Summary Operations Management

Introduction

What is OM?

Operations Management deals with the **design** and **management** of products, processes, services and supply chains. It considers the acquisition, development, and utilization of resources that firms need to deliver the goods and services their clients want.

Goods (physical items) vs **services** (activities) → occur jointly

Decision horizon: **strategic** issues → **tactical** issues → **operational** issues

Productivity

= output/input
= efficiency + effectiveness

➔ Impact of the environment, intangible factors and time lags

Strategy and competition

The customer order decoupling point (CODP)

= inventory point in the value chain for a product, where the product is linked to a specific customer order (order penetration point).

- Downstream: customer order driven
- Upstream: forecast-drives

Possible CODP positions: DTS → MTS → ATO → MTO → ETO

- Why downstream:
  - To buffer shortcomings
  - Market requirements
- Why upstream:
  - To match productions-distribution lead time and customer order lead time
  - To deal with demand uncertainty
  - To reduce inventory costs

Managing and analyzing business processes

Performance management

- Performance scoreboard: supply chain dashboard
- KPI's = Key Performance Indicators
- SCOR (= Supply Chain Operations Reference) Measures
  - Reliability
  - Responsiveness
  - Flexibility
  - Costs
  - Asset management

Process mapping

Techniques:

- Value Stream Mapping (VSM)
- Flow Process Chart and Flow diagram
- Gantt chart
- Cumulative in- and outflow

Little's Law

$I = R \times T$

Forecasting

Subjective forecasting methods

The Delphi method

Individual opinions are compiled and reconsidered. Repeat until an overall group consensus is reached.

Objective forecasting methods

Causal models

$Y = f(X_1, X_2, \dots, X_n)$

Time series methods

$F_{t,t+\tau} = forecast\ made\ in\ period\ t\ for\ the\ demand\ in\ period\ t + \tau$

Time series forecast:

$$F_t = \sum_{n=1}^{\infty} a_n D_{t-n}$$

Evaluation of forecasts

$e_t = forecast\ error\ in\ period\ t$

Measures of forecast accuracy (see formulas on slides)

- Mean absolute deviation (MAD)
- Mean squared error (MSE)
- Mean absolute percentage error (MAPE)

Forecasting for stationary series

Stationary time series: $D_t = \mu + \varepsilon_t$

Moving Averages

MA(N) → uses the **mean** of the **N** most recent observations

One-step-ahead forecast: $F_t = (\frac{1}{N})(D_{t-1} + D_{t-2} + \cdots + D_{t-N})$

Weighted Moving Averages

Attaches importance to certain data over other data → Weighting factors

Exponential Smoothing

New Forecast = α (most recent observation) + (1 – α) (last forecast)

➔ Where $0 < \alpha \leq 1$ is the smoothing constant

In symbols:

$$F_{t+1} = \alpha\, D_t + (1 - \alpha)\, F_t$$

Infinite expansion for F_{t+1}:

$$F_{t+1} = \sum_{i=0}^{\infty} \alpha(1-\alpha)^i D_{t-i}$$

Effect of α value:

- Small values of α → forecasted value will be stable (low variability)
- Large values of α → forecast will more closely track the actual time series (quick reaction to changes)

➔ Small α is recommended

Trend-based methods

Regression for times series forecasting

Model: $\widehat{D}_t = a + bt$

➔ See formularium for a and b

Double exponential smoothing – Hold

Holt's method

To forecast when there is a linear trend present.

τ-step-ahead forecast: $F_{t,t+\tau} = S_t + \tau \times G_t$

➔ See formularium for S and G

Methods for seasonal series

Forecasting for seasonal series

Multiplicative seasonal factors: $c_t\ (for\ 1 \leq t \leq N)$

$\sum c_t = N$ with N = number of observations

Quick and dirty method

1) Compute the **sample mean** of the entire data set
2) **Divide** each observation by the sample mean
3) **Average** the factors for like seasons

Deseasonalizing a series

4) **Divide** each observation in the series by the appropriate seasonal factor

Method of centered moving averages

See slides (+ ex 9)

Smoothing the seasonalized technique

Winter's method

3 smoothing equations: the series, the trend and the seasonal factors

➔ See formularium

$F_{t,t+\tau} = (S_t + \tau \times G_t)\, c_{t+\tau-N}$

Initialization procedure

1) Compute sample means for two separate cycles of data (V_1 and V_2)

$$V_1 = \frac{1}{N} \sum_{j=-2N+1}^{-N} D_j$$

$$V_2 = \frac{1}{N} \sum_{j=-N+1}^{0} D_j$$

2) Define $G_0 = (V_2 - V_1\,)/N$ as the initial slope estimate
3) Set $S_0 = V_2 + G_0[(N-1)/2]$
4) Determine seasonal factors
   a) The initial seasonal factors are computed for each period

   $$c_t = \frac{D_t}{V_i - \left[\frac{(N+1)}{2} - j\right] G_0} \qquad for - 2N + 1\ \le t \le 0$$

   $where\ i\ is\ the\ cycle\ and\ j\ is\ the\ period\ of\ the\ cycle$

   b) Average the seasonal factors (assuming exactly two cycles of initial data)

   $$c_{-N+1} = \frac{c_{-2N+1} + c_{-N+1}}{2}, \ldots, c_0 = \frac{c_{-N} + c_0}{2}$$

   c) Normalize the seasonal factors

   $$c_j = \left[\frac{c_j}{\sum_{i=-N+1}^{0} c_i}\right] \times N \qquad for - N + 1 \le j \le 0$$

