MST Michaelmas 2009

Operations Management

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Housekeeping

- Part I (lecture 1-4): Factory-level planning
- Part II (lecture 5-8): Supply chain management
- Four supervisions (see Camtools for groups and dates)

  Not always right answer, so no cribs!
- Past exams / “The Goal” Goldratt (session 5)

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Session Overview

Part I

1. Process Fundamentals and types of manufacturing
- Information Flow, Material Flow
- Productivity, Improvement, Capacity, Utilisation
- Objectives and Tradeoffs

2. Inventory Management
- Reordering Policies
- ABC Analysis, Pareto Chart
- Little’s Law
- EOQ, EPQ, POQ models and their limitations

3. Forecasting and Assembly Line Balancing
- Moving Average
- Exponential Smoothing
- Decomposition and Fourier Analysis
- Forecast errors
- Assembly Line Balancing

4. Machine-level Scheduling
- Single machine: Minimising average completion/flow time, maximum lateness, number of late jobs, average tardiness
- Two machines in-line: minimising makespan

Part II

5. Factory-level Scheduling and MRP Systems
- Order Fulfilment strategies
- Push versus Pull scheduling
- MRP systems
- Just-in-Time and Kanban systems

6. Toyota Production System and Lean Thinking
- 7 Wastes, 5 Lean Principles
- Lean Toolbox, Lean Services
- Implementing Lean

7. Quality Management, Six Sigma, Project Man.
- Service industry
- Demand and revenue management
- Sigma Level of processes
- Project Management and NPD, differences to manufacturing operations. Critical path method.

8. Supply Chain Management
- SCM as competitive advantage
- Difference OM and SCM
- Managing Supplier Relations
- Supply Chain Collaboration
- Course Review

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Learning Objectives

- Understand the basic decisions in Operations Management, and their implications on firm performance
- Be able to manage inventory, schedule processes, develop basic forecasts
- Understand the Lean, Six Sigma and TOC improvement concepts
- Be able to manage a project (Critical Path Method)
- Understand the need to manage the wider supply chain

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What is Operations Management?

– Operations Management (OM) is the activity of managing the resources which are devoted to the production and delivery of products and services to end customers.

– OM uses **process thinking** to meet and exceed customer demand while using all resources efficiently in order to maximise the value of the organisation.

– Anything which **repeats** in the operation can be seen as a ***process.*** The repetitive nature of processes allows for improvement.

– ***Project*** management : low volume, high variety operations with defined beginning and end.

– Distinction between operations which manufacture ***goods*** and those which provide ***services*** **(***but is this distinction really meaningful?***)**

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Why does OM matter?

- One of the three core activities of the firm
  - Marketing and sales
  - Product/service development
  - Operations
- Operational decisions have strong financial implications...
- ... and often forgotten: also determine the day-to-day service level at the customer end!

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Session 1
Process Fundamentals
OM objectives and trade-offs

Objectives for Today

- Representing processes diagramatically
- Quantitative and qualitative measures we use to describe processes
- Categorise different types of manufacturing processes
- Identify the objectives involved in operations management, the costs, and the trade-offs

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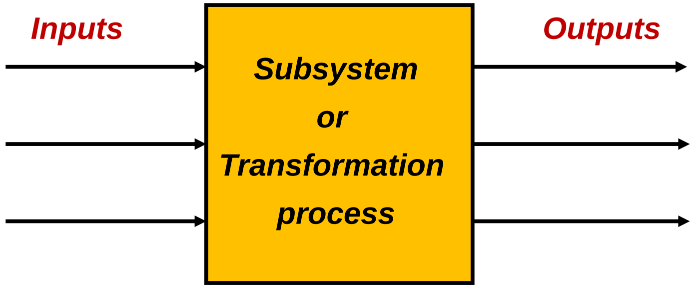
Input - Output Diagram



Flows of orders, information, data, energy, material, people, etc.

Input-output diagrams are a way of defining a system, e.g. a manufacturing System

Productivity, Efficiency and Improvement

Basic definitions in Operations Management all relate to the Input-Output process model:

– **Productivity = Ratio of Σ Outputs to Σ Inputs**
  - E.g. Vehicles produced per labour hour
  - "Benchmarking" as comparative analysis across firms
  - What are the main mechanisms for increasing productivity?

– **Efficiency**
  - Aims at using the least amount of resources to produce a given good or service at the lowest possible unit cost

– **Improvement = [Productivity(t) / Productivity(t-1) -1]*100**
  - Considers output per unit resource over time
  - Tracks productivity development over time

Example: A Bakery I

- Processes are shown as boxes, inventories as triangles, arrows depict flows

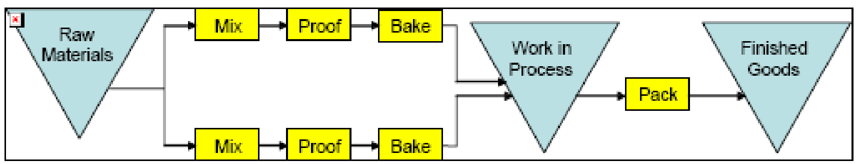


Figure 1: Process Flow Diagram for Bread-Making with Two Parallel Baking Lines

Example: A Bakery II

- What are the implications of making this change to the flow?

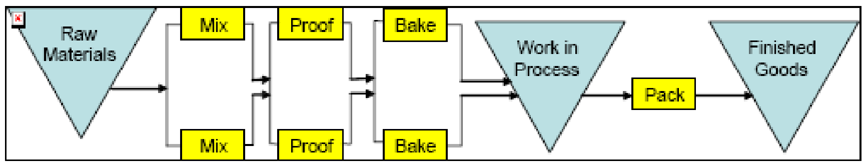


Figure 2: Process Flow Diagram for Bread-Making with Two Mixers, Proofers and Ovens

Example: A Bakery III

- Product variety adds complexity

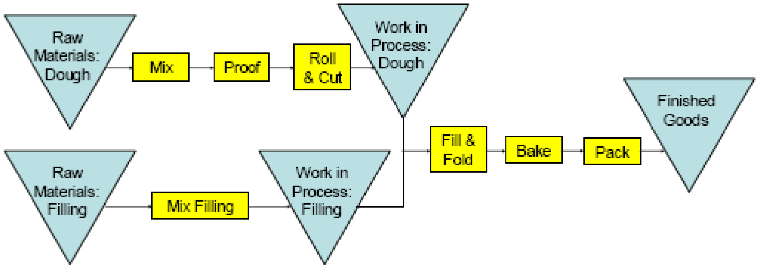
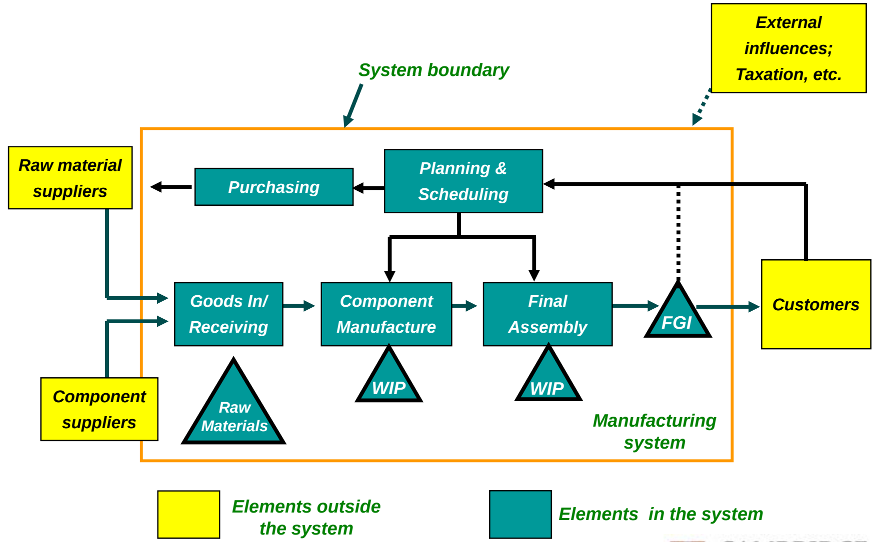
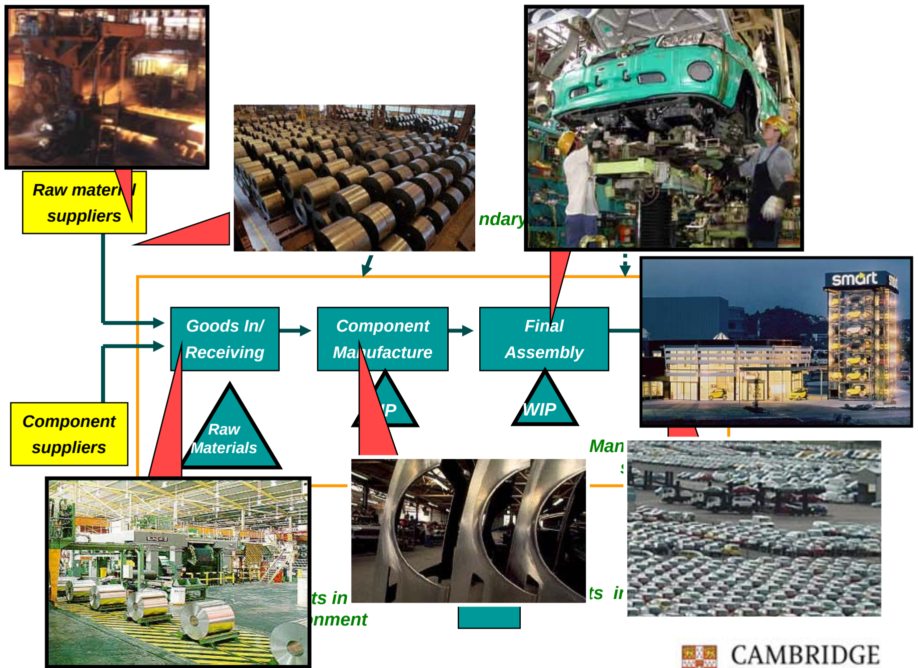


Figure 3: Process Flow Diagram for Croissant-Making

A Simplified Manufacturing System





Capacity and Utilisation

- **Cycle time**: average time between units of output emerging from process
- **Capacity**: maximum level of value-added activity a process is capable of over a period of time (units/time)
- **Utilisation**: Ratio of the actual output from a process to its design capacity (potential output if all capacity was used)
- **Throughput**: the time for a unit to move through a process

What determines the throughput of a system?

Capacity utilisation is a critical success factor :

- What happens if you don't have sufficient capacity?
- Can you think of examples of costs incurred by unused resources?

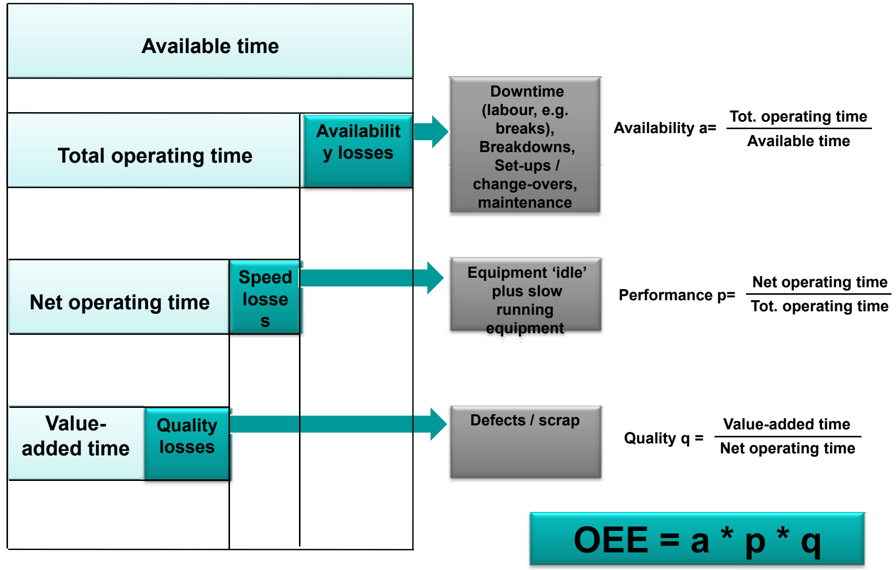
Exercise capacity utilisation

Work station A	Work station B	Work station C	Cycle Time (min/unit)	Capacity (Output / hour)	Capacity Utilisation (%)
1 worker, 3 mins	1 worker, 5 mins	1 worker, 2 mins			
1 worker, 3 mins	2 workers 2.5 mins	1 worker, 2 mins			
1.2 workers 2.5 mins	2 workers, 2.5 mins	0.8 workers 2.5 mins			

"Load balancing"

→Efficiency is generally driven by capacity utilisation and labour productivity...

Overall Equipment Effectiveness (OEE)



OEE = a * p * q

Exercise OEE

Maximum time available:

Management decides machine works 150 hrs: available time

Availability losses: 10 hrs (machine set-up) + 5 hrs (breakdowns)

Total operating time: available time – availability losses:

Speed losses: 5 hrs (idling) + 10% (*when* the machine runs):

Net operating time: total operating time – speed losses:

3% defects, valuable operating time: net operating time – quality losses

a: *p*: *q*:

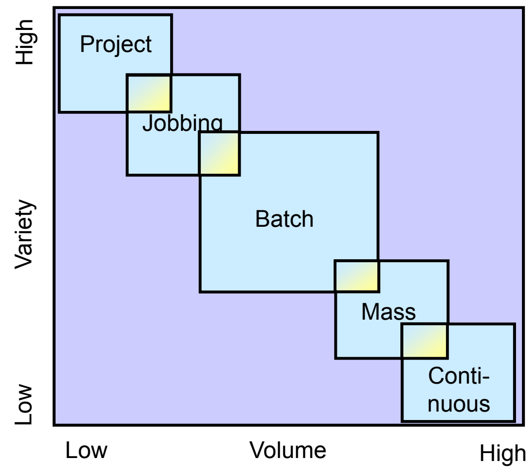
OEE (*a* * *p* * *q*) =

Types of Manufacturing and Service Operations

Plane and car manufacture

- How do these two operations differ?

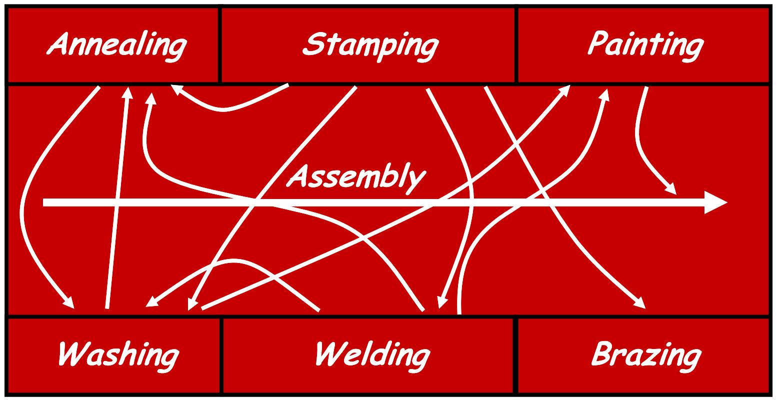
Manufacturing Process Types



Projects - Millau Viaduct

- **Labour and equipment is often brought to location of assembly**
- **Physical size and degree of customisation key factors**

Job Shop - Flow Chart



Process-driven split into centres, complex routing and scheduling.

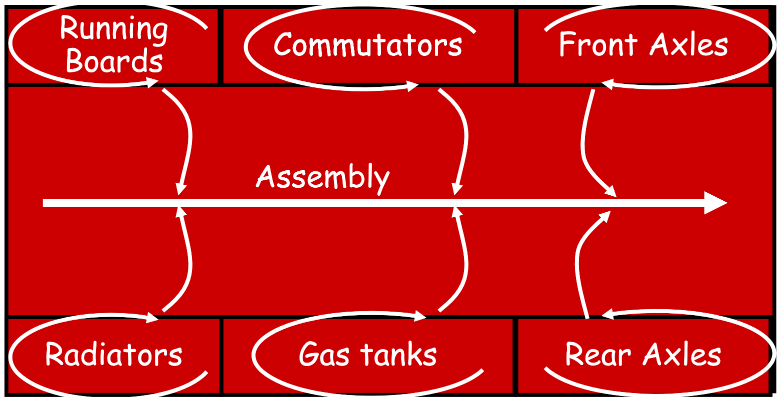
Job Shop: Aero Engines & Machine Tools

- Volume does not justify dedicated lines or machinery
- Parts often travel between work-shops, thus ‘job shop’
- Work centres are grouped by type of process: welding, drilling, painting

Batch: Textile Production

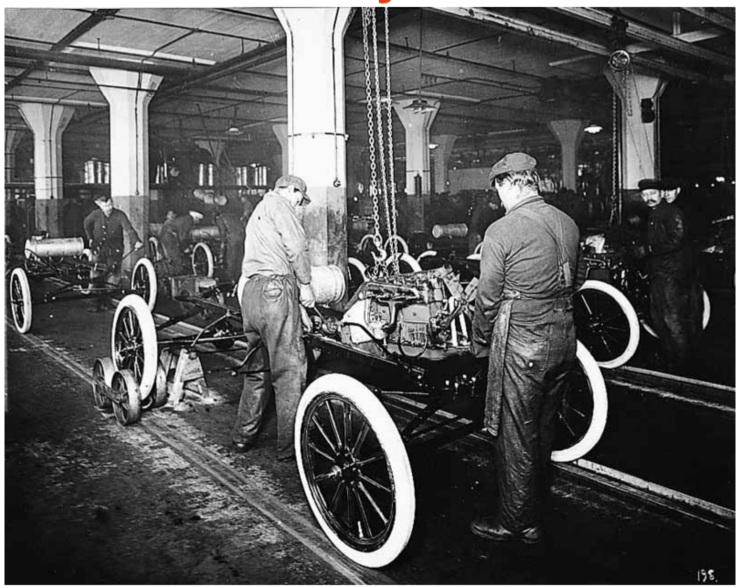
- Volume key factor in justifying automation
- Short life-cycle means that machines need to be flexible for re-use with next batch/product
- Changeovers between products

Ford Highland Park Moving Assembly Line in 1913



250,000 Vehicles Per Year, One Model

Model T Assembly Line



Mass/Line production: Automobiles

- Volume does justify dedicated lines
- Cycle time is set to pace entire factory
- Multi-model lines
- Limited flexibility regarding volume and new models

Continuous processing: Oil refinery

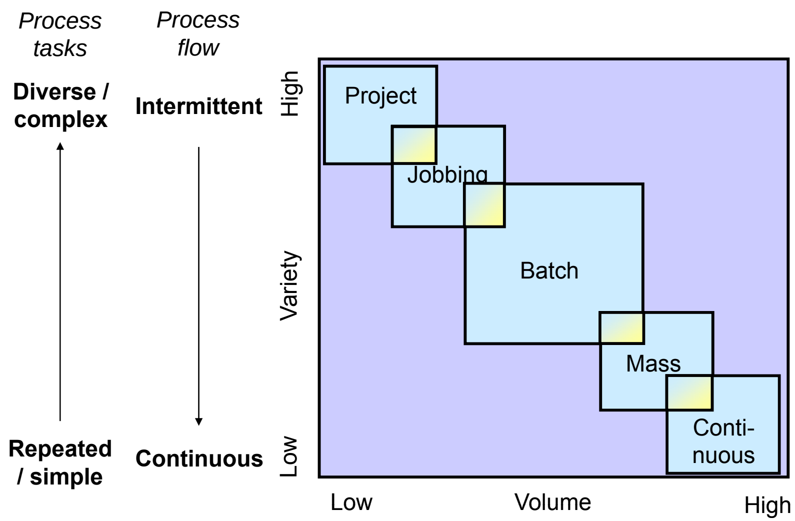
- Flow processes, often driven by chemical/physical needs
- Individual product is often not an entity (e.g. petrol)

Process Characteristics

The single most important feature of a process in a business operation is the trade-off in its design between **production volume** and **product variety**

- Defines types of job design required
- Defines necessary tools and technology
- Defines cost structure
- Defines relationship with suppliers
- Establishes customer expectations

Manufacturing Process Types



Objectives and Trade-offs

What are we trying to achieve in OM?

Internal objectives: “shareholder value”

- 100% effective use of resources
- Minimal operating expenses: Zero defects, zero stock

External objectives:

-
-
-
- Additional metrics: Flexibility, Safety and Service

“The right product, at the right time, at the right quality, at the right price”

Cost Implications of OM Decisions

Cost of inventory

- Cost of capital & warehousing
- Cost of handling, quality implications, obsolescence

Cost of production

- Cost of inventory is a function of production batch sizes
- Cost of machines, labour
- Opportunity cost of set-ups

Cost of logistics & distribution

- Cost of transportation, depending on frequency

Cost of sales

- Opportunity cost of lost sales

Cost of making a sale (interface to marketing...)

All OM Decisions are Trade-offs

Customer service vs. operational cost

- Response time, order fulfilment

Setup cost vs. inventory

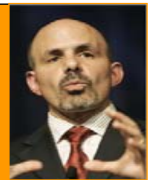
- What are the optimal batch sizes in production?

Inventory cost vs. ordering cost

- What are optimal order quantities?

…Where to find the balance?

FORTUNE May 22, 2006
Interview with Bill Amelio, CEO of Lenovo



Q: Will you manufacture everything in China?

A: For notebooks it's definitely in China, but for desktops we'll do final assembly close to the customer. You don't want to stick them on a boat, because a PC's value drops each week anywhere from half-a-percent to a percent and a half.

Session 2
Inventory Management

Objectives Today

- What is inventory?
- Inventory cycles
- Arguments in favour and against inventory
- Little's Law
- Parts classification: Pareto and ABC Analysis
- Batch sizing decisions

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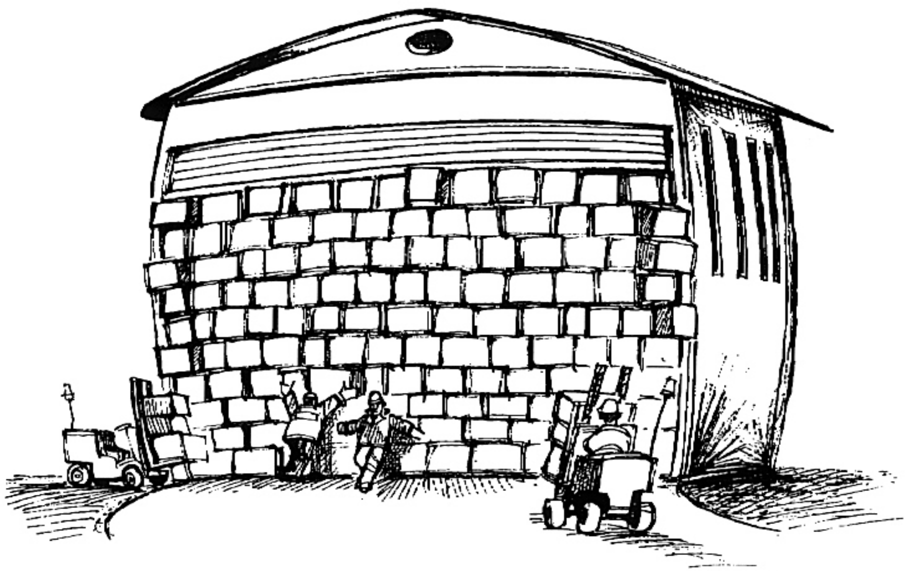

What is needed, what is waste?

