Inventory Management

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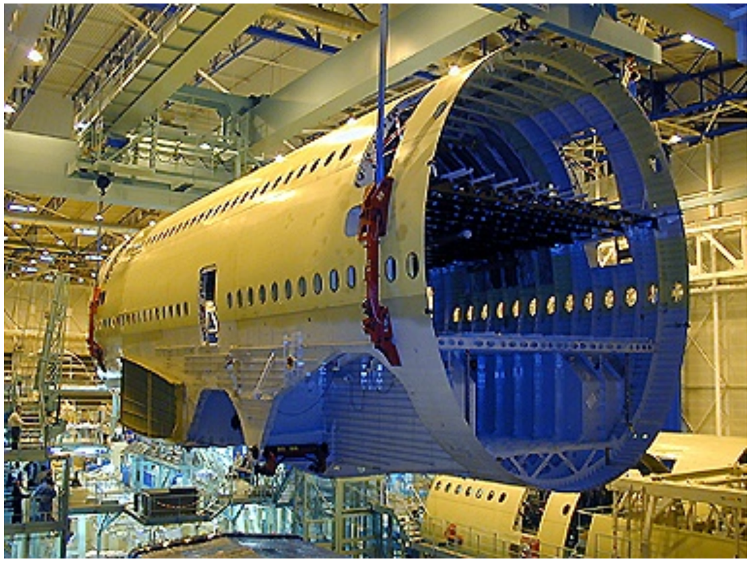
Design of Manufacturing Operations

Plane and Car Manufacture

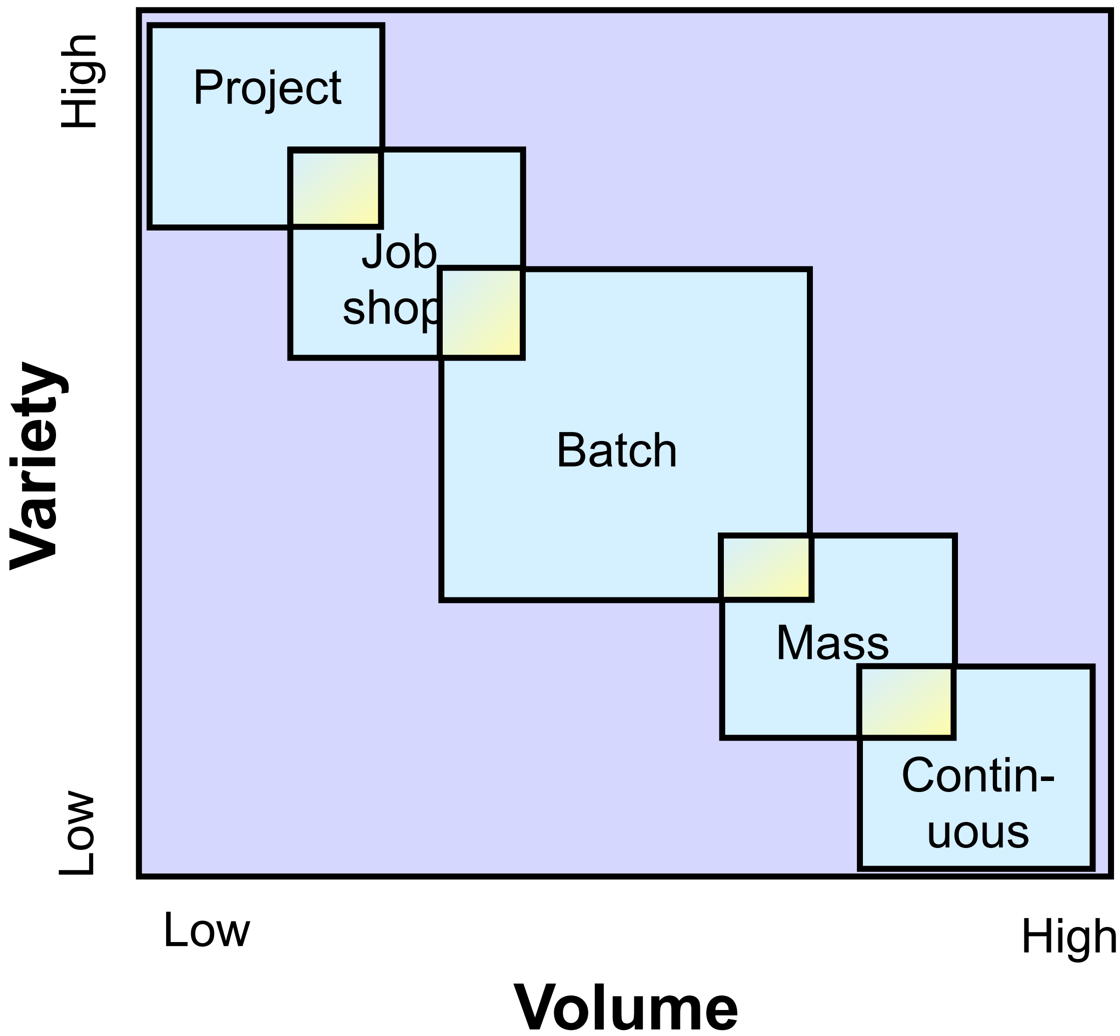
- Observe the manufacturing operations in these two videos
- How do these two operations differ?



Typology of Operations – The 4V's

Low repetition Each staff member performs more of job Less systemization High unit costs	← Low	**Volume**	High →	High repeatability Specialization Systemization Capital intensive Low unit costs
Flexible Complex Match customer needs High unit cost	← High	**Variety**	Low →	Well defined Routine Standardized Low unit costs
Changing capacity Anticipation Flexibility In touch with demand High unit cost	← High	**Variation in demand**	Low →	Stable Routine Predictable High utilization Low unit costs
Short waiting tolerance Satisfaction governed by customer perception High contact skills Received variety is high High unit cost	← High	**Visibility**	Low →	Time lag between production and consumption Low contact skills High staff utilization Centralization Low unit costs

