SUMMARY DMSO

2015-2016

Abstract

This summary contains all material from the slides, reading texts and videos available on the platform from the blended learning concept. All copyrights go to professor Van Landeghem and his department.

Disclaimer: It could be that some details were overlooked when making this. It is therefore wise to study all the material and keep this summary as an extra.

Inhoud

Introduction

How to obtain operational excellence?

1) Clarify business model and sources of competitive advantage
2) Install a philosophy for improvement
3) Design architecture, processes and production system to create advantage
4) Disaggregate improvements into digestible pieces driven by leaders
5) Align organization with objectives and reinforce with execution

Step 2 to 5 are dealt with in this course. (2,4,5 are lean management; 3 is facility design)

Barriers

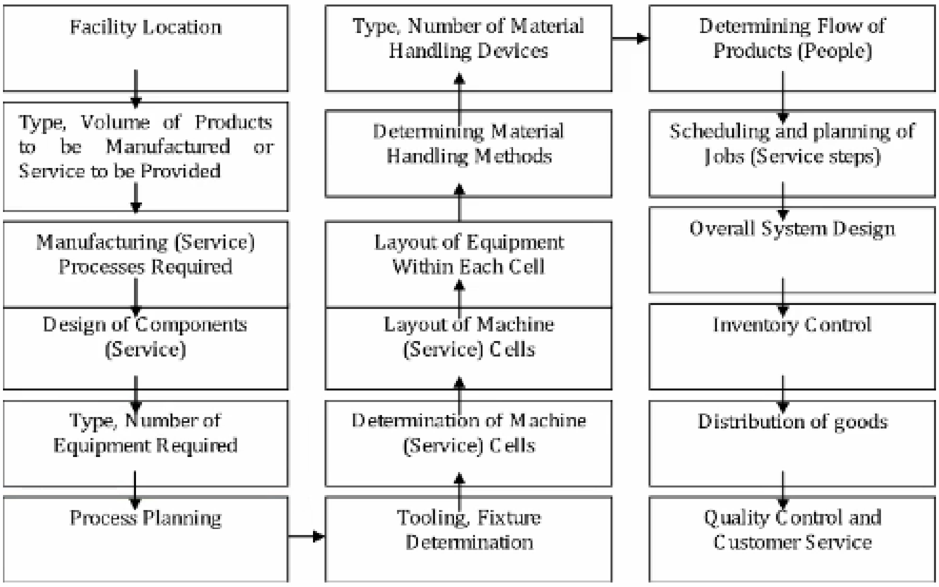
Inability to rapidly adapt business processes to change; ineffective or inadequate IT systems; lack of accurate or timely information; complexity of management

➔ Need for methodological improvement

Levels of decisions

- Strategic (long-term)
- Planning (intermediate)
- Operational (short-term)

Typical design and planning issues



Overall system design: evaluating the entire system using simulations

Why is facilities layout important?

- 20-75% of product cost attributed to materials handling
- Layout of facilities affects materials handling costs
- Good layout increases productivity efficiency
- Reducing congestion permits smooth flow of people and material
- Space utilization is effective and efficient
- Facilitates supervision and communication
- Safe and pleasant working environment

Additional material

Flanders drive is an organisations existing of several car manufacturers in Flanders + the University of Ghent. It improves the organisation of manufacturing in different plants to give the factories an advantage.

Chapter 1: Determining capacity of facilities

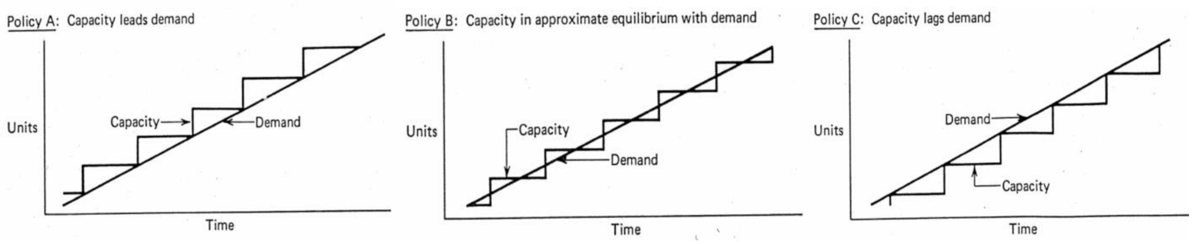
Determining the need for a (new) facility, and the capacity it should be capable of, is a strategic decision. Once the facility is built, it will be there for a long time. Any time market demand does not evolve as expected, serious mismatches can occur, which will have a negative impact on customer service and/or company performance. So the decisions should be carefully prepared and contain possibilities for adjustment later on.

