Production Systems (Part 6)
Traditional Production Planning and Control

Chapter 32
Planning and Scheduling Processes

- Production environments
- Forecasting
- Aggregate planning
- Master scheduling
- Requirements and capacity planning
- Scheduling and production control
- Material planning
- Manufacturing resource planning
Production Environments

(Selection is a Strategic Decision)

• Manufacture–to–stock
• Assembly–to–order
• Manufacture–to–order
• Engineer–to–order
Manufacture-to-Stock

- Products are finished prior to order

- Customer orders then filled from stock
  - E.G. televisions, tools, off the shelf items
Assemble-to-Order

- Products are assembled after receiving customers order
- Key components and sub assemblies are already in stock
- Receipt of order initiates assembly
  - E.G. Automobiles, office furniture and similar products made of multiple subassemblies
Manufacture-to-Order
or
Made-to-Order

• Product is made after receiving order
• Environment relies on standard components and simple custom variations
• Longer lead time required
  – E.G. vehicle chassis, standard conveyor systems
Engineer-to-Order

- Products that require unique engineering design to meet customer specifications
- Each order is a unique order assembly
- Extensive time required from order to delivery
  - E.G. capital equipment, space vehicles, escalators and elevators
Forecasting Principles

- Accuracy of the forecast is indirectly proportional to the length of time in the forecasting period
- Accuracy of the forecast is directly proportional to the number of items in the forecast group
- Forecast error is always present and should be estimated and measured on all forecasts
- No single forecast method is best
Levels of Corporate Planning

• Long term: determines products to manufacture, facility location
• Intermediate term (aggregate): impacts employment, inventory, output, immediate and short term planning
• Short term: operationalizing daily and weekly schedules
Aggregate Planning
or
Production, Sales and Inventory Planning (PSI)

- Developed by senior management

- Two Parts: Business plan and the sales and operation plan
Business Plan

• At least one year into the future
• Projects what is to happen
• Specifying gross revenues, profits and cash flows
• Typically fixed for the fiscal year
• Used as a benchmark for judging performance
Sales and Operations Plan

• Planning horizon extends beyond the fiscal year
• Provides guidance for activities requiring long lead times
  – E.G. capital equipment, supplier negotiations, and new methods of distribution
Master Production Schedule (MPS)

- (MPS) translates the aggregate plan into a separate plan for individual items and operates at a part-number level
- Produced by the production planning department after authorization from top level management
- (MPS) is input into a material requirements planning (MRP) system
Master Production Schedule (MPS)

F 32-1 (Courtesy K.W. Tunnel Company, Inc.)
Capacity Requirement Planning (CRP)

- A more detailed refined schedule using time-phased information from the MRP system
- CRP considers work-in-progress when calculating work center capacities
- CRP also accounts for replacement parts
- The production planning process involves tradeoffs between changes in production and inventory investment
Scheduling and Production Control Components

• specify the jobs to be done first, second, third and so on
• allow for quick updating of the main concerns as priorities and actual conditions quickly change, and
• be objective. If jobs are overstated, and “informal” system determines which jobs are really needed.
Scheduling Priority Methods

• First-in / first-out
• Start date
• Due date
• Critical ratio
First-In/First-Out (FIFO)

• Assumes first order to work center is the first shop order to work on
• Advantage: does not require a computer system to determine priorities
• Major disadvantage: assumes all jobs have equal priority
• Doesn’t allow for redistribution of priorities or schedules
Start Date Priority

- A subset of (FIFO) with the earliest start date the first job to start
- Assumes all shop orders are released on time
- Start date can be calculated from a backward rather than forward calendar
Due Date Priority

- The due date is the time period when the material must be available.
- Most useful with an MRP system that is continuously updated with the shop floor environment.
Critical Ratio Priority

- Relates the total standard lead time remaining to complete the job relative to the total time remaining to the due date of that order
- Critical ratio < 1.0 is behind schedule
- Critical ratio > 1.0 is ahead of schedule
- Critical ratio 1.00 exactly on schedule
- Therefore orders with the higher ratios have the lowest priority
Critical Ratio

\[ C_r = \frac{D_d - T_d}{L_t} \]

where:

- \( C_r \) = critical ratio
- \( D_d \) = due date
- \( T_d \) = today’s date
- \( L_t \) = lead time remaining
Purpose of Material Planning