Manufacturing Process Types



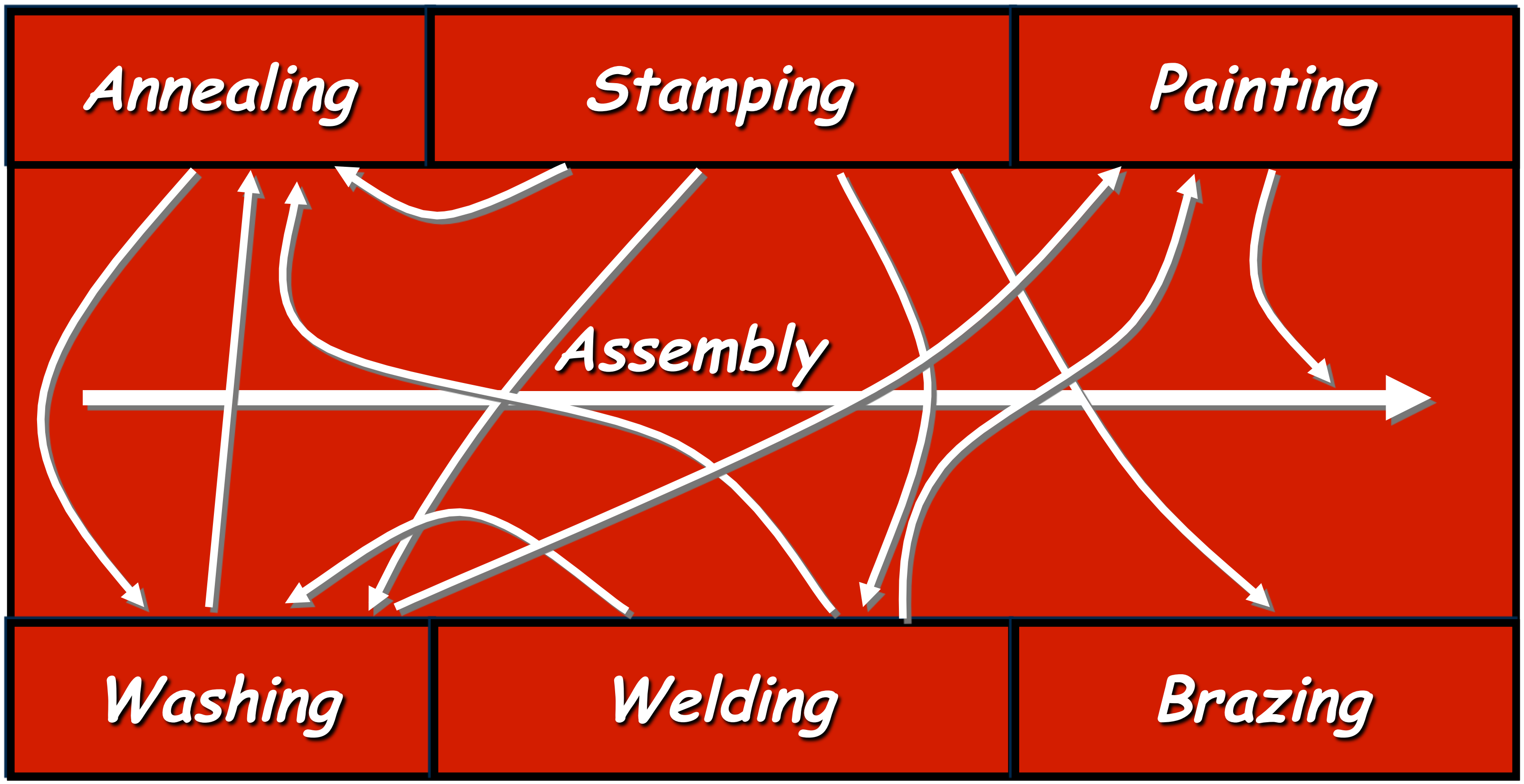
Projects: Millau Viaduct

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

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

Job Shop: Flow Chart



- Process-driven
- Split into centres
- Complex routing and scheduling

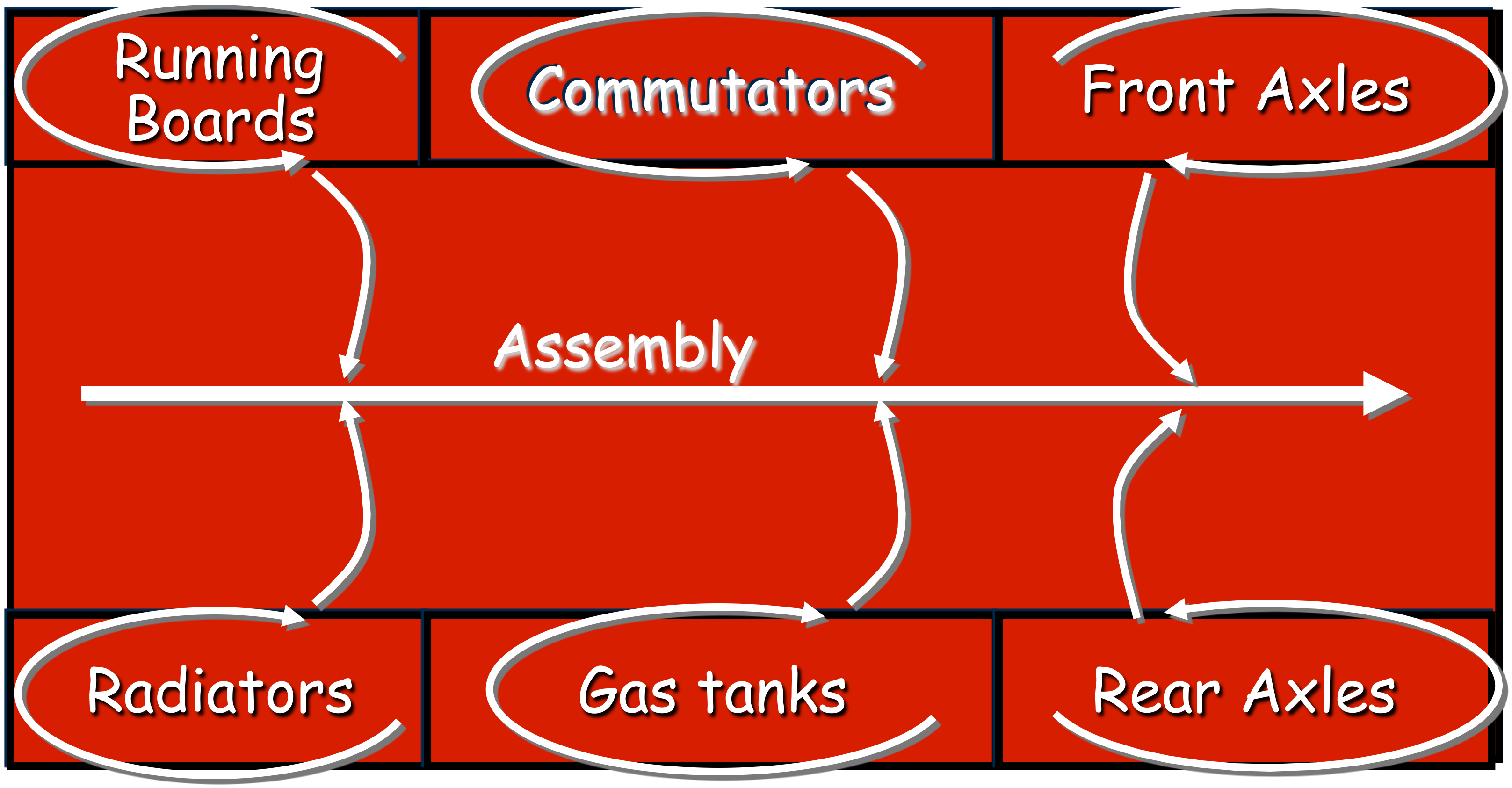
Batch: Textile Production

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

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

Ford Highland Park
Moving Assembly Line in 1913



250,000 Vehicles Per Year, One Model

Continuous Processing: Oil Refinery

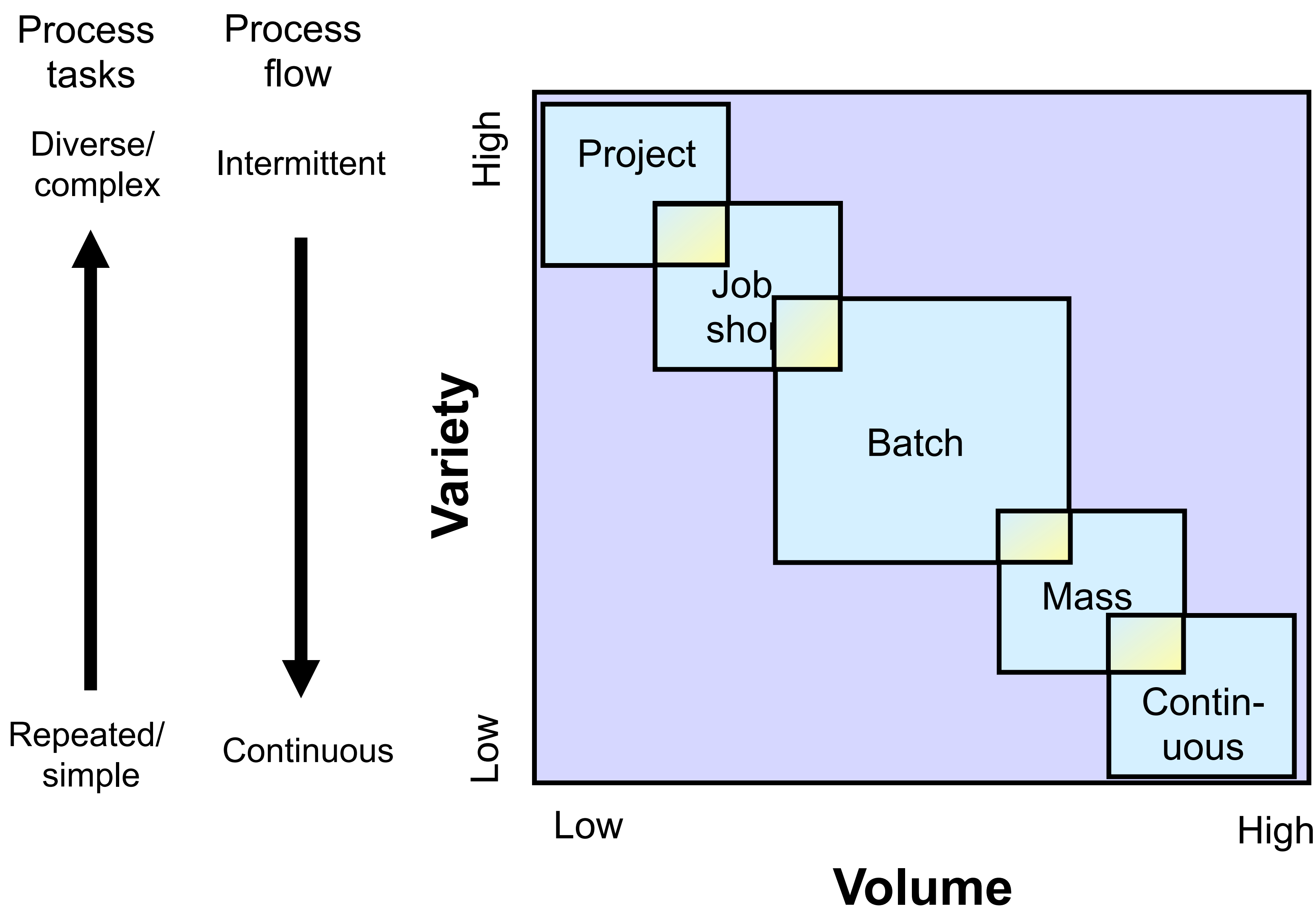
- Flow processes, often driven by chemical/physical needs
- Individual product is often not an entity (e.g., petrol)

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 - cheap or customised

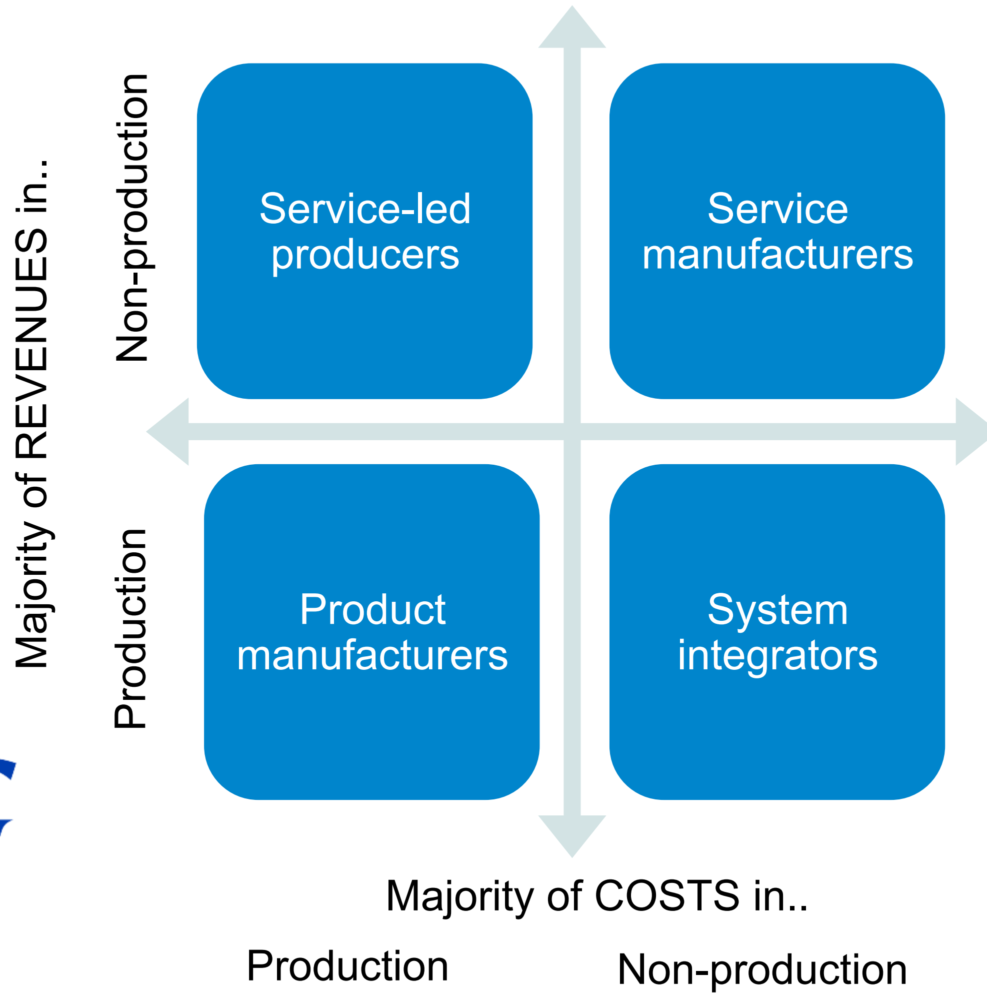
Manufacturing Process Types



The “Natural” Diagonal

- There is a **trade-off** between high flexibility and high volume/low cost per unit. For example:
  - **Project or job shop** processes provide a high degree of flexibility and a variety of products but with limited volume and at a high cost per unit
  - **Mass and continuous** processes are limited in flexibility but produce a high volume of product at a low cost per unit
- **Technology** can facilitate increased flexibility because may be used to make changes to processes without needing new equipment
- Nevertheless there are **extra costs** involved in having too much or too little flexibility

Manufacturing and Service are Inevitably Linked: Where is the "Centre of Gravity"?



Source: High-value manufacturing, IfM, 2006

Design of Service Operations

Goods versus Services

Pure Goods

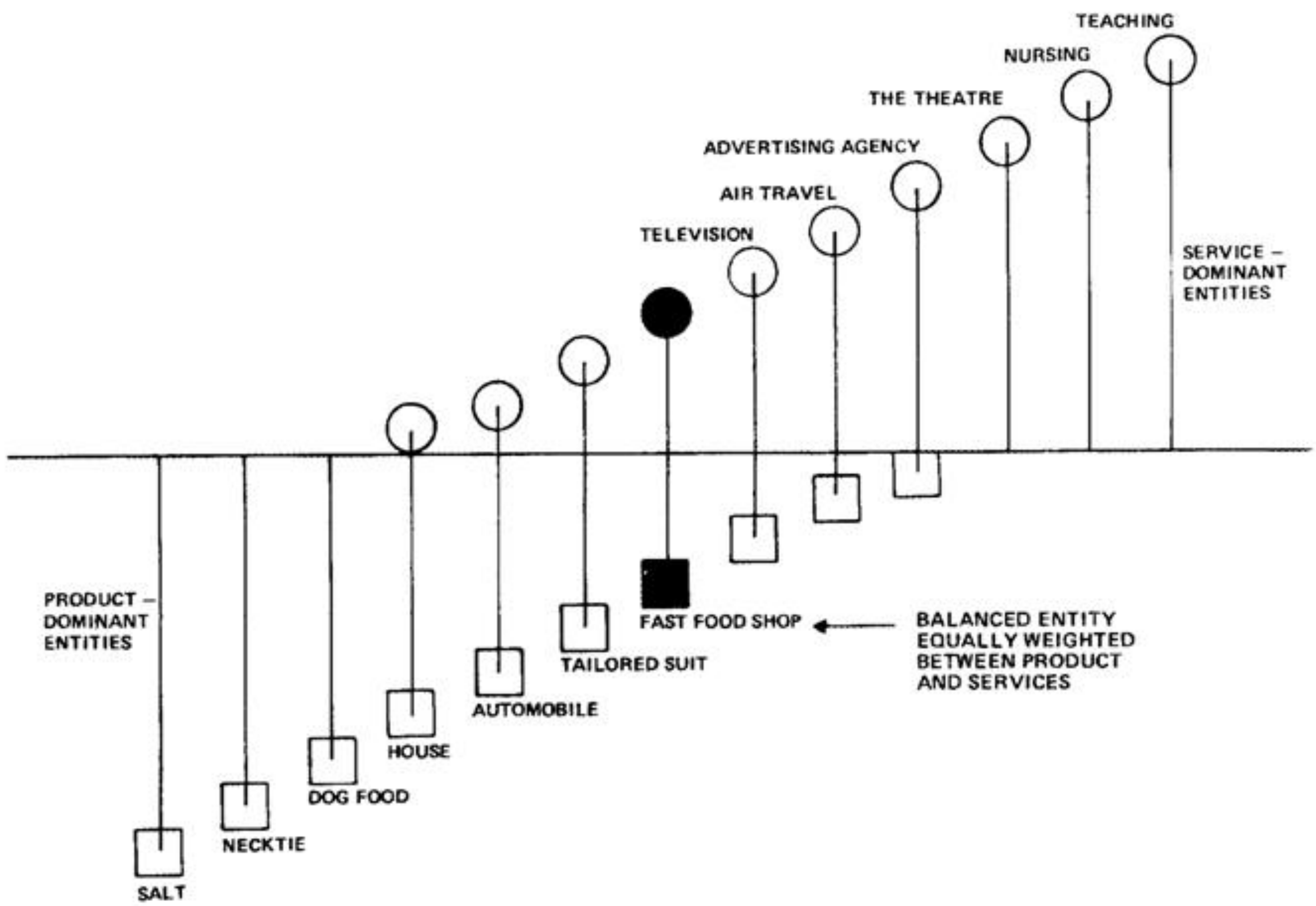
- Tangible
- Can be stored
- Production precedes consumption
- Low customer contact
- Can be transported
- Quality is evident

Pure Services

- Intangible
- Cannot be stored
- Production and consumption are simultaneous
- High customer contact → inherent variability
- Cannot be transported
- Quality difficult to judge