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Inventory – Definitions

'An accumulation of a commodity that will be used to satisfy future demand.'

- Johnson and Montgomery (Operations Research)

'The stocks or items used to support production (raw materials and work-in-process items), supporting activities (maintenance, repair, and operating supplies), and customer service (finished goods and spare parts).'

- APICS (Association for Operations Management) Dictionary

'Dead material.'

- Taiichi Ohno (Father of the Toyota Production System)

'A substitute for information.'

- Michael Hammer (Process Reengineering Guru)

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Types of Inventory

Raw Materials:

- Materials to which the manufacturer has not yet added value

Work-in-progress or Work-in-process (WIP):

- Materials to which the manufacturer has added some value but still has more to add

Finished Goods

- Goods ready for shipment to the customers, with no more value to be added
- Also consider service parts...

Safety and Cycle Stock

- Safety stock: non-active component to protect against fluctuations of demand, production and supply
- Cycle stock: active component that depletes over time, and is replenished cyclically

Terminology: Stock-keeping Unit (SKU): an item at particular location

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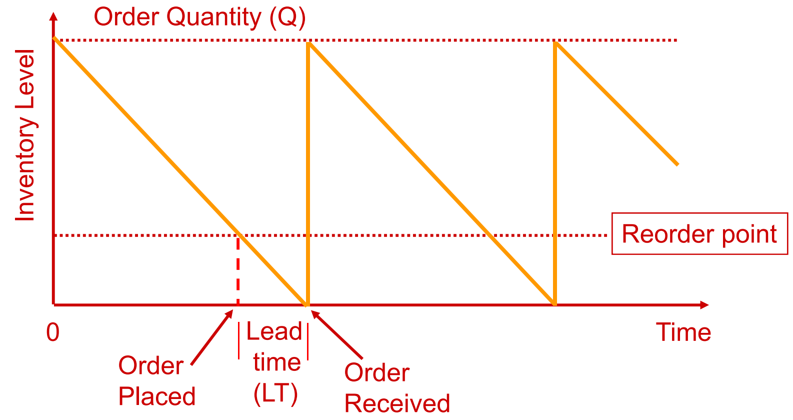
The Inventory Cycle ('*Sawtooth*')



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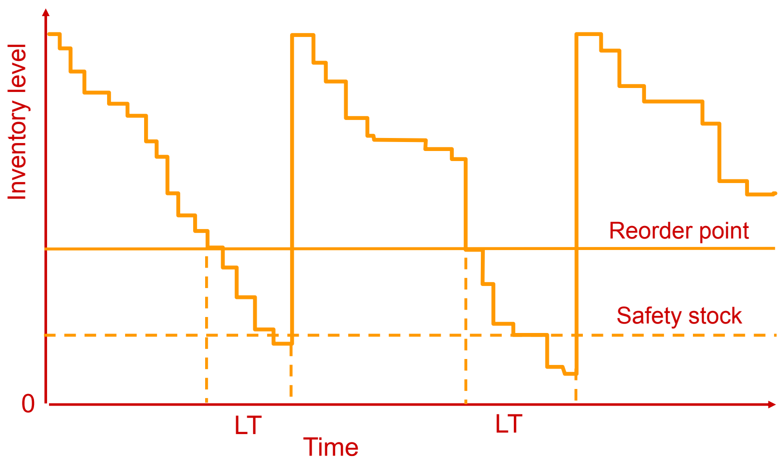
Reorder Point with Safety Stock



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Inventory – Arguments in favour

Little's Law (see later) implies:

- There is a minimum inventory needed to run the factory

Buffer against uncertainty

- Market demand (seasonality, promotions, etc.)
- Production throughput (quality, machine breakdown, etc.)
- Supply of components

Exploitation of price fluctuations

- Raw materials: cocoa, coffee, etc

Smoothing or levelling of production

- Small variation can be buffered through final goods inventory

Enables the achievement of economies of scale

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Inventory – Arguments against

Cost involved:

- Cost of capital: value*i, i=interest rate per unit time
- Opportunity cost: How much would the capital earn otherwise?
- Depreciation of goods
- Stock obsolescence and deterioration
- Quality defects due to handling
- Labour and handling
- Warehousing, rent and energy
- Insurance and overhead to admin labour, space, etc.

Overall costs:

- Typical estimate is 20-30%, but often excludes quality, depreciation, and opportunity cost
- Key issue: estimates *almost always* too conservative!

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Hidden Costs of Inventory

- Longer lead times
- Reduced responsiveness
- Underlying problems are hidden rather than being exposed and solved
- Quality problems are not identified immediately
- No incentive for improvement of the process

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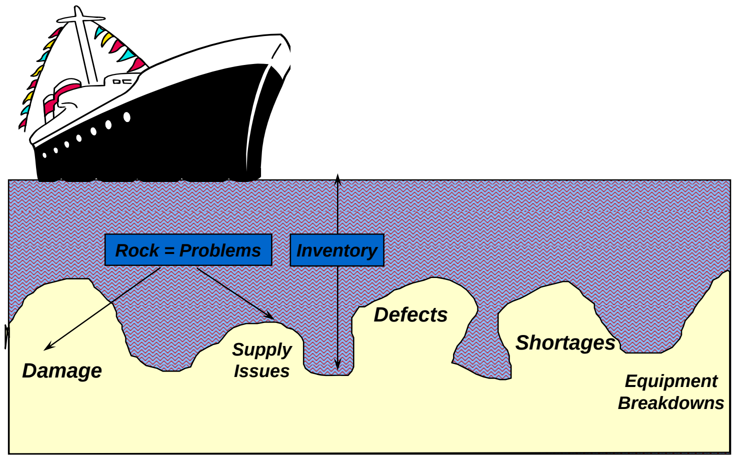
Rock – Boat analogy



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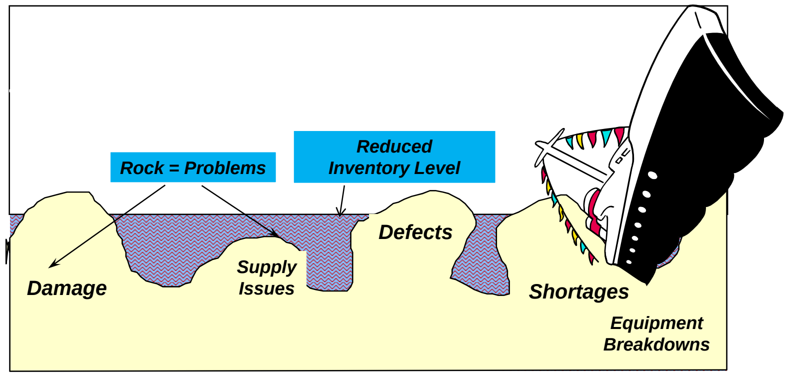
Inventory reduction only is fatal!



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Little's Law

John D.C. Little's Theorem (or Little's Law) gives a simple relation between inventory and lead-time. Applies to all types of systems!

$$I = R * T$$

- I is the number of items or inventory in a system [units]
- R is the production rate at which items arrive/leave [units/day]
- T is the lead-time (here, the time a job spends in the system) [days]
- all based on average, steady-state values.

I determines the minimum pipeline stock needed!

Exercise Little's Law

- A company assembles computers. The process has three stages – assembly, testing and packing – which take 975 minutes in total
- A work day has 7.5 hours
- Average daily demand is 1,600 units
- Current WIP levels (for all three presses combined) are 4,800 units. Consultants hired by the CEO think this is too much, and suggest to reduce stock by 50%
- Your reply?

Measuring Inventory Performance

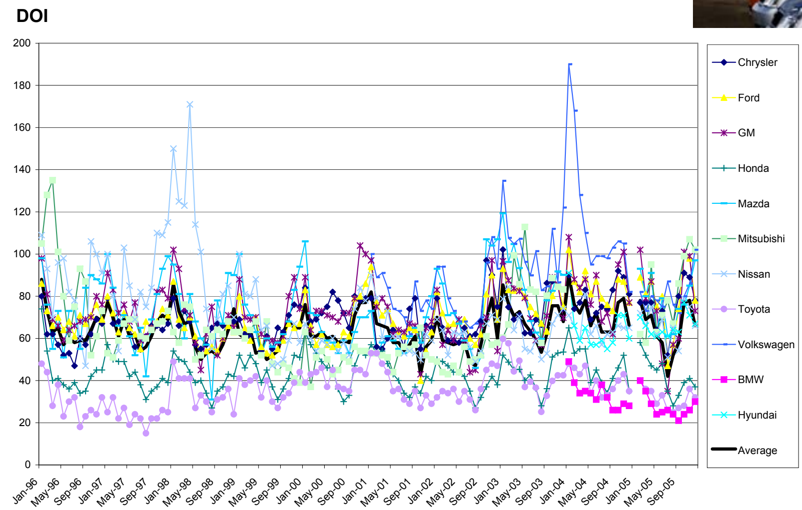
$$\text{Days of Inventory (DOI)} = \frac{\text{Quantity of Inventory [units]}}{\text{Average Demand [units/day]}}$$

Stock Turns is the number of times an organisation replaces its stocks during a period (usually measured annually)

$$\text{Stock Turns} = \frac{\text{Cost of Goods Sold in Period [£]}}{\text{Average Inventory Valuation [£]}}$$

- Typical stock turns: 5 to 20, world-class lean manufacturers achieve >40.
- Company A had a starting WIP of £1.75m, and a closing WIP of £1.25m at the end of the year. Total sales in the year were £36m. Calculate stock turns.

New Vehicle Inventories in the US



Part Classification

All inventory control models are part-specific

- Attention given to part depends on cost impact

ABC Classification, H Ford Dickie, 1951

- Number of parts versus Value x Volume
  - A: 20% of parts = 80% of cost (unit cost x quantity)
  - B: 30% of parts = 15% of cost
  - C: 50% of parts = 5% of cost

(exact percentages differ from one author to another)

Pareto's Law or Analysis, the '80-20 Rule'

- Vilfredo Pareto (1848-1923), study of income in Italy in 1897

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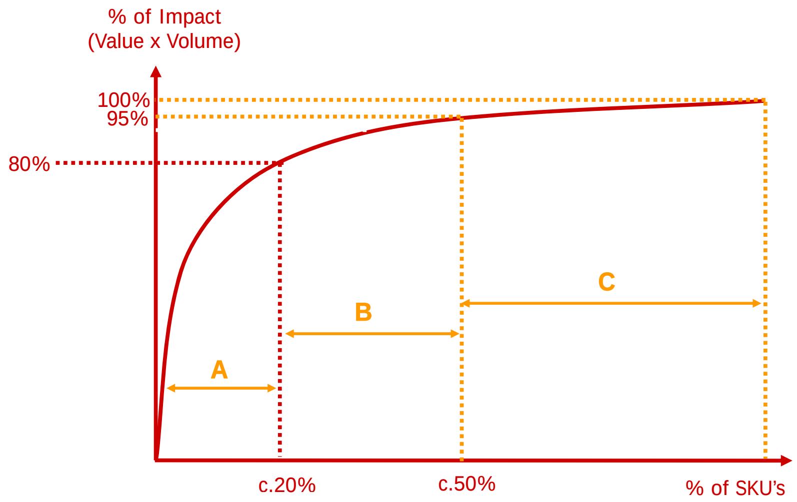
Pareto, ABC & the '80-20 Rule'



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ABC Classification: Impact

- **A-parts**: watch closely, minimise stock, aim for flow
- **B-parts**: review ordering policy from time to time, observe
- **C-parts**: automate replenishment, use reorder point as a trigger

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Runners, Repeaters, Strangers

Try to ensure *regularity* in operations

Classify parts by order frequency:

- **Runners**: high demand, aim to make continuously, use JIT.
- **Repeaters**: repetitive demand, but does not justify continuous production. Try to produce regularly, even if quantity varies.
- **Strangers**: spare parts etc., rarely ordered. Make to order, as demand does not justify stock holding.

Phil Crosby: "ballet, not hockey"

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Ordering and Batch Sizing Decisions

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Basic Approaches to Ordering

- 1. Fixed Order Quantity Models
  - Economic Order Quantity (EOQ)
  - Re-order Point
- 2. Fixed Period Requirements
  - Fixed Period Ordering
  - Lot-for-Lot ordering
  - Period Order Quantity
- 3. Variable order quantity and ordering interval
  - Least Unit Cost
  - Least Total Cost
  - Part-Period Balancing
- 4. Material Requirements Planning (MRP)
  - Calculates time-phased requirements

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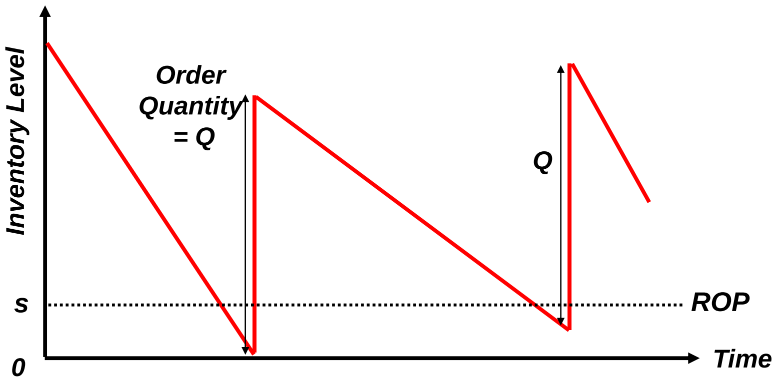
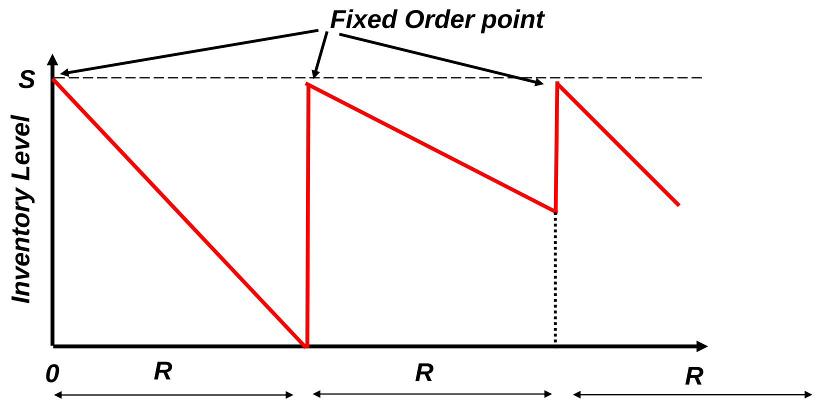
Fixed Order Quantity Systems (s,Q)



- (s,Q): Order time interval is variable, order quantity Q is fixed

Fixed Period Ordering Systems (R,S)



- Order Quantity is variable, ordering time interval R is fixed
- Order up to level S
- Every R time periods, system orders to replenish to S but only if stock currently below s

'Lot-for-Lot' Ordering

- Also called 'pass-on-orders', or 'order-up-to' model (OUT)
- Simply passes on customer orders to the supplier as they come in, without interference
- One only orders from the supplier what is demanded by the customer
- No fixed order quantity, but fixed time intervals (each period)
- ***Optimal solution for inventory cost!***
- ***...but ordering cost an issue?***

Batch Sizing: Determination of Q when ordering

- Using a large order size (i.e. ordering infrequently): we suffer a large inventory ***holding cost***.
- Using a small order size (i.e. ordering frequently): we suffer a large ***fixed cost of ordering***
  - Clerical / labour cost of processing an order
  - Any fixed costs imposed by supplier
  - Inspection and return of poor quality products
  - Transport costs
  - Handling costs
  - Labour cost of organising transportation
- Where to find the balance?

Economic Order Quantity

The order quantity that minimizes the total cost per period

- Derived by F.W. Harris, manufacturing engineer with Westinghouse Corp., in 1913
- Rediscovered and applied by management consultant R.H. Wilson in 1934, thus often called ***Wilson-Harris lot size formula***

Total Cost Formula

There are two parts to the total cost per period

- The holding cost depends on *average* stock: Q/2
- Ordering cost depends on number of orders per period: D/Q

This gives the total cost per period formula, as a function of the batch size ordered (Q)

$$T(Q) = \frac{Q}{2} C_H + \frac{D}{Q} C_O$$

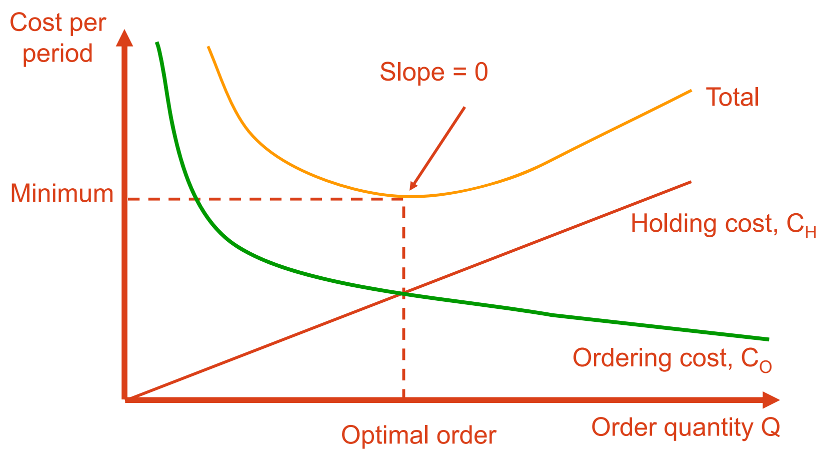
D = annual demand

Q = batch (lot) size

C_O = (fixed) cost of placing one order

C_H = cost of holding one item in store for one period

EOQ basic trade-off model



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Economic Order Quantity

$$EOQ = \sqrt{2D\frac{C_O}{C_H}}$$

Ordering Cost → C_O

Holding Cost → C_H

Annual Demand → D

(Fixed) Cost per order placed = C_O [£]

Cost per unit to hold one item for one period = C_H [£]

Demand rate per period = D [units/time]

Order quantity = Q [units]

Length of Order Cycle = (Q/D) [time]

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Why didn't we include the variable (unit) cost?

Shouldn't the formula for total cost per period be:

$$T(Q) = \frac{Q}{2}C_H + \frac{D}{Q}C_O + DC_V$$

where C_V = variable cost (cost per item)?

Yes, though here it makes no difference to the optimal Q, so we often ignore the term DC_V

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Example - EOQ

A retailer expects to sell about 200 units of a product p.a. The storage space taken up in his premises by one unit of this product is valued at £20 per year. Interest rates are expected to remain close to 10% per year and one unit is bought at £100.

1. If the cost associated with ordering is £35 per order, what is the economic order quantity?
2. For administrative convenience, we can only order in minimum order quantities of multiples of 10. What is the total cost in case of ordering 20, and 30?
3. How does the EOQ change if we assume a more realistic 20%, or even 40% inventory holding cost, in addition to storage?

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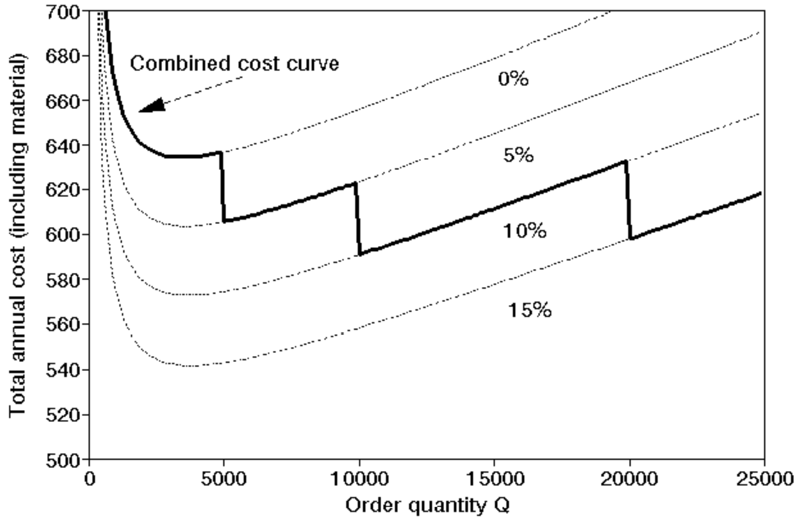
EOQ considering volume discounts



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Period Order Quantity (POQ)

EOQ logic, modified so that we order to cover demand for a whole number of periods, while still minimising cost

Example:

- D = 200 units per year and EOQ = 58 units, with "period" equal to one month
- EOQ/D = 58 units / 200 units = 0.29 years between orders
- 0.29 years = 3.48 months, so order every 3 months to cover expected demand in the next 3 months

Same logic as EOQ, except that ordering interval is computed, not ordering quantity.

Also known as Economic Time Cycle

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Batch Sizing: Determining Q in Production

- What if we are producing the batch ourselves, rather than ordering it in from an external supplier?
- Most of the issues are the same as they were when we were ordering the batch in. The differences are:
  - (1) The cost of ordering becomes the **cost of setup**
    - Clerical / labour cost of setting up a machine
    - Loss of production while set-up takes place
    - Return of poor quality products after start-up
  - (2) The batch does not now arrive instantaneously
- The optimum batch size is known as the Economic Production Quantity (EPQ)

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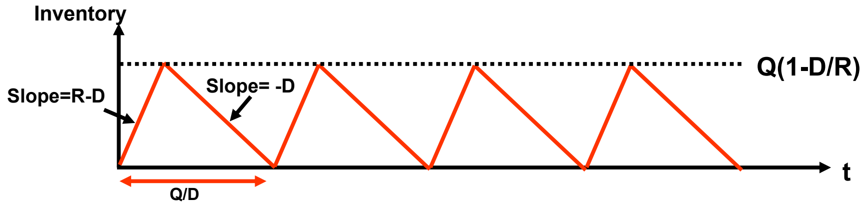
Economic Production Quantity (EPQ)

Assume a constant production rate of R>D for each batch



Analysis is as before, except C_H is replaced by $C_H(1 – D/R)$

$$EPQ = \sqrt{\frac{2\,D\,C_S}{C_H\,(1 - D/R)}}$$

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Problems with EOQ and EPQ

Rigid Assumptions!