- What do we need?
- How much do we need?
- When do we need it?
Methods of Material Planning

• Rate-based planning

• Time-based planning
Rate-Based Planning

• Limited to a small range of products
• Limited revision of products
• Produced in high volumes
• Advantages: decreased overhead and work in progress costs
  – E.G. Assembly lines and (JIT) systems
Rate Based Material Planning
(Quantity Based Using Reorder Points and Two Bin System)

• Reorder points: determined by calculating the average demand during the replenishment lead time, plus safety stock

• Two-Bin system: Similar to the reorder points system but does not require daily inventory transactions, it separates inventory into two locations
Time Phased Planning
(Batch Processing)

• Used for many products in low volume systems
• Advantage: results in higher capacity utilization
• Disadvantage: generates high overhead and work in progress cost
  – E.G. an Materials Requirement Planning (MRP) system
Material Requirements Planning (MRP)

- A highly disciplined set of procedures, rules and policies to govern many of the decisions required in the manufacturing schedule.
- Imperative to improving operations through an (MRP) is that all functions related to scheduling are integrated and driven by a master production schedule (MPS).
- (MRP) systems are not for controlling finished goods.
Elements of an MRP Database

- Process Routing
- Item master inventory
- Bill of material
- Forecasting and master schedule
- Work center
- Purchase order data
- Shop order
- Customer order data

F 32-2 (Courtesy K.W. Tunnel Company, Inc.)
Manufacturing Resource Planning (MRPII)

- Total integration into planning and scheduling all of the resources required by manufacturing companies
  - Aggregate planning
  - Master scheduling
  - Master planning
  - Capacity planning
  - Shop scheduling
  - Supplier scheduling
F 32-3 MRPII
(Mitchell, 1998)
Production Systems

- Mass production are systems in which the greater the number of goods produced, the lower the cost – Model T Ford (1914)
- Lean production uses less of everything: human effort, manufacturing space, investment in tools, hours to develop, inventory levels, and load defect rates – Toyota (1980’s)
Lean Production Employs

• Teams of multi skilled workers at all levels

• Highly flexible machines to produce high volumes and variety

• Systems that are dynamic and geared towards continued improvement
Lean Implementation Mandates

• That the total system is embraced

• All (personnel) involved in implementation

• Management commitment to job security
Components of Lean Production

- Value stream analysis
- Takt time
- Kanban
- Kaizen
- Visual control
- Total productive maintenance
- One-piece flow

- Error Proofing
- Standardization
- Autonomation
- Production leveling
- Problem solving circle
- 5S
Value Steam Analysis

• Problem solving: running from concept through detailed design and engineering to production

• Information management: running from order taking through detailed scheduling to delivery

• Physical transformation: proceeding from raw materials to a finished product in the hands of the customer
Value Steam Analysis

Process Advantages

• Unambiguous value-adding steps

• Steps that do not add value but that are unavoidable

• Steps that create no value and are immediately avoidable
Takt Time

- Used to determine how often a product should be produced based on the rate of sales to customers
Kanban System

• The type and quality of units are written on a tag-like card that is sent from one process to the next

• When all parts are depleted, the card is the mechanism for reorder
Kaizen

• Ongoing improvement involving all of management and workers

• Refers to aggressive proactive improvement activities
Visual Control

• Workers use their eyes to monitor the state of the line and production flow

• If severe problems are sited any worker can stop the line
Total Productive Maintenance

- All equipment is in a safe operating system and has predictable process capability and uptime
One-Piece Flow System

• A worker completes a job within a specified cycle time; the introduction of one unit is balanced by the completion of another unit of finished product.

• Advantages: reduces inventory and lead time and aligns production mix and volume to sales
Traditional Functional Layout

F 33-1 (Veilleux and Petro, 1988)
One-Piece Flow Layout

F 33-2 (Veilleux and Petro, 1988)
Proofing

• *Error proofing*: attempts to eliminate mistakes by making it impossible to do a job incorrectly

• *Mistake proofing*: attempts to ensure that a mistake is caught before the next operation
Standardization

- Shows the sequential routine of various operations performed by multi-functional workers who operate multiple machines
- Jobs are standardized across operators and shifts
- Lean systems attempt to improve and standardize the process
Autonomation

• Autonomation means to build in a mechanism to prevent mass production of defective work

• It is the autonomous check of the abnormal occurrences in the process
Production Leveling