The Product/Service Continuum

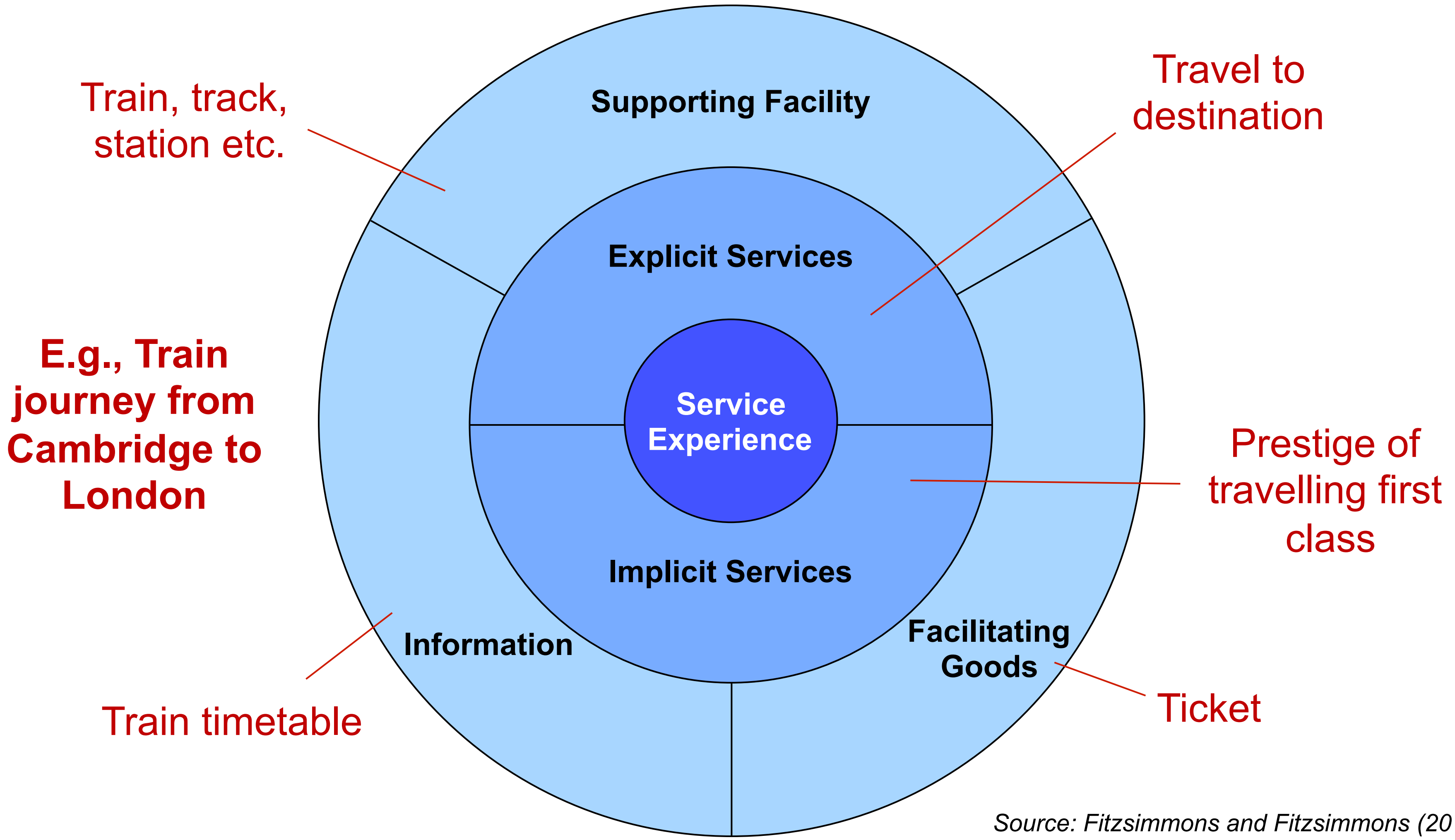
There are very few pure products or pure services



Source: Shostack (1982) "How to design a service", European Journal of Marketing 16(1) 49-63

The Service Package

The service experience comes from a package of goods, services and information



Source: Fitzsimmons and Fitzsimmons (2011) Service Management

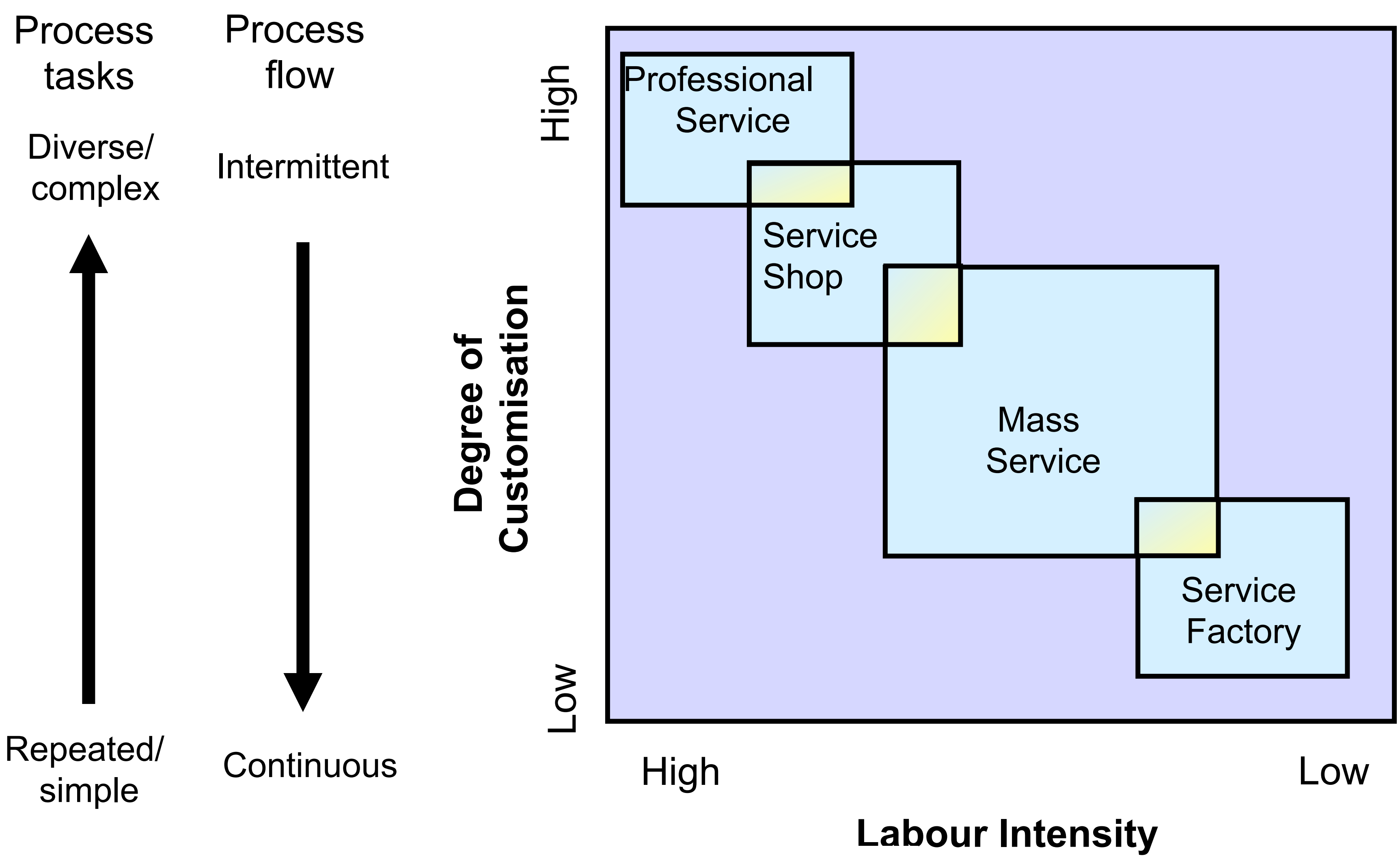
Schmenner's Service Process Matrix

Degree of customisation

Labour intensity	Low	High
Low	**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	**Mass Service** *Customers treated as similar* *e.g. Retailing, banking*	**Professional Service** *Costs principally for 'elite' labour.* *e.g. Lawyers, accountants*

Source: Roger Schmenner, Service Operations Management: Prentice Hall

The "Natural" Diagonal for Services?

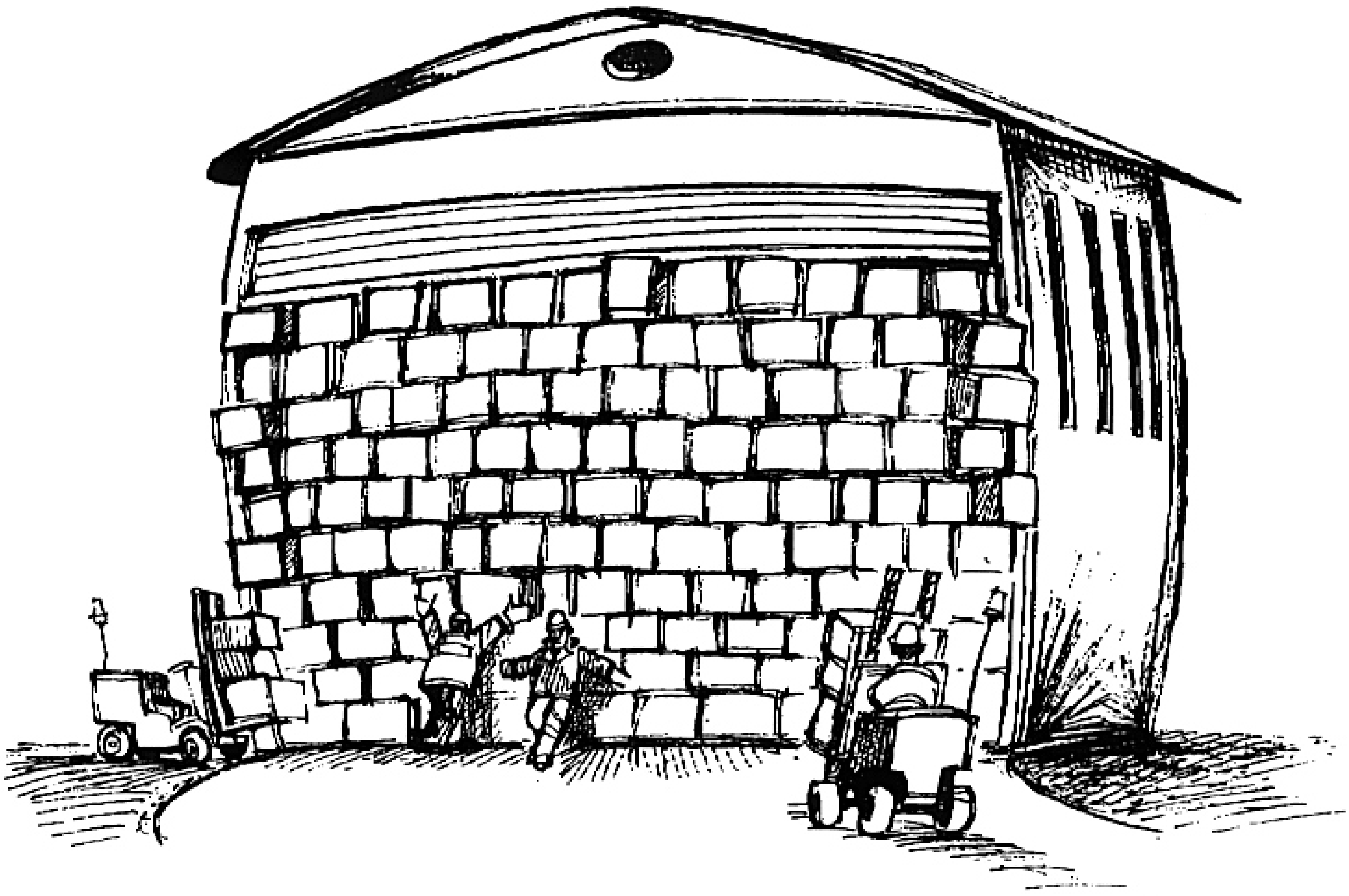


Recap of Last Lecture

- The **process** is the basic unit of analysis in OM
- Process effectiveness is determined based on:
  - **Quality, Speed, Dependability, Flexibility and Cost**
- There are **trade-offs** between these performance objectives that can be shifted but not broken
- Manufacturing and service processes conform to distinct types depending on **variety** and **volume**
- The design of service processes shares many similarities with the design of manufacturing processes

Objectives for Today

- What is inventory?
- Arguments for and against inventory
- What is Little's Law?
- Parts classification: ABC analysis
- Economic Order Quantity (EOQ) formula
- Batch sizing decisions



What is Inventory?

Inventory: Definitions

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

- Johnson and Montgomery (OR prof's)

"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

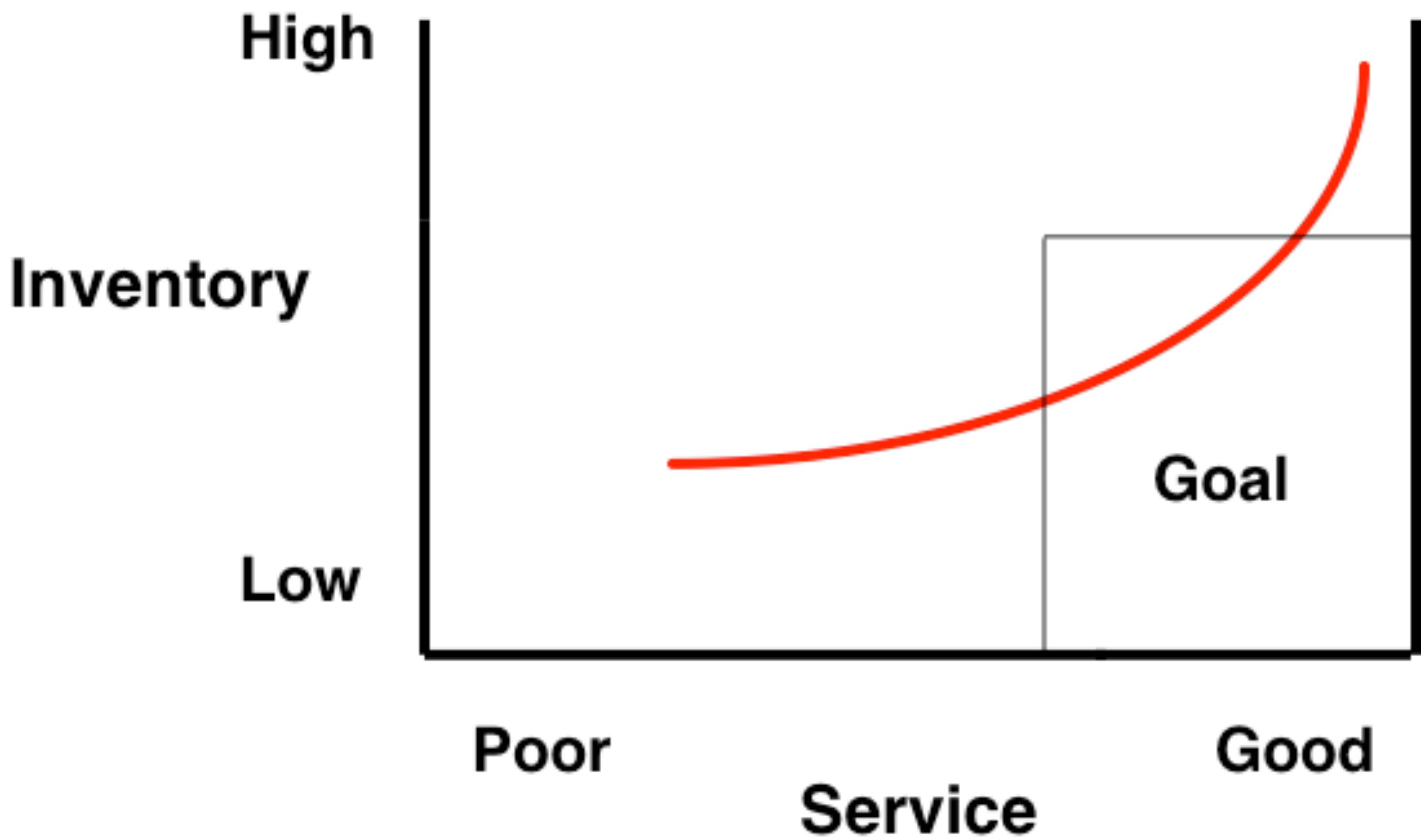
"Dead material."