Inventory control – Subject to Deterministic Demand

Inventory control

Motivation for holding inventories

- Economies of Scale → Cycle inventory
- Uncertainty → Safety inventory
- Speculation
- Smoothing to account for changes in the demand pattern
- Control costs
- Transportation → In-Transit or Pipeline inventory
  - ⇨ Transportation takes time
- Logistics

Characteristics of inventory systems

- Demand
- Lead time (or flow time) τ
- Review time
- Treatment of excess demand
- Inventory that changes over time

Relevant costs

- Item cost: c
- Holding cost (inventory cost): $h = Ic$
- Order cost (production cost): fixed ordering + variable purchasing cost
  - ⇨ $c(x) = \begin{cases} 0 & if\ x = 0 \\ K + cx & if\ x > 0 \end{cases}$
  - ⇨ K = setup costs (in case of a production order)
- Penalty cost (shortage cost): p

Basic EOQ model

Economic Order Quantity model

Minimizing total costs

EOQ = Q to minimize the average annual cost G(Q) → see formularium

- $Reorder\ interval\colon\ T = \frac{Q}{\lambda}$
- $EOQ\colon\ Q^* = \sqrt{\frac{2K\lambda}{h}}$
  - ⇨ $Optimal\ number\ of\ orders\ per\ year = \frac{\lambda}{Q}$
  - ⇨ $Optimal\ reorder\ interval =$ T

<u>Inclusion of order lead time ≤ T</u>

- Constant order lead time $\tau \leq$ T
- R = level of on-hand inventory at the instant an order should be placed: $R = \lambda\tau$

Robustness of the solution – Sensitivity Analysis

See formularium

EOQ with finite production rate

Items are produced internally at a rate P (> λ, the consumption rate)

Optimal production quantity (~ EOQ):

$$\Rightarrow \quad Q^* = \sqrt{\frac{2K\lambda}{h\prime}} \qquad with\ h' = h(1 - \frac{\lambda}{P})$$

Average cost of holding and setup:

$$\Rightarrow \quad G(Q) = \frac{K}{T} + \frac{hH}{2} = \frac{K\lambda}{Q} + \frac{hQ}{2}\left(1 - \frac{\lambda}{P}\right) = \frac{K\lambda}{Q} + \frac{h\prime Q}{2}$$

- H = maximum level of on-hand inventory = $Q\left(1 - \frac{\lambda}{P}\right)$
- Q = lot size = size of each production run
- $T_1 = \frac{Q}{P} = uptime \ \& \ T_2 = T - T_1 = downtime$

Profit:

- Earnings = $\lambda(\mathrm{sp} - \mathrm{c})$ with sp = selling price
- Costs = $\mathrm{G(Q)}$
- Profit = earning – costs = $\lambda(\mathrm{sp} - \mathrm{c}) - \mathrm{G(Q)}$

Quantity discounts (see example slides)

Quantity discounts for larger orders: $Q \geq breakpoint$

All-units discounts

Optimal solution = lot size with lowest average annual cost.

$$\rightarrow \quad G_j(Q) = \lambda c_j + \lambda\frac{K}{Q} + Ic_j\frac{Q}{2}$$

Incremental discounts

$$\rightarrow \quad G(Q) = \lambda\frac{C(Q)}{Q} + \lambda\frac{K}{Q} + I\frac{C(Q)}{Q}\frac{Q}{2}$$

Resource-constrained multiple product systems

Inventory of n items in which the total amount available to spend is C.
Items cost respectively $c_1, c_2, \dots, c_n$

$$Minimize \sum_{i=1}^{n}\left[\frac{h_iQ_i}{2} + \frac{K_i\lambda_i}{Q_i}\right] \qquad subject\ to\text{:} \sum_{i=1}^{n} c_iQ_i \leq C$$

$$IF \qquad \sum_{i=1}^{n} c_iEOQ_i \leq C$$

$$THEN\ optimal\ solution\ is\ Q_i^* = EOQ_i$$

$$IF \quad \sum_{i=1}^{n} c_i EOQ_i > C$$

$$THEN\ at\ the\ optimal\ solution: \sum_{i=1}^{n} c_i Q_i = C$$

$$THEN \quad minimize\ G(Q_1, Q_2, \dots, Q_n, \theta) = \sum_{i=1}^{n} \left[\frac{h_i Q_i}{2} + \frac{K_i \lambda_i}{Q_i}\right] + \theta \left(\sum_{i=1}^{n} c_i Q_i - C\right)$$

⇨ $\theta = Lagrange\ multiplier$

$$IF \quad \sum_{i=1}^{n} c_i EOQ_i > C$$

$$AND \quad \frac{c_1}{h_1} = \frac{c_2}{h_2} = \cdots = \frac{c_n}{h_n}$$

$$THEN \quad Q_i^* = mEOQ_i \qquad with\ m = \frac{C}{\sum_{i=1}^{n} c_i EOQ_i}$$

EOQ models for production planning

n items with known demand rates λ_j, production rates P_j, holding costs h_j, and setup costs K_j.
Choose the cycle time T = $\max(T^*, T_{min})$ as the optimal cycle.

See slides + HB!

Inventory Control – Subject to Uncertain Demand

The nature of randomness

Normal distribution: $N(\mu, \sigma^2)$

The value of deterministic models

1) A basis for understanding fundamental trade-offs
   - Between holding costs and order costs
   - Minimizing total costs
2) They may be good approximations, depending on the degree of demand uncertainty
   - Demand: $D = D_{deterministic} + D_{random}$

Stochastic models: What is safety stock?

Safety stock ss: satisfying demand the exceeds the amount forecasted in a given period.