1. Demand is constant and steady, and continues indefinitely
2. EOQ assumes whole replenishment lot arrives at same time
3. Replenishment lead-time is known
4. Order size is not constrained by supplier, no min/max restrictions
5. Holding cost per item per period is a constant
6. Cost of ordering/setup varies linearly with replenishment size
7. Item is independent of others; benefits from joint reviews are ignored
8. Doesn't encourage us to decrease fixed ordering/setup costs

Problem Cost Accuracy:

- How much does a set-up or placing an order cost?
- Holding costs: often calculated at interest level (cost of capital)

Conclusion

- Simple model, often reasonable, though with limitations

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Variable Order Quantity and Ordering Interval

Methods that allow lot size & ordering interval to vary from period to period

- We still assume that demand is known, even if it is not constant
- Seek to cover demand for a whole number of periods (why?)
- As in EOQ, objective of minimising the sum of setup and inventory cost

LUC - Least Unit Cost

- See next slide

LTC - Least Total Cost

- Consider seeking to cover demand for next 1,2,3... periods (as LUC)
- Choose n to most closely balance set-up and inventory cost for this batch

PPB - Part-Period Balancing

- Basic version as LTC, but advanced versions include 'look-ahead / look-back' facility to see if simple modifications to schedule reduce total costs.

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Least Unit Cost

- Heuristic (Greek: 'find'): 'quick and dirty', or 'sub-optimal' method
- Basic idea: Consider seeking to cover demand for next 1,2,3... periods. Find cost/unit for each case. Stop just before this starts to rise. Restart calculation from there.
- Assume we suffer holding cost on only items held over from one period to the next
- Example
  - Set-up Cost £100, inventory holding cost = £1 / period / item

Period	1	2	3	4	5	6	7	8
Requirements	25	30	0	50	0	65	35	35

Exercise LUC

Period	1	2	3	4	5	6	7	8
Requirements	25	30	0	50	0	65	35	35
End of Period Stock								

1. Cover demand	***Batch***	***Cost***	***Cost /Unit***
for 1			
for 1,2			
for 1,2,3			
for 1,2,3,4			
2. Cover demand	***Batch***	***Cost***	***Cost /Unit***
for 4			
for 4,5			
for 4,5,6			
for 4,5,6,7			
3. Cover demand	***Batch***	***Cost***	***Cost /Unit***
for 7			
for 7,8			

Session 3

Forecasting

Assembly Line Balancing

Objectives for Today

- Why forecasting is needed
- Different types of demand fluctuations
- Moving averages (MA)
- Exponential smoothing (ES)
- Advantages and disadvantages of MA & ES
- Other forecasting methods
- Assembly line balancing

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Why do we need to forecast? Example I

- You are the plant manager at Manufacturing Excellence Ltd., a local producer of metal parts for the automotive industry. You are currently running at over 100% of your capacity, causing a significant increase in unit costs. However, you can still not satisfy all of your customers' orders.
- Expanding your production capacity would take 6 months and cost about £2 million.
- Should you make the investment?

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Why do we need to forecast? Example II

- You are the store manager at one of AllFoodYouNeed Plc.'s stores. Recently, you have noticed that you lose money on selling freshly squeezed orange juice due to a high percentage of unsold juice that cannot be kept overnight.
- You have made the following observations over the past two weeks:

Week	1							2						
Day	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su
Juice produced (litres)	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Juice unsold (litres)	19	27	38	27	18	7	5	17	28	36	29	17	6	4
Demand (litres)	81	73	62	73	82	93	95	83	72	64	71	83	94	96

- What improvements would you suggest?

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Two Forms of Demand

- Independent demand
  - finished products
  - based on market demand
  - requires forecasting
- Dependent demand
  - parts that go into the finished products
  - dependent demand is a known function of independent demand
  - no forecasting is required
- Can products have partially dependent and independent demand at the same time?

Forecasting Methods - Overview

1. Qualitative (long-term, 2-10 years)

- Market Surveys
- Delphi Study: ask the experts...
- Problems: bias, ignorance

2. Quantitative (short to medium term, 0-2 years)

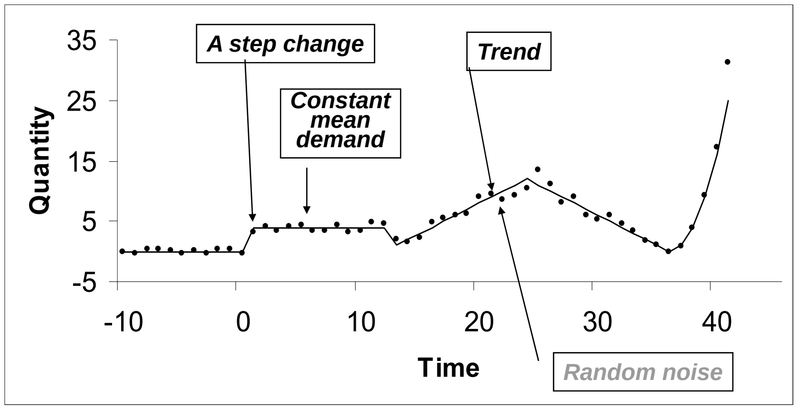
A. Extrinsic (based on external patterns beyond firm level)

- Regression, correlation and econometrics, medium term (1-2 years)
- Problem: will miss unusual events and short term issues

B. Intrinsic (based on patterns of actual data at firm level)

- Short term (up to 12 months)
- Moving average, exponential smoothing (extrapolation methods)
- Time series, Decomposition/Fourier Analysis
- Problem: almost exclusively based on historical data!

Patterns of Demand



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Forecast via Moving Average

- ***Most basic approach; we assume mean demand constant***
- ***To forecast demand in next period we average demands in the recent past periods***
- ***A 4-period moving average is the average of the last 4 time periods***
- ***The general formula for moving average is:***

$$S_t = (x_t + x_{t-1} + .. + x_{t-n+1}) / n$$

NB: by convention, S_t is an average based on data up to time t, but used as a forecast for time t+1

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Exercise 4-Period Moving Average Forecasting

Time	Demand	Forecast
-3	504	
-2	484	
-1	493	
0	423	
1	458	
2	440	
3	485	
4	395	
5	368	
6	344	

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Exercise 4-Period Moving Average Forecasting

Time	Demand	Forecast
-3	504	
-2	484	
-1	493	
0	423	
1	458	
2	440	
3	485	
4	395	
5	368	
6	344	

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Age of Data and Weights

The more data periods are used, the older the data gets:

- 1 period MA: average age of data is 1 period
- 2 period MA: average age is (1+2)/2 = 1.5 periods
- 3 period MA: average age is (1+2+3)/3 = 2 periods
- ...
- n period MA: average age is (1+2+...+n)/n=(n+1)/2 periods

- In a MA forecast, each period has a weight of 1/n
- Perhaps the more recent past should have greater weight?

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Exponential Smoothing

- Like a moving average, but weight given to each period is a fixed proportion of weight given to succeeding period

$$S_t = k \cdot \left\{ x_t + (1-\alpha) \cdot x_{t-1} + (1-\alpha)^2 \cdot x_{t-2} + (1-\alpha)^3 \cdot x_{t-3} + \ldots \right\}$$

- $0 < \alpha < 1$, so weights get smaller as we recede into the past

$$k \quad k(1-\alpha) \quad k(1-\alpha)^2 \quad k(1-\alpha)^3 \quad \ldots$$

- The constant k is chosen so that the weights sum to 1:

$$k + k(1-\alpha) + k(1-\alpha)^2 + k(1-\alpha)^3 + \ldots = 1$$

and this (it can be shown) requires $k=\alpha$

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Exponential Smoothing Forecast

- Exponential smoothing forecasts contain information on all previous demands, each demand is given a weight that is decreasing exponentially back in time.
- Smoothing constant: $0 < \alpha < 1$
- The general formula for exponential smoothing is:

$$S_t = \alpha \cdot x_t + \alpha \cdot (1-\alpha) x_{t-1} + \alpha \cdot (1-\alpha)^2 x_{t-2} + \alpha \cdot (1-\alpha)^3 x_{t-3} + \ldots$$

S_t is based on all (available) data up to period t to forecast x_{t+1}

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Exponential Smoothing: Updating Formula

- Forecast for period (t+1) can be quickly calculated from the forecast for period t:

$$S_t = \alpha x_t + \alpha(1-\alpha)x_{t-1} + \alpha(1-\alpha)^2 x_{t-2} + \alpha(1-\alpha)^3 x_{t-3} \ldots$$

$$S_8 = \alpha x_8 + \alpha(1-\alpha)x_7 + \alpha(1-\alpha)^2 x_6 + \alpha(1-\alpha)^3 x_5 \ldots$$

$$S_9 = \alpha x_9 + \alpha(1-\alpha)x_8 + \alpha(1-\alpha)^2 x_7 + \alpha(1-\alpha)^3 x_6 \ldots$$

$$= \alpha x_9 + (1-\alpha)[\alpha x_8 + \alpha(1-\alpha) x_7 + \alpha(1-\alpha)^2 x_6 + \ldots]$$

$$= \alpha x_9 + (1-\alpha) S_8$$

$$S_t = \alpha x_t + (1-\alpha) S_{t-1}$$

Alternative notation:

$$S_t = S_{t-1} + \alpha\varepsilon_t \qquad \varepsilon_t = x_t - S_{t-1}$$

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Exercise Exponential Smoothing Forecasting

Time	Demand	Forecast α=0.1	Forecast α=0.9
0	504		
1	484		
2	493		
3	423		
4	458		
5	440		
6	485		
7	395		
8	368		
9	344		

Exercise Exponential Smoothing Forecasting

Time	Demand	Forecast α=0.1	Forecast α=0.9
0	504		
1	484		
2	493		
3	423		
4	458		
5	440		
6	485		
7	395		
8	368		
9	344		

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Exponential Smoothing: α = ?

Choosing α: depends on how rapidly we want the smoothed value to respond to changes in demand

- Usually α=0.1 to 0.3
- The larger α, the more responsive (nervous) is the forecast
- The smaller α, the less reactive and more stable the forecast

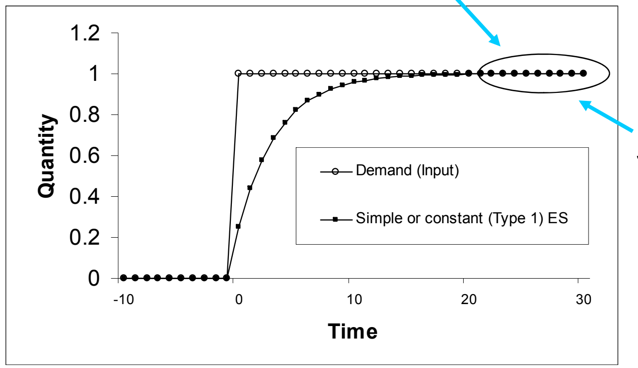
$$S_t = \alpha\, x_t + \alpha\,(1-\alpha)\,x_{t-1} + \alpha\,(1-\alpha)^2\,x_{t-2} + \alpha\,(1-\alpha)^3\,x_3\ ..$$

• α=0.1	*10%*	*9%*	*8.1%*	*7.3%*	Weights
• α=0.9	*90%*	*9%*	*0.9%*	*0.09%*	

It can be shown that the average age of data = $1/\alpha$

ES: Step change in demand

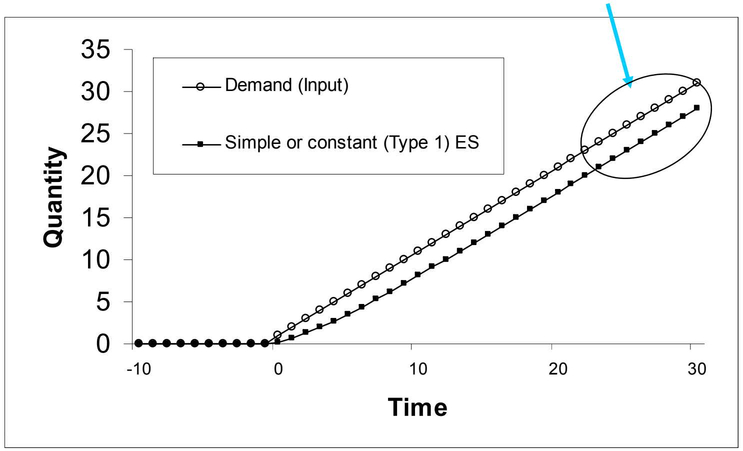
The forecast "locks-on" to the demand (that's good)



Steady state

ES: "ramp" (linear trend) demand

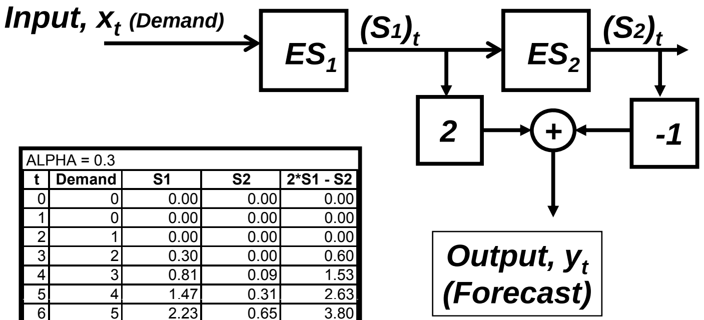
The forecast does not "lock-on" (that's not so good)



Summary of Simple ES

- The method we have seen so far is known as *simple* exponential smoothing
- It copes OK with step changes in demand
- It does not cope well with linear trends
- An adaptation of simple exponential smoothing can cope with linear trends: double exponential smoothing (sometimes known as Type 2 exponential smoothing)

Definition of Double ES



ALPHA = 0.3

t	Demand	S1	S2	2*S1 - S2
0	0	0.00	0.00	0.00
1	0	0.00	0.00	0.00
2	1	0.00	0.00	0.00
3	2	0.30	0.00	0.60
4	3	0.81	0.09	1.53
5	4	1.47	0.31	2.63
6	5	2.23	0.65	3.80
7	6	3.06	1.13	4.99
8	7	3.94	1.71	6.18
9	8	4.86	2.38	7.34
10	9	5.80	3.12	8.48
11	10	6.76	3.93	9.60
12	11	7.73	4.78	10.69
13	12	8.71	5.66	11.76
14	13	9.70	6.58	12.82
15	14	10.69	7.51	13.86
16	15	11.68	8.47	14.90

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Approaches to Forecasting

- One approach is to extrapolate past data (MA, ES)
  - This works fine for minor variability
  - Problem: response to step changes not immediate, forecast may be late in reacting to trends
- Another approach is to learn about the underlying properties of the demand time series
  - E.g. demand for turkeys goes up every Christmas
- How to analyse:
  - Regression analysis: what factors matter? E.g. weather and sporting events to predict beer consumption
  - Decomposition/Fourier analysis: the idea is that one complex demand time series can be decomposed into a set of simpler series

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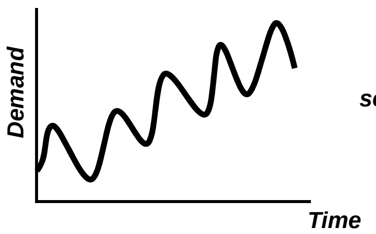
Decomposition Models



Trend with seasonal pattern

- Additive Model:

  Demand = (Trend) + (Seasonal) + (Cyclic) + (Randomness)
- Multiplicative Model:

  Demand = (Trend) * (Seasonal) * (Cyclic) * (Randomness)
- Cyclic component is like the seasonal component, but with a longer cycle period: simple models ignore it

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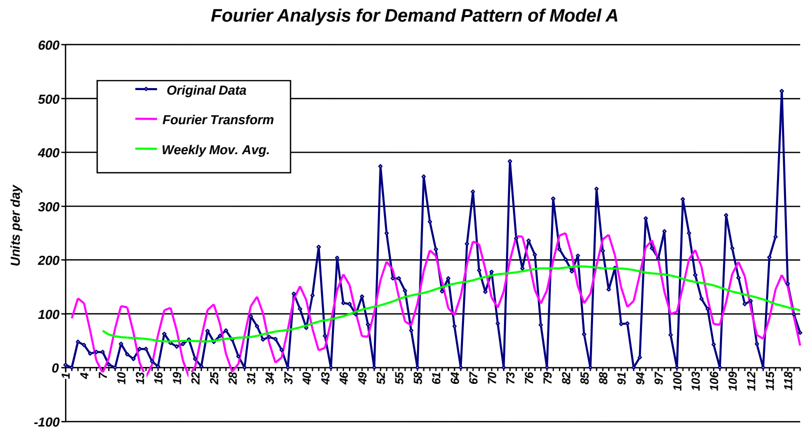
Fourier Analysis Example: New Vehicle Orders



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Forecast Accuracy

- The forecast is always wrong!
- The longer the forecast horizon, the worse the forecast
- The less aggregated, the worse the forecast

Forecast Error

- We define $e_t = x_t - S_{t-1}$ as the forecast error in period t
- Let $e_1, e_2, \ldots, e_n$ be the forecast errors observed over n periods
- A measure of forecast error over n periods is the **Mean Absolute Deviation (MAD):**

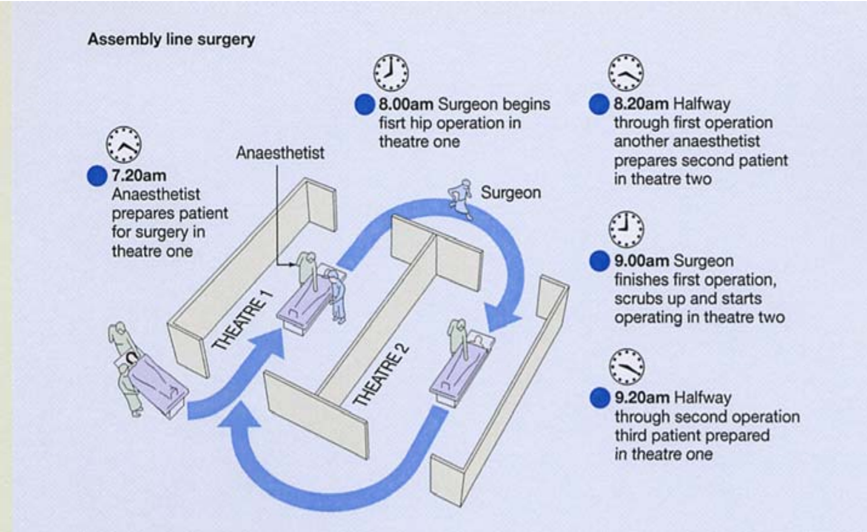
$$\text{MAD} = \frac{1}{n}\sum_{i=1}^{n}|e_i|$$

- Another measure of forecast error is the **Mean Squared Error (MSE):**

$$\text{MSE} = \frac{1}{n}\sum_{i=1}^{n}e_i^2$$

Assembly Line Balancing

Traditional Assembly Line



Assembly Line

- An assembly line consists of a sequence of operations
- Some operations modify a single part or item
- Other operations assemble two or more parts together

Operations and Stations

- Crucial question: how many people do we need to do the work?
- Naïve answer: n operations need n people
- Problem:
  - Some operations may take less time than others, so some operators will be idle part of their time
  - We might not need to produce items at such a high rate
- Thus, one person can cover more than one operation

Station 1	***Station 2***	***Station 3***
Operation 1 *Operation 2*	*Operation 3* *Operation 4*	*Operation 5*

- Hence we group operations into *stations*

Remember our solution from week 1:

Work station A	Work station B	Work station C	Cycle Time (min/unit)	Capacity (Output / hour)	Capacity Utilisation (%)
1 worker, 3 mins	1 worker, 5 mins	1 worker, 2 mins	5	12	67%
1 worker, 3 mins	2 workers 2.5 mins	1 worker, 2 mins	3	20	83%
1.2 workers 2.5 mins	2 workers, 2.5 mins	0.8 workers 2.5 mins	2.5	24	100%

"Load balancing"

→Efficiency is generally driven by capacity utilisation and labour productivity...