- Taiichi Ohno (Father of the Toyota Production System)

"A substitute for information."

- Michael Hammer (Process Reengineering Guru)

Inventory/Service Tradeoff Curve



Types of Inventory: By Time

Raw Materials

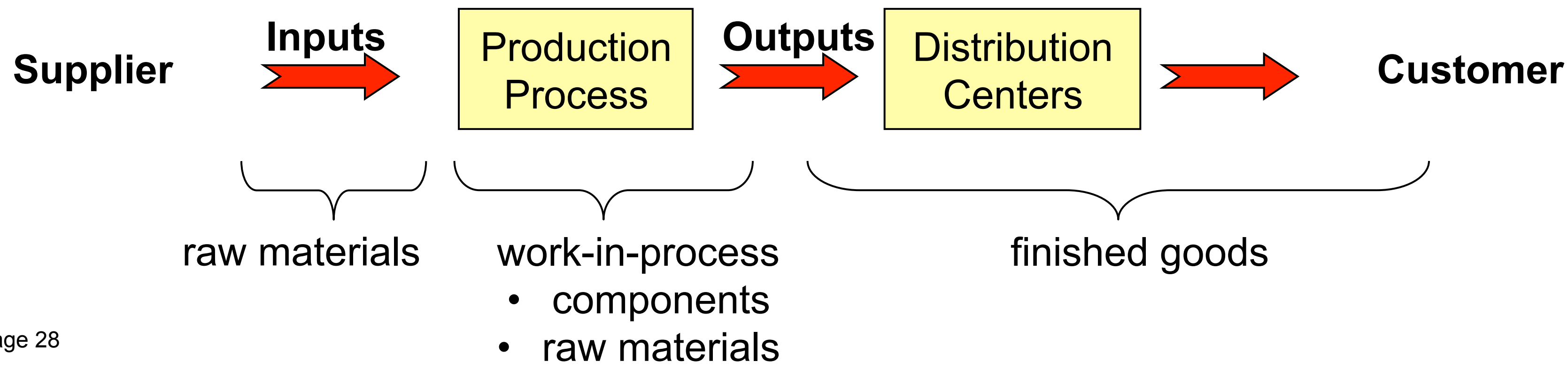
- Materials to which the manufacturer has not yet added value

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 (FGI)

- Goods ready for shipment to the customers, with no more value to be added
- Also consider service parts (maintenance and repair)



Types of Inventory: By Function

Cycle Stock

- Active component that depletes over time, and is replenished cyclically

Safety Stock

- Surplus held to protect against fluctuations of demand, production and supply

Pipeline Stock

- Stock created by the time spent to move and produce inventory

Anticipation Stock

- Stock held to smooth output rates by stockpiling during the slack season or overbuy before a price increase or capacity shortage

Why Do We Care?

At a macro level

- The total investments by firms in inventory in the US = 10-15% of GNP
- US inventory level (8/2012): $1.6 Trillion
  - 31% held by retailers
  - 31% held by wholesalers
  - 38% held by manufacturers
- Enormous potential for efficiency increase by controlling inventories

Why Does Inventory Matter?

Walmart

- Has sales of over $300 billion and operates more than 3,500 stores in the US and more than 2,500 stores in 15 other countries
- Employs more than 1.3 million people
- Has more than 6,000 stores and 10,000 stock-keeping units (SKUs) at each stores
- Manages 60 million individual stocking locations and at least a quarter of a million line-item orders per day
- Became the world's largest retailer in large part because of its excellent management of inventory

Walmart
Save money. Live better.

Walmart’s Inventory Reduction

- Walmart announced a major effort to reduce its inventory costs by $6 billion in 2006, or 20 percent of its yearly total, and suppliers took notice
- Walmart accounts for 10 to 30 percent of many suppliers’ sales
- The correction of Walmart’s inventory also affects shippers, with estimates of a $300 to $400 million reduction in freight revenue
- Walmart’s inventory reduction reflects its strategy of cutting costs and improving margins

Arguments For Inventory

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

Arguments Against Inventory

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.

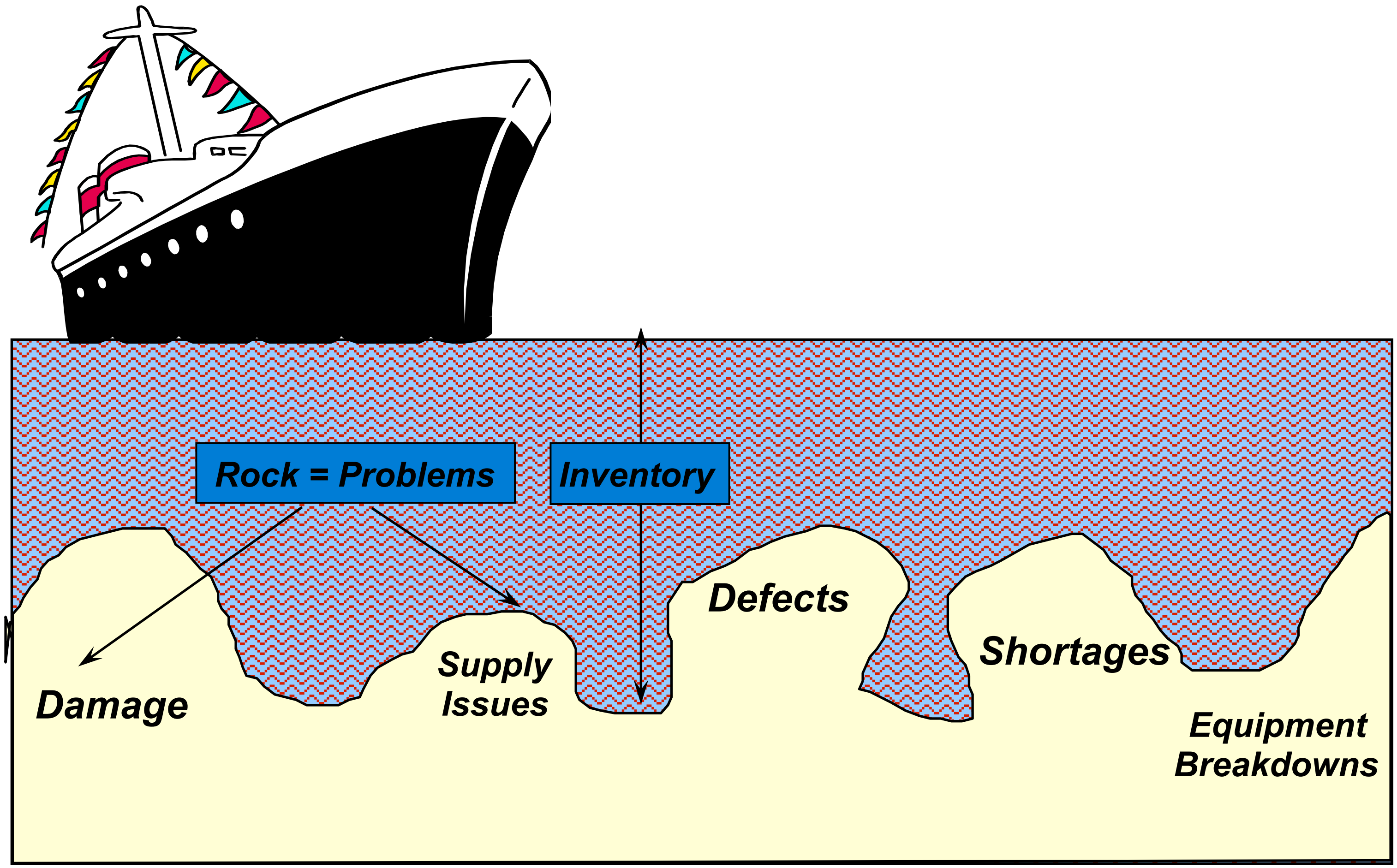
Overall costs:

- Typical estimate is 20-30% of value per annum
- In practice, often quality, depreciation, and opportunity cost are not considered
- Key issue: estimates *almost always* too conservative!