➔ See formula on formularium

SS for single period inventory models

Uncertainty period = complete period

SS for multiple period inventory models

Continuous review: (Q,R) policy

- Fixed order size Q, timing fluctuates
- Order at reorder point R
- Uncertainty period = lead time τ

Periodic review: (s,S) policy

- Fixed interval T, order quantity Q fluctuates
- Order up to inventory level S
- Uncertainty period = lead time τ + review period T

Lead time variability → see formularium

Single period inventory: Newsboy model

Trade-off between overage cost (~ holding cost) and underage cost (~penalty cost)

Solving a newsboy problem

1) Develop an expression for the cost
    - $c_0 = unit\ cost\ of\ overage$
    - $c_u = unit\ cost\ of\ underage$
        - G(Q,D)
2) Determine the expected cost
    - $G(Q) = see\ formularium = \ c_0 \int_0^Q (Q-x)f(x)dx + c_u \int_Q^\infty (x-Q)f(x)dx$
3) Determine the optimal policy
    - $F(Q^*) = \frac{c_u}{c_0+c_u} = critical\ ratio$
    - $Q^* = \sigma z + \mu \qquad with\ safety\ stock = \sigma z$
    - Normal probability distribution (see formularium)

Newsboy problem with discrete demand

Locate the critical ratio between two values of F(Q) and choose the Q corresponding to the higher value.

Newsboy problem – Poisson distribution

$$f(x) = \frac{e^{-\mu}\mu^x}{x!} \qquad for\ x = 0, 1, 2, \ldots$$

- Mean = μ
- Variance = μ

➔ See formularium: Poisson Distribution Function Table

Newsboy problem with starting inventory

Starting inventory u > 0:

- If u < Q* → order (Q* - u)
- If u ≥ Q* → do not order

➔ Q* = order-up-to point

Newsboy problem – Multiple planning periods

If all excess demand is back-ordered:

- c_0 = holding cost
- c_u = penalty cost (lost profit and/or loss-of-goodwill cost)

Performance measures

<u>Expected lost sales</u>

See formularium

<u>Expected sales</u>

Expected sales + Expected lost sales = Expected demand (μ)

<u>Expected leftover inventory</u>

Expected sales + Expected leftover inventory = Q (order quantity)

<u>Expected profit</u>

$$= [(\text{Price} - \text{cost}) \times \text{Expected sales}] - [(\text{Cost} - \text{Salvage value}) \times \text{Expected leftover inventory}]$$

<u>In-stock probability (Type I service level α)</u>

- In-stock probability = F(Q) = F(z)
- Stock-out probability = 1 – F(Q) = 1 – F(z)

<u>Fill rate (Type II service level β)</u>

$$\text{Fill rate} = \frac{\text{Expected sales}}{\text{Expected demand}}$$

Other objectives for choosing an order quantity

- Determine Q that satisfies a target in-stock probability
- Determine Q that satisfies a target fill rate
  - $L(z) = \left(\frac{\mu}{\sigma}\right) \times (1 - Fill\ rate)$

Multiple period inventory models

- Include a setup cost for placing an order
- Allow for a positive lead time

Higher customer service while lower safety inventory

- Reduce demand uncertainty σ_D
- Reduce supplier lead time L
- Reduce lead time uncertainty σ_L
- Safety stock aggregation

ABC analysis

PARETO EFFECT = the distribution of the value of inventory items in a multi-item system follows an increasing exponential curve.

Remember: What gets measured gets improved

- Annual inventory turnover

- Inventory holding period
- Inventory to assets ratio
- Customer service

Supply Chain Management

The role of information in the supply chain

Bullwhip effect

Order variation increases dramatically as one moved from retailers to distributors to the factory.

$$Bullwhip = \frac{Variance\ of\ orders}{Variance\ of\ demand} = \frac{\sigma^2_{orders}}{\sigma^2_{demand}}$$

➔ Variance amplification if the measure > 1

Information Transfer: VMI

Vendor Managed Inventory (VMI) → Just-in-time distribution (JITD)

Enabling technologies

- Electronic commerce
  - EDI: Electronic Data Interchange
  - Web-based transaction systems
- Radio Frequency Identification (RFID) → example Wal-Mart

Risk pooling

Impact on cycle stock

Centralization: **order costs** are **shared** over different regions.

Impact on safety stock

Centralization and safety stock aggregation: risk pooling to **reduce uncertainty**.

Risk pooling

1) Location pooling
   - Drawback: inventory further away from demand
2) Consolidated distribution
3) Product pooling
   - Using one universal design (no product differentiation)
   - Drawback: product offerings are limited
4) Delayed differentiation
5) Virtual pooling
   - Share inventory data

Designing for supply chain efficiency

1) Design for Logistics (DFL)
2) Postponement in supply chains

    - Postponing the final configuration of the product until the last possible point.
3) Configuration of the supplier base
    - Streamlining the supply chain: reducing the number and variety of suppliers.
4) Outsourcing arrangements
5) Channels of distribution → Intermediate storage locations

Management of waiting lines

Waiting lines

Queuing theory = mathematical approach to the analysis of waiting lines.

Why is there waiting?