Supply does not match demand…. EVER!

Different capacity Strategies

Long haul strategies that work best when sustained over time:

- Policy A: Capacity leads demand. Extra capacity is installed before it is demanded by the customer. E.g. electricity companies.
- Policy B: Capacity is installed when there is a small shortage in capacity, but enough capacity is installed to have an excess of capacity for a while. So it balances out. E.g. road construction.
- Policy C: Capacity lags demand. So the company is always short in capacity. E.g. public services or production of garments by Zara.



Other Strategies:

- Countercyclical: Build capacity when no one is considering is this. So before the upturn. Discourages competitors but risky if the upturn is less than expected or not happening at all.
- Follow the leader: Build when they build. Not a good long term strategy because the overshoot in capacity on the market causes prices to drop. It does prevent the competition from gaining an advantage.

When to increase capacity

When the Option Value of Waiting (OVW) is negative you should increase capacity.
OVW = NPV(wait) – NPV(not waiting)

Summary of *Restoring our competitive edge – competing through manufacturing*

Capacity strategies should be based upon assumptions about

- The predicted growth and variability of primary demand
- The costs of building and operating different sized plants
- The rate and direction of technological evolution
- The likely behaviour of competitors
- The anticipated impact of international competitors, markets, and sources of supply.

Even is a strategy is not spelled out exactly, if looked at the decisions made by the company, a strategy will become clear.

The capacity of a firm is difficult to be measured. Often you have to take different capacities in account: physical space, hours, people, machines, product flow and output, …

An important relationship is the one between capacity of a facility and the cost of a unit of output. The economies of scale play an important role herein. Equally important are the **diseconomies of scale**.

The **capacity cushion** is an amount of capacity in excess of expected demand. Unused capacity can be expensive. But is needed to respond to unexpected demand surges. This prevents overtime and the disruptions of the normal production schedule and still maintains a fast delivery.

When using policy B, and you see that your capacity you're adding will take too long to match the demand, you can either extend the capacity of the current facility (overtime, weekends, …) or subcontract to outside companies so you don't lose sales. If your capacity will be bigger than the real demand, you can delay construction of the extra capacity.

Capacity can be seen much wider as **the ability of a company to meet the demands of the market**. So the use of stocks of finished products is also a form of capacity. Al be it a more riskier one, because when forecasts are wrong. The company could be stuck with a large stock of obsolete products.

4 forms of capacity, from high speed to slow:

1) Inventory of finished products or stock of components that can be quickly assembled. Most risky option.
2) Partial capacity cushion, of for example only plant and equipment but not people. So in case of higher demand you can hire more people or let people do overtime. Less risky, but also slower.
3) Capacity cushion in the form of cash that is put aside for expansion. The least risk, but also very slow.
4) General purpose cash reserves. The company board will still have to approve the entire capacity expansion. Even slower then number 3.

The size of the capacity cushion is proportional to the magnitude of the ratio $(C_S-C_X)/C_S$. If it's bigger than 0.5 a positive cushion is needed, when it's less than 0.5 a negative cushion is called for. C_S is the cost of a lost opportunity and the costs of overtime, and C_X is the annualized cost of having an unneeded unit of capacity.
These costs however are sometimes difficult to calculate. When looking at C_X, you also have to include the fact that the cost changes over time as the plant ages, the product mix is altered, production technology is modified, … For C_S you should also look at long term effects of not being able to meet the demands of customers who then turn to another supplier, or even being named as an "unreliable supplier".

3 types of economies of scale:

- Short-term: To produce a product there are fixed costs (wages, insurance, property taxes,…) and variable costs depending on the amount produced (energy, material, …). Thus when increasing production, the overhead costs become more spread out and the cost per product will decrease. It's called short term because fixed costs can be variable too and by adding capacity the situation changes quickly from full utilization to underutilised.