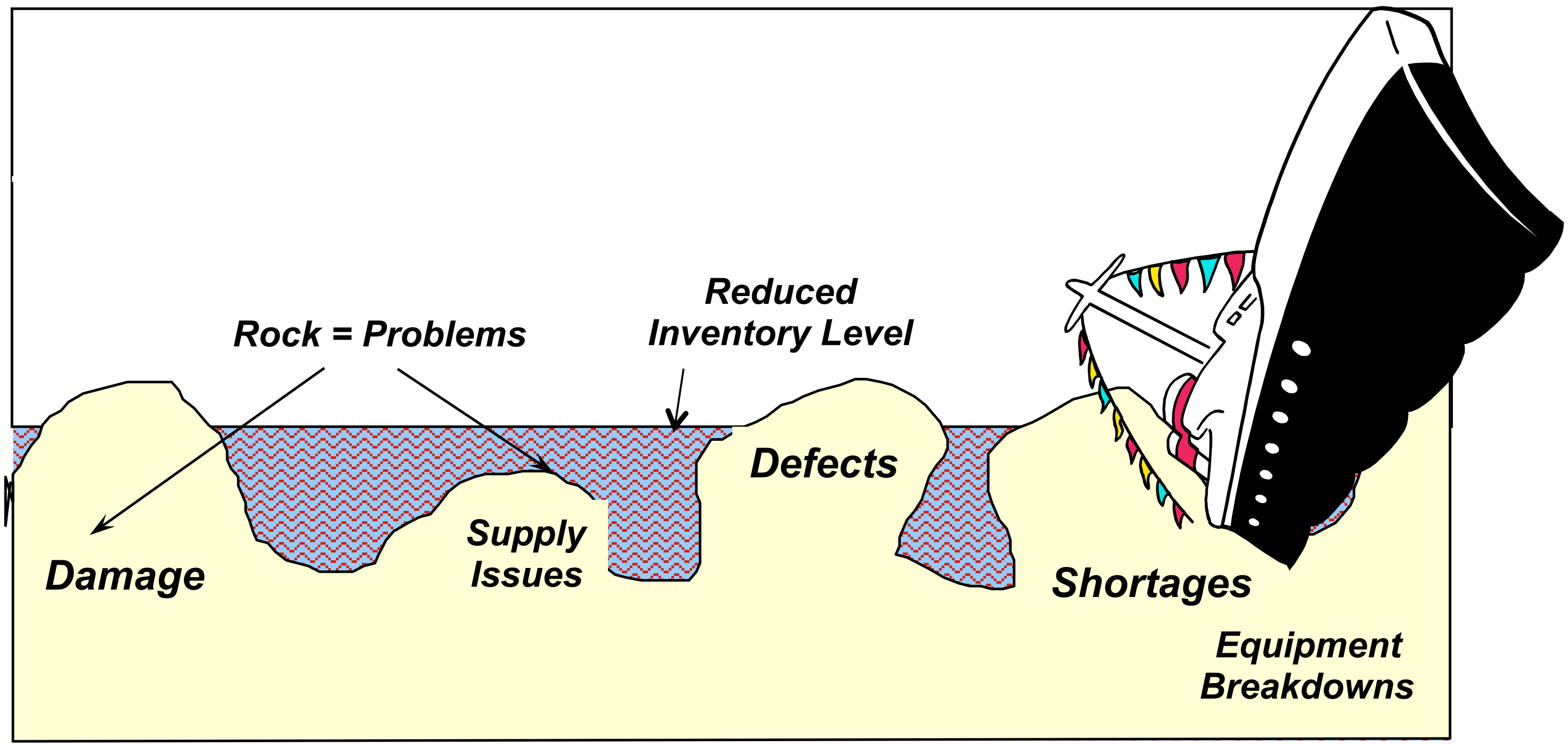
Hidden Costs of Inventory

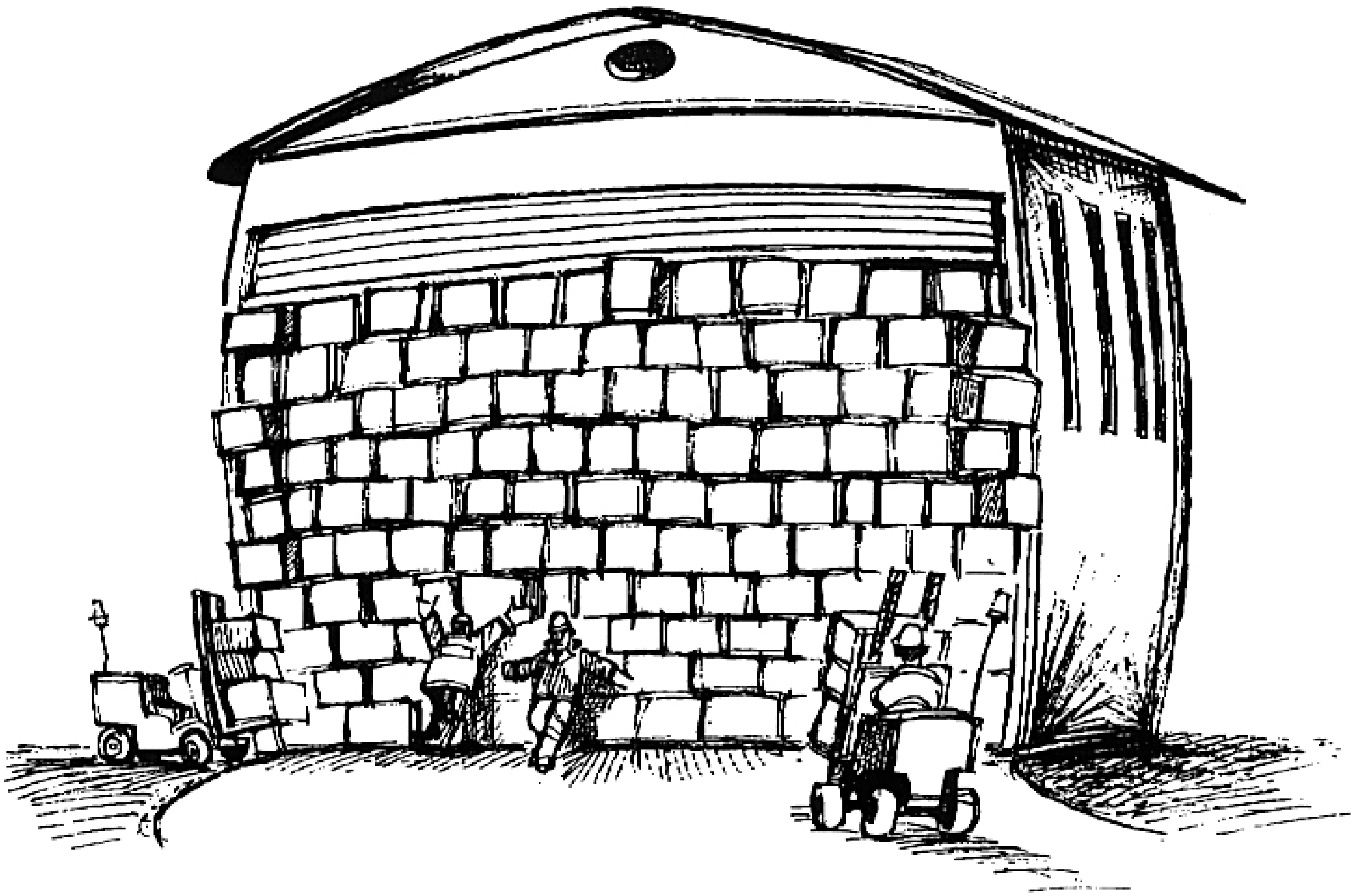
- Longer lead times
- Reduced responsiveness
- Underlying problems are hidden rather than being exposed and solved
- Quality problems are not identified immediately
- No incentive for improvement of the process

Rock – Boat Analogy



Inventory Reduction Only is Fatal!





Little's Law

Little’s Law

John D.C. Little’s Theorem (or Little's Law) gives a simple relation between inventory, production rate and lead-time:

$$I = r * T$$

I: the number of items or inventory in a system [units]
r: the production rate at which items arrive/leave [units/day]
T: the throughput lead-time (the time spend in the system) [days]

- All based on average, steady-state values.
- Applies to all types of systems!
- *I* determines the minimum pipeline stock needed!

Example

- 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 processes combined) are 4,800 units
- The business consultants hired by the CEO think this is too much, and suggest to reduce stock by 50%
- Your reply?

Two More Examples

1. The average queue at the post office counter is 6 people and the average wait to be served is 10 minutes. How many people on average are served each hour?
2. The average number of customers in a restaurant is 50. About 30 customers arrive and leave per hour. How long does a customer spend in the restaurant on average?

Measuring Inventory Performance

Days of Inventory (DOI) is the number of days an organisation can satisfy demand using its inventory

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

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

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

Stock Turns

Typical stock turns: 5 to 20, world-class lean manufacturers achieve >40.

INVENTORY TURNOVER RATIO FOR DIFFERENT MANUFACTURERS

Industry	Upper quartile	Median	Lower quartile
Electric components and accessories	8.1	4.9	3.3
Electronic computers	22.7	7	2.7
Household audio and video equipment	6.3	3.9	2.5
Paper mills	11.7	8	5.5
Industrial chemicals	14.1	6.4	4.2
Bakery products	39.7	23	12.6
Books: Publishing and printing	7.2	2.8	1.5

Source: Based on a survey conducted by Risk Management Associates (2001)

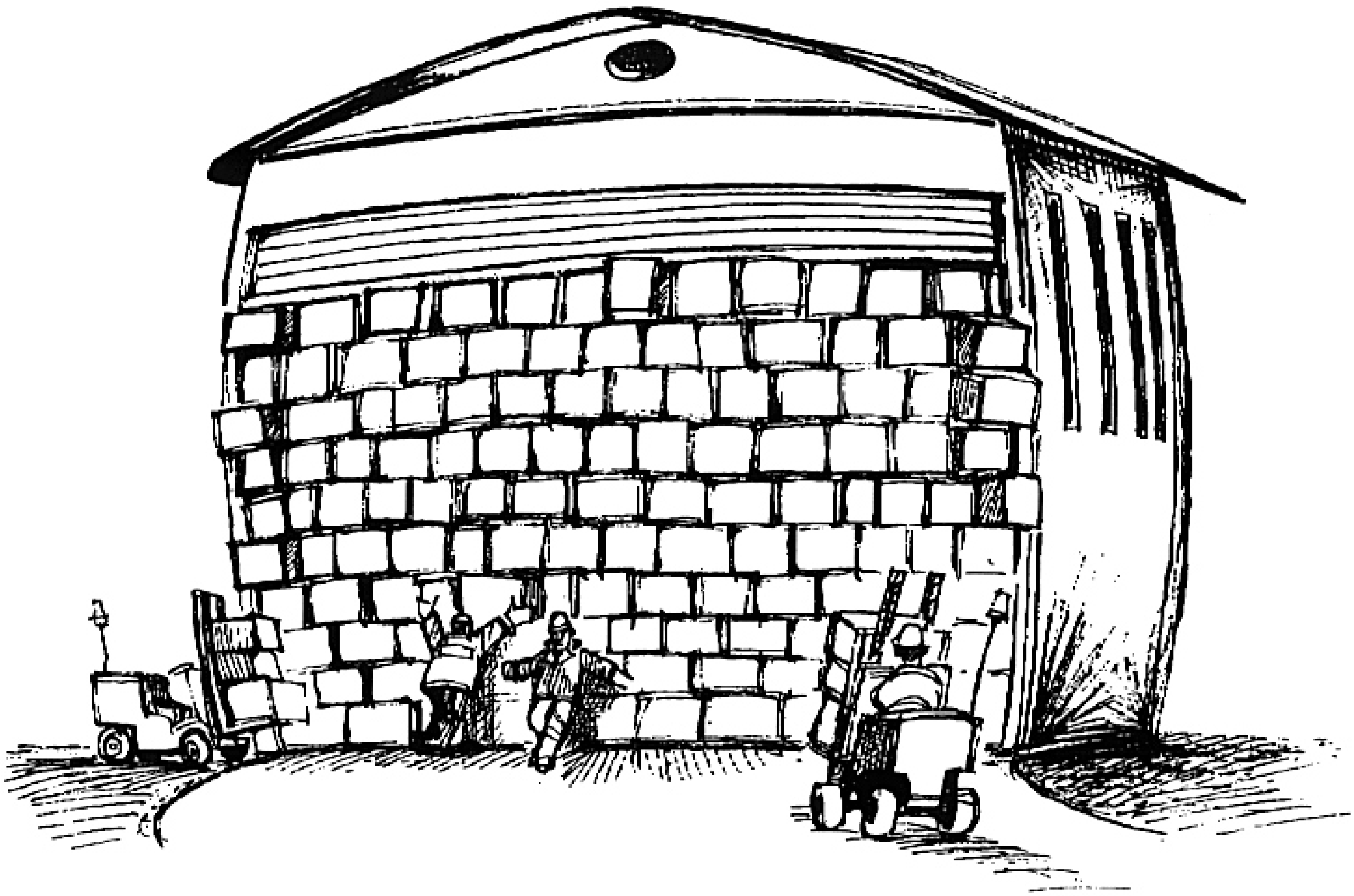
Example: Company A had a starting WIP of \$1.75m, and a closing WIP of \$1.25m at the end of the year. Total COGS in the year were \$36m. Calculate stock turns.

The Link Between Stock Turns and Holding Cost

- Suppose stock turnover is 5 times per year
- Thus, each item sits in the warehouse for about 1/5 of a year
- 22-40% represent *realistic* stock holding cost, including handling, cost of quality, obsolescence and warehousing
- The cost of holding inventory is hence approximately:

1/5 * (22 to 40%) = 4.5% to 8% of sales value

- Stock turns is often used as key measure for operational and cost efficiency



ABC Analysis

Part Classification

All inventory control models are part-specific

- Attention given to part depends on cost impact

ABC Classification (H Ford Dickie, 1951)

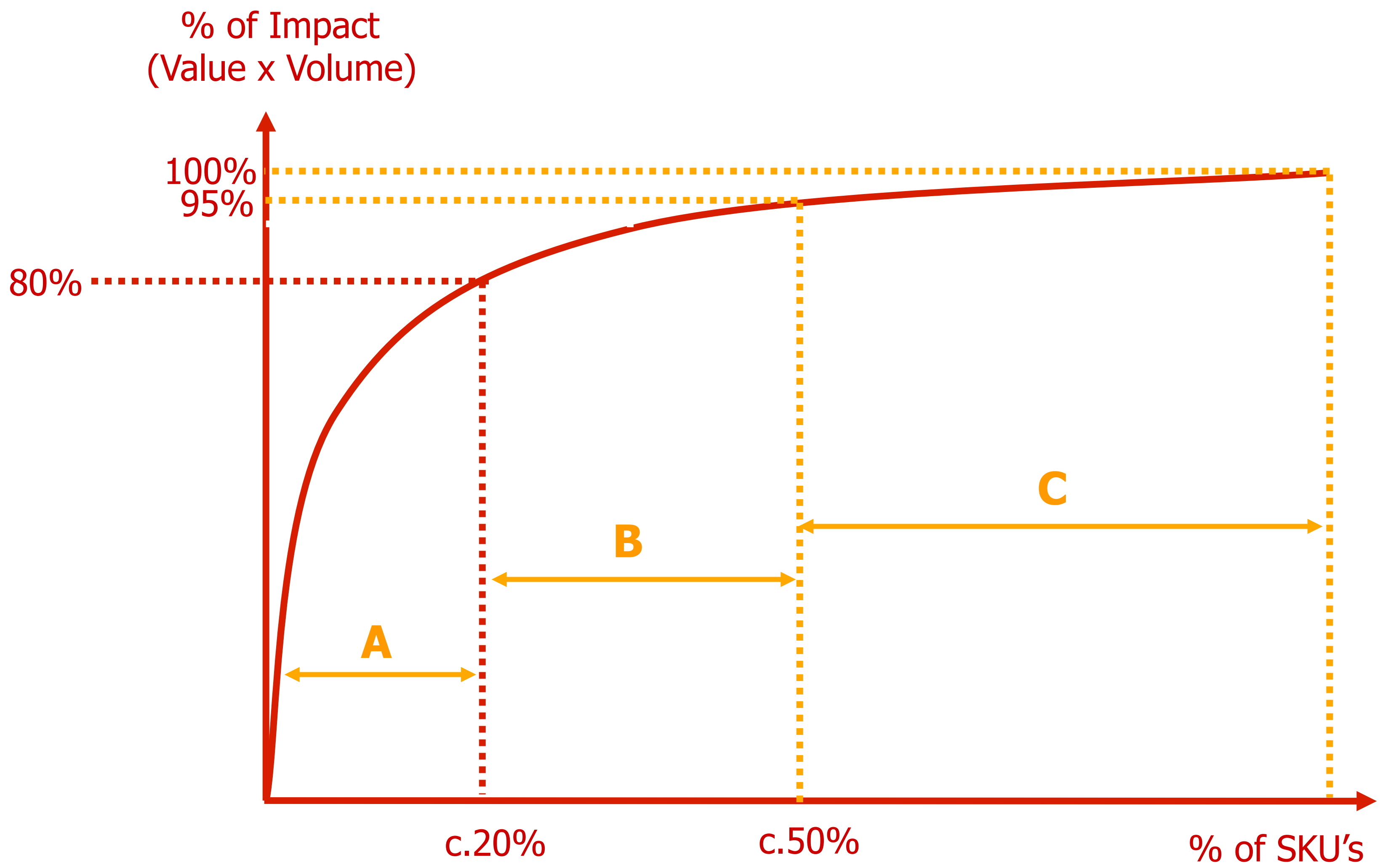
- Number of parts versus Usage Value (Value x Volume)
  - A: 20% of parts = 80% of usage value
  - B: 30% of parts = 15% of usage value
  - C: 50% of parts = 5% of usage value