- Assures a constant flow from suppliers and appropriate use of workers
- Producing too much is waste
- Too little doesn’t meet needs
- Overtime and fatigue cause waste
Problem Solving Circles

• Meet outside of production time to solve specific problems
• Many suggestions emanate from these circles
• Best groups elicit 50-100 suggestions per year, a 90% implementation rate
• 90% of the employees contribute at least one suggestion
5S Strategy

• Sort: clutter free work area
• Straighten: orderly work area
• Shine: clean work area
• Standardize: standard best practices
• Sustain: discipline to maintain total 5S strategy
Just-In-Time
(Lean Production Systems)

• Philosophy: elimination of waste

• Waste examples: rejected parts, excessive inventory or material handling, interoperation queues, long setup, and changeover times
Characteristics of JIT

- Change from batch production to one piece flow
- Level capacity loads
- Reduction of work in progress
- Fewer changeovers
- Quicker setup times
- Versatile processes

- Visual cues for shop floor workers
- Direct links with suppliers
- Process improvement
- Preventive maintenance
- Error proofing and mistake proofing (poka-yoke)
- Pull system
Pull Systems

- Only allows parts to be made after authorization (pull signal) from the previous operation
- Drastically reduces inventory levels
- Excellent integration into JIT
Pull System Types

• Over-lapped system: utilize empty space as the pull signal between production operations

• Linked system: utilized when parts compete for the same resource and can not be made on a one-for-one bases with end-item demand
Process Engineering

Chapter 34
Requirements of Process Planning

• Determining the process to be used
• The development of operation flow charts
• Production layouts
• Routings and operation (process) sheets
• Setup charts and machine tool layouts
• Equipment selection and sequence
• Material handling details
• Tooling requirements
• Inspection plans for quality assurance and quality control
Tolerance Stack

• Occurs when acceptable tolerances on individual dimensions combine in such a way to create an unacceptable part

• Design tolerance stacks: created by the designer and found on the part print

• Process tolerance stacks: the result of improper processing
Process Selection

• Dependent on: wall thickness, symmetry, draft, cavities, finish, tolerances, and material

• *Best process*: meets the requirements with the least cost
Equipment Selection Justification

- For a part not previously produced
- For a part previously made by hand
- To replace old equipment
- To lower production costs
- To extend production
Computer-Aided Process Planning (CAPP)

- Expert computer systems that collect and store the knowledge of a specific manufacturing situation
- Optimum plan specifies:
  - The machinery used for production
  - Sequence of operations
  - Tooling
  - Required feeds and speeds
(CAPP) System

- Part is first designed on a CAD/CAM system
- Part file is transferred into the CAPP system
- Part characteristics are matched to the machine floor and processes available
- CAPP system outputs all of the process and routing sheets to make up the process plan
Jigs and Fixtures

• Jig: a device to locate and hold a workpiece while guiding or controlling a cutting tool

• Fixture: only a holding device
3-2-1 Principle
Locating Devices

- Machined surface on the fixture to support the work piece with pins for alignment
- V-blocks
Clamping

• Types: screw, cam, level, toggle, wedge, latch and combinations

• Clamps should hold the workpiece against a locating surface with the force transmitted through a fixed support point without distorting the workpiece
5 Basic Types of Assembly Systems

- Single station
- Synchronous
- Nonsynchronous
- Continuous-motion
- Dial (rotary)
Single-Station Assembly

• Machines with a single workstation and used most extensively when a specific operation is performed many times on one or a few parts.

• They are incorporated into multistation assembly systems and may be used when different operations are performed and if the required tooling is not too complicated.
Synchronous Assembly

• Available in dial, inline and carousel varieties.
• All pallets or work-pieces are moved at the same time and the same distance.
• Used primarily for high-speed and high volume applications on small lightweight assemblies with similar cycle times.
Nonsynchronous Assembly

- Nonsynchronous transfer assembly systems, with free or floating pallets or workpieces and independently operated individual stations.
- Used where the times required to perform different operations vary greatly.
- Also for larger products with many components.
- Major advantage of these so-called “power-and-free systems” is increased versatility.
Continuous-Motion Assembly

• Assembly operations are performed while the work-pieces or pallets move at a constant speed and the workheads reciprocate.
• High production rates are possible because indexing time is eliminated.
Dial (Rotary) Assembly

- Dial or rotary index machines of synchronous design were one of the first types used for assembly.
- Workstations and tooling can be mounted on a central column or around the periphery of the indexing table.
- Limited to small-and medium-sized lightweight assemblies with relatively few uncomplicated operations.
Facility Layout

- Defined as the planning and integration of the paths of the component parts of a product to obtain the most effective and economical interrelationship between employees, equipment, and the movement of materials from receiving, through fabrication, to the shipment of the finished product.
Facility Layouts

- Process

- Product process (cellular)

- Fixed station
Process Layout

• Most common in manufacturing

• Groups together similar functions: drilling, milling, turning, grinding, etc.