- Variability
- Mismatch between supply and demand

Waiting line management

<u>Goal</u>: Minimize Total cost = Customer waiting cost + Capacity cost

Characteristics of waiting lines

Population source

- Infinite-source situation
- Finite-source situation

Number of servers (channels)

- Single- vs multiple-channel
- Single- vs multiple phase

Arrival and service patterns

- Customer service times → (negative) exponential distribution
- Customer arrivals per unit of time → Poisson distribution

We assume customers are patient.
Other possibilities:

- Reneging: leave the line
- Jockeying: switch to another line
- Balking: not enter the line

Queue discipline (order of service)

- First-come, first-served (fcfs)
- Other priority rules

Queuing models: infinite source

Notation and basic relationships

$\lambda = customer\ arrival\ rate$

$\mu = service\ rate\ per\ server$

➔ $Average\ number\ of\ customers\ being\ served:\ r = \frac{\lambda}{\mu}$

$L_q = average\ number\ of\ customers\ waiting\ for\ service$

$L_s = average\ number\ of\ customers\ in\ the\ system\ (waiting\ and/or\ being\ served)$

➔ $Average\ number\ of\ customers:\ L_s = L_q + r$

$W_q = average\ time\ customers\ wait\ in\ line$

$W_s = average\ time\ customers\ spend\ in\ the\ system\ (waiting\ in\ line\ and\ service\ time)$

➔ $Little's\ law:\ L_s = \lambda W_s\ \ and\ \ L_q = \lambda W_q$

$\rho = the\ system\ utilization \rightarrow see\ formularium$

$\frac{1}{\mu} = service\ time$

➔ $W_s = W_q + r$

$M = number\ of\ servers$

$P_0 = probability\ of\ zero\ units\ in\ the\ system$

$P_n = probability\ of\ n\ units\ in\ the\ system$

$L_{max} = maximum\ expected\ number\ of\ customers\ waiting\ in\ line$

Assumptions

- System operating under steady-state conditions: average arrival and service rates are stable.
- No limit on the length of the queue.

Kendall's notation: A/B/C

- A: Distribution of inter-arrival times of customers (time between arrivals to the queue)
- B: Distribution of service times
- C: Number of servers

➔ M: Exponential Distribution (Markovian)
➔ D: Deterministic Distribution

M/M/1 infinite-source fcfs queuing model

See formularium

M/D/1 infinite-source fcfs queuing model

Effect of **constant** service time:

- Cut in half the average number of customer waiting in line (L_q)
- Cut in half the average customers spend waiting in line (W_q)
  - ⇨ Automatically done because L_q is already cut in half!

➔ Elimination or reduction of the variability: shortening of waiting lines

M/M/S infinite-source fcfs queuing model

Assumptions

- Servers all work at the same average rate → number of servers = S
- Customers form a single waiting line

Notations

$W_a = average\ waiting\ time\ for\ an\ arrival\ not\ immediately\ served$

$P_w = probability\ that\ an\ arrival\ will\ have\ to\ wait\ for\ service$

Table for values of L_q and P_0

➔ See formularium

Maximum line length

Determine the approximate line length n that will satisfy a specified percentage.

➔ See formularium for n

M/M/S multiple-priority model

Assumptions

- Arriving customers are assigned to priority classes
- Highest class first, within each class: first-come, first-served
- Revising priorities is possible

Notations

$W_k = average\ waiting\ time\ in\ line\ for\ units\ in\ kth\ priority\ class$

$W = average\ time\ in\ the\ system\ for\ units\ in\ the\ kth\ priority\ class$

$L_k = average\ number\ waiting\ in\ line\ for\ units\ in\ kth\ priority\ class$

➔ See formularium

Queuing models: finite source

Assumptions

- Arrival rates → Poisson
- Service times → Exponential

See formularium

- ✸ Downtime = Waiting time + Service time
- ✸ Probability of not waiting = 1 – Probability of waiting

Cost analysis

Designing systems that achieve a balance between (service) capacity and customer waiting time.

Other solutions:

- Reduce variability
- Reduce the cost of waiting

- Reduce perceived waiting time (as opposed to actual waiting time)
- Derive benefit from customer waiting

Simulation

Basic steps for all simulation models

1) Identify the problem and set objectives.
2) Develop the simulation model.
3) Test the model to be sure that it reflects the system being studied = VALIDATION
4) Develop one or more experiments.
5) Run the simulation and evaluate results.
6) Repeat step 4 and 5 until satisfied.

Monte Carlo simulation

Random sampling from probability distributions.

1) Identify a probability distribution for each random component of the system.
2) Work out an assignment so that intervals of random numbers will correspond to the probability distribution.
3) Obtain the random numbers needed for the study: computer generated or tables.
4) Interpret the results.

Simulating theoretical distributions

- Poisson:
  - ⇨ Obtain discrete cumulative distribution from a table
- Normal:
  - ⇨ $Simulated\ value = \mu + (Random\ number\ \times \sigma)$
- Uniform distribution:
  - ⇨ $Simulated\ value = a + (b - a)(Random\ number\ as\ a\ percentage)$
- Negative Exponential Distribution :
  - ⇨ $P(t \geq T) = e^{-\lambda t}\ \ and\ \ P(t \geq T) = Random\ number$
  - ⇨ $t = -\frac{\ln(Random\ number)}{\lambda}$

Discrete-event simulation

Discrete-event simulation (DES) models the operation of a system as a discrete sequence of events in time.

- Each event → change of state
- Between consecutive events → no change assumed

➔ Simulation jumps in time

Limitations

- No optimum solution
- Approximate behavior
- Large-scale simulation requires considerable effort

Decision-making process

See slide 29

Manufacturing Planning and Control – Aggregate Planning / S&OP

Manufacturing Planning and Control (MPC)

MPC system provides the information upon which managers make effective decisions.

- Long-range plans → strategic level
    - Long term capacity
    - Location/layout
- Intermediate plans → tactical level
    - Employment
    - Output
- Short-range plans → operational level
    - Machine scheduling

Enterprise Resource Planning (ERP)

Planning and controlling the business.