(exact percentages differ from one author to another)

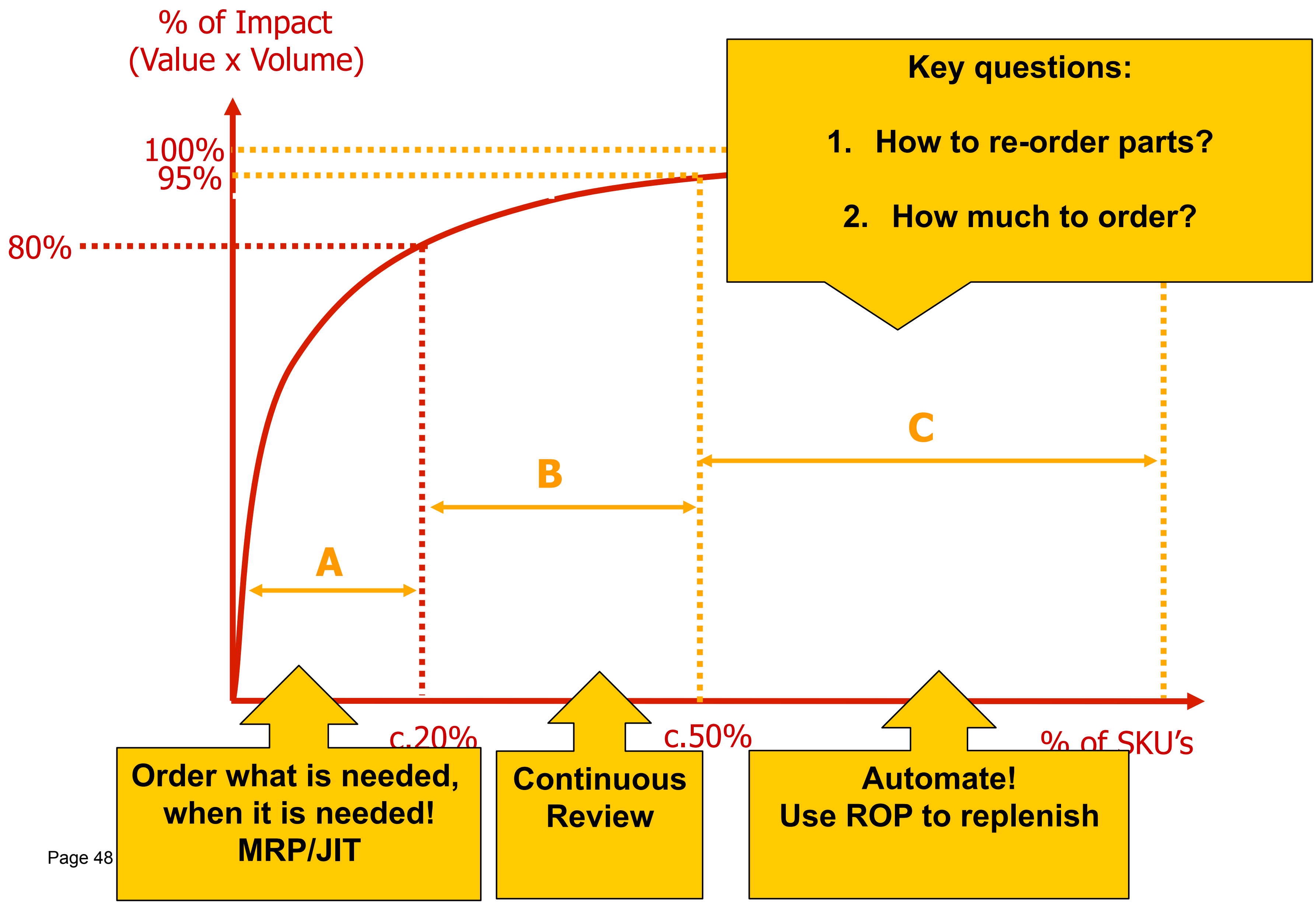
Pareto’s Law or Analysis, the “80-20 Rule”

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

Pareto, ABC & The "80-20 Rule"



Pareto, ABC & The "80-20 Rule"



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

Inventory Management Example

Let’s say you manage a car dealership and you have inventories of

- Cars
- Transmissions
- Automotive fuses

How do you manage each of these categories?

- Cars: Track each individual car (A)
- Transmissions: Count the number on hand (B)
- Automotive fuses: Buy a box or two and make sure there’s always a box on the shelf (C)

Ordering and Batch Sizing Decisions

Basic Approaches to Ordering

1. **Fixed Order Quantity Models**

   Economic Order Quantity (EOQ)

   Re-Order Point (ROP)

2. **Fixed Time Period Models**

   Fixed Period Ordering

   Lot-for-Lot (LfL) ordering aka Order-Up-To (OUT)

   Period Order Quantity (POQ)

3. **Variable Order Quantity and Ordering Interval**

   Least Unit Cost (LUC)

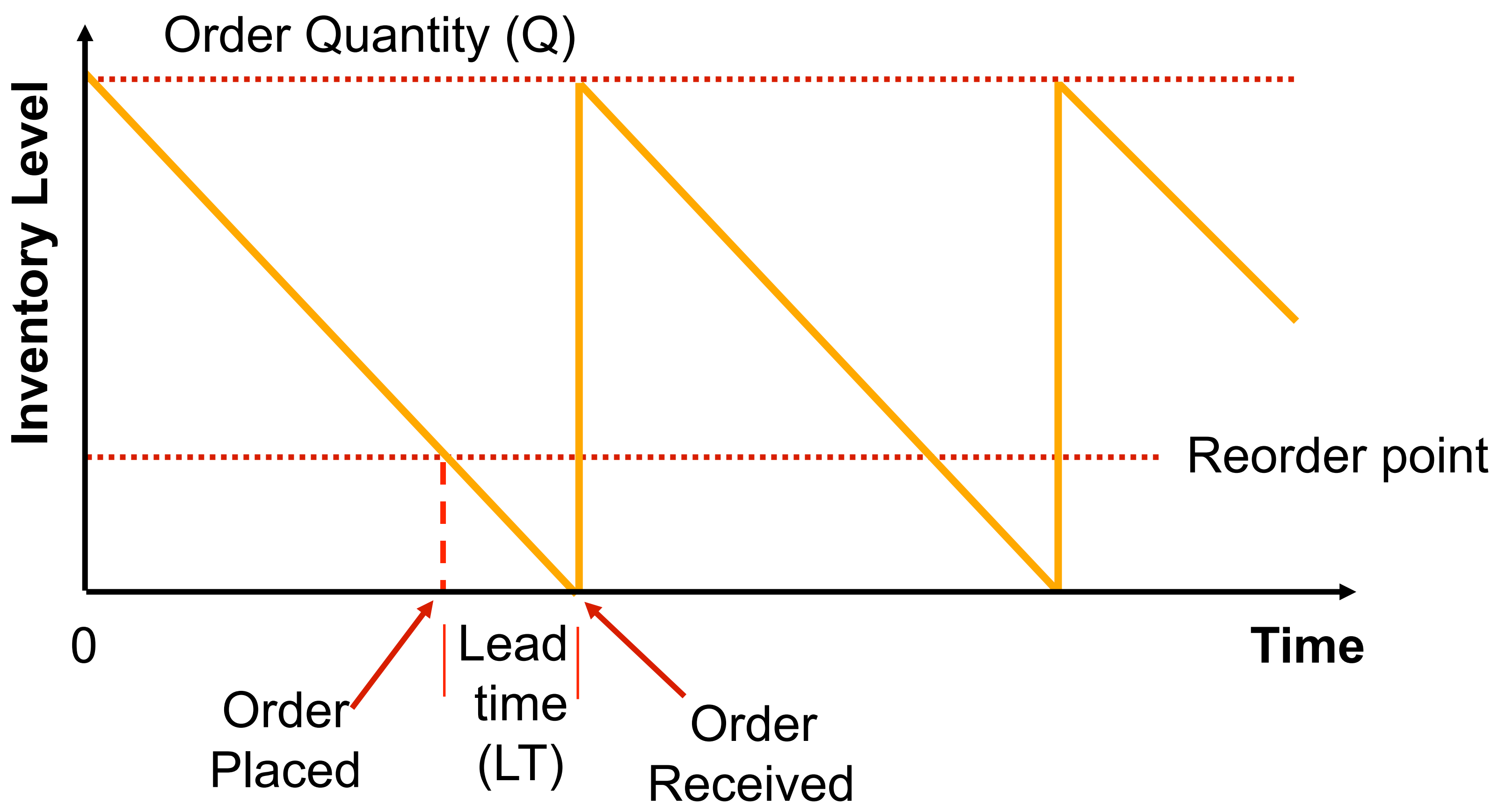
   Least Total Cost (LTC)

   Part-Period Balancing (PPB)

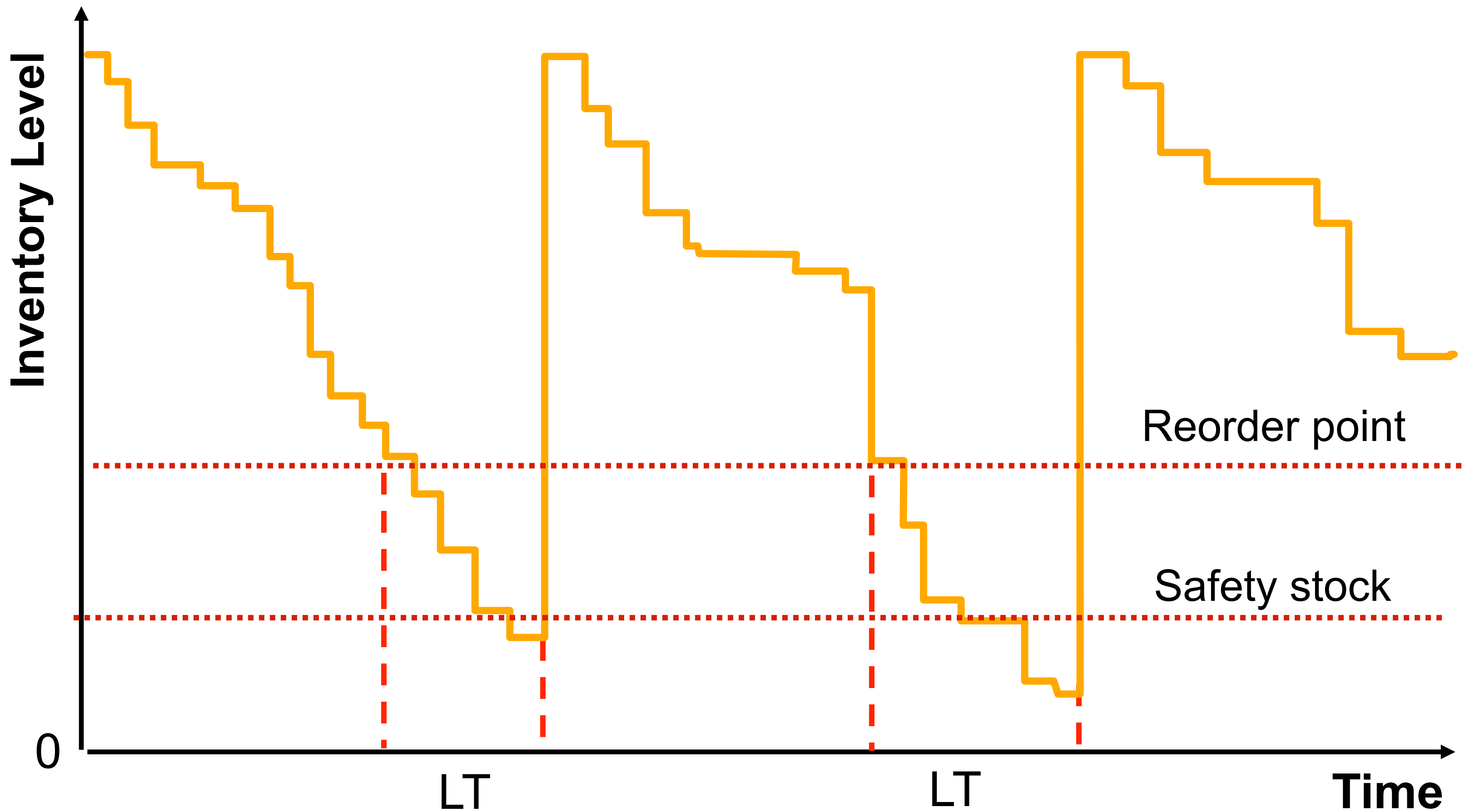
4. **Material Requirements Planning (MRP)**

   - Calculates time-phased requirements

The Inventory Cycle ("*Sawtooth*")