Balancing the Assembly Line

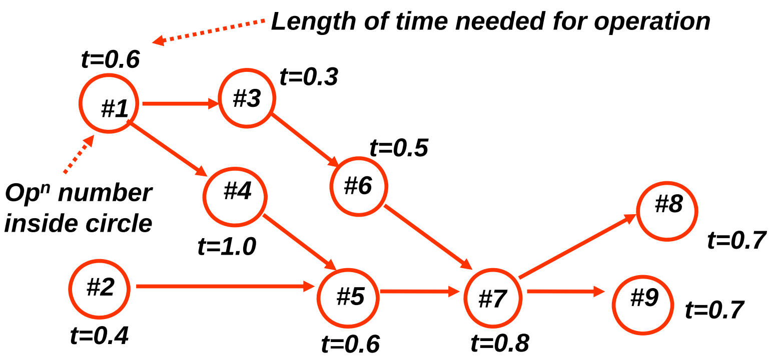
- Ideally, the time required for stations to carry out their operations should not vary much from one station to another, otherwise:
  - some stations will be partly idle
  - and/or some stations will be overloaded
- This is called *"balancing"* the assembly line

Balancing the Assembly Line

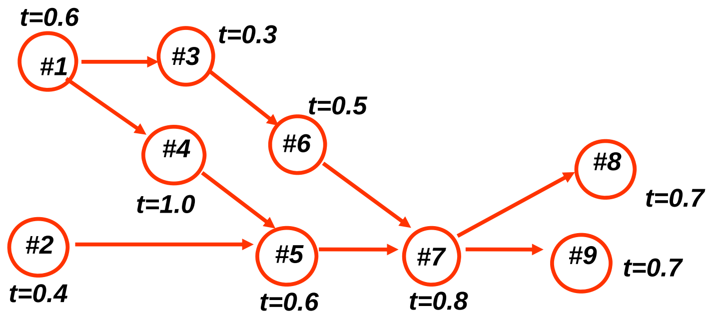
- We ask each station to complete its work within a fixed time, known as the cycle time
- Then we allocate operations to stations, ensuring that:
  - each station can complete its operations with the cycle time
  - there is a similar amount of idle time at each station
- NB: the cycle time is also the time between successive items reaching the end of the assembly line
- Hence by reducing the cycle time, we increase the production rate
- "Takt time" = adjusting the cycle time needed to meet customer demand

Precedence Constraints

- Some operations cannot be done before others
- Arrow means that one operation has to be completed before another can start

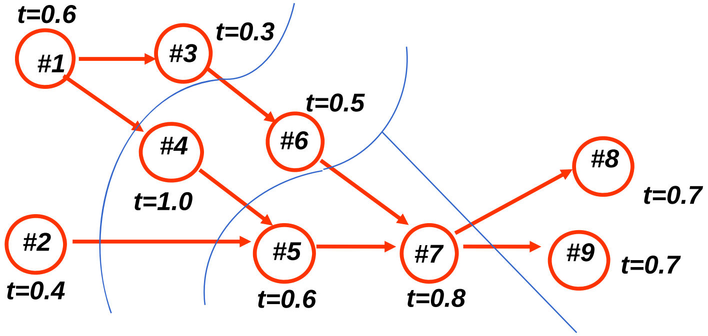


Example



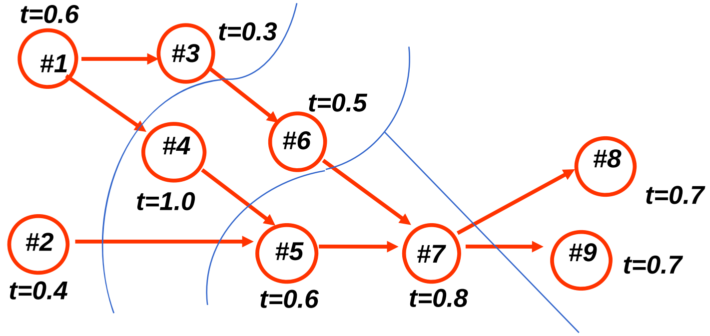
- Suppose we want to produce 40 items/hour
- 60 min per hour / 40 items per hour = 1.5 min cycle time
- Work content = sum of all operation (processing) times
  = 5.6 minutes
- Minimum number of stations 5.6min / 1.5min = 3.73 (i.e. 4 stations)

A possible allocation of operations



- Station 1: #1,#2,#3 = 1.3 mins
- Station 2: #4,#6 = 1.5 mins (is this OK?)
- Station 3: #5,#7 = 1.4 mins
- Station 4: #8,#9 = 1.4 mins

Evaluating our allocation



- We define:

$$\text{Balancing Loss} = 1 - \frac{\textit{Total processing time per item}}{\textit{Number of stations * Cycle time}}$$

- Here, balancing loss =

Heuristic Methods for Assembly Line Balancing

- Small problems can be solved "by eye"; larger ones need heuristic methods
- In allocating operations to stations, allocate 'most deserving' operation first, followed by second 'most deserving', etc.
- Examples of heuristics:
  1. Longest sequential chain of followers
  2. Total number of followers
  3. Ranked positional weights (not part of syllabus now)

Longest Sequential Chain of Followers

- Operation: #1 (4 followers), #2,#3,#4 (3 followers), #5,#6 (2 followers), #7 (1 follower), #8,#9 (0 followers)
- Allocate jobs with more followers first
- Break ties by taking jobs with longest processing times first, thus Op# 4 (1.0) before #2 (0.4) before #3 (0.3)…

#1 (0.6)	***#4 (1.0)***	***#5 (0.6)***	***#8 (0.7)***
#2 (0.4)	***#6 (0.5)***	***#7 (0.8)***	***#9 (0.7)***
#3 (0.3)			
1.3	***1.5***	***1.4***	***1.4***

Order of allocation:
#1 to Station 1
#4 to Station 2
(no room on Stn.1)
#2 to Station 1
#3 to Station 1
#5 to Station 3
(no room on Stn. 2)
#6 to Station 2
etc

Total Number of Followers

- Operation: #1 (7 followers), #2,#3,#4, (4 followers), #5,#6 (3 followers), #7 (2 followers), #8, #9 (0 followers)
- Take longest first

#1 (0.6)	*#4 (1.0)*	*#5 (0.6)*	*#8 (0.7)*
#2 (0.4)	*#6 (0.5)*	*#7 (0.8)*	*#9 (0.7)*
#3 (0.3)			
1.3	*1.5*	*1.4*	*1.4*

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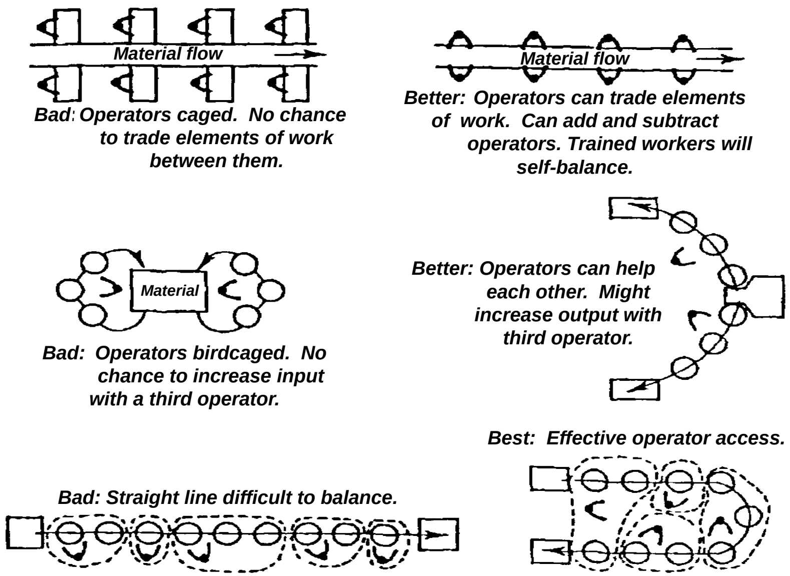
The good, the bad, the ugly...



Manufacturing Cell

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Session 4
Machine-level Scheduling

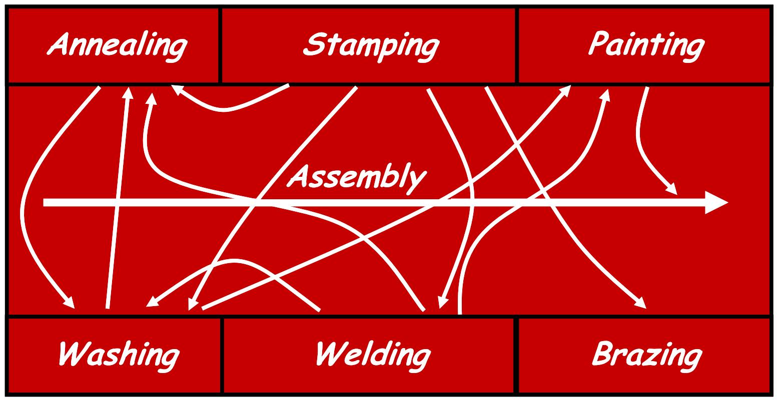
Objectives for Today

- What is scheduling?
- Scheduling machines in a job shop environment
  - Minimising average completion/flow time
  - Minimising maximum lateness
  - Minimise number of late jobs
  - Minimise average tardiness
  - Minimise makespan in a 2-machine flowshop

Scheduling

- Deciding in what order and when particular operations should be carried out
- For projects:
  - Scheduling is essentially project management
  - Critical Path Analysis (CPA)
- For batch and flow production:
  - Standard routing, but some variety. Computer-planned schedules (MRP / MRPII / ERP), or visual tools (Just-in-Time / Lean)
  - Cyclic scheduling, capacity planning key (bottlenecks)
- For job shops (our topic today)
  - No standard routing, no standard lead-times
  - Multiple machines, identical or different, parallel or in-line, etc...

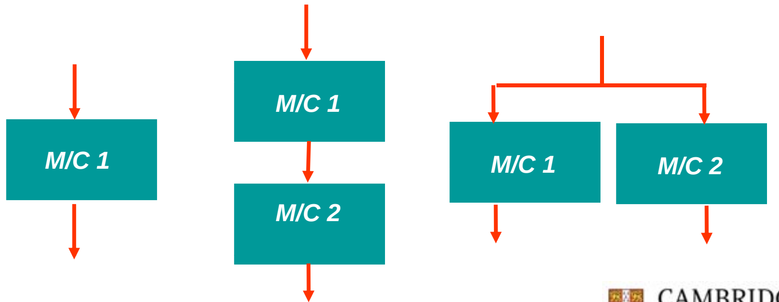
Job Shop - Flow Chart



Process split into independent work centres, complex routing and scheduling.

Types of Problems in Job Shop

- In a job shop situation, different jobs have different routings and different processing times
- Analysis of complex cases is often based on concepts from simple cases such as just one machine, or two sequential machines, or two parallel machines



Scheduling Objectives

The objectives we might face in scheduling are:

- Minimise average completion/flow time of a set of jobs
- Minimise the maximum lateness
- Minimise the number of late jobs
- Minimise average lateness/tardiness
- Minimise "makespan" (time between first job starting and last job finishing)

For each objective, an algorithm or heuristic exists to help us achieve our objective

- Algorithm: gives us the optimal solution
- Heuristic: gives us a reasonable, but not necessarily optimal solution

Minimising Average Completion Time (1 m/c)

Job	A	B	C	D
Processing Times	11	3	4	2

→ M/C 1 →

- If we do jobs in alphabetical order, and start at t=0, the schedule is:

  $A_{11}B_{14}C_{18}D_{20}$ NB useful notation: $Job_{Completion\ time}$
- The *overall* completion time (20) is does not depend on the schedule, but we might want to minimise *average* completion time.
- For our schedule, average completion time = (11+14+18+20)/4 = 15.75
- We can do better: put jobs with **S**hortest **P**rocessing **T**imes earlier:

  $D_2B_5C_9A_{20}$
- For new schedule, average completion time = (2+5+9+20)/4 = 9
- SPT Rule: minimises average completion/flow time on one machine
- Flow time = time that a job spends in the system

Minimising Maximum Lateness (1 m/c)

Job	A	B	C	D
Processing Time	3	3	4	5
Due Date	9	8	16	9

→ M/C 1 →

- If we do jobs in alphabetical order, the schedule is:

  $A_3B_6C_{10}D_{15}$
- For this schedule, maximum lateness (job D) = (15-9) = 6
- For this problem, it is *impossible* to avoid some job being late
- We might want to minimise the maximum lateness: to do this, put the jobs in order of **E**arliest **D**ue **D**ate:

  $B_3A_6D_{11}C_{15}$
- For new schedule, maximum lateness (job D) = (11-9) = 2
- EDD Rule: minimises maximum lateness on one machine

Minimising the number of late jobs (1 m/c)

Job	A	B	C	D	E	F	G	H	I
Processing Time	2	7	3	8	4	4	6	8	5
Due Date	5	10	15	22	23	24	25	30	33

→ M/C 1 →

- For this problem, it is *impossible* to avoid some jobs being late
- We might want to minimise the number of late jobs (egg to minimise the cost of subcontracting them)
- Moore's Algorithm:
  1. Schedule jobs by EDD
  2. If no job is late, go to step 6
  3. Find the first late job (call it the k^{th} job)
  4. From amongst jobs 1 to k, remove the job with the longest processing time
  5. Return to step 1 with one fewer job to consider
  6. The schedule is the EDD schedule, plus removed jobs (in any order)

Exercise Moore's Algorithm I

Job	A	B	C	D	E	F	G	H	I
Processing Time	2	7	3	8	4	4	6	8	5
Due Date	5	10	15	22	23	24	25	30	33

→ M/C 1 →

- Jobs already listed in EDD order, so start with this schedule

Job									
Processing Time									
Completion Time									
Due Date									

Exercise Moore's Algorithm II

Job	A	B	C	D	E	F	G	H	I
Processing Time	2	7	3	8	4	4	6	8	5
Due Date	5	10	15	22	23	24	25	30	33

→ M/C 1 →

- New EDD order is:

Job									
Processing Time									
Completion Time									
Due Date									

Exercise Moore's Algorithm III

Job	A	B	C	D	E	F	G	H	I
Processing Time	2	7	3	8	4	4	6	8	5
Due Date	5	10	15	22	23	24	25	30	33

→ M/C 1 →

- New EDD order is:

Job									
Processing Time									
Completion Time									
Due Date									

Exercise Moore's Algorithm IV

Job	A	B	C	D	E	F	G	H	I
Processing Time	2	7	3	8	4	4	6	8	5
Due Date	5	10	15	22	23	24	25	30	33

→ M/C 1 →

- Final schedule is:

Job									
Processing Time									
Completion Time									
Due Date									

- Moore's Algorithm: minimises the number of late jobs on one machine

Minimising Average Tardiness I

M/C 1

- Observation: minimising average lateness is a daft idea!
- Lateness = (completion date) – (due date) hence it could be negative
- But in real life, there is often little/no benefit from finishing a job early
- Instead, define Tardiness of a job = maximum of 0 and the Lateness of the job (we write: max(0,Lateness))
- Minimising average tardiness is a meaningful objective
- How do we achieve it?

Minimising Average Tardiness II

M/C 1

- We could try EDD; if there is only one late job, EDD minimises the average tardiness
- But for more than one late job, there is no algorithm for this problem
- However, there is a heuristic: the Modified Due Date (MDD) Rule: put jobs in order of increasing MDD
- At time t, MDD = the maximum of the due date and the earliest time at which we can complete a job:

  i.e. $MDD_i = \max(d_i, t+p_i)$
  where d_i = due date, p_i = processing time for job i

Exercise MDD I

M/C 1

Job	A	B	C	D	E	F	G	H	I
Processing Times	2	7	3	8	4	4	6	8	5
Due Dates	5	10	15	22	23	24	25	30	33

Exercise MDD II

M/C 1

- At t=0, Modified Due Date = Due Date for each job j:

Job	A	B	C	D	E	F	G	H	I
Processing Times	2	7	3	8	4	4	6	8	5
Due Dates	5	10	15	22	23	24	25	30	33
Modified Due Dates									

Here, ... has the smallest MDD (...), and completes at t= ...

Exercise MDD III

M/C 1

- t=

Job	A	B	C	D	E	F	G	H	I
Processing Times	2	7	3	8	4	4	6	8	5
Due Dates	5	10	15	22	23	24	25	30	33
Modified Due Dates									

***Here,** ... **has the smallest MDD (**...**), and completes at t=** ...*

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Exercise MDD IV

M/C 1

- t=

Job	A	B	C	D	E	F	G	H	I
Processing Times	2	7	3	8	4	4	6	8	5
Due Dates	5	10	15	22	23	24	25	30	33
Modified Due Dates									

***Here,** ... **has the smallest MDD (**...**), and completes at t=** ...*

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Exercise MDD V

M/C 1

- t=

Job	A	B	C	D	E	F	G	H	I
Processing Times	2	7	3	8	4	4	6	8	5
Due Dates	5	10	15	22	23	24	25	30	33
Modified Due Dates									

***Here,** ... **has the smallest MDD (**...**), and completes at t=** ...*

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Exercise MDD VI

M/C 1

- t=

Job	A	B	C	D	E	F	G	H	I
Processing Times	2	7	3	8	4	4	6	8	5
Due Dates	5	10	15	22	23	24	25	30	33
Modified Due Dates									

***Here,** ... **has the smallest MDD (**...**), and completes at t=** ...*

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Exercise MDD VII

→ M/C 1 →

- t=

Job	A	B	C	D	E	F	G	H	I
Processing Times	2	7	3	8	4	4	6	8	5
Due Dates	5	10	15	22	23	24	25	30	33
Modified Due Dates									

Here, ... has the smallest MDD (...), and completes at t= ...

Exercise MDD VIII

→ M/C 1 →

- t=

Job	A	B	C	D	E	F	G	H	I
Processing Times	2	7	3	8	4	4	6	8	5
Due Dates	5	10	15	22	23	24	25	30	33
Modified Due Dates									

Here, ... has the smallest MDD (...), and completes at t= ...

Exercise MDD IX

→ M/C 1 →

- t=

Job	A	B	C	D	E	F	G	H	I
Processing Times	2	7	3	8	4	4	6	8	5
Due Dates	5	10	15	22	23	24	25	30	33
Modified Due Dates									

Here, ... has the smallest MDD (...), and completes at t= ...

Exercise MDD X

→ M/C 1 →

- t=

Job	A	B	C	D	E	F	G	H	I
Processing Times	2	7	3	8	4	4	6	8	5
Due Dates	5	10	15	22	23	24	25	30	33
Modified Due Dates									

Final job is ..., which completes at t=...

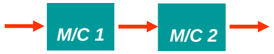
How to measure the quality of my schedule?

Final Schedule:

Original Due Dates:

Total tardiness is , the average tardiness is

Job shop scheduling with more than one machine

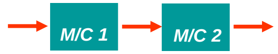


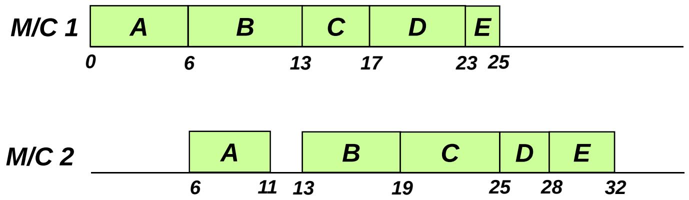
- Forget due dates
- **Makespan:** time between first job starting and last job finishing
- **Flowshop:** every job visits the same machines in the same order
- Problem: Minimise makespan in a 2-machine flowshop

Jobs	A	B	C	D	E
Processing Time - m/c 1	6	7	4	6	2
Processing Time - m/c 2	5	6	6	3	4

Try ABCDE….

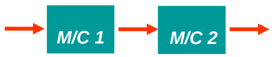
Jobs	A	B	C	D	E
Processing Time - m/c 1	6	7	4	6	2
Processing Time - m/c 2	5	6	6	3	4





➔ ***Makespan = 32. Can we do better?***

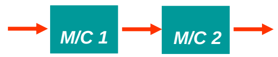
Minimising Makespan



Observations

- The makespan on m/c 1 is fixed
- Thus, to minimise overall makespan, we need to minimise makespan on m/c 2
- Two ways to do that
  - Minimise amount of time m/c 2 continues to process beyond m/c 1
  - Minimise amount of time m/c 2 needs to wait before starting to process jobs
- Conclusion:
  - Last jobs in schedule should have short processing times on m/c 2
  - First jobs in the schedule should have short processing times on m/c 1

Johnson's Rule



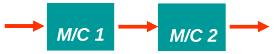
1. From the jobs not yet assigned, find the job with shortest processing time on either m/c.

2. Which machine does that processing time occur on?
   - If that shortest processing time occurs on m/c 1, assign the job to the next free slot in the schedule
   - If that shortest processing time occurs on m/c 2, assign the job to the last free slot in the schedule.

3. Go back to Step 1 until all the jobs are assigned.

Exercise Johnson's Rule I

Jobs	A	B	C	D	E
Processing Time - m/c 1	6	7	4	6	2
Processing Time - m/c 2	5	6	6	3	4

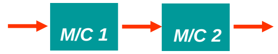


- Job   on m/c
- Job   on m/c
- Job   on m/c
- Job   on m/c
- Job   → between jobs already allocated

This yields the schedule:

Exercise Johnson's Rule II

Jobs	A	B	C	D	E
Processing Time - m/c 1	6	7	4	6	2
Processing Time - m/c 2	5	6	6	3	4



M/C 1

M/C 2

Makespan =

Johnson's Rule: minimises makespan in a two machine flowshop

Summary of Scheduling Rules

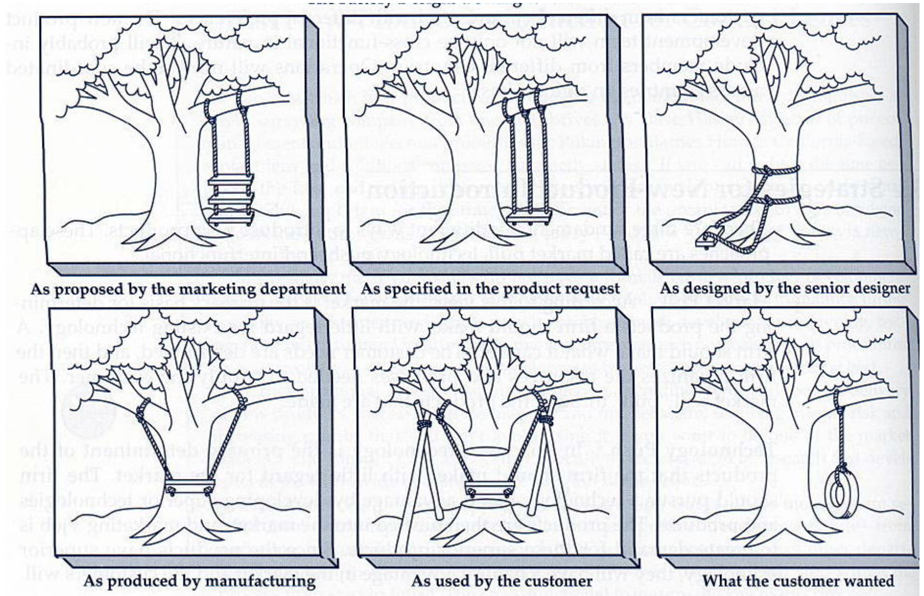
- SPT Rule: minimises average completion/flow time on one machine
- EDD Rule: minimises maximum lateness on one machine
- Moore's Algorithm: minimises the number of late jobs on one machine
- MDD Rule: (heuristic) minimises average tardiness on one machine
- Johnson's Rule: minimises makespan in a two machine flowshop

- Flow time = time that a job spends in the system
- Lateness = (completion date) – (due date)
- Tardiness = max(0, lateness)
- Makespan = time between first job starting and last job finishing

Session 5
Factory-level Scheduling

Order Fulfilment Strategies

Marketing, Design, Manufacture



Conflicting Objectives

Conflicting objectives:

- 100% utilisation of resources
- Zero stock
- Any volume and product mix
- No lead time

Supply (100% utilisation of resources; Zero stock)

Demand (Any volume and product mix; No lead time)

This requires co-ordination within and between firms aiming at:

- Balanced flow of work - all tasks take the same time
- Steady demand for products - and hence for inputs

Ideal demand is smooth and predictable:

- Total demand = maximum output capacity of resources
- Any changes are perfectly forecast in sufficient time to allow capacity change

But….

- Real demand is usually not predictable
- Demand has peaks - lunchtime/Saturday/summer etc
- Demand varies through product life cycle & competition

How to deal with Customer Orders?

Order Fulfilment Process

- From 'order to delivery' (OTD)
- Key process, day-to-day challenge!
- Determines customer service and majority of cost

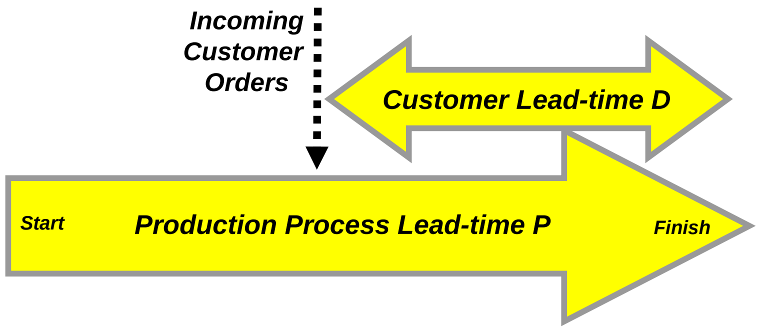
Order fulfilment strategy

- How far back does the order go into the supply chain?
- Which is appropriate under which circumstances?