Performance measures

- Delivery performance
- Fill rate by line item
- Perfect order fulfilment
- Order fulfilment lead time
- Warranty cost of % of revenue
- Inventory days of supply
- Cash-to-cash cycle time
- Asset turns

Aggregate planning / Sales and Operations Planning (S&OP)

Goal

Determine aggregate production quantities and the levels of resources required to achieve these production goals.

Problem

Determine both work force levels (W_t) and production levels (P_t) to minimize total costs over the T period planning horizon.

Assumption

Demand is known with certainty.

Aggregate Units

- Actual units of production
- Weight
- Volume
- Dollars
- Fictitious aggregated units

Costs in aggregate planning

- Smoothing costs
- Holding costs
- Shortage cost
- Regular time costs
- Overtime and subcontracting costs
- Idle time costs

Strategies

Balance the advantages of producing to meet demand closely against the disruptions caused by changing the levels of production and/or the workforce levels.

Chase strategy (Zero Inventory Plan)

Vary production rates to meet changes in demand.

Level strategy (Constant Workforce Plan)

Fix production rates and using inventory and/or time to meet changes in demand.

Hybrid strategy (Mixed strategies)

Use a combination of chase and level.

⇨ Make use of LP to optimize the trade-off between inventory and capacity costs.

Linear programming

Constraints!

1) Conversation of workforce constraints → $W_t = W_{t-1} + H_t - F_t$
2) Conservation of units constraints → $I_t = I_{t-1} + P_t + S_t - D_t$
3) Constraints relating production levels to workforce levels → $P_t = Kn_t W_t + O_t - U_t$
4) Non-negativity constraints for all variables

Objective function

$$Minimize \sum_{t=1}^{T} (c_H H_t + c_F F_t + c_I I_t + c_R P_t + c_O O_t + c_U U_t + c_S S_t)$$

Rounding the variables

Conservative rounding approach: number of workers to the next larger integer.

Master Production Scheduling (MPS) and Materials Requirements Planning (MRP)

Master Production Scheduling (MPS)

MPS translates S&OP into a plan for producing specific products in the future: quantities and timing.
Tracks following information:

- Booked orders vs forecasted demand
- Available-to-Promise (ATP)

Time-phased record

$$\begin{aligned} &Projected\ available\ balance \\ &\qquad = Beginning\ balance + Master\ production\ schedule - Forecast \end{aligned}$$

Rolling through time

- Actual sales may be different
- Forecasts may change

➔ Production changes: expensive

Order promising

<u>For every period in the planning horizon:</u>

$$\begin{aligned} &Projected\ available\ inventory \\ &\qquad = Previous\ available\ inventory + MPS - MAX(Forecast, Actual\ orders) \end{aligned}$$

➔ For fixed periods: $-\ actual\ orders$

<u>For the first period:</u>

$ATP = On - hand + MPS - Sum\ of\ the\ orders\ until\ the\ next\ MPS$

<u>For each period when a subsequent:</u>

$ATP = MPS - Sum\ of\ the\ orders\ until\ the\ next\ MPS$

MPS planning horizon and stability (time fences)

Time fences:

- Frozen zone (closest to current date)

➔ DEMAND TIME FENCE

- Slushy zone

➔ PLANNING TIME FENCE

- Liquid zone

MPS and the customer order decoupling point (CODP)

Items for which MPS is done depends on the CODP:

- Make to stock (MTS) → MPS on final products
- Assemble to order (ATO) → MPS on ‘intermediate’ modules
- Make to order (MTO) → MPS on components / raw materials

Super bill of materials → describes the options or modules that make up the average end item.

Material Requirements Planning (MRP) basics

MRP = process of translating a production schedule for an end product (MPS) to a set of requirements for all of the subassemblies and parts needed to make that item.

PUSH system: one produced, subassemblies are pushed to next level whether needed or not.

Explosion calculus

A set of rules for converting MPS to a requirements schedule.

Two basic operations:

1) Time phasing → shifting backwards by the lead time
2) Multiplication → multiplicative factor if more than one subassembly

The lot sizing problem

What production quantities will minimize total holding and setup costs over the planning horizon?

- Set of requirements: $(r_1, r_2, \dots, r_n)$
- Set up cost: K
- Holding cost: h
- Production quantities: $(y_1, y_2, \dots, y_n)$

Feasibility condition: no stock-outs in any period

$$\sum_{i=1}^{j} y_i > \sum_{i=1}^{j} r_i \quad for\ 1 \le j \le n$$

Alternative lot-sizing schemes

EOQ lot sizing

$$EOQ = \sqrt{\frac{2K\lambda}{h}}$$

$$Ending\ inventory = Beginning\ inventory + Planned\ deliveries - Net\ requirements$$

Silver-Meal heuristic

$C(T) = average\ holding\ and\ setup\ cost\ per\ period$

Forward method: determining C(T) and stopping when this function first increases.

$$C(j) = \frac{K + hr_1 + 2hr_2 + \dots + (j-1)hr_j}{j}$$

➔ Once C(j) > C(j – 1) → STOP

- Set $y_1 = r_1 + r_2 + \dots + r_{j-1}$
- Begin process again starting at period j.

Least unit cost

Similar to Silver-Meal, but:

$$C(j) = \frac{K + hr_1 + 2hr_2 + \cdots + (j-1)hr_j}{(r_1 + r_2 + \cdots + r_{j-1})}$$

Part period balancing

Set the order horizon equal to the number of periods that *most closely matches* the total holding cost with the setup cost over that period.