- Intermediate-term: Reducing the costs of changeovers.
  $avg\ cost = \frac{changeover\ cost}{\#\ units\ per\ run} + cost\ per\ unit$. Changeover costs include the actual cost of changing the equipment, run-in and run-out costs (cost of excess scrap and reduced efficiency), and the cost of lost production (machines are not running at full capacity while in changeover). Increasing run length brings the risk of an unbalanced stock of products. For example when running out of stock of product B when product A is still running, resulting in more backorders, emergency runs or lost sales.
  Other methods are dedicated lines or specialized equipment & tools.
- Long-term: Static economies of scale include the size of equipment: $C=K*V^k$ with V the volume of the machine. For plants the same rule is applied since constructing a plant has fixed costs (architects, engineers, …) who don't get more expensive proportional to the size of the plant. Dynamic economies of scale include the skills and experience of the organization. This happens when the needed technology is not obtainable from equipment suppliers alone.

Four categories of diseconomies of scale:

- Distribution: When increasing production, the area served by the plant also increases. If the density of customers decreases, the transport costs increase much faster. So goods with high transport costs/unit are more constrained to small geographical areas, but are more invulnerable to competition too. Too few large plants will increase transport costs but also lose customers to competition closer to clients which can provide a better service.
- Bureaucratization: As the workforce grows, more people are needed to supervise, and so the number of layers grows. Each manager also often needs supporting personnel. This increases the management costs, but also lowers the ability to respond to problems (external + internal). Operators also often lose their identity. Also the dependency of surrounding community grows as they employ more of their residents. Therefore the community leaders will want to participate in the decision making process.
  control cost is proportional to number of links between departments.
- Confusion: The impact of increasing the number of products, processes, and specialists. It increases the complexity and thus the coordination costs. (=/= supervisory costs)
- Vulnerability of risk: When one puts to many resources in plant, the company will depend strongly on that plant. So when a natural disaster or a human one (strike, accident, mismanagement,…) strikes, it will affect the company seriously.

Capacity expansion can be used aggressively as a strategic weapon. A capacity increase may cause the demand to increase faster than it would have done without it, or it may make competitors hesitate to increase capacity of their own. Because the total capacity of the market rises, smaller companies will not be able to follow big increases because it will cause price wars.

Causes of overbuilding capacity:

- Technological: Adding large increments, economies of scale, long lead times in adding capacity, minimum efficient scale increasing over time, changes in production technology
- Structural: significant exit barrier, motivation from suppliers, building credibility with customers, integrated competitors, effect of capacity share on market share, effect of age and type of capacity on demand
- Competitive: large number of firms, lack of credible market leaders, entry of new competitors, advantages of being an early mover

- Information flow: inflation of future expectations, divergent assumptions or perceptions, breakdown of market signalling, structural change, financial community pressures
- Managerial: management background and industry experiences, attitude towards different types of risk
- Governmental: Perverse tax incentives, desire for indigenous industry, pressure to increase or maintain employment

Determining the nominal capacity of a system

Three factors determine the capacity of a system, flow rate determined by the bottleneck, the demand and the input of the suppliers.

Two kinds of utilization: Implied utilization, the ratio of demand over capacity, and normal utilization which is the ration of the process flow rate over the capacity. Thus the regular utilization is determined by the capacity of the bottleneck.

How much is needed?

- ***C_{excess} = cost of having one unit capacity too much (cannot be sold)***
- ***C_{short} = cost of having one unit capacity too short (lost sales revenue)***

$$P(demand \leq Capacity) \geq \frac{C_{short}}{C_{excess} + C_{short}}$$

The demand for which capacity should be installed is given by:

$$Q = \mu + z * \sigma$$

In which z can be found by looking it up in the table of the normal distribution using P(demand<cap) and the assumption that the demand is normally distributed.

Options to increase capacity

1) Add parallel lines with the same functionality (duplication)
2) Increase the amount of workers on each workstation on the existing line
3) Increase the number of workstations on the existing line

What is flexibility?