Two basic factors are important

- Production Lead-time P: How long does it take to make the product?
- Demand Lead-time D: How long is the customer willing to wait for the product?

The P:D Ratio



Hal Mather, 1988, 'Competitive Manufacturing', Prentice Hall

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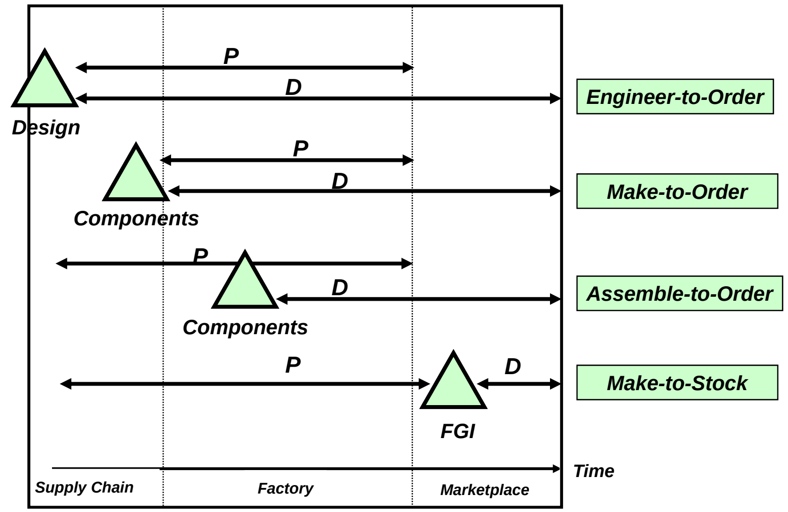
P:D Ratio



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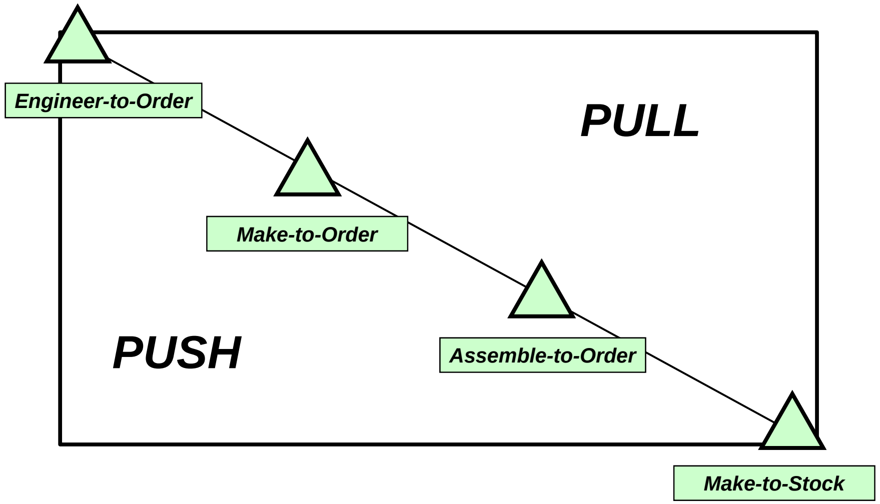
P:D ratio



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MTS, ATO, MTO, ETO

Make-to-Stock (MTS/BTS) / Make-to-Forecast (MTF/BTF)

- Goods made to be placed in stock prior to receiving an order. Typical of commodities and continuous processing.
- Efficient production, but risk of obsolescence / high stock cost

Assemble-to-Order (ATO)

- Producers hold components stock to assemble an order as required by the customer. Typical of line/ batch production.
- Responsive for customised products, but still cost of stock

Make-to-Order / Build-to-Order (MTO/BTO)

- Material ordered and product or service made only after the buyers order is received. Line and job shop production.
- No FGI cost, but potentially less efficient production.

Engineer to order (ETO)

- Product designed & built to customer order. Typical of projects.

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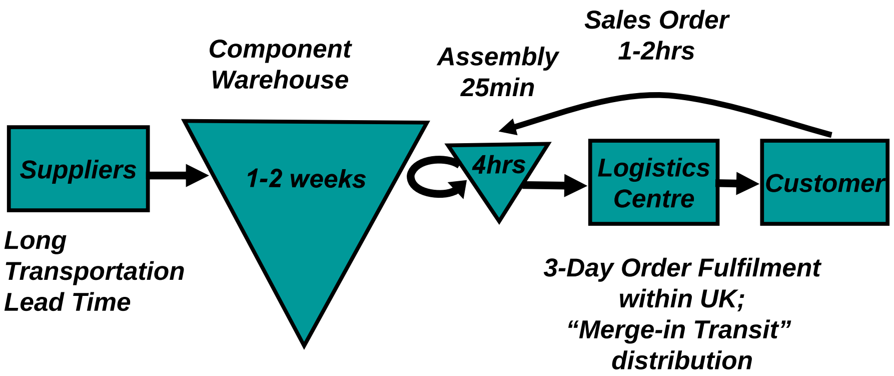
Order Fulfilment in Electronics Sector - Example: DELL



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Mass Customization

..an oxymoron?

The need to 'customize' mass-produced goods to customer needs

An umbrella concept

- Build-to-Order
- Assemble-to-Order
- Late Configuration
- Customisation at point of use
- Customisation through service

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Production Planning and Control

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Production Planning and Control

Basic problem: how to convert customer orders into:

- A production schedule for the multiple process stages on the shop-floor (work orders)
- A supplier schedule for the required materials and components (purchase orders)
- A delivery schedule at the customer interface (delivery promise)

Two basic approaches: **PUSH** and **PULL** scheduling

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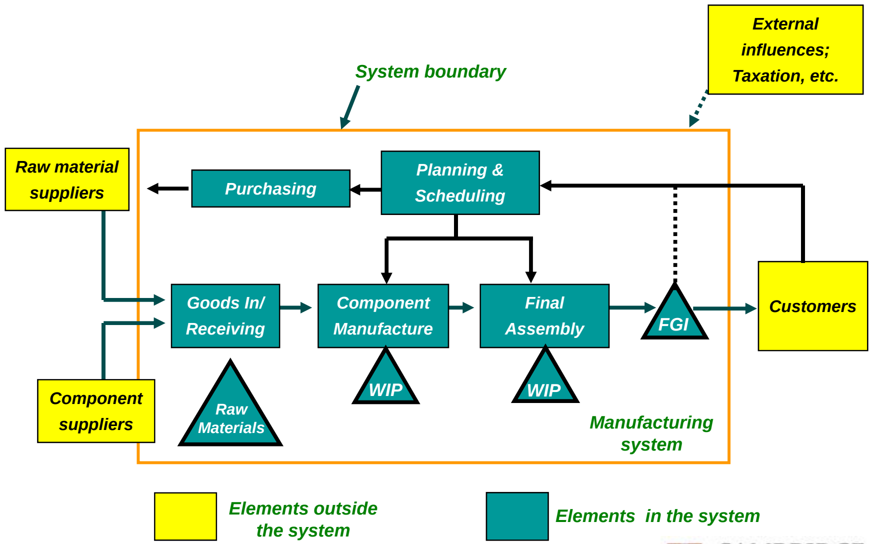
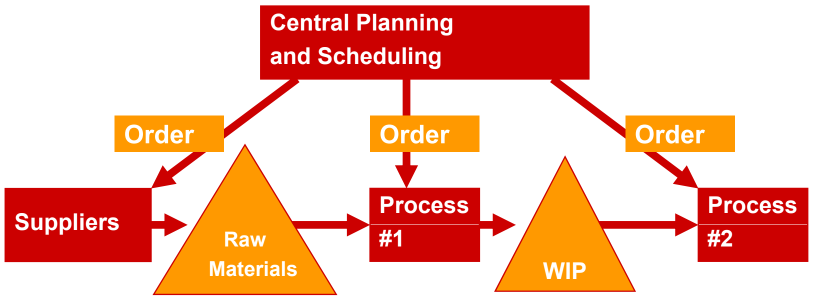
A Simplified Manufacturing System



Material Requirements Planning (MRP)

"Push" Scheduling



– In a **PUSH** system, the orders are planned and issued centrally

– Upon completion, the order is moved forward, until the next process is issued with the order to start processing it

– Hence, the **LAST** process sees the new order **FIRST**

– This is called **BACKWARD** scheduling

MRP – Material Requirements Planning

MRP system were invented in 1960s to cope with computational complexity of scheduling

- Need to plan at top level-item, for all items made in the plant
- What happens if components are used in several final products?

– Computerised inventory control & production planning system

– Schedules component items and processes when needed - no earlier and no later

Definitions:

'MRP is a set of priority planning techniques for planning component items below the product or end item level'

'A set of techniques which uses the bill of materials (BOMs), inventory data and the master production schedule to calculate future requirements for materials. It essentially makes recommendations to release material to the production system.'

New Names, but mostly same Logic...

MRP / MRP I - Material Requirements Planning

- Typical systems: BPICS
- OUTDATED! No capacity feedback loop

→ 'Closed loop' MRP

MRP II - Manufacturing Resource Planning

- Typical systems: Manugistics, i2, Peoplesoft

DRP - Distribution Resource Planning

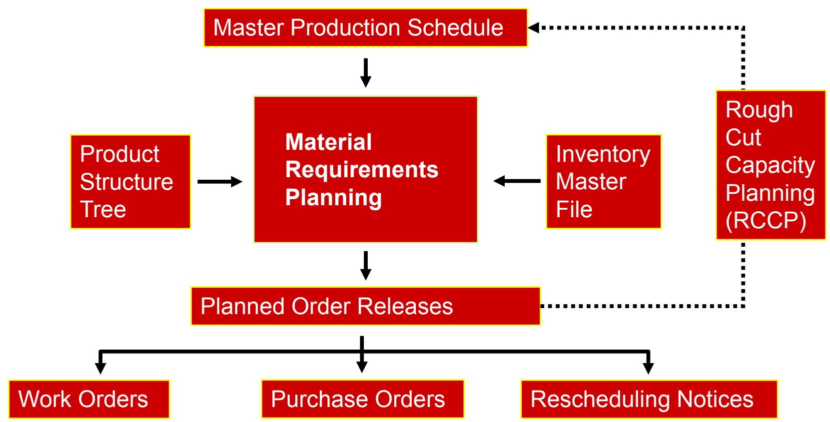
ERP- Enterprise Resource Planning

- updates MRP II with relational DBMS, GUI & client/server architecture
- Typical systems: SAP R/3, mySAP, Baan

APS – Advanced Planning and Scheduling

- Often add-ons to support ERP, short-term planning and scheduling
- Typical systems: i2 Rhythm

MRP: 3 Inputs, 3 Outputs



1. Master Production Schedule

Drives MRP process with a schedule of finished products

Outlines production schedule for top-level items only

Quantities represent production, not demand!

Quantities may consist of a combination of customer orders & demand forecasts

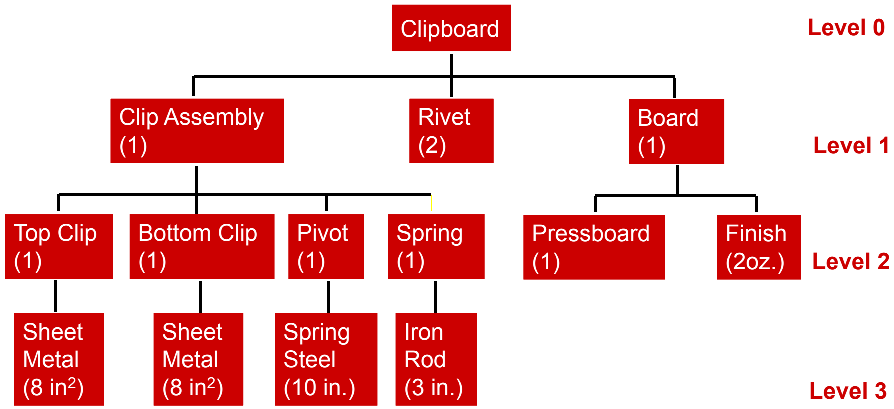
Quantities represent what needs to be produced, not what can be produced

Should be checked by Rough-Cut-Capacity Planning (RCCP) routine

1. Master Production Schedule

MPS	Period							
Item	1	2	3	4	5	6	7	8
Clipboard	86	93	119	100	100	100	100	100
Lapboard	0	50	0	50	0	50	0	50
Lapdesk	75	120	47	20	17	10	0	0
Pencil Case	125	125	125	125	125	125	125	125

2. Product Structure Tree or: Bill-of-Materials (BOM)



2. Bill of Materials

LEVEL	ITEM	Unit of Measure	Quantity
0 - - - -	Clipboard	Ea	1
- 1 - - -	Clip Assembly	Ea	1
- - 2 - -	Top Clip	Ea	1
- - - 3 -	Sheet Metal	In^2	8
- - 2 - -	Bottom Clip	Ea	1
- - - 3 -	Sheet Metal	In^2	8
- - 2 - -	Pivot	Ea	1
- - - 3 -	Iron Rod	In	3
- - 2 - -	Spring	Ea	1
- - - 3 -	Spring Steel	In	10
- 1 - - -	Rivet	Ea	2
- 1 - - -	Board	Ea	1
- - 2 - -	Press Board	Ea	1
- - 2 - -	Finish	Oz	2

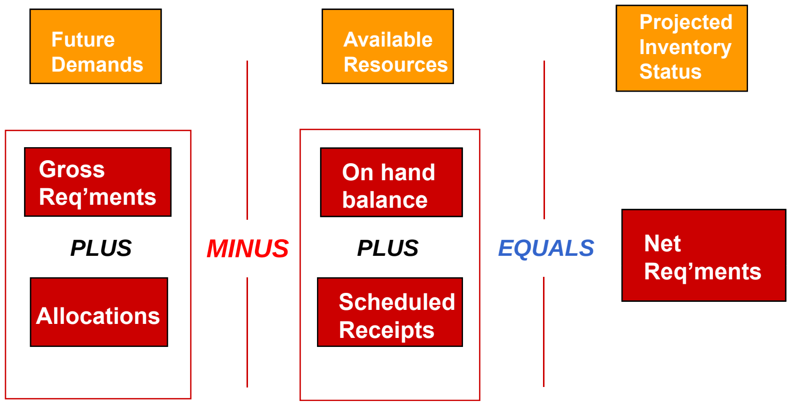
3. Inventory Master File

Description		Inventory Policy	
Item	Board	Lead time	2
Item no.	7341	On-hand stock	53
Item type	Manuf.	Holding cost	1
Product/sales class	Ass'y	Ordering/setup cost	50
Value class	B	Safety stock	25
Buyer/planner	RSR	Reorder point	39
Vendor/drawing	07142	EOQ	316
Phantom code	N	Minimum order qty	100
Unit price/cost	1.25	Maximum order qty	500
Pegging	Y	Multiple order qty	100
LLC	1	Annual demand	5,000

MRP Order Action Logic

Determine	net requirements by
Adding	allocations
to	gross requirements
minus	scheduled receipts
minus	on-hand balance
equals	net requirements

The MRP Gross to Net Logic



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Problems with MRP Systems

- MRP Systems tend to hold more inventory than necessary
- MRP Systems are designed for batch & queue, not for flow
- MRP Systems lengthen lead times unnecessarily
- MRP Systems inherently distort demand patterns in the supply chain

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MRP is...

A good database

A good transaction processor

Essential source of information and almost impossible to replace in many companies!

MRP is not..

A good scheduler

Why?

– Assumes infinite capacity

– Works on fixed batches

– Works on fixed lead times

– Schedules backwards, therefore cannot synchronise

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Just-in-Time & Lean Production

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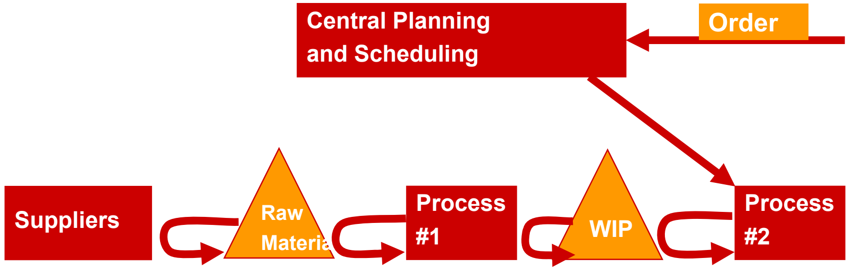
"Pull" Scheduling



– In a **PULL** system, processes are triggered by a replenishment signal

– Upon withdrawal of material from inventory, the preceding process is authorised to start processing, and **ONLY THEN!**

– Hence, the **FIRST** process sees the new order **FIRST**

– This is called **FORWARD** scheduling

– Simplest form: two-bin approach

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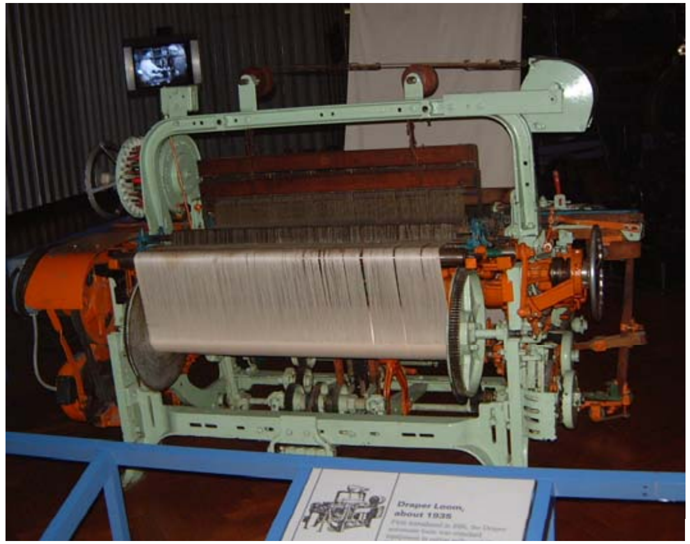
The Automatic Loom of Sakichi Toyoda



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Toyota Production System (TPS)

Taiichi Ohno starts developing TPS in engine shop in 1948

- Pillars of TPS are 'autonomation' (*jidouka*), based on Sakichi's loom, and Just-in-Time (JIT), which came from Kiichiro Toyoda.
- Toyoda Kiichiro: "..in a comprehensive industry such as automobile manufacturing, the best way to work would be to have all the parts for assembly at the side of the line just in time for their user". Ohno 1997.

Principles of TPS:

- Only make what is required, when it is required, just in time
- Use small batches
- Reduce seven wastes (overproduction, inventory, transportation, motion, inappropriate processing, defects, waiting/delay)

Toyota overcame obstacles of economically producing a high variety of products in small batches

Supported by tightly synchronised supplier network at close proximity

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Just-in-Time Scheduling

The idea of JIT merges:

- The supermarket concept of "on-the-shelf inventory"
- The two-bin replenishment system

Production orders are based on replenishment

The demand signal is conveyed via **kanban** cards

- Type 1: Production kanban
- Type 2: Withdrawal kanban

The system is tightly controlled, as it is "fragile", i.e. unable to cope with large swings in volume or product mix

Need to keep schedule variability within 5-10%

Just-in-Time is central part of the Toyota Production System (TPS), also referred to as "Lean Production"

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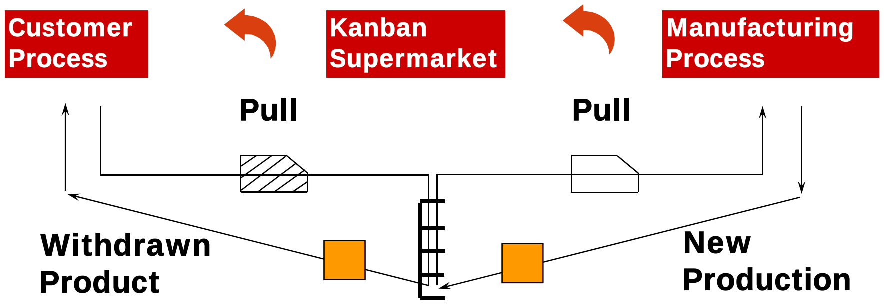
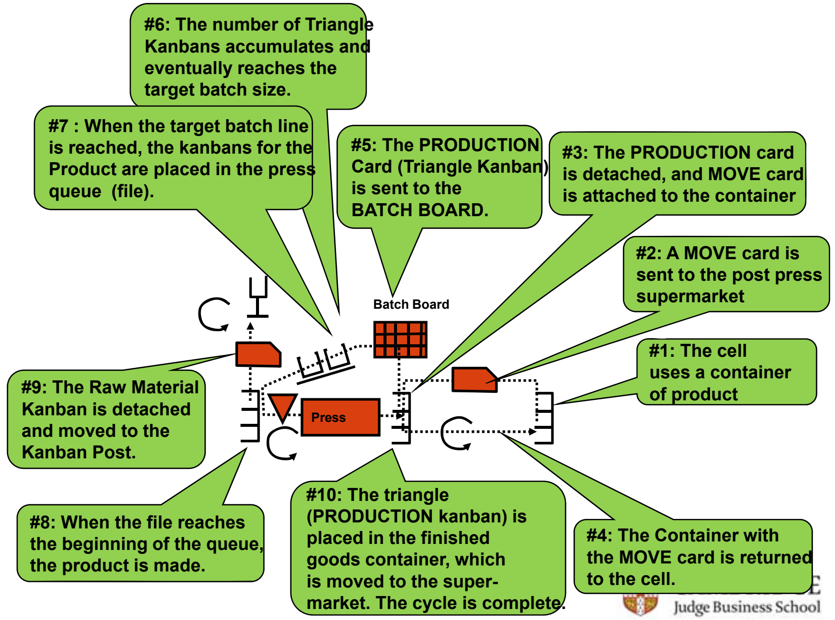
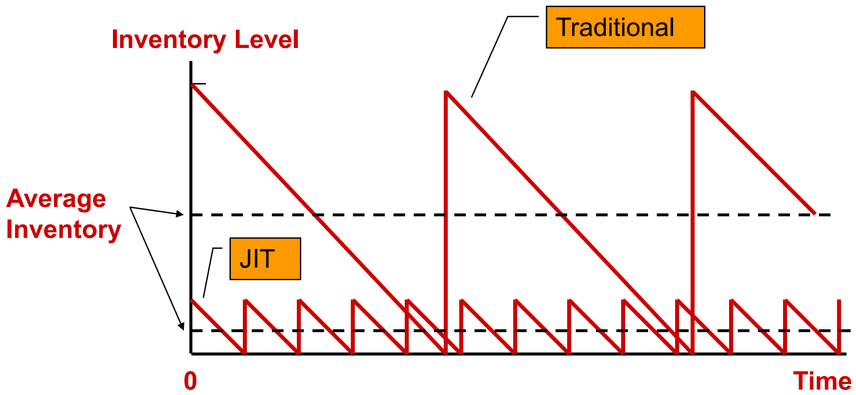
A two kanban system



A Typical Kanban Sequence



Traditional vs.. JIT Inventory



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TPS Elements - Taiichi Ohno

All processes driven to be in control and capable

- Standardised work practices
- "Simplify, highlight deviations, mistake-proof"

Problems are natural and are opportunities to learn, not to blame!