Lot sizing with capacity constraints

Detecting an infeasible problem

An infeasible problem: r = (52, 87, 23, 56) and c = (60, 60, 60, 60)

Obtaining a feasible solution for a feasible problem

A feasible problem: r = (20, 40, 100, 35, 80, 75, 25) and c = (60, 60, 60, 60, 60, 60, 60)

➔ Approximate lot-shifting technique: back-shift demand to prior periods

Improving a feasible solution

By shifting, starting from the last period and working backward to the beginning.

Shortcomings of MRP

- Uncertainty
- Capacity planning
- Rolling horizons and system nervousness
- Lead times dependent on lot sizes
- Quality problems
- Data integrity
- Order pegging

Just-in-time and Kanban

Push and Pull

Push systems: schedule release of work based on information from outside the system.

- ⇨ Actual or forecasted demand
- ⇨ Due date drive
- ⇨ Do not limit WIP

Pull systems: authorize release of work based on information from inside the system.

- ⇨ System status
- ⇨ Rate driven
- ⇨ Limit on WIP

Kanban

Kanban is a mechanism for implementing pull.
All goods must be accompanied by a Kanban (card).

Kanban cards help create a demand-driven system.

Types:

- Conveyance/transportation Kanban
- Production Kanban
- Sales/vendor Kanban

How many Kanban cards needed in 1 loop?

See formularium

- ⇨ Lead time: processing time + waiting time + conveyance time
- ⇨ Setting number of Kanban cards = maximum inventory

Kanban card count for multiple products

Take into account:

- Changeover times
- Minimum batch sizes
- Takt time: amount of time that must elapse between two consecutive unit completions in order to meet the demand.

Setting minimum batch sizes (MBS)

MBS = minimum number of cards → low water level (<-> high water)

- ⇨ Number must be rounded up (for feasibility) to an integer number of Kanbans

Comparison of MRP and JIT

MRP: push system

- Based on forecasts of sales of end items.
- Once produced, subassemblies are *pushed* to next level whether needed or not.

JIT: pull system

- Production at one level only happens when initiated by a request at the higher level.
- Unit are *pulled* through the system by request.

Setup time reduction – SMED

Definition of setup

Setup or changeover = preparation and after-adjustment before and after each lot is processed.

Why setup time reduction?

- Economic lot size
- Changing market conditions
  - ⇨ Changing market demands: need for diversified, low-volume production.
  - ⇨ Frequent setups necessary to produce a variety of goods in small lots.
- Benefits:
  - o Increased flexibility
  - o Increased bottleneck capacity
  - o Reduced costs

What is SMED?

Single-Minute Exchange of Die

- ⇨ A theory and techniques for performing setup operations in under ten minutes.

History of SMED

Shigeo Shingo

Two different types of setup operations:

1) Internal setup (IED: inner exchange of die)
   - ⇨ Can only be performed when the machine is stopped
2) External setup (OED: outer exchange of die)
   - ⇨ Can be performed while machine is in operation

Fundamentals of SMED

1) Preliminary stage (stage 0): Mixed stage
   - ⇨ Internal and external setup not distinguished
2) Stage 1: Separated stage
   - ⇨ Separating internal and external setup
3) Stage 2: Transferred stage
   - ⇨ Converting internal to external setup
4) Stage 3: Improved stage
   - ⇨ Streamlining all aspects of the setup operation

Techniques for applying SMED

Techniques for improvement stage 1

- Using a checklist
- Performing function checks
- Improving transportation of dies and other parts

Techniques for improvement stage 2

- Preparing operating condition in advance
- Function standardization
  - Shape standardization
  - Function standardization
- Using intermediary jigs

Techniques for improvement stage 3

- Radical improvements in external setup operations
  - Improvement in the storage and transportation of parts
- Radical improvements in internal setup operations
  - Implementation of parallel operations
  - Use of functional clamps
  - Elimination of adjustments → setting right the first time

Operations scheduling

Factory planning:

1) Forecasts of future demand
2) Aggregate planning
3) Master production schedule (MPS)
4) Materials requirements planning (MRP) system
5) Detailed job shop schedule

Dynamic vs static scheduling

Job shop scheduling problem

Problem

How to sequence the different jobs to optimize some specified criterion.

Objectives

- Meet due dates
- Minimize work-in-process (WIP) inventory
- Minimize average flow time
- Maximize machine/worker utilization
- Reduce setup times for changeovers
- Minimize direct production and labor costs

Terminology

- Flow shop
- Job shop
- Parallel processing vs sequential processing
- Flow time of job i
- Makespan
- Tardiness (positive)
- Lateness (may be negative)

Common sequencing rules

- First-come, first-served (FCFS)
- Shortest processing time (SPT)
- Earliest due date (EDD)
- Critical ratio (CR)
  - ⇨ Ratio of processing time of the job and remaining time until the due date
  - ⇨ $CR = \frac{processing\ time}{due\ date - current\ date}$ → schedule job with largest CR value next
  - ⇨ $CR = \frac{due\ date - current\ date}{processing\ time}$ → schedule job with smallest CR value next

Scheduling n jobs on 1 machine

Total makespan → independent of sequencing algorithm

SPT → minimizes mean flow time

EDD → minimizes maximum lateness

Moore's algorithm → minimizes number of tardy jobs

Scheduling n jobs on m machines

Permutation schedules: schedules in which the sequence of jobs is the same on both machines.

