variety is transparent, unimportant, and confusing to the customer (e.g., Nissan - steering wheels)

• **Internal Variety**
  - Excessive and unnecessary variety of parts, features, tools, fixtures, raw materials, processes

• **Cost of Variety**
  - Is the sum of all the costs of attempting to offer customers variety with inflexible products that are produced in inflexible factories and sold through inflexible channels
  - Includes cost of customizing, excess parts, procedures, and processes, excess operations costs
• Reactive vs. proactive modes of customization

• Must consider cost, control, time constraints

• Best to strive for platforms – product and process – that allow you to be proactive