- Most problems arise from not following standards
- Every problem has root cause and counter-measures

Every activity must add value

- Eliminate waste

Make what customers want when they want it, just-in-time

- Smooth production "pulse"

Select and invest in people

- Managers chosen as best teachers/problem-solvers
- Empowerment & multi-skilling

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Theory of Constraints

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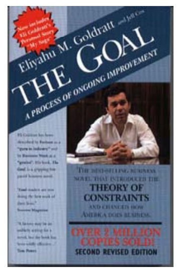
TOC - Key Concepts



– The main concept is FLOW - the importance of constraints and bottlenecks!

– What is a bottleneck?

– Idea: bottlenecks control the performance of a system: "An hour lost at a bottleneck is an hour lost to the system" (Goldratt)

– Only three measures matter: Throughput, Operating Expense, Inventory

– Focus improvement on the bottlenecks, allow the bottleneck to control the activity of the system

– A busy operation is NOT necessarily a productive one

→ Balance flow, not capacity!

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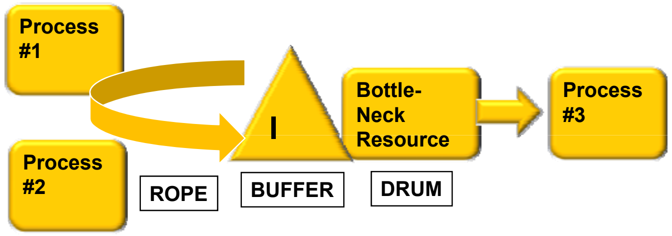
Drum, Buffer + Rope Scheduling

How to schedule operations to maximise throughput?

- Protect throughput at bottleneck with buffer
- Bottleneck becomes pacemaker for entire process



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Session 6

Toyota Production System and Lean Thinking

Improvement

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Two Types of Improvement

1. 'Kaikaku' or 'Kaizen-Blitz'

- Step change
- Short-term execution
- 2-3 day workshops - implement changes on the spot!
- Limited / narrow scope (e.g. one machine or area on shop-floor)

2. 'Kaizen' or Continuous Improvement (CI)

- Literally "Changing something for the better" by eliminating waste
- Long-term activities
- Gradual / incremental improvements
- No limit in focus, often extends to suppliers and distribution

Kaizen Office: dedicated team leading improvement activities

→ ***Kaizen*** and ***Kaikaku*** only work in conjunction!

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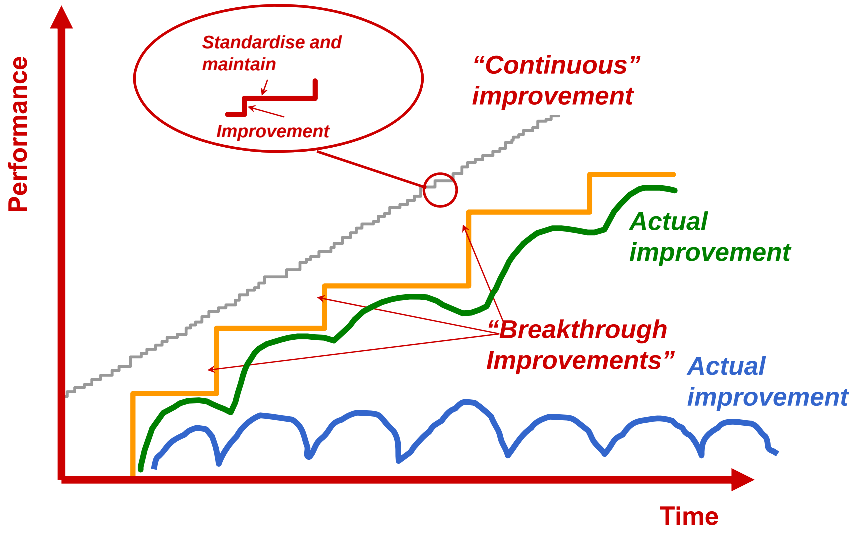
Radical vs. Incremental Improvement



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Lean Thinking

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Where does the term 'LEAN' come from?

- MIT International Motor Vehicle Program
- Started in 1979, ongoing to date!
- 5 Year - 5 Million Dollar Program
- Coordinated by MIT – Researchers from around the World
- Research into all aspects of the Toyota Production System
- Developed assembly plant methodology
- Comparative research – the International Assembly Plant Study
- Policy forums for senior industry, government and union officials
- 'Lean Production' coined by John Krafcik (1989)

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The NUMMI Experience

Joint Venture GM/Toyota plant, closed 1982, reopened in 1984

Dramatic improvements compared to previous GM plant

- Assembly hours/car 36 to 19
- Assembly defects/car 1.5 to 0.5
- Worker absenteeism 15% to 1.5%

Changes:

- Toyota management – Lean Production principles
- Work organization – teams, few job classifications, focus on quality,
- Still unionized workforce

Transfer to other GM plants took many years

- GM management lacked commitment – embarrassment for Roger Smith
- NUMMI plant visits for management were for brief time periods only
- Visiting teams below critical size

→..but: NUMMI showed that lean was not culturally bound!

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The "DNA" of TPS

Should Toyota be afraid of copycats?

- It is possible to copy shop-floor techniques
- Some improvement in productivity and quality will result
- Lack of flexibility in adjusting to change will persist
- System will not able to learn autonomously
- Continuous improvement needs to be driven by workforce, cannot be dictated by management

Dynamic learning capability is key advantage:
Lean is a mindset, a system -- not a 'toolbox'!

Waste – the central Focus of Lean!

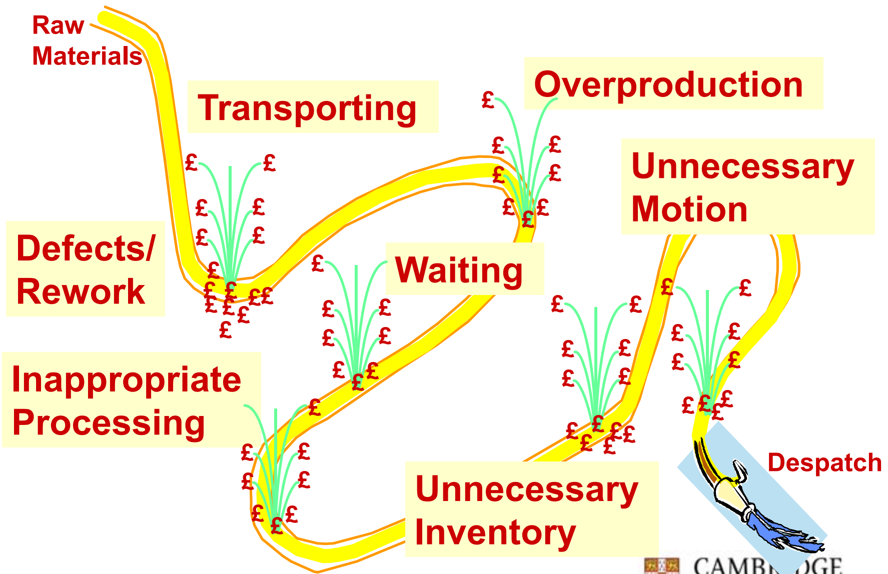
Waste is anything which does not add value to a product or service in any office or manufacturing activity!

..essentially everything the customer is not prepared to pay for!

Frequently used term: "muda" (=waste)

- Muda (waste)
- Muri (excessive strain)
- Mura (unevenness or irregularity)

Ohno's 7 Wastes



Think about a Petrol Station…

Does this add more Value?

Formula 1:

100 litres of fuel

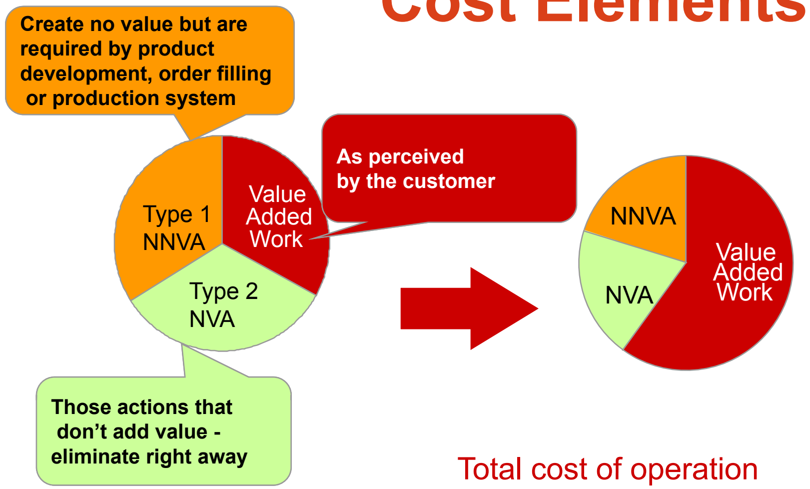
12 litres/second

4 new tyres

Clear 'windscreen'

…in 7-10 seconds!

Cost Elements

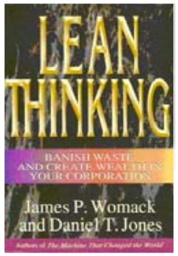


Total cost of operation
- Actual condition -

Total cost of operation
- Condition under continuous improvement -

Five Lean Principles

1. Specify what creates ***value*** from the customers perspective
2. Identify all steps across the whole ***value stream***
3. Make those actions that create value ***flow***
4. Only make what is ***pulled*** by the customer just-in-time
5. Strive for ***perfection*** by continually removing successive layers of waste



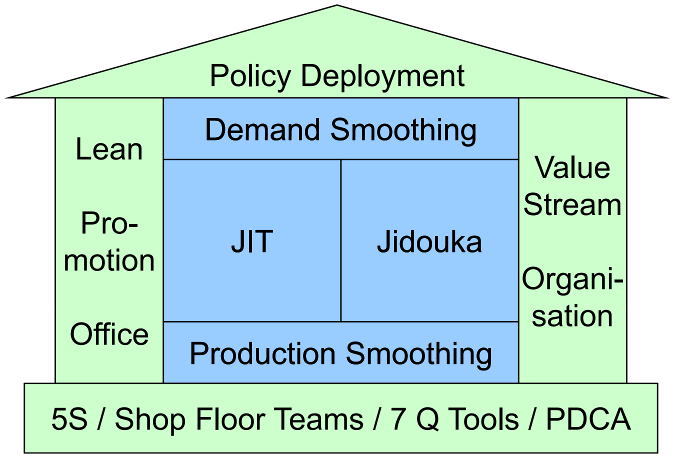
Features of a Lean Organisation

So what does it look like if these principles are put into practice?

Features to look for:

- The learning organisation: mistakes are opportunities!
- Visual management: targets and achievements
- Continuous Improvement activities
- Standard operating procedures (SOPs)
- Empowerment
- Multi-skilling
- Teamwork

The “House of Lean”



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Cases:
Lean Retailing
Lean Services

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Exercise 7 Wastes

Identify examples of the 7 Wastes in a **posh restaurant**, from a customer’s point of view!

Are there additional wastes?

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Case I: Lean Retailing at Tesco

Tesco: Lean Road Map

- How to make products flow right to the shelf?
- Making products flow requires involvement of partners in the value chain

Aim:

- To ensure that the product flowed from the supplier through the distribution centre to store with minimal delays, so giving true “one touch replenishment”.

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Before Merchandisable Units

After Merchandisable Units

Case III: Fujitsu

FUJITSU

Fujitsu service operations (call centre)

- Efficiency-driven, standard times and op/procedures
- Main measures: calls per man day, av. call handling time

→ *Is this "lean"?*

Main idea:

- Use customer feedback to eradicate root cause problem!
- Prevent errors from recurring- "failure demand"
- 40-90% of call volume was preventable

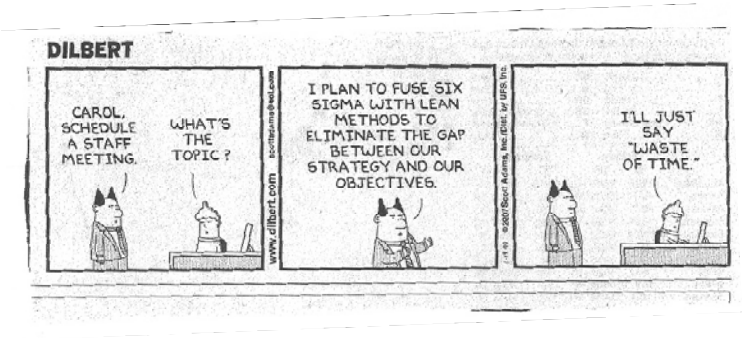
Outcomes:

- Demand down by 60%, cost reduction of 64%, productivity increased by 45%
- Customer satisfaction up 28%, employee satisfaction up 40%
- £200m new business generated

The Seven Service Wastes

1. **Delay** on the part of customers waiting for service, for delivery in queues, for response, in queues, not arriving as promised. The customer's time is not free to the provider!
2. **Duplication.** Having to re-enter data, repeat details on forms, copy information across, answer queries from several sources within the same organisation
3. **Unnecessary movement.** Queuing several times, lack of "one-stop shopping", poor ergonomics in the service encounter
4. **Unclear communication**, and the wastes of seeking clarification, confusion over product or service use, wasting time finding a location that may result in misuse or duplication
5. **Incorrect inventory**. Being out-of-stock, unable to get exactly what was required to the customer
6. **Opportunity lost to retain or win customers**, failure to establish rapport, ignoring customers, unfriendliness, rudeness
7. **Errors** in the service transaction, product defects in the product-service bundle, lost or damaged goods

Source: Bicheno (2004) "The Lean Toolbox"



Implementation of Improvement programs

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Sid's Heroes – Case Study

Sid's Heroes was a BBC series on manufacturing improvement based on lean techniques in the late 1980s

Six companies were visited by Sid, three-day workshops were held in each company

Most were very successful…

1. What operational improvements been made, and will these improvements be sustainable?
2. What are the root causes for the failure, and who is to blame?
3. Could this failure have been prevented, and if so, how?

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Successful Implementation

1. Senior management buy-in and support is a critical enabler
   - Rewards and responsibilities often need to be changed
2. Long-term support & consistent objectives are key
   - Beware of "Fad of the Month" Problem
3. Ownership of improvements needs to reside at process level
   - Beware of how consulting resources are used
4. Measures need to be aligned to top-level goal
   - "What you get is what you measure"!
   - The "Bottom-up" myth

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Session 7
Service
Quality and Six Sigma
Project Management

Service Operations

Service Process Matrix

Degree of customisation (Low → High)

Customer contact (Low → High)

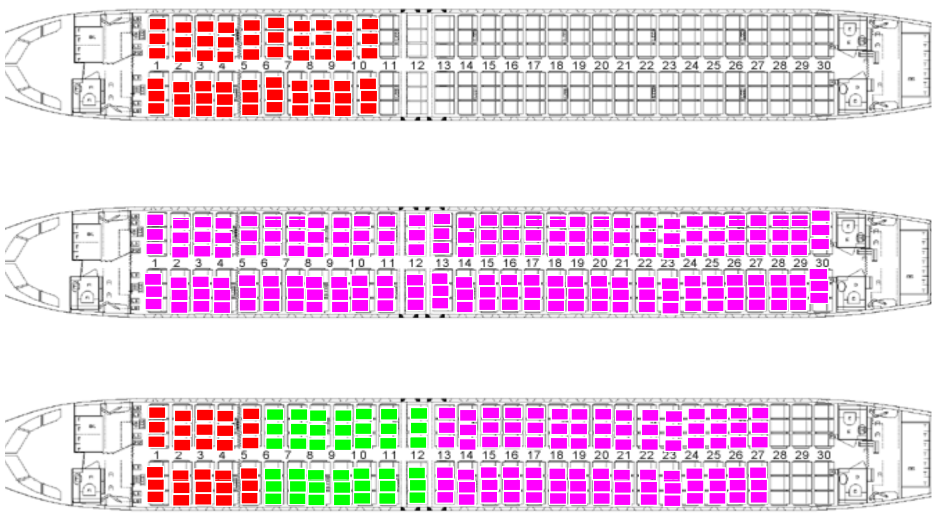
	Low customisation	High customisation
Low contact	***Service Factory*** *Costs associated with facility & equipment e.g.. Airlines, Hotels, Fast food*	***Service Shop*** *'Customised mass services'. e.g.. Car repair, 'Routine' hospitals*
High contact	***Mass Service*** *Customers treated as similar e.g.. Retailing, banking*	***Professional Service*** *Costs principally for 'elite' labour. e.g.. Lawyers, accountants*

Source: Service Operations Management, Roger Schmenner, Prentice Hall

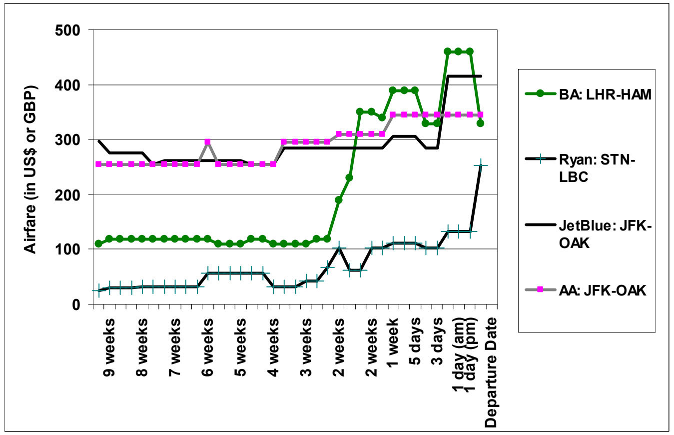
What are the key differences between **Manufacturing** and **Service** Operations?

What are the implications for Operations Management?

Demand and Revenue Management



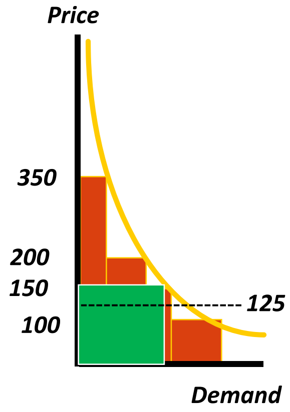
Demand & Revenue Management



Revenue Management: How does it work?

Problem: finite capacity, uncertain demand

1. Segmentation
   - Some customers value time
   - Some customers value money
2. Differentiation
   - Change demand by adjusting price
   - Different price for each customer-time combo
3. Adaptation
   - Simplification needed
   - Stochastic problem → deterministic LP
   - Continuous re-calculation



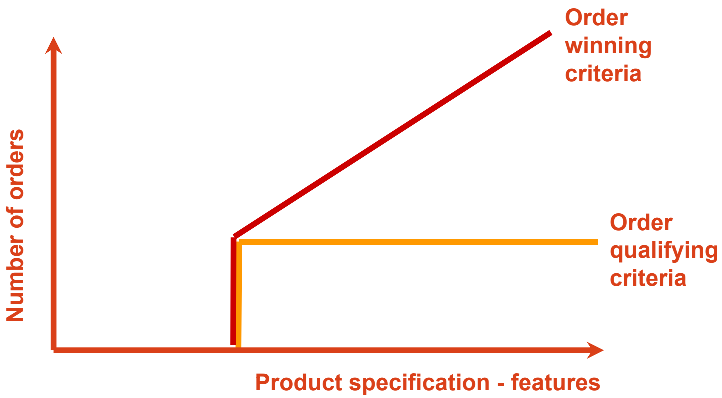
→***It might make sense to sell below cost at times, if price paid > (variable cost for empty seat+ marginal cost for full seat)***

→***Max profit might not occur at full load!***

Distinguish Order Winners from Order Qualifiers

Order Qualifiers: hygiene factor, needed to be considered by customer

Order Winners: distinguishing factors that drive customer choice



The Kano Model I - Product Features

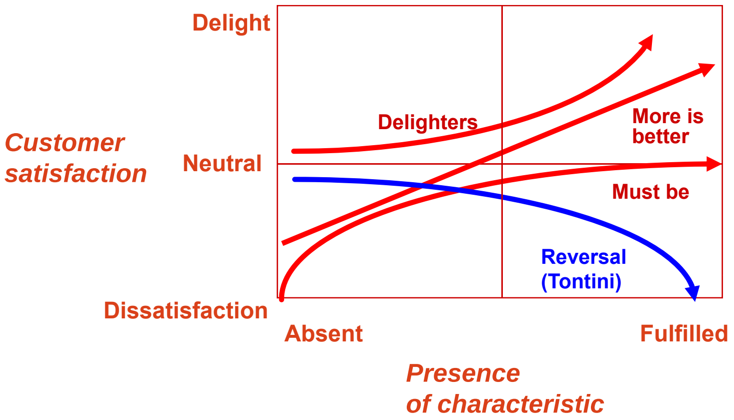
Must be (Basics): characteristics or features taken for granted. (Hotel: clean sheets & hot water)

More is better (Performance): we are disappointed if a need is poorly met, but have increasing satisfaction the better it is met. (Hotel : response time for room service).

Delighter: features that surprise and delight in a positive way (Hotel: wine and flowers upon arrival)

Reversal (Tontini): features that annoy (TV in a smart restaurant)

The Kano Model



Apply the Kano Model..

..to a one-week skiing holiday package!

What are the *Must Be* factors?

What are the *Performance* factors?

What are the *Delighters?*

What are the *Reversal* factors?

Quality

"It costs five to seven times as much to get a new customer as it does to satisfy and keep one."

(TARP research; Struebing, 1996)

Quality Failures in the news

The Challenger Space Shuttle disaster (1986)
- Ignoring "O ring" problems

The Japan-BNFL scandal
- £100m compensation for faked quality data (size of pellets)

The Paris Concorde disaster (2000)
- Poor maintenance on main gear, overload, poor wing tank protection

The Bridgestone - Firestone / Ford Defender debacle (2000)
- Tires decomposing at high speeds, killing 121 people in US
- Recall alone cost £7.5bn

Mercedes A-Class "Elchtest" (1997)
- Retrofitting of ESP systems!