Johnson's Rule for n jobs on 2 serial

Rule: $Job\ i\ precedes\ job\ (i+1)\ if\ Min(A_i, B_{i+1}) < Min(A_{i+1}, B_i)$

- $A_i = processing\ time\ of\ job\ i\ on\ machine\ A$
- $B_i = processing\ time\ of\ job\ i\ on\ machine\ B$

Implementation:

1) List all jobs with their M1 and M2 process times
2) Select the shortest processing time on the list
   - If it is a M1 time, schedule job first
   - If it is a M2 time, schedule job last
   - Cross this job off list
3) Repeat Step 2 through the rest of job

Build optimal schedule (Gantt Chart) and compute makespan, mean flow and mean idle.

Johnson's Rule for n jobs on 3 serial

Rule: $\text{If } \mathrm{Min}(\mathrm{A_i}) \geq \mathrm{Max}(\mathrm{B_i}) \text{ or } \mathrm{Min}(\mathrm{C_i}) \geq \mathrm{Max}(\mathrm{B_i})$

- ➔ 3-machine problem can be reduced to a 2-machine problem.
- ➔ Define $A_i' = A_i + B_i\ and\ B_i' = B_i + C_i$ and solve the problem.

Facilities layout and design

Designing new facilities or redesigning existing facilities.

Types of layouts

- Fixed position layouts → for large items
- Product layouts → flow shop, product oriented
  - ⇨ Work centers organized around the operations needed to produce a product
  - ⇨ Create optimal flow
- Process layouts → job-shop, process oriented
  - ⇨ Grouping similar machines with similar functions
  - ⇨ Optimize machine utilization
- Group technology layouts / Work cells
  - ⇨ Based on the needs of part families

Product oriented production

- Limited range of high quantity products
- Highly capital intensive
- Not work intensive (reduced material handling costs)
- Little WIP inventory and short lead times
- ➔ Low flexibility but high efficiency

Process oriented production

- Many low quantity products
- General-purpose machinery
- Reduced capital intensity
- Work intensive (higher material handling costs)
- Production in batches → higher WIP inventory and longer lead times
- ➔ High flexibility but low efficiency

Patterns of flow

- Activity relationship chart
  - ⇨ Each pair of operations is given a **letter** to indicate the desirability of locating the operations near each other.
- From-To chart
  - ⇨ Can show:
    - o Distances between work centers
    - o Numbers of materials handling trips
    - o Materials handling costs

Quadratic assignment problem

Material handling costs depend on the location of other facilities.

See slides

Computerized layout techniques

- CRAFT → improvement technique
  - ⇨ Improves materials handling costs
  - ⇨ Consider pair-wise interchanges of departments:
    - o Have adjacent borders
    - o Have the same area
- ALDEP → construction routine
  - ⇨ First department is chosen random
  - ⇨ Next based on closeness rating
- CORELAP → similar to ALDEP, but uses more careful selection criteria
  - ⇨ First department is chosen based on Total Closeness Rating (TCR)
  - ⇨ Highest TCR first

Line balancing

Single-model line balancing

Manufacturing a product on an assembly line:

- Tasks: {1, 2, …, K}
- Task times t_k
- Precedence constraints (precedence graph)
- Cycle time c: time between the completion of two consecutive products.
  - ⇨ $c = takt\ time$
    $= \frac{available\ production\ time\ per\ day}{total\ demand\ per\ day} = \frac{T}{d}$

➔ Feasible line balance = assignment of each task to a station such that the precedence constraints and further restrictions are fulfilled.

Main objective: minimizing idle time over all stations {1, 2, …, n}

$$Minimize\ \left(nc - \sum_{k=1}^{K} t_k\right) = nc - cst$$

- ⇨ By minimizing number of stations for a given cycle: SALB I
- ⇨ By minimizing cycle time for a given number of stations: SALB II

Branch-and-bound

Systematically enumerating candidate solutions by proceeding through a search tree. Every node in the three is a subset of a solution.

Update first-fit heuristic (IUFF):

1) Assign a numeric score n(x) to every task
2) Update the set of eligible tasks → immediate predecessors
3) Assign the task with the highest score to the first station
   - ⇨ Keep in mind capacity- and precedence constraints!
   - ⇨ Go to step 2

Numeric score functions n(x):

- Positional weight
- Reverse positional weight
- Number of successors
- Number of immediate successors
- Task time
- Backward recursive positional weight
- Backward recursive edges

Enumeration procedure Hoffmann

1) Minimize station idle time → assigned to station 1
2) Repeated for station 2 using an updated precedence feasible list.
3) Repeated for each station until all tasks have been assigned.

Evaluation of heuristics

Balance Delay (BD)

Total idle time as a percentage of total available working time.

$$BD = \frac{nc - \sum_{k=1}^{K} t_k}{nc}$$

Line Efficiency (LE)

$$LE = 1 - BD = \frac{\sum_{k=1}^{K} t_k}{nc}$$

Smoothness Index

$$Index = \sqrt{\sum_{i=1}^{n} (maximum\ station\ time - station\ time_i)^2}$$

- → Perfect balance: index = 0

Assembly Line Balancing (ALB)

Single assembly line balancing (SALB)

- 1 product
- Serial production
- 1 processing scheme
- Deterministic task times

General assembly line balancing (GALB)

- Stochastic task times
- Multi/mixed-model lines
- Processing alternatives
- Additional constraints
- …

Different objectives

Minimize the number of stations subject to a given output target for a certain planning horizon (→ specified by the cycle time c or the production rate).

- Minimize cycle time c → or maximize production rate
- Minimize cost for a given output target
- Maximize profit

SALB with stochastic task times

$m_k = average\ task\ time\ for\ task\ k$

Reduce the problem to a deterministic problem:

- Assign tasks to stations until a predetermined proportion of the cycle time is reached.
- Assign tasks to stations while the probability that the tasks assigned to that station are finished within the cycle time is greater than a predetermined value α.