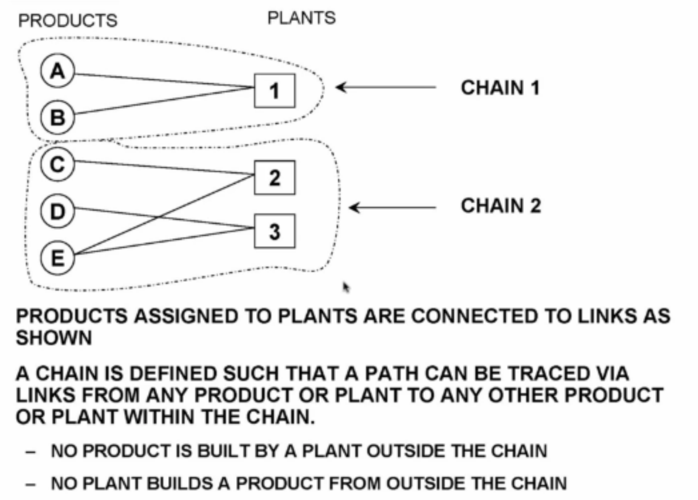
It is the ability to respond to change. Which has 3 parts: the range over which the change can be accommodated, how fast the plant can react to the change, and what the cost effect of the change is (how flat the curve is). Types of change: demand volume, demand mix, product features, technology changes, job priorities or process yield.
Demand stays uncertain till shortly before production.

Adding flexibility to a factory so it's able to make products of different families is also a way of improving the capacity.

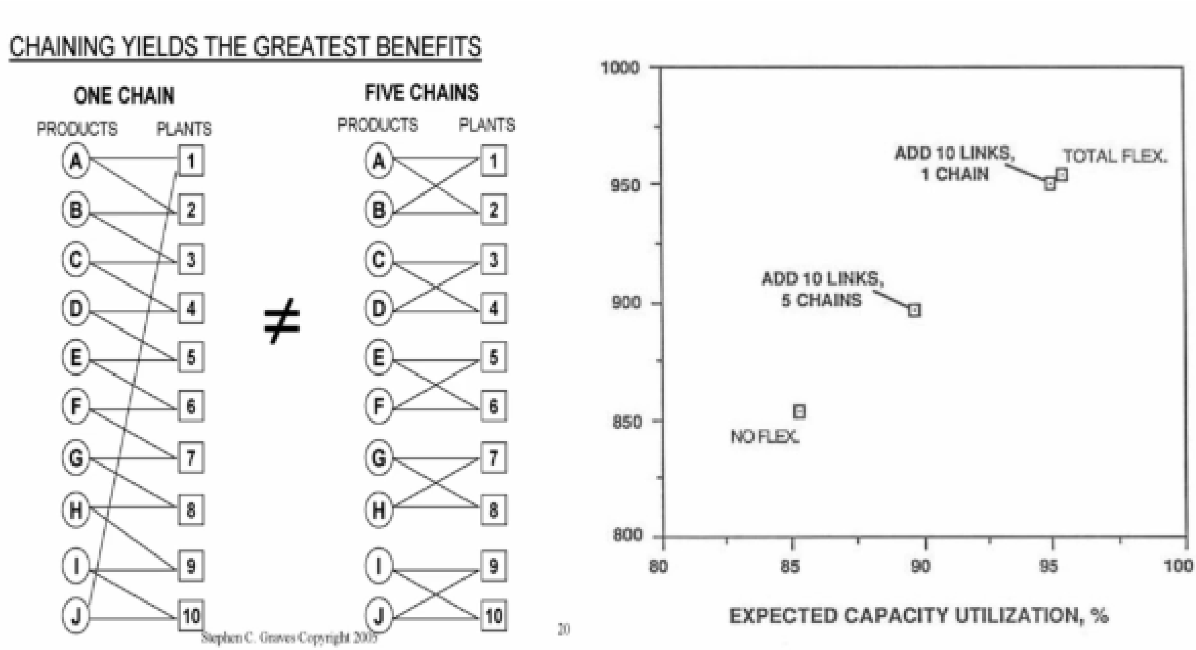
The value of flexibility

When adding links between products and plants so that one product can be produced in multiple plants, it increases the chances of meeting the demand and thus increasing utilization and sales.