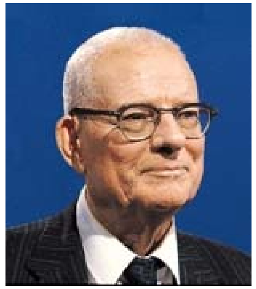
History of Quality Philosophies

1. **Inspect & Reject** (SPC to reduce cost)

2. **Quality control:** aim at Zero Defects: SPC in effect makes a certain number of defects inevitable

3. **Quality assurance:** Use quality standards to ensure documentation of a 'quality process'

4. **Total Quality Management:** standards are self limiting, unresponsive and resented so make quality a "moral" issue for everyone



"In God We Trust …

- all others must bring data"

W Edwards Deming

Deming – Father of the Quality Movement

Taught Statistical Process Control (SPC)

Insisted that top management attended his courses

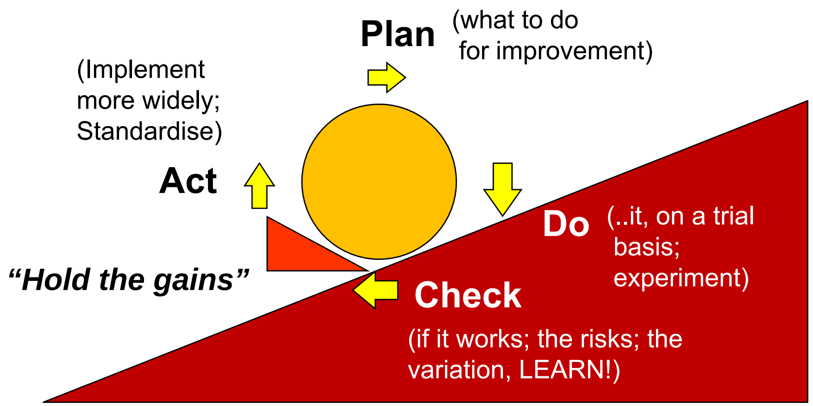
Thesis: natural variation is inherent in all processes. It is the task of management to understand and control the causes of undue variation

Management is responsible for about 85% of quality problems, shop floor employees only control 15%

Emphasis on continuous improvement

Proposed PDCA Wheel

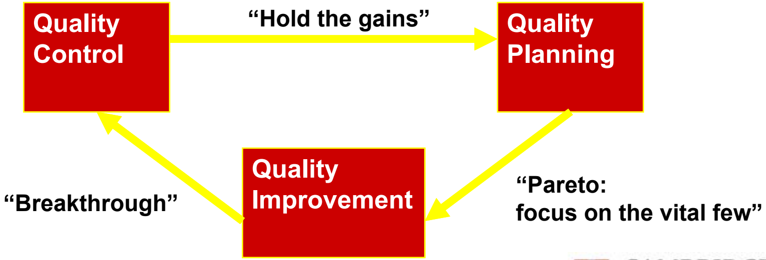
PDCA: The Deming Cycle



Joseph Juran's Trilogy

Juran's Trilogy

- Quality Planning
- Quality Control
- Quality Improvement



Cost of Quality (after Juran)

Appraisal Costs

- To assure outgoing & incoming quality
- Appraisal activities to detect nonconforming items
- Acceptance sampling, inspection, final testing

Prevention Costs

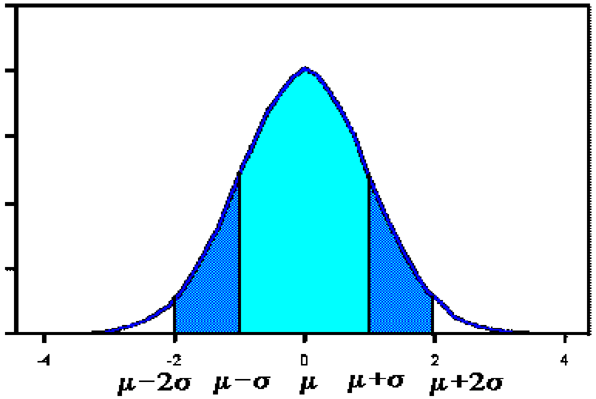
- Prevent rework, scrap, and other failures
- Activities include process control, preventive maintenance, most ISO 9000 activities, training

Failure Costs

- Internal failure: scrap, rework, rectification, retest, and including opportunity costs
- External failure: warranty, returns, customer dissatisfaction, customer defection

Six Sigma

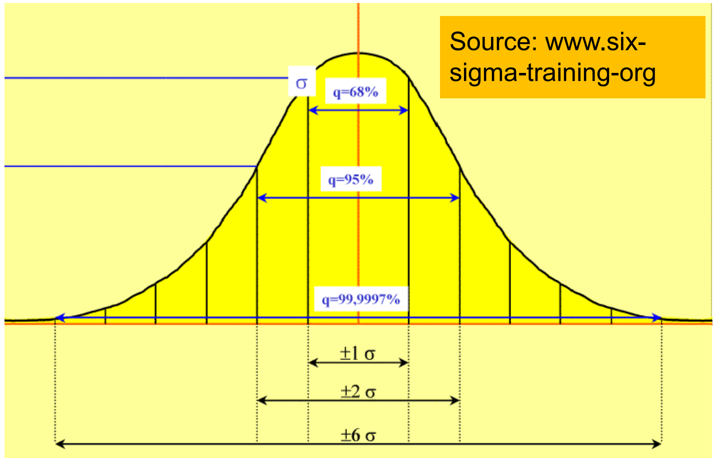
Six Sigma: Normal distribution



Source:
www.stat.yale.edu

Normal distribution
μ: mean
σ: standard deviation

Where are those six sigma's?



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History of Six Sigma

6σ Goal declared by Motorola in 1987

- At the time it was operating at 3.8σ = defects 10,000ppm

Key Steps

- Statistical tools used to analyse processes
- Reached quality plateau of 5.2σ (108 ppm) in 1 year and reduced throughput time by 90% in many processes
- Dedicated 'Black Belt' resources in 1991
- A formal discipline and structured approach developed

Outcome: achieved 5.83σ (7 ppm) in three years

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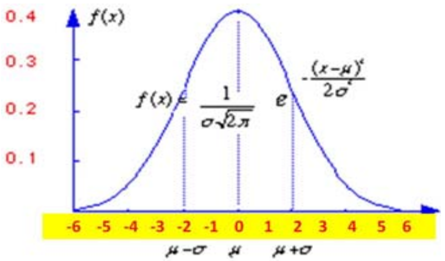
Six Sigma background

Core Principles:

- Everything is a process
- Every process has **variation**
- Every process can be measured
- Every process can be improved and variation reduced
- The target is 3.4 defects per million opportunities in customer output



$$\sigma = \sqrt{\frac{\sum (x-\bar{x})^2}{n}}$$

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Sources of variability

1. Supply uncertainty
   - Materials and component quality
   - Supplier delivery reliability
   - Raw material prices
   - Shifts in technology
2. Throughput uncertainty
   - Machine breakdown
   - Defects and rework
3. Demand uncertainty
   - Variability in product use & product purchase
   - Seasonality and trends in demand
   - Fashion & product life cycle effects
   - Competitor action

Source: adapted from Davis 1993

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The Six Sigma Approach

- Six Sigma aims to define the causes of defects, measure those defects, and analyze them so that they can be reduced.
- During the Measure Phase, the overall performance of the core business process is measured.
- A Six Sigma defect is defined as **anything outside of customer specifications**
- This is called an "opportunity" (to do better, essentially…)
- A Six Sigma opportunity is the total quantity of chances for a defect

The Inspection Exercise I

The Inspection Exercise II

How to calculate a sigma level?

Step 1: Calculate the DPMO

First we calculate Defects Per Million Opportunities (DPMO) and based on that a Sigma is decided from a predefined table (see handout):

$$\text{DPMO} = \frac{\text{Number of defects observed}}{\text{Number of Units}} \times 1{,}000{,}000$$

Where:

- Number for defects is total number of defects found;
- Number of units is the number of units produced ;

Step 2: Covert DPMO into a Sigma Level

- Use the conversion table

***Cave:* A *1.5 Sigma process walk* is not considered here, but is commonly factored into the calculation!**

Yield to Sigma Conversion Table

Yield %	Sigma	Defects Per Million Opportunities
99.9997	6.00	3.4
99.9995	5.92	5
99.9992	5.81	8
99.9990	5.76	10
99.9980	5.61	20
99.9970	5.51	30
99.9960	5.44	40
99.9930	5.31	70
99.9900	5.22	100
99.9850	5.12	150
99.9770	5.00	230
99.9670	4.91	330
99.9520	4.80	480
99.9320	4.70	680
99.9040	4.60	960
99.8650	4.50	1,350
99.8140	4.40	1,860
99.7450	4.30	2,550
99.6540	4.20	3,460
99.5340	4.10	4,660
99.3790	4.00	6,210
99.1810	3.90	8,190
98.9300	3.80	10,700
98.6100	3.70	13,900
98.2200	3.60	17,800
97.7300	3.50	22,700
97.1300	3.40	28,700
96.4100	3.30	35,900
95.5400	3.20	44,600
94.5200	3.10	54,800
93.3200	3.00	66,800
91.9200	2.90	80,800
90.3200	2.80	96,800
88.5000	2.70	115,000
86.5000	2.60	135,000
84.2000	2.50	158,000
81.6000	2.40	184,000
78.8000	2.30	212,000
75.8000	2.20	242,000
72.6000	2.10	274,000
69.2000	2.00	308,000
65.6000	1.90	344,000
61.8000	1.80	382,000
58.0000	1.70	420,000
54.0000	1.60	460,000
50.0000	1.50	500,000
46.0000	1.40	540,000
43.0000	1.32	570,000
39.0000	1.22	610,000
35.0000	1.11	650,000
31.0000	1.00	690,000

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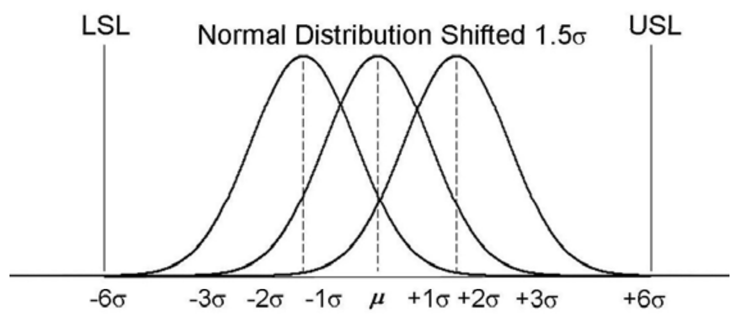
1.5σ Process walk



LSL: Lower Specification Limit
USL: Upper Specification Limit

Source: *Integrated Enterprise Excellence Volume III*

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The Magnitude of Difference...

Sigmas	*% Good*	*Spelling*	*Time*	*Distance*	*PPM*
1s	*31%*	*170 spelling errors per page*	*31.75 years per century*	*From here to the moon*	*632,120*
2s	*69.1%*	*25 spelling errors per page*	*4.5 years per century*	*1.5 laps around the world*	*308,537*
3s	*93.3%*	*1.5 spelling errors per page*	*3.5 months per century*	*One trip from North to South Brazil*	*66,803*
4s	*99.4%*	*1 spelling error in each 30 pages*	*2.5 days per century*	*45-minute drive on a highway*	*6,210*
5s	*99.98%*	*1 spelling error in one encyclopedia*	*30 minutes per century*	*A short drive to the closest gas station*	*233*
6s	*99.9997%*	*1 spelling error in all books in one small library*	*6 seconds per century*	*4 steps in any direction*	*3.4*

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How to use Six Sigma

1. A statistical measure of products, processes, and service excellence.
   - Using "sigma"-levels allows for the comparison across industries, processes and services
2. A business goal for achieving operational excellence:
   - Improve process performance
   - Reduce cycle times
   - Reduce defects
3. A disciplined, data-driven problem solving technique:
   - Customer-focused
   - Team-based
   - Results-oriented

Process Six Sigma, Design for Six Sigma, New Six Sigma

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Six Sigma – DMAIC Technique

			Focus	
	Define	***Problem Definition***		Practical Problem
		A Identify Project CTBs		
		B Develop Team Charter		
		C Define Process Map		
Characterize	Measure	***What is the frequency of defects?***		Statistical Problem
		1 Select CTB Characteristic	Y	
		2 Define Performance Standards	Y	
		3 Validate Measurement System	Y	
		4 Establish Process Capability	Y	
Characterize	Analyze	***When, where and why do defects occur?***		Statistical Solution
		5 Define Performance Objective	X's	
		6 Identify Sources of Variation	X's	
Optimise	Improve	***How can we improve the process?***		Practical Solution
		7 Screen Potential Causes	Vital few X's	
		8 Discover Variable Relationships	Vital few X's	
		9 Establish Operating Tolerances	Vital few X's	
Optimise	Control	***How can we maintain the improvement?***		Guaranteed Life
		10 Validate Measurement System	Vital few X's	
		11 Determine Process Capability	Vital few X's	
		12 Implement Process Controls	Vital few X's	

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Lean, Six Sigma, TOC:
When to use which approach?

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TABLE 2 Comparison of Improvement Programs

Program	Six Sigma	Lean thinking	Theory of constraints
Theory	Reduce variation	Remove waste	Manage constraints
Application guidelines	1. Define. 2. Measure. 3. Analyze. 4. Improve. 5. Control.	1. Identify value. 2. Identify value stream. 3. Flow. 4. Pull. 5. Perfection.	1. Identify constraint. 2. Exploit constraint. 3. Subordinate processes. 4. Elevate constraint. 5. Repeat cycle.
Focus	Problem focused	Flow focused	System constraints
Assumptions	A problem exists. Figures and numbers are valued. System output improves if variation in all processes is reduced.	Waste removal will improve business performance. Many small improvements are better than systems analysis.	Emphasis on speed and volume. Uses existing systems. Process interdependence.
Primary effect	Uniform process output	Reduced flow time	Fast throughput
Secondary effects	Less waste. Fast throughput. Less inventory. Fluctuation—performance measures for managers. Improved quality.	Less variation. Uniform output. Less inventory. New accounting system. Flow—performance measure for managers. Improved quality.	Less inventory/waste. Throughput cost accounting. Throughput—performance measurement system. Improved quality.
Criticisms	System interaction not considered. Processes improved independently.	Statistical or system analysis not valued.	Minimal worker input. Data analysis not valued.

Lean, 6 Sigma, TOC

Source: Dave Nave, *Quality Progress* 2002

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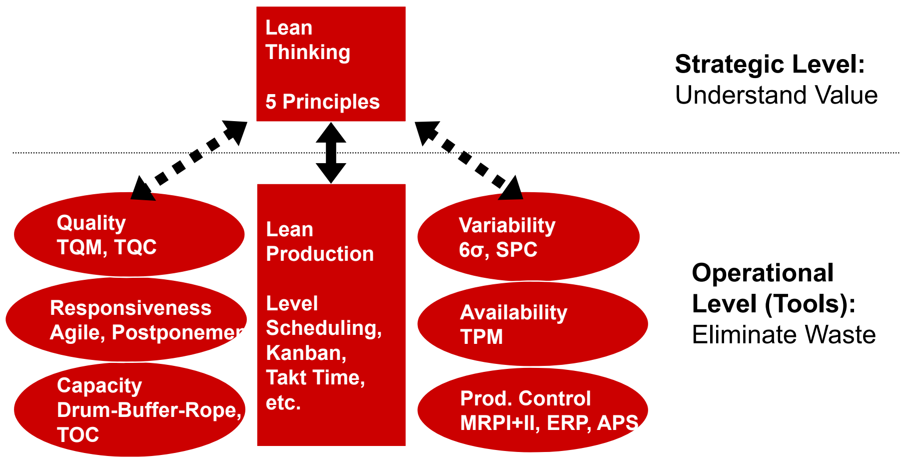
Strategic vs. Operational Perspective



Source: Hines, Holweg, Rich (2004) "Learning to Evolve, A Review of Contemporary Lean Thinking", IJOPM

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Project Management

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Project Management & New Product Development (NPD)

- The key distinction to manufacturing and service is **n=1**!
- Project Management
  - There can be a fixed deadline (2012 Olympics)
  - There can be a fixed budget (public procurement)
  - There generally is a set of constraints that need to be balanced
- New Product Development
  - The process from idea, concept, design engineering, prototyping, testing, to product launch ("Job zero")
  - New product development is a critical capability, no more or no less important than manufacturing, or marketing & sales
- From an operational point of view, NPD is a special case of project management

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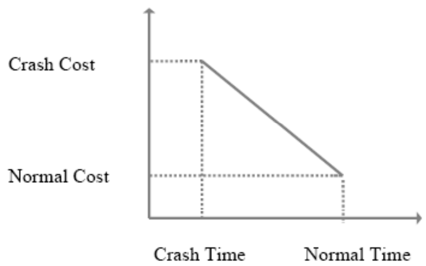
Critical Path Method: "Time is Money"

- Key question in project management: how to schedule activities in the project to meet the given objectives of time, budget, or both?
- The method that does this is called the "Critical Path Method", developed by Lockyer in 1978.
- In simple terms, **the critical path is the least amount of time needed for the whole project to complete**.
- However, **most activities can be expedited at extra cost (called "crash" time, and "crash" cost)** through overtime, outsourcing, etc.
- CPM helps determine whether or not this is beneficial!



The Steps in CPM

Step 1. *A Network diagram is used to show precedence relationships among activities that comprise project:* Activities appear on arcs ("Activity on arc"); arcs define precedence.

Step 2. Four pieces of information required for each activity:

- *Normal time: time to complete activity under normal conditions*
- *Normal cost: cost of activity if completed in normal time*
- *Crash time: minimum time in which activity can be completed*
- *Crash cost: cost of activity if completed in minimum time*

Step 3. Project network is assumed to use normal times and costs for all activities.

Step 4. If resulting project completion time is satisfactory, all activities are scheduled at normal completion times.

- If completion time is too long, project can be completed in less time at greater cost by 'crashing' (reducing the activity time of) some activities:

$$\text{Crash cost /unit time} = \frac{\text{Crash cost} - \text{normal cost}}{\text{Normal time} - \text{crash time}}$$

Note: In general, do not crash an activity as far as possible, only as far as necessary.

Step 5. Cost of project is given by total normal cost of all activities plus the cost incurred by crashing

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Exercise Addenbrooke's Hospital I

- The Head of Department at Haematology wants to establish a new diagnostic service for Leukaemia patients.
- The project budget is **£40,000**, it needs to be in place within **six weeks**, and the procedure requires a new piece of equipment to conduct the test.
- The project has the initial steps:
  - Select operators for the new equipment
  - Procure the new piece of equipment
  - Complete auditing paperwork on Medical Equipment Purchases
- Further steps include
  - Train the operators
  - Test the equipment for safety

Exercise Addenbrooke's Hospital II

The Department Head knows how long each activity takes, its cost, and the cost and extent that expediting is possible:

(a) *Select operators normally takes 3 weeks at a cost of £4000,* but could be reduced to as little as 1 week, if he is willing to expend £8000.

(b) *Procure equipment takes 2 weeks at a cost of £5000. He* cannot obtain the equipment more quickly, at any price.

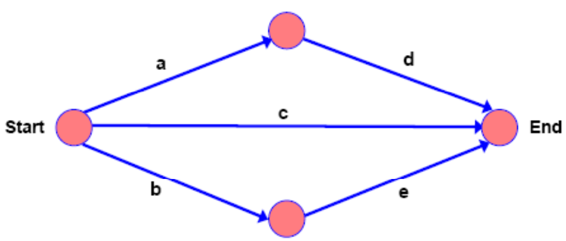
(c) *Complete EU paperwork takes 6 weeks at a cost of £10,000,* which can be expedited by hiring more clerks, who can get this down to 4 weeks, if he is willing to pay £14,000.

(d) *Train operators normally takes 4 weeks, at a cost of £8000,* but can be done in 2 weeks, but then the cost is £13,000.

(e) *Test equipment normally takes 3 weeks and costs £6000,* but can be done in 1 week, if he will pay £14,000 instead.

Exercise Addenbrooke's Hospital III

Activity		Predecessors	Normal Time (wks)	Normal Cost (£)	Crash Time (wks)	Crash Cost (£)
Select operators	a	none	3	4000	1	8000
Procure equipment	b	none	2	5000	2	5000
Complete EU paperwork	c	none	6	10,000	4	14,000
Train operators	d	a	4	8000	2	13,000
Test equipment	e	b	3	6000	1	14,000



Exercise Addenbrooke's Hospital IV

- The normal project time is the longest path through the network, from Start to End, called the **critical path.** Here, the critical path is *......, with length ..... weeks.*
- The normal project cost is the sum of the normal costs for **all activities.** Here, the normal activity costs sum to £..........
- The project completion time can be reduced only by **crashing an activity on the critical path, i.e., reducing the** time of the activity by an appropriate amount. Here, we can reduce the completion time to .... weeks by crashing either activity .... or activity ....
- It costs **£........./week to crash activity "...." [ ]**
- It costs **£........./week to crash activity "...." [ ]**
- Thus, we choose to crash .... *by ..... week, which costs £..........* Although it is **possible to crash "....." *by as much as* ..... *weeks, we* only need to crash it ..... week in order to meet the ...... week** deadline.
- Outcome:

PERT, Critical Chain and Gantt Chart

Program (or **Project**) **Evaluation and Review Technique (PERT)**

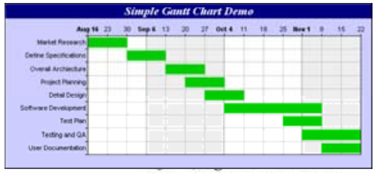
- Charts events in numbers (10s, 20s, 30s,..)
- Is able to assign probabilities to tasks

Critical Chain (adoption of TOC in NPD by Goldratt)

- Focus on resources and their dependencies in order to understand critical path
- Do not search for *optimal solution* due to uncertainty. 80/20 rule.
- Add buffers (time, resources)
- Monitor progress via consumption of buffers, not by task completion

Gantt chart

- Graphical representation of critical path



Session 8
Supply Chain Management

Why do we talk about it?

Traditional thinking: competition is driven by the 4P's

- Supply chain capabilities significant determinant of competitiveness
- *Wal-Mart* versus *K-Mart*
- *Compaq/HP* versus *Dell*

A final product is not the sole achievement of the OEM

- Customer experience is determined by supply chain: quality, cost, delivery
- Significant proportion of value sourced from suppliers!

Supply chains are connected systems:

- Competitiveness of one tier is a function of the supply and distribution functions, i.e. surrounding tiers.

"Value Chains compete, not individual companies!" (M Christopher)

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Supply Chain Management (SCM) as Competitive Advantage

How do companies use SCM as competitive instrument?

Examples?