Multi/mixed-model ALB

Multi-model lines → batches of two or more models are produced on one and the same line

Mixed-model lines → different models are produced on the same line (lot sizes = 1)

Mixed-model line sequencing

Inefficiencies:

- Idleness
- Work deficiency
- Utility work
- Work congestion

Time and Space constrained ALB problems

- Balancing the line is subject to layout constraints → available space in each station
- One-dimensional approach to area constraints
- Each task:
    - Determined duration t_i
    - Fixed know area requirements a_i
- Stations:
    - Fixed time = cycle time c
    - Fixed area = A

Lean Management

Operational Excellence

QCD (= Quality, Cost, Delivery) is what the customer wants.

What is Lean?

- Management method
- Aimed at improving the customer experience
- By striving towards excellent internal processes
- Through empowered employees
- Supported by a specific management style
    ⇨ Coaching, consensus, avoid to dictate solutions
- Lean tools

Toyota Production System

The core of the Lean concept.

Lean manufacturing = manufacturing philosophy which shortens the time line between the customer order and the product shipment by *eliminating waste*.

Foundation of Lean

Resource efficiency vs flow efficiency

Muda, mura, muri

Eliminate:

- MUDA = waste → 7 categories of non-value added activities (NVA)
- MURA = unevenness → variations in production planning, in manufacturing targets, workloads
- MURI = overburden → overburdening of people (mentally or physically) or machines

What is waste?
= anything that adds Cost to the product without adding Value.

7 types of waste:

- Rework
- Motion
- Overproduction
- Transportation
- Inventory → worst kind: hides the other wastes and therefore perpetuates them
- Processing
- Waiting

Lean 'trains' people in thinking and exploring

- TWI = training within industry
- KATA = developing routines
- PDCA = methodical solving of problems
- Poka-Yoke = safeguarding solutions

Value, Waste, Flow, Pull, Improve

Lean thinking in 5 steps:

1) Specify the **value** that the customer wants
2) Identify the **value stream** & eliminate **waste** in it
3) Make the product **flow**
4) Let the customer **pull**
5) And strive for **perfection** every day

Lean management

Human Resource practices:

- Employee participation
- Teamwork
- Feedback
- Training
- Reward and recognition

Value stream mapping

Typical process data:

- C/T (cycle time), P/T (process time, process lead time), C/O (change-over time)
- Uptime % → time during which a machine is in operation
- EPE (process batch)

- Number of operators & work content = C/T x number of operators
- Number of product variants
- Working time (minus breaks)
- Scrap rate

Convert units into lead time using Little's law: I = R x T → T = I/R

Future state questions:
- Demand:
  1) What is the takt time for the chosen product family?
  2) Will you build to a finished goods supermarket from which the customer pulls, or directly to shipping?
- Material flow:
  3) Where can you use continuous flow processing?
  4) Where will you need to use supermarket pull systems in order to control production of upstream processes?
- Information flow:
  5) What single point in the production chain (pacemaker process) should you schedule?
  6) How should you level the production mix at the pacemaker process?
  7) What consistent increment of work should you release and takeaway at the pacemaker process?
- Work plan:
  8) What process improvements will be necessary for the value stream to flow as your future-state design specifies?

Continuous improvement with Lean Management

Roadmap for productivity improvement

Preparing for change

1) <u>Formal decision to change</u>
   - Employees get more to say and become more empowered
   - Management plays a more supporting role (instead of imposing solutions)

2) <u>Organizing for change</u>
   - Improvement KATA:
     - Understand the direction: what does the customer really want?
     - Understand the current state
       - Grasp current situation → swimlane, VSM, Makigami, process map
       - Identify muda, mura , muri → WASTE (7 types: downtime)
     - Define the next target state
     - PDCA (= Plan, Do, Check, Action) towards target state: what do we have to improve?

3) <u>Learning about Lean</u>

   ⇨ Eliminate Waste, Maximize Value Adding, Minimize Non Value Adding

Improving step by step

4) Local Diagnosis
   ⇨ Starting shot → Generate ideas → Prioritize ideas → Analyze initiatives

5) Local Improvement
   - Problem solving techniques
     - Problem = difference between the current situation and the ideal situation.
     - Root cause analysis and 5x Why
       - Identify root causes (inputs) associated with specific problems (outputs)
   - Visual management
     - The ability to understand the status of (production) zone in 5 minutes or less by simply observing, without the use of computers and without talking to someone.
       - Example: traffic signs, low fuel sign in auto's, orange bicycle pad, …
       - Use of lights, colors and signs
   - 5S
     - S1: Sort → discard what no longer needed (necessary vs non necessary)
     - S2: Stabilize/Straighten → everything a fixed place (ex. shadow boards)
     - S3: Shine/Scrub → cleaning and inspection
     - S4: Standardize → make sure that everything we have realized in the first three steps becomes a standard (tools, checklists)
     - S5: Sustain → hold on to the applied changes (checklists, audits)
   - Standard Work

6) Kaizen Showcase
   - Kaizen = 'to continuously improve'
   - Kaizen showcase/event = intensive improvement activity, from analysis to implementation.
   - Daily Kaizen vs Kaizen events

Making improvement sustainable

7) Sustaining
   - KPI's → Key Performance Indicators
   - Visualizing data (ex. bar graph, trend graph, pie graph, pareto graph)
   - Improvement boards

8) Networking and comparing

9) Integration with management follow-up
   - 100 % employee education
   - People empowerment