Important here is the concept of a chain:

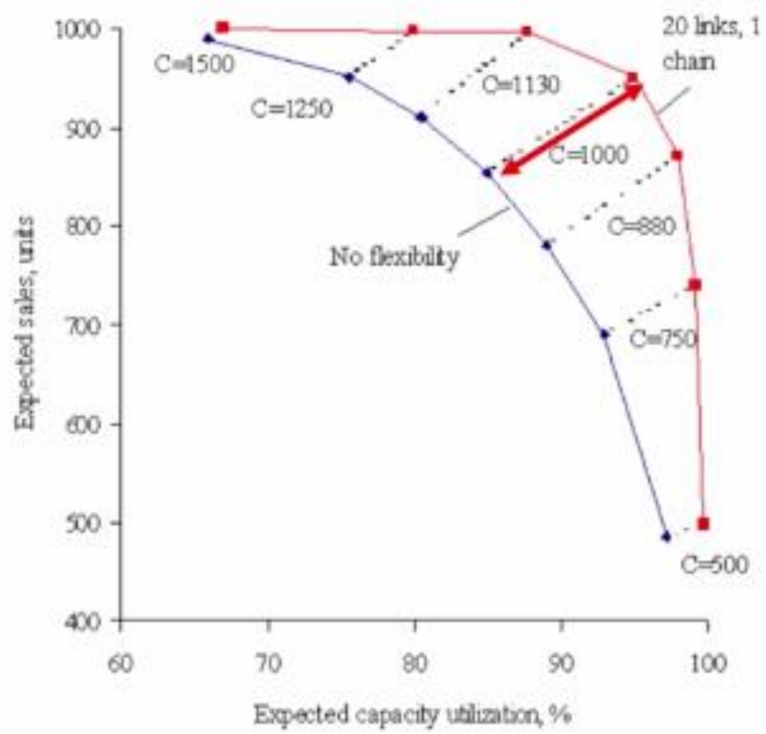


From research it appears that making a long as possible chain is the most profitable. It doesn't need as much links as full flexibility but it does give approximately the same benefits.



When is flexibility most valuable?

- ➔ When capacity approximately equals demand. It is least valuable when the capacity is very high or low with respect to the demand.
- ➔ When there is a configuration with 1 chain.


20 links, 1 chain
C=1500
C=1250
C=1130
C=1000
C=880
C=750
C=500
No flexibility
Expected sales, units
Expected capacity utilization, %
1000
900
800
700
600
500
400
60
70
80
90
100

Chapter 2: Design of warehouses and storage operations

Warehouses are an important type of facility, housing a multitude of material handling processes with a large labour content. Most techniques of facility design and organization are readily applicable to this type of facility, with a wide range of dedicated technology.

Warehouse types

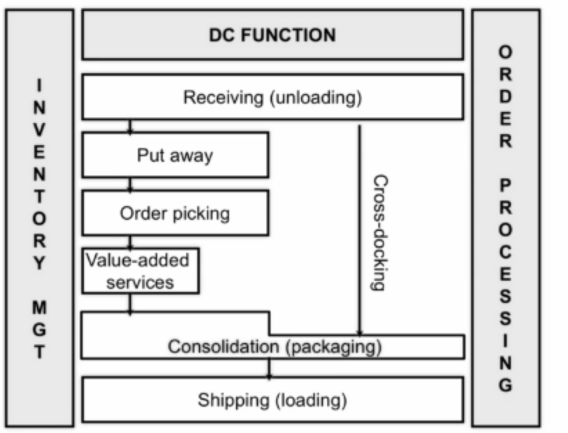
- Factory warehouse: Contains all finished products and is thus the interface between production and the wholesalers. Small number of large orders daily, advanced info about order composition from forecasts by wholesalers. Goal is to deliver timely and with the lowest distribution cost possible. Congestion at the entrance is possible in case of sudden increase in production.
- Retail distribution warehouse: Serves a number of captive retail units (captive = they have no other choice). They too have info in advance about order composition. Many different items in one order, so a forward picking area is needed. Goals are availability, a high fill rate and to lower costs. Responsiveness depends heavily on truck routing schedules. If retail units are not captive, responsiveness is crucial!
- E-commerce retailer: Contains the orders of online webstores. Has to fulfil a very large number of order which contain only one item of a kind. No advance info about composition. Focus on cost and response time. Important problem is the large volume of return items to need to be restocked.
- Support of manufacturing operations: A stock room providing raw material and/or WIP to manufacturing operations. Orders come from the internal planning system, production planning thus depend from the stock. Time requirements are strict. Focus on response time, but also cost and accuracy.