• Disadvantage: requires increased material handling
Process Facility Layout

F 34-2 (Tompkins and White, 1984)
Product-Process (Cellular) Layout

- One product family is produced in a cell using group technology
- Equipment for the product family is arranged linearly or radially
- Advantages: least material handling and work in progress inventory and easiest to automate with robots
Product-Process (Cellular) Layout

F 34-3 (Tompkins and White, 1984)
Fixed Station Layout

• Has a fixed or stationary product with manufacturing and assembly around it

• Used in large, low-volume products: E.G. machine tools and aircraft

• Highly flexible layout, however, requiring greater skill for personnel
Fixed (Station) Production Layout

F 34-4 (Tompkins and White, 1984)
Basic Guidelines for Layout Optimization

- A planned materials flow pattern
- Adequate, straight aisles
- Minimal backtracking
- Minimal work in process
- Some built in flexibility
- Maximum ratio of processing time to overall time
- Minimum travel distances for material handling
- Optimal quality practices
- Ergonomics within the workplace
- Smooth and adequate materials flow
- Good housekeeping
- Access to maintenance
Maintenance Plans

- Corrective
- Preventive
- Predictive
Corrective Maintenance

• Fix it when it breaks

• Expensive and least desirable
Preventive Maintenance Outcomes

- Machines will last longer
- Maintenance time and cost will be cut
- Severity and frequency of breakdowns will be reduced
- Safety levels will rise
- Product quality will be maintained
- Production costs will be cut by increasing asset utilization time and decreasing time lost by idle operators
Predictive Maintenance

• Uses various types of sensors to predict breakdowns

• Monitoring vibration signatures is a common method used

• Sophisticated computer usage has made predictive maintenance easy to use
Methods Engineering

- Focuses on analyzing methods and equipment used in performing a task
- Tools for data collection
  - Process charts
  - Micromotion
  - Memomotion
  - Work measurement
Work Measurement

- By allowing times for specific tasks, engineers plan and schedule production cost estimating and line balancing.
- Normal time-compares the performance of the operator with an analyst's opinion of normal work.
- Standard time-to compensate for material delays and other interruptions, a standard time is calculated by increasing the normal time by an allowance.
Normal Time

\[ N_t = \frac{A_t \times P_r}{100} \]  

(34-1)

where:

\( N_t \) = normal time

\( A_t \) = average time

\( P_r \) = percent rating

With machine downtime, material delays, and other interruptions, the normal time is not completely accurate. To compensate for delays and interruptions, a standard time is calculated by increasing the normal time by an allowance. The standard time is calculated by:

\[ S_t = \frac{N_t(100 + P_a)}{100} \]  

(34-2)
Standard Time

\[ S_t = \frac{N_t (100 + P_a)}{100} \]
Materials Management

Chapter 35
Inventory Management

- Inventory is one of the most important financial assets present in manufacturing companies.

- The shorter the period that inventory is held, the more productive the asset.
Inventory

• Is an asset representing stored value that, when sold will provide income and hopefully a profit

• Is a major investment that is financed by equity or debt
Types of Inventories

- Work-in-process and in-transit inventories
- Raw material
- Finished goods or semifinished products, manufactured to cover anticipated demand and prone to significant forecast error
Types of Inventories

• Inventory buildup in anticipation of a new product introduction or special promotion

• Purchase of a stockpile inventory in anticipation of a supply interruption such as an impending strike, or a substantial price increase

• Manufactured products to cover seasonal demands that exceed near-level production requirements
Demand

• Item demand is considered to be an *independent demand* when the demand is unrelated to the demand for other items.