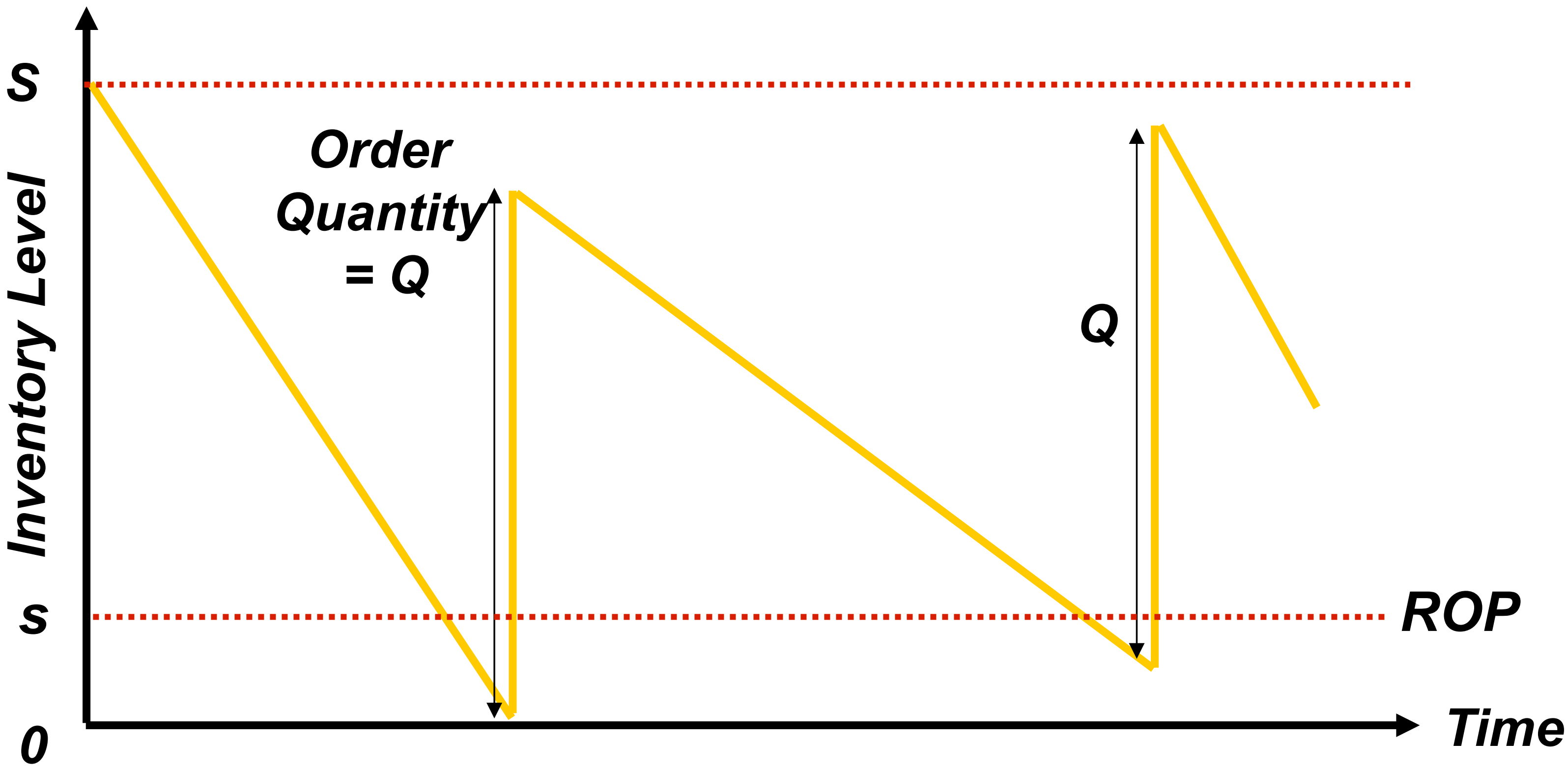
Reorder Point with Safety Stock



1. Fixed Order Quantity

- A system where the order quantity remains constant but the time between orders varies
- Preferred for important or expensive items because average inventory is lower
- Provides a quicker response to stockouts
- Is more expensive to maintain due to inventory record-keeping costs
- **Example:** Always purchasing a dozen eggs when there are only two eggs left in the refrigerator.

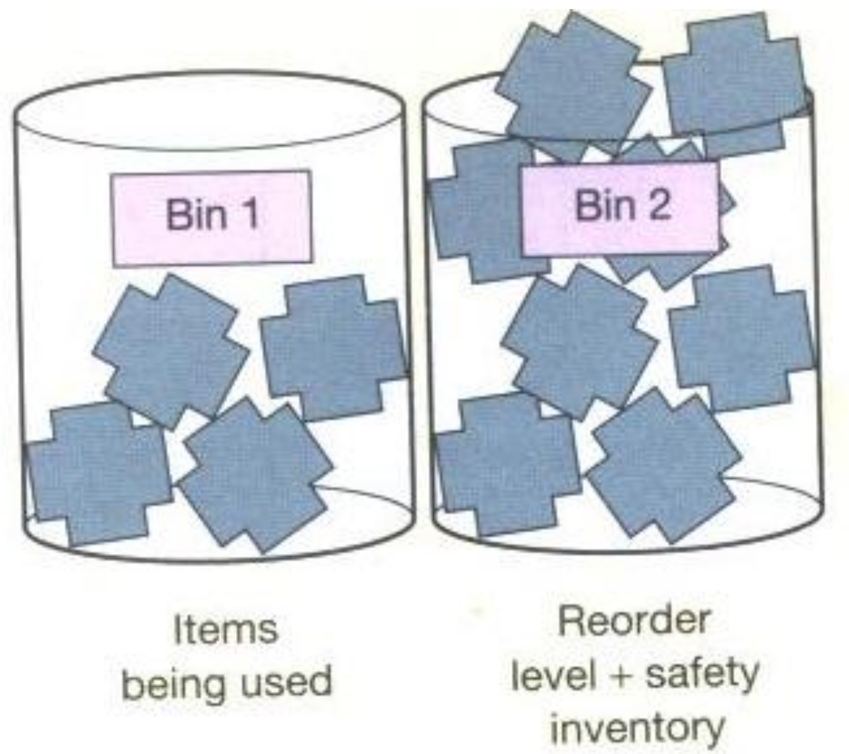
1. Fixed Order Quantity: (s,Q)



- (s,Q): Order time interval is variable, order quantity Q is fixed
- Safety level can be considered
- Sometimes implemented as two-bin system
- Derivative: (s,S): Order to make inventory up to S

Two-Bin and Three-Bin Re-ordering

- Reorder when Bin 1 is empty.
- In 3-bin system, safety inventory stored in a third bin
- Use of third bin makes it clear when demand exceeding expectations; i.e., second bin empties before replenishment



Batch Sizing: Determination of Q when Ordering

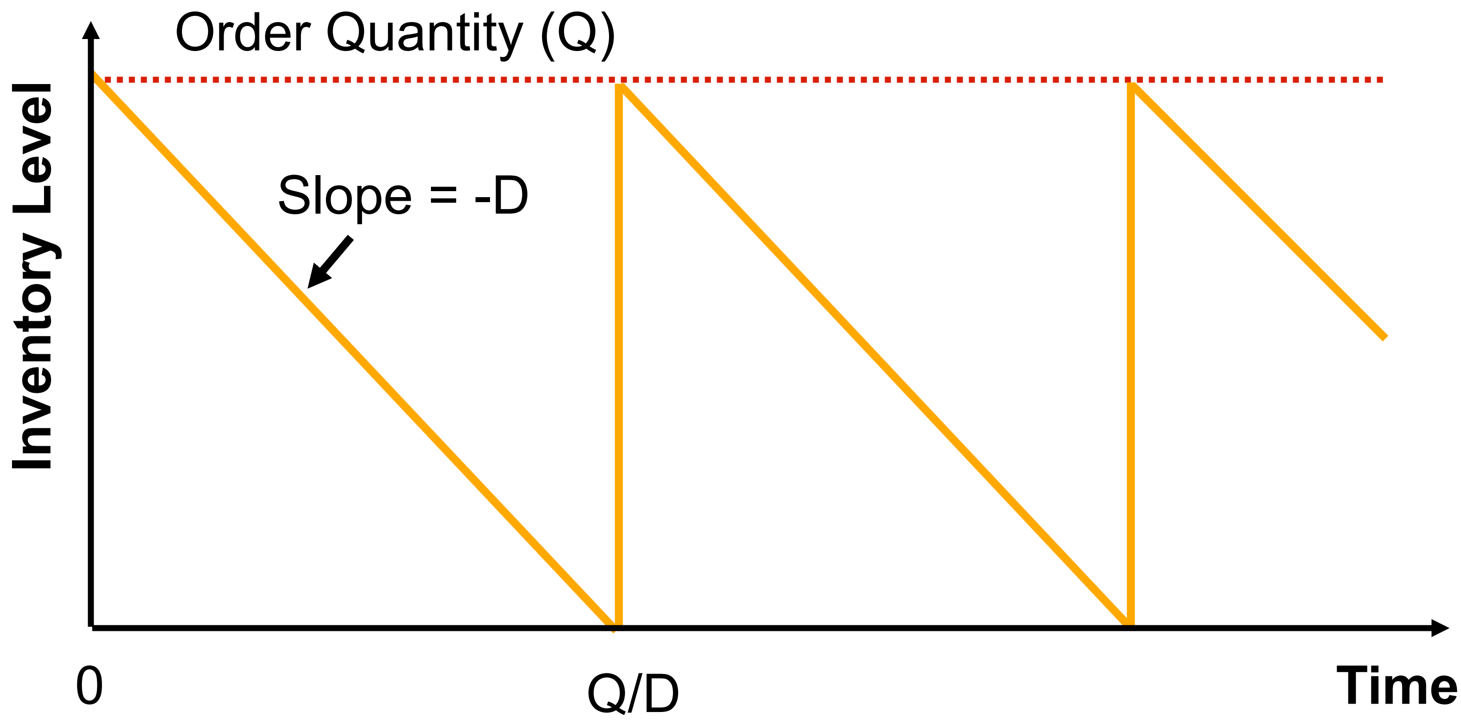
- Using a large order size (i.e., ordering infrequently): we suffer a large inventory ***holding cost***.
- Using a small order size (i.e., ordering frequently): we suffer a large ***fixed cost of ordering***
  - Clerical / labour cost of processing an order
  - Any fixed costs imposed by supplier
  - 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 is called the "Economic Order Quantity" (EOQ)

- 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***

The Inventory Cycle ("*Sawtooth*")



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)

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

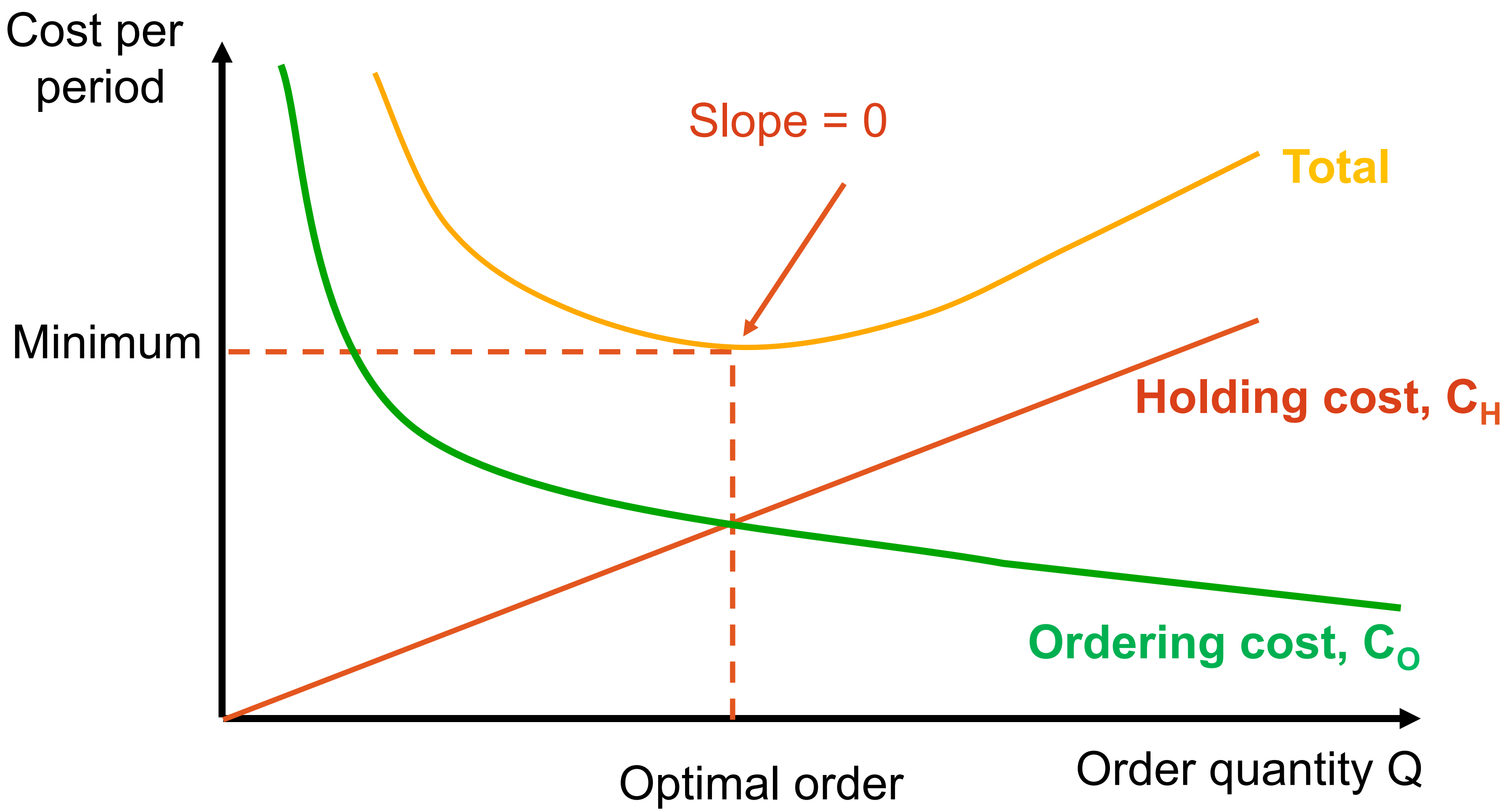
D = demand per period

Q = batch (lot) size

C_O = (fixed) cost of placing one order

C_H = cost of holding one item in store for one period (financing and physical storage)

Basic Tradeoff Model: The Economic Order Quantity (EOQ)



Economic Order Quantity

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

Ordering Cost

Holding Cost

Annual Demand

(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]

Reorder Point

The point in time by which stock must be ordered to replenish inventory before a stockout occurs.

$$R = dL + SS$$

R = Reorder point

d = Average demand per time period (constant)

e.g., d = D/working days in the year

L = Number of time periods between placing order and delivery

SS = Safety stock

Why Didn't We Include Other Costs?