The average warehouse

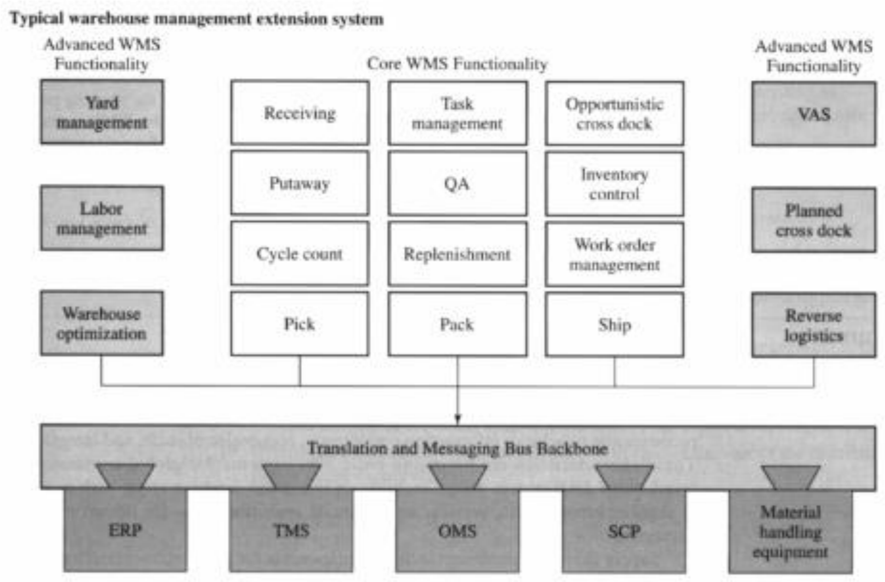
- Size: 21 925 m²
- Clear height: 9.55 m
- Shipping: 2 314 713 lines per year or 544 345 orders per year
- SKU's: 57 735 total or 38 467 active
- Occupancy of 82% at normal inventory levels and 96% at peak levels

An SKU or stock keeping unit is a distinct type of item for sale, such as a product or service, and all attributes associated with the item type that distinguish it from other item types.

Core activities of a distribution centre



Warehouse management system controls operations



Yard management: If there are a lot of trucks and/or trailers, you need to manage them.
Labour management: Picking is a labour intensive process, so management of people is necessary.
Cycle count: Counting only a subset of your inventory on a specific day can avoid errors and can expose errors in the inventory control. It should be mainly focused on the most valuable items. It is less disruptive as a full inventory count.
VAS: value added service
TMS: transportation management system
OMS: Order management system
ERP: Enterprise resource planning
SCP: Supply chain management
Material handling equipment: controlling all equipment, including automatic vehicles.

Performance measures

Indicators of order fulfilment:

- On-time delivery: % of all order delivered on time
- Order fill rate: % of all orders delivered in full
- Accuracy of orders: % of all order picked correctly