• Demands for parts or raw materials are considered to be *dependent demands* when they are derived directly from the demands for other items.
Inventory Replenishment

• Primary objective to balance the cost of carrying inventory with the service level required

• Inventory turn ratio is the principal measure used
# Inventory Turn Ratios

<table>
<thead>
<tr>
<th>Types</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional/Traditional Manufacturers</td>
<td>2-10</td>
</tr>
<tr>
<td>Just-In-Time (JIT) Manufacturers</td>
<td>10-50</td>
</tr>
</tbody>
</table>
Economic Order Quantity (EOQ)

- Attempts to balance inventory carrying costs with ordering costs

- Most common statistical calculation used in inventory control

- It is an estimate based upon estimates
Inventory Turn Ratio

\[ I_t = \frac{A_y}{A_i} \]

where:

\[ I_t \] = inventory turns
\[ A_y \] = annual inventory usage at cost ($)
\[ A_i \] = average inventory at cost ($)
Order Cost vs. Inventory Carry Cost

F 35-1 (K.W. Tunnell Company, Inc.)
Economic Order Quantity

\[ EOQ = \sqrt{\frac{2AS}{ic}} \]  

(35-2)

where:

- \( EOQ \) = economic order quantity (units)
- \( A \) = annual usage (units)
- \( S \) = setup and order costs per order ($)
- \( i \) = interest and storage costs (%)
- \( c \) = unit cost of one part ($)
Economic Order Quantity

Example 35.2.1 Calculate the EOQ for a product that has an annual usage of 20,000 units, setup and order costs of $50, a unit cost of $20, and an interest and storage cost of 12%.

Solution.

\[ \text{EOQ} = \sqrt{\frac{2AS}{ic}} \]

where:

- \( A \) = 20,000
- \( S \) = $50
- \( I \) = 0.12
- \( c \) = $20

\[ \text{EOQ} = \sqrt{\frac{2(20,000)(50)}{0.12(20)}} \]

EOQ = 913
ABC Inventory Analysis

- Technique requires sorting items by the amount of dollar demand (at cost) recorded over a period of time.

- Usually observed that only 20% of the items in inventory will be involved in 80% of the usage in dollars; therefore, with good management of the top 20% the lower-dollar items can be handled less often with little effect on the total dollar investment.
ABC Analysis

Table 35-1. ABC analysis of $1,000,000 annual inventory usage at cost

<table>
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<tr>
<th>Number of Parts</th>
<th>Cost</th>
<th>Percent</th>
<th>Inventory Category</th>
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<tr>
<td>6</td>
<td>680,000</td>
<td>68</td>
<td>A</td>
</tr>
<tr>
<td>16</td>
<td>200,000</td>
<td>20</td>
<td>B</td>
</tr>
<tr>
<td>80</td>
<td>120,000</td>
<td>12</td>
<td>C</td>
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(Veilleux and Petro 1988)
ABC Analysis of $1,000,000 Annual Inventory Usage at Cost

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(Veilleux and Petro, 1988)
ABC Analysis Results

• Review A items weekly and order 1 week’s supply when less than a lead time plus 1 week’s supply remains

• Review B items biweekly and order 4 weeks’ supply when less than a lead time plus 2 weeks’ supply remains

• Review C items monthly and order 12 weeks’ supply when less than a lead time plus 3 weeks’ supply remains
Just-In-Time (JIT) Inventory

• Referred to as zero inventory (ZI) by (APICS)

• Most popular misconception “it is a method based on someone else holding inventory for you until you need it”
Manufacturing Inventory

• Used to compensate for the uncertainties associated with material flow related to lead times
• Used to cover the risks associated with the failure of prior processes to deliver quality materials.
Steps to Approach Near-Zero Inventory

• Reduce the overall quantity of suppliers
• Design long-term partnership programs to make both vendor and customer more profitable
• Devote human resources in the purchasing department to long-term cost and quality gains, not adversarial negotiating and expediting
• Concentrate the supplier base near the manufacturing facility
• Order small lots, demand short lead times, and accept no defects
Supply Chain Management

• Extends the linkage from the company upward to the customers’ customers and downward to the suppliers’ suppliers

• It coordinates and tunes the chain of business entities to accept fulfill customers orders

• Information, money, and materials flow in the supply chain
Supply Chain Flow
Supply Chain Flow Direction

- Typically physical material (product) flows from left to right
- Recycled packaging and damaged products flow from right to left
- Information must flow bidirectionally
- Client orders move right to left
- Information about orders move left to right
- Money in the form of payments from right to left
- Money from rebates and returns from left to right