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

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

where C_V = variable cost (cost per item)

SS = safety stock

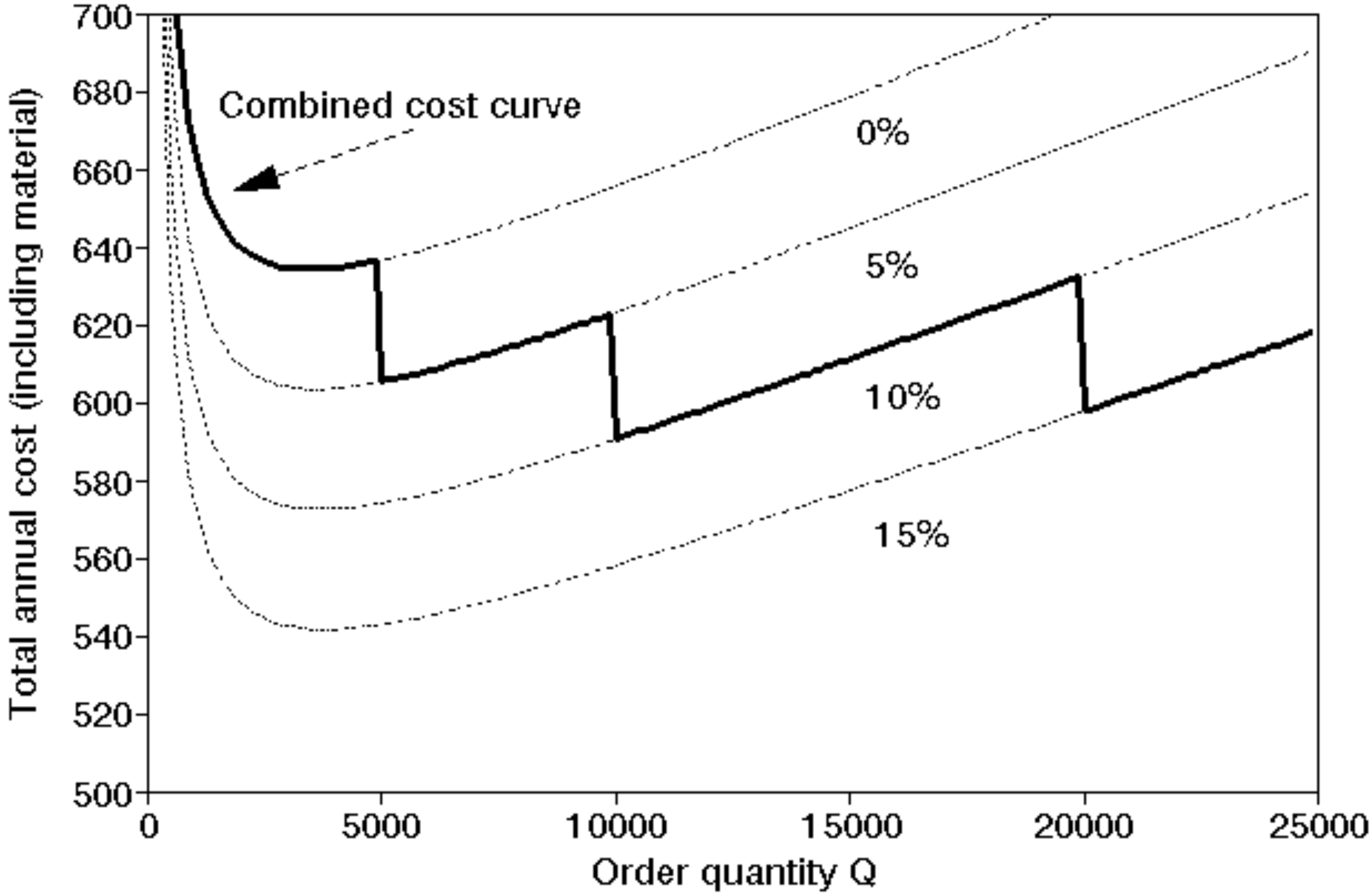
Yes, though here it makes no difference to the optimal Q, so we often ignore the terms DC_V and $SS*C_H$

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?

EOQ Considering Volume Discounts



Batch Sizing: Determining Q in Production

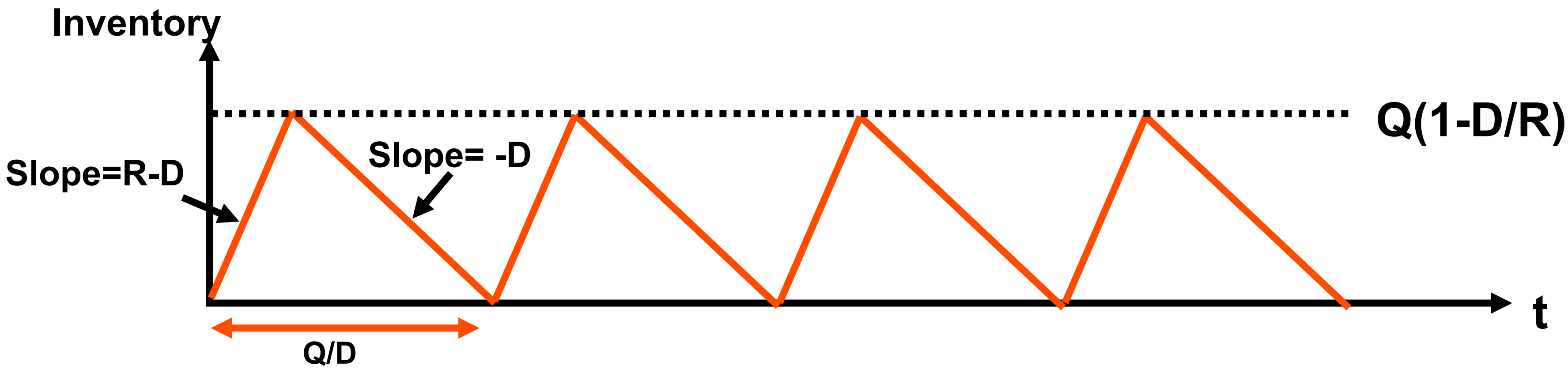
- What if we are producing the batch ourselves, rather than ordering it in from an external supplier?
- Most of the issues are the <u>same</u> as they were when we were ordering the batch in. The differences are:

  (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 <u>not</u> now arrive instantaneously
- The optimum batch size is known as the Economic Production Quantity (EPQ)

Economic Production Quantity (EPQ)

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



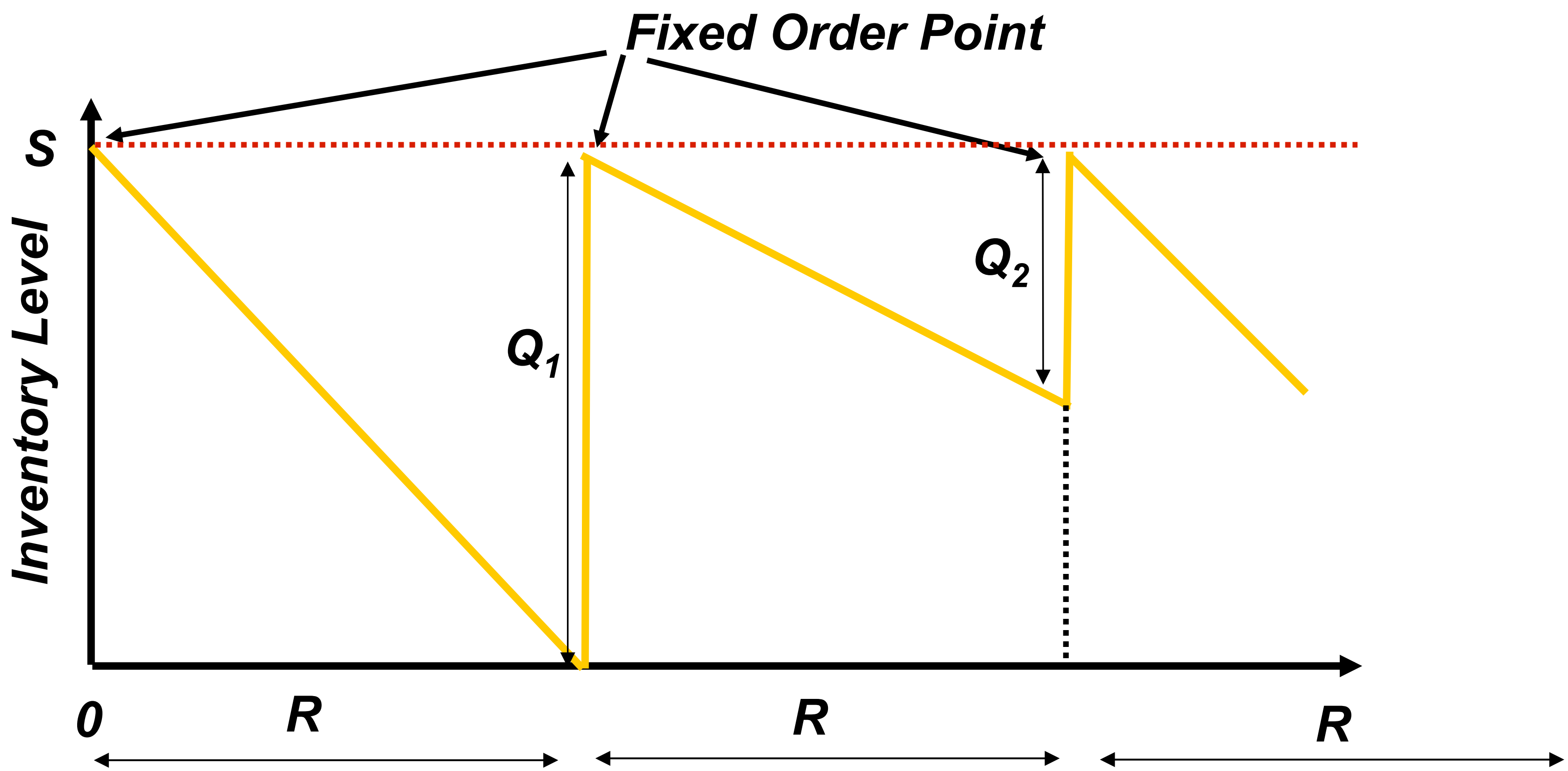
Analysis is as for EOQ, except C_H is replaced by $C_H(1 – D/R)$ reflecting lower average stock held over the period

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

2. Fixed Time Period Ordering

- A system where the time period between orders remains constant but the order quantity varies
- Has larger average inventory to prevent stockouts
- Useful when purchasing multiple items from one vendor to save on costs
- **Example:** Always refilling the petrol tank of a delivery truck at the end of each day.

2. Fixed Time Period Ordering: (R,S)



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

2. Fixed Time Period Ordering: "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
- Only order 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?

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:

- Say 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, but NOT ordering quantity

Also known as “Economic Time Cycle”

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 is a constant
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)

EOQ/EPQ Benefits/Features

- EOQ/EPQ is robust; relatively insensitive to errors in estimating D, C_H, C_O/C_S
- Tends to inflate batch/ order sizes
- Can be adapted to different situations and the type of inventory being used
- Empirically, EOQ/EPQ models are <12% away from optimum

3. Variable Order Quantity and Ordering Interval

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

- We still assume that demand is known, even if it is not constant
- Seek to cover demand for a whole number of periods
- 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 n=1,2,3... periods (as LUC)
- Choose n to most closely balance set-up and inventory cost for this batch (average cost per period for the batch is minimised)

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.

3. Variable Order Quantity and Ordering Interval: Least Unit Cost (LUC)

- 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

LUC - Example

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

1. Cover demand	***Batch***	***Cost***	***Cost /Unit***	
for 1	*25*	*£100*	*£4*	
for 1,2	*55*	*£100+30*	*£2.36*	
for 1,2,3	*55*	*£100+30*	*£2.36*	← Best
for 1,2,3,4	*105*	*£100+30+3(50)*	*£2.67*	
2. Cover demand	***Batch***	***Cost***	***Cost /Unit***	
for 4	*50*	*£100*	*£2*	
for 4,5	*50*	*£100*	*£2*	
for 4,5,6	*115*	*£100+2(65)*	*£2*	← Best
for 4,5,6,7	*150*	*£100+2(65)+3(35)*	*£2.23*	
3. Cover demand	***Batch***	***Cost***	***Cost /Unit***	
for 7	*35*	*£100*	*£2.86*	
for 7,8	*70*	*£100+35*	*£1.93*	← Best

Takeaways from Today

- Understand different types of inventory
- Understand basic inventory dynamics
- Understand and calculate Little's Law
- Application of different inventory models (EOQ/EPQ)
- Appreciate limitations of EOQ/EPQ models in reality
- Least unit cost can be used to minimise holding and setup costs by varying order quantity and order time

Preparation for Next Class

Readings:

- Slack et al., "Operations Management": Supplement to Chp. 6 (Forecasting)

Preparatory Questions:

- Why do we need to forecast?
- What are the principles of forecasting?

Operations Management

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