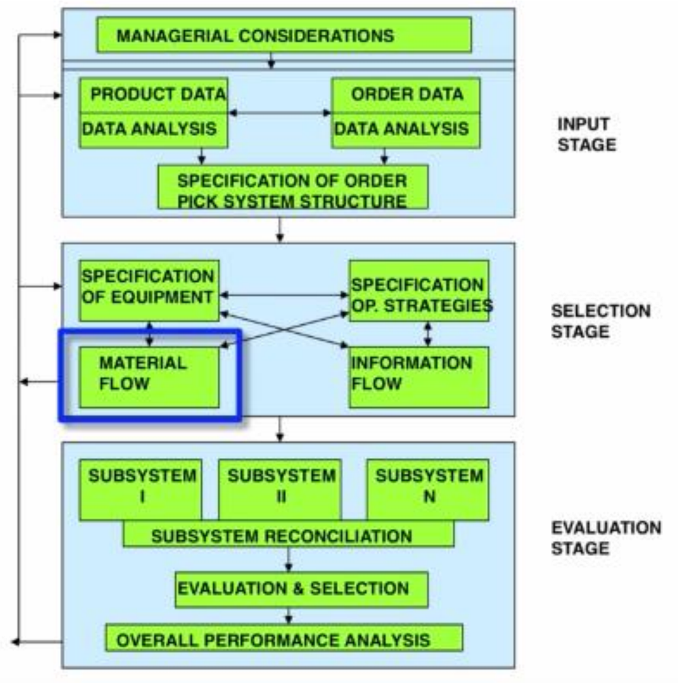
Indicators of management

- Inventory accuracy: absolute value of unit count deviations per SKU
- Inventory shrinkage: damage as % of inventory (eg theft)
- Days of inventory: average inventory/daily sales during last month (also indicates how efficiently the supply chain is designed)

Indicators of spatial organisation:

- Floor occupation rate (m^2)
- Filling rate (positions in rack)
- Cubic filling rate (m^3)

Design procedure



Kinds of data: product (activity level, requested quantities, product properties, vendor types) & order (number of line items, number of items, cubic volume, shipping priorities, product correlation)

From the analysed data following decisions should be made:

- Definition of major functional area's
- Definition of departmental subsystems
- Storage and material handling modes
- Operational policies: storage, replenishment, order picking (batching, sorting, zoning, routing), receiving & shipping policies.

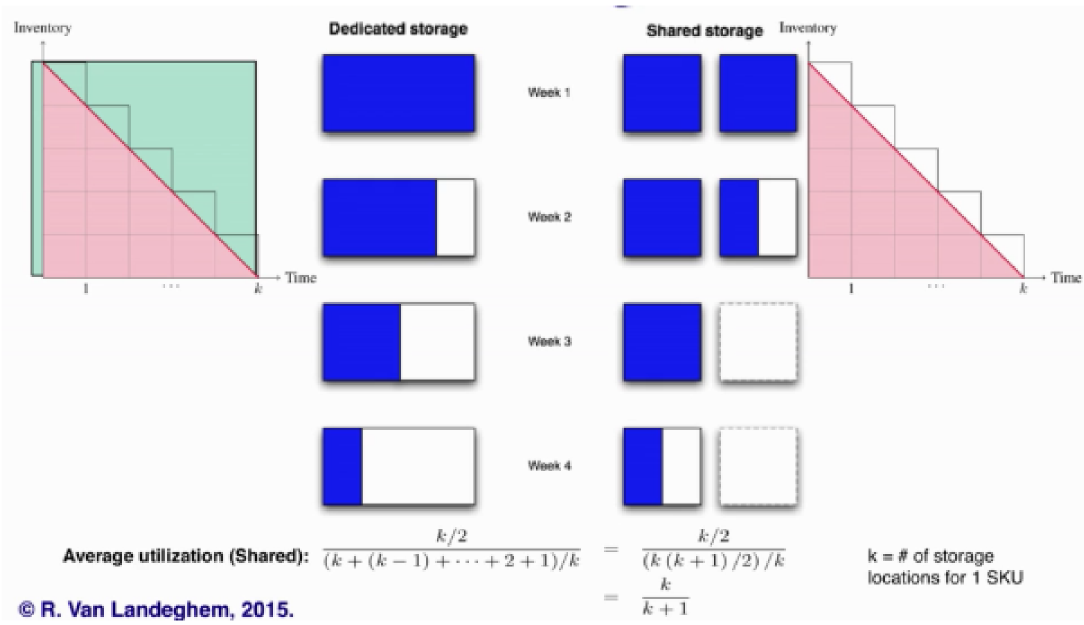
Different levels of decisions:

1) Strategic level: process flow design, equipment selection
2) Tactical level: sizing facility areas and equipment, storage layout, storage and replenishment schemes + batch sizing
3) Operational level: assignment and control problems of people and equipment

The most important cost in warehousing is the cost of labour of blue collar workers. The second cost is the cost of the plant and equipment. In some cases the cost of white collar workers is also important.