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Operations vs. SCM

Operations Management

- Main concern is to maximise the efficiency of the internal processes involved
- Focus: focal firm only
- "Optimises" intra-firm processes with respect to the impact on the focal firm, and immediate customer

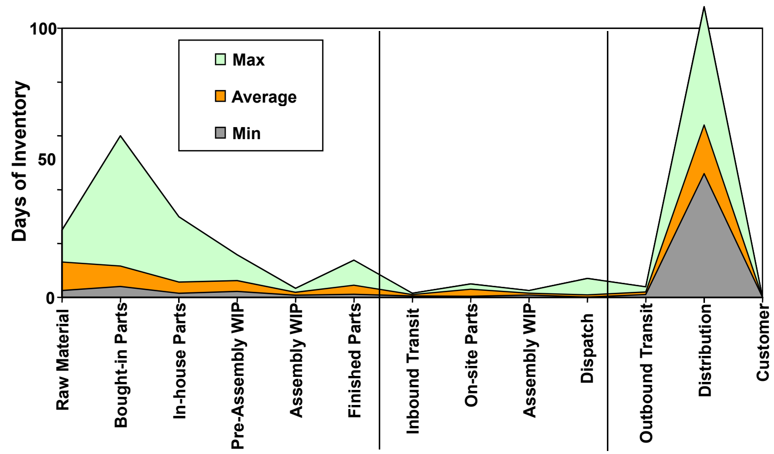
Supply Chain Management

- Main concern is to manage inter-firm networks to maximise the value to the ultimate customer ("user/chooser")
- Focus: dynamic interplay between firms
- Sub-optimisation of the operation at the local firm in order to support holistic strategy

***Local** versus **Global** Optimisation:*

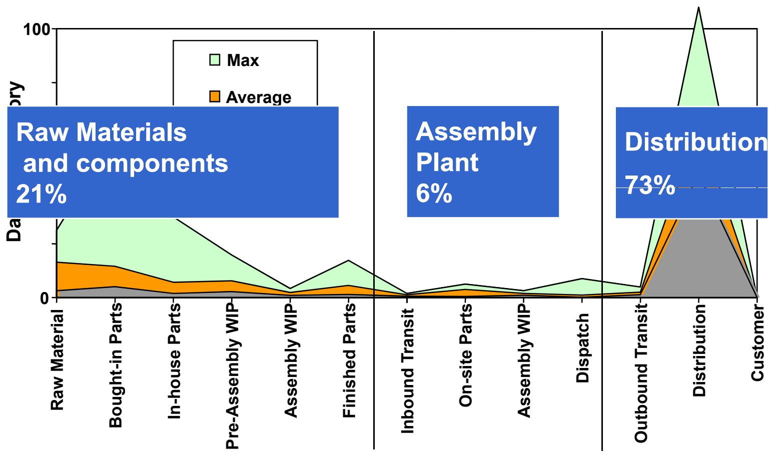
SCM is the differential decision making when considering the firm within its value chain network!

Inventory Profile of the UK Automotive Supply Chain



Source: Holweg and Pil 2004

Inventory Profile of the UK Automotive Supply Chain



Source: Holweg and Pil 2004

Aligning Supply Chain Incentives

Supply chain management involves managing *".. upstream and downstream relationships with suppliers and customers in order to create enhanced value in the final market place at less cost to the supply chain **as a whole**" (M Christopher)*

What mechanisms are at hand to implement this "sub-optimisation"?

1. **Power** balance: dictate strategy
2. **Shared rewards**: long-term lock-in, shared gains

How to go about it (Narayanan and Raman, HBR 2004)?

1. Acknowledge that an incentive misalignment exists
2. Diagnose the cause for the misalignment
3. Change incentives (contracts, performance measures) to reward partners for acting in the supply chain's best interests
4. Review periodically, and educate managers across tiers.

Power in the Supply Chain

– Everyone in the supply chain seeks to appropriate value for themselves from participation!

– Certain players recognise that they have limited power to appropriate value, but would seek to leverage more value if they could

– **Understanding power structures is important for explaining inter-organisational dynamics**

– Toyota model: based on transforming power through creation of hierarchies of structural dominance

– Toyota is dominant player in the system, able to control key resources that appropriate value

– Creates dependents (suppliers) who provide no threat to the flow of value appropriation

Source: Cox 1999

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Managing Supplier Relations

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The Supplier Relationship I

Strategic Coalitions (Porter, 1985)

- Idea of setting up strategic coalitions within the value system to broaden up the effective scope of the company's chain.
- Importance and impact of coalitions as means of gaining the cost or differentiation advantages by vertically linking companies without actually integrating them.
- Long-term agreements among independent firms that go beyond normal market transactions.

"Co-makership", (Merli 1991)

- Supplier-client relations as a main business asset.
- long-term and stable relationships, a limited number of suppliers, a global certification system and supplier rating based on cost, rather than on price.
- The cost rating considers: quality cost, delivery related cost (for reserve inventory, production interruptions and even lost sales), response time cost, supply lot cost, costs linked to lack of improvement, technological obsolescence cost.

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The Supplier Relationship II

Adversarial versus collaborative sourcing

- *Arms-length & price driven*

  versus
- *Collaborative, trust-driven supplier relationships*

Research shows that

- plants with fewer suppliers have better quality
- trusting relationships show better performance

Linked to debate on Lean Production & JIT

- Japanese model showed superiority also in the supply chain
- See: Womack, Jones and Roos "The Machine", 1990

Key studies

- Macbeth & Ferguson 1994: "Partnership Sourcing"
- Lamming 1993: "Beyond Lean Supply"
- Hines 1994: "Creating World-Class Suppliers"

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Why are the Japanese so much better…?

Performance Indicator	Suppliers to US auto plants	Suppliers to Japanese transplants	Suppliers of… Chrysler	Ford	GM	Honda	Nissan	Toyota
Inventory turns	25.4	38.3	28.3	24.4	25.5	38.4	49.2	52.4
Percentage change in manufacturing costs compared with previous year	+ 0.65%	- 0.85%	+ 0.69%	+ 0.58%	+ 0.74%	- 0.9%	- 0.7%	- 1.3%
Percentage of late deliveries	2.96%	1.38%	4.45%	1.70%	3.04%	2.11%	1.08%	0.44%
Emergency shipment costs in US$m	714	371	1,235	446	616	423	379	204

Source: Liker and Wu 2000

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Secrets of Japanese Success

1. Long-term collaborative relationship
   - Trust and commitment, respect of the right of mutual existence
2. Dual sourcing
   - Component volume is adjusted according to performance
   - Constant positive pressure
3. Improvement
   - Collaboration with suppliers on operational improvement; example: Toyota's Supplier Support Center (TSSC) in Kentucky
   - Annual cost reductions are realised in collaboration, not isolation
4. Operations and logistics
   - Level production schedules to avoid spikes in the supply chain
   - Milk-round delivery systems that can handle mixed-load, small-lot deliveries
   - Disciplined system of JIT delivery windows at the plant; suppliers deliver only what is needed, even if this compromises load efficiency in transport

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From 'Exit' and 'Voice' to 'Hybrid Collaborative' Mode of Exchange

EXIT	VOICE	HYBRID COLLABORATIVE
Arms-length & transactional	Long-term & relational	Long-term & relational
Open for new suppliers to bid	Set of potential suppliers mostly closed	Open to new suppliers, after a vetting period
Competitive selection by low bid – frequent and speedy exit	Selection based on capabilities -- exit rare and slow	Competitive assessment -- intermediate frequency and speed of exit
Design simplified by customer to enlarge pool of suppliers	Design controlled by customer, supplier involved via resident engineer	Larger design role for supplier, attention to supplier design capabilities
No equity stake	Often an equity stake	Equity stake depends on criticality of technology
Contracts for governance	Norms /dialogue for governance	Norms + process management routines for governance
Codified procedures	Tacit procedures	Process management routines make procedures explicit

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Source: Helper 2005

Supplier Relations: Critical Choices

- Long-term collaboration or short term flexibility?
- Problem solving: exit, voice or hybrid strategy?
- Single, dual or multiple sourcing?

→ What strategic value does the supplier contribute?

→ Quality, Cost, Delivery, Service.. but also Innovation, Technology, Responsiveness, etc.

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Building Deep Supplier Relations

Conduct joint improvement activities.
- Exchange best practices with suppliers.
- Initiate kaizen projects at suppliers' facilities.
- Set up supplier study groups.

Share information intensively but selectively.
- Set specific times, places, and agendas for meetings.
- Use rigid formats for sharing information.
- Insist on accurate data collection.
- Share information in a structured fashion.

Develop suppliers' technical capabilities.
- Build suppliers' problem-solving skills.
- Develop a common lexicon.
- Hone core suppliers' innovation capabilities.

Supervise your suppliers.
- Send monthly report cards to core suppliers.
- Provide immediate and constant feedback.
- Get senior managers involved in solving problems.
- Turn supplier rivalry into opportunity.
- Source each component from two or three vendors.

Create compatible production philosophies and systems.
- Set up joint ventures with existing suppliers to transfer knowledge and maintain control.
- Understand how your suppliers work.
- Learn about suppliers' businesses.
- Go see how suppliers work.
- Respect suppliers' capabilities.
- Commit to co-prosperity.

Source: Liker and Choi 2004.

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The Renault-Nissan Case

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Crisis at Nissan

	FY'99	FY'06
Global sales	2.53 million units	3.48 million units
Global market share	4.9%	9% (combined with Renault)
Domestic market share	19.7%	13.2%
Consolidated operating profit margin	1.4%	9.2% (2007: 7.3%)
Net income	-684 billion JPY	461billion JPY
Debt	2 trillion JPY	2001: *zero*

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Problems identified by Alliance team

- Lack of profit orientation
- Insufficient focus on customers
- Lack of cross-functional, cross-border, intra-hierarchical lines within the company
- Lack of a "sense of urgency"
- No shared vision or common long-term plan

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Solution: Reduction..

50% in the number of suppliers

20% in overall purchasing costs

50% in lead times

50% in number of platforms

30% in capacity

20% in administration and sales cost

20% in number of distribution subsidiaries

10% in number of retail outlets

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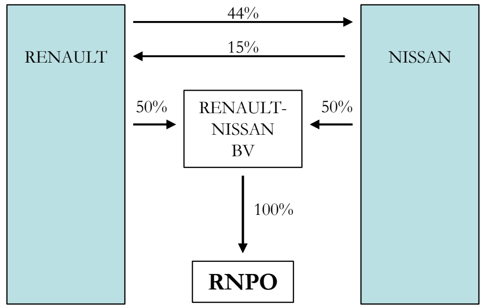
Purchasing: Organizational change I RNPO (2001)



Attempt to have best of both worlds?

Common global purchasing turnover Nissan and Renault

2001: 30% → 2008: 85%

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Purchasing: Organizational change II MC-AFL (2003)

MC-AFL: Administration for Affiliated Companies, set up to improve relationship with suppliers after rigorous supply chain restructuring

New Group Enforcement: part of the Nissan Production Way

E.g. 2005: Nissan acquired 42% of previous supplier Calsonic-Kansei

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Did Nissan go too far?

2004: industry-wide steel shortage

Nissan stopped production for 5 days in November-December 2004, and again for 2 days in March 2005

→ 40,000 cum. units loss of production

→ 16 billion JPY (£120 million) loss in profit

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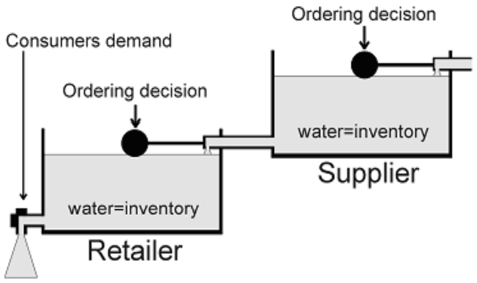
Implications

1. Inflicting a "blanket change" on an entire productive system as Nissan tried to achieve, can cause unwanted results.
2. Nissan and Renault attempted to get the "best from both worlds", but did not fully consider the consequences of "mixing and matching" parts of systems that had been developed as intrinsic wholes.
3. The lead-time for adjusting the various features of supplier relationships differs considerably, first and foremost for trust!
4. With hindsight it can be argued that a more balanced evaluation of the supply chain, i.e. not only financial but also operational, would have led to a more balanced approach to reform.

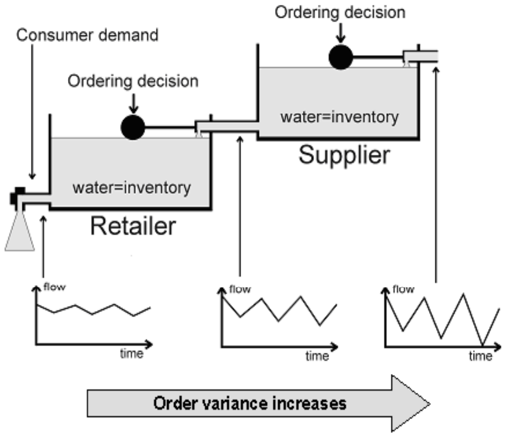
Supply Chain Collaboration

The traditional Supply Chain I



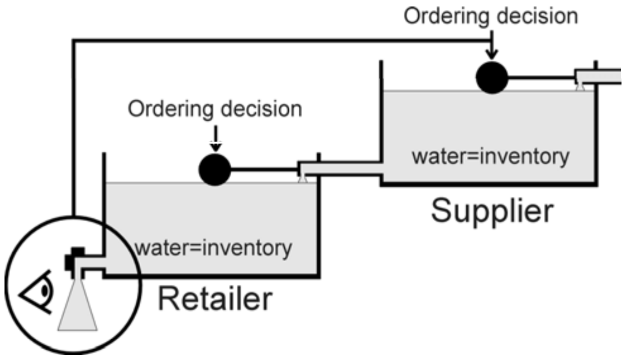
Source: Holweg et al 2005

The traditional Supply Chain II



Source: Holweg et al 2005

Type 1: Information Sharing (EPOS and/or Forecast)



Source: Holweg et al 2005

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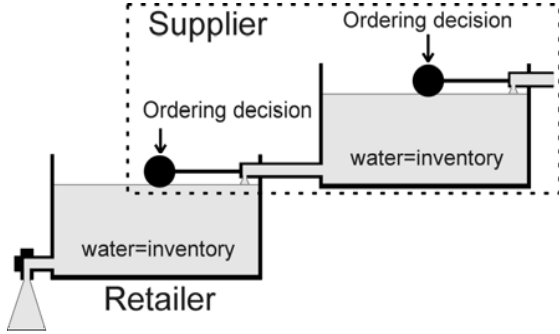
Type 2: Vendor Managed Inventory



Source: Holweg et al 2005

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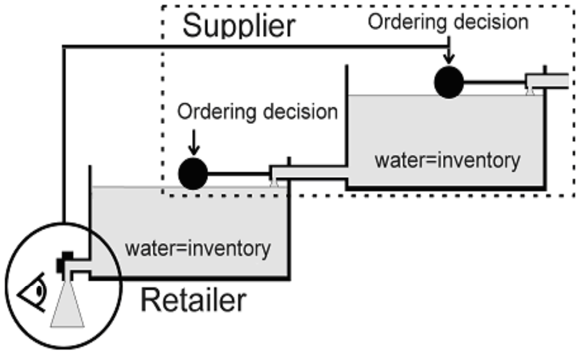
Type 3: Collaborative Forecasting and Replenishment (CPAR/CPFR)



Source: Holweg et al 2005

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Supply Chain Collaboration

Forecast Collaboration		Inventory Collaboration: No	Inventory Collaboration: Yes
	Yes	**Type 1** Collaborative Forecasting/ EPOS Exchange	**Type 3** Collaborative Forecasting and Replenishment
	No	**Type 0** Traditional Supply Chain	**Type 2** Vendor Managed Replenishment

Source: Holweg et al 2005

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Managing the Global Supply Chain Outsourcing

What is Outsourcing?

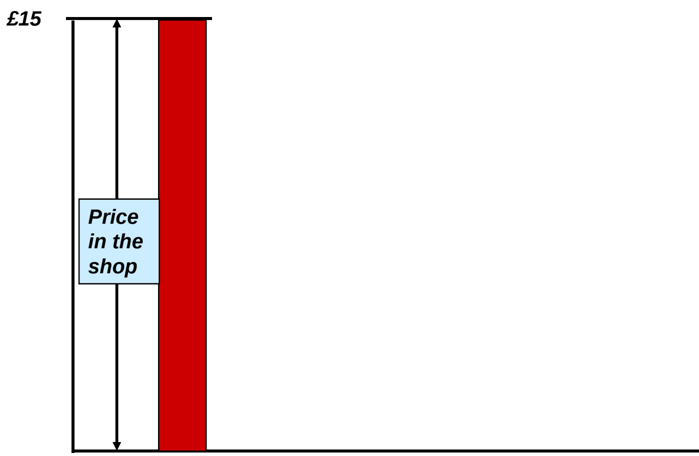
Traditional economic theory suggests that a firm should not make in house what a supplier can provide for less

But: what about long-term competitiveness?

Key question: what is ***core competence***, what is not?

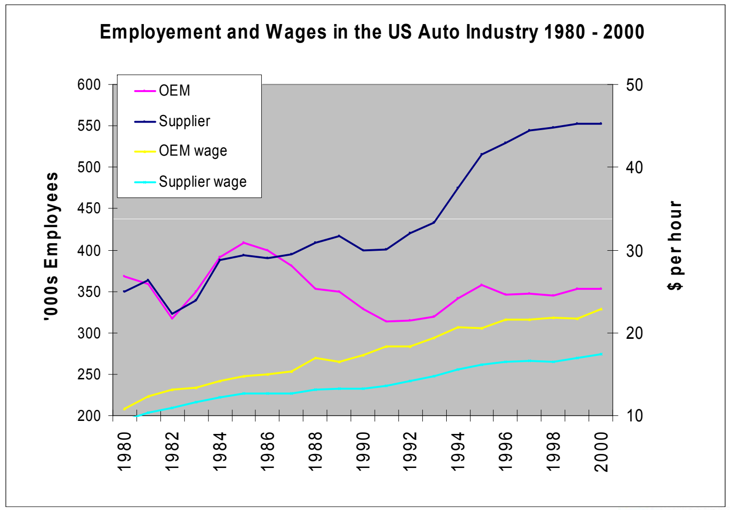
1. Manufacturing outsourcing (e.g. Flextronics, BenQ, Magna Steyr)
   - Contract manufacturing
2. Design outsourcing (e.g. Pininfarina, Bertone)
   - Specialist design houses
3. Business process outsourcing (e.g. Xchanging, Capita)
   - HR services, call centres, indirect purchasing
   - Transaction-based versus customised services
   - The role of tacit knowledge

Where does the money go? Take a £15 'Made in China' plastic 'Professor Dumbledore' figure …



Adapted from Slack et al. 2007

Key Driver of outsourcing: Labour Cost Differential (domestic)



Source: Holweg and Pil (2004)

Key Driver of outsourcing: Labour Cost Differential (internat.)

Germany	$29.91	Korea	$10.28
US	$21.97	Czech Rep.	$4.71
UK	$20.37	Brazil	$2.67
Japan	$20.09	Mexico	$2.48
Spain	$14.96	China	$1.3

Source: US Department of Labor Statistics, Wards, ONS.

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But not only labour costs: Assessing Market Potential

Measure of potential: (Persons per vehicle)		*Vehicles in operation: passenger cars (CV), ratio of passenger cars/CVs*			
▪ Argentina:	5.5	▪ *Argentina:*	*5.7m*	*(1.5m)*	*3.8*
▪ Brazil:	7.7	▪ *Brazil:*	*19.4m*	*(4.8m)*	*4.0*
▪ Mexico:	4.6	▪ *Mexico:*	*15.6m*	*(7.9m)*	*2.0*
▪ China:	37.5 (2002: 87.6)	▪ *China:*	*11.0m*	*(24m)*	*0.46 (2002: 0.30)*
▪ India:	85.8	▪ *India*	*8.1m*	*(4.9m)*	*1.7*
▪ Czech Rep:	2.2	▪ *Czech Rep*	*4.1m*	*(562k)*	*7.3*
▪ Russia:	4.3	▪ *Russian Fed:*	*26.8m*	*(5.9m)*	*4.5*
▪ Poland:	2.5	▪ *Poland:*	*13.4m*	*(2.3m)*	*5.8*
▪ USA:	1.6	▪ *USA:*	*135.1m*	*(108.9m)*	*1.2*
▪ Germany:	1.7	▪ *Germany:*	*46.6m*	*(3.2m)*	*14.6*
▪ Japan:	1.7	▪ *Japan:*	*57.5m*	*(16.7m)*	*3.4*

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Dialectics of Outsourcing

Pros

- Focus on core competences
- Harness lower labour cost at supplier
- Access to technology
- Stable and predictable financial planning in fee-for-transaction services
- Less investment risk

Cons

- Loss of control over process
- Limited ability to improve processes
- Risk of opportunistic behaviour of supplier
- Loss of human capital and tacit knowledge

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Outsourcing: A Word on China…

China: threat and opportunity

- Domestic sales increase

Problems:

- Abundant low-cost labour resources..
- ..but most high-value parts still imported
- Education & knowledge base
- IPR: the 'copycat cars'
  - GM Chevy Spark - Chery QQ
  - Honda motorcycles, VW parts…

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Outsourcing: A word on Nike...

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The 3 Supply Chain 'Enemies'

1. Inventory & delays

- Time worsens 'swing' of amplification
- Decision delays require stock
- Safety stock decisions send false signals

2. Unreliability or uncertainty

- Any kind of uncertainty needs to be covered with inventory
- Unreliable processes cause unreliable delivery

3. Hand-offs or decision points

- Every hand-off or tier in the system bears danger of distortion!

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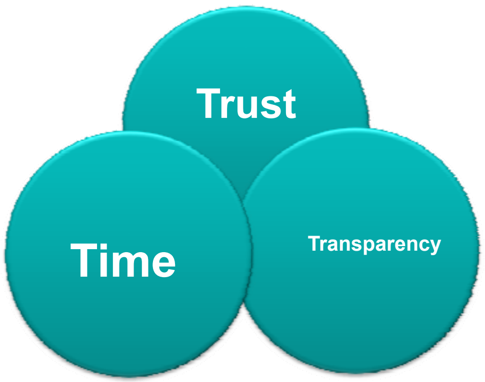
3T's of Effective Supply Chains



R Wilding: "The 3T's of highly effective supply chains"

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Review of Learning Objectives

- Understand the basic decisions in Operations Management, and their implications on firm performance
- Be able to manage inventory, schedule processes, develop basic forecasts
- Understand the Lean, Six Sigma and TOC improvement concepts
- Be able to manage a project (Critical Path Method)
- Understand the need to manage the wider supply chain

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Thank you &

Good luck!

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