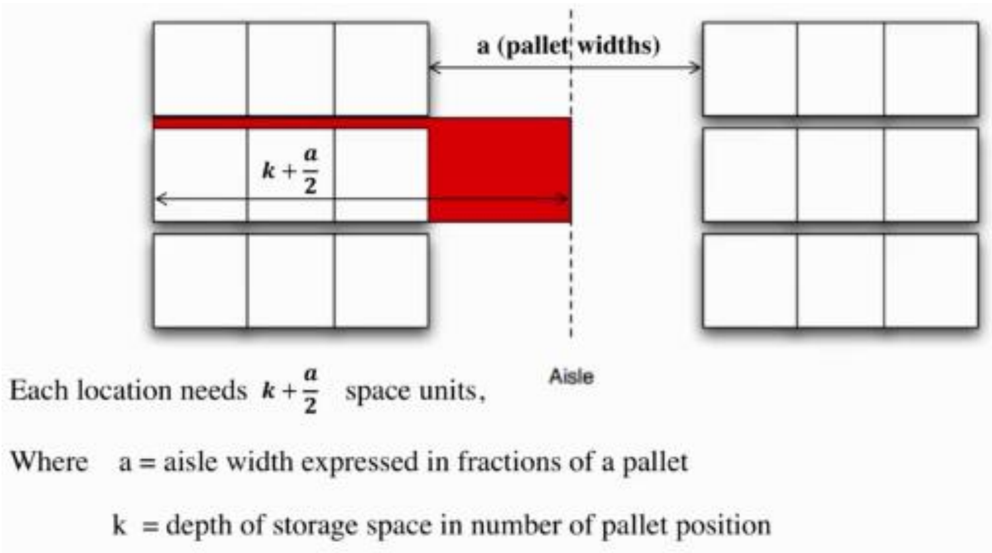
Dedicated vs shared storage

When shared, different SKU's can be put together as soon as a full location is available.

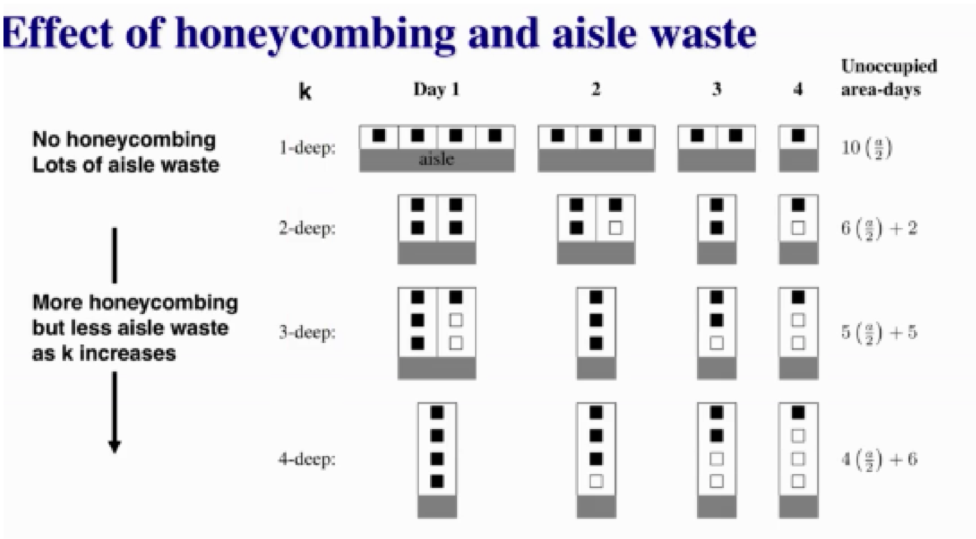


Determining optimal depth for pallets (or cartons)

In this section we will determine the optimal storage depth.



2 kinds of space losses: aisle loss and the honeycombing effect (because you can't use the full depth if there are still items in the back of the rack)



Other important parameters:
D_i: demand of sku I (in pallets/year)
q_i: order quantity of sku I (in pallets)
z_i: number of stackable levels (pallets) -> one floor position becomes available every z_i/D_i years
k: depth of storage space (in pallets) -> a lane becomes available after k z_i/D_i years

If a position becomes available every z/D years, than the following positions are available on average till the lane can be used to store another SKU:

$$1 * \frac{z_i}{D_i} + 2 * \frac{z_i}{D_i} + 3 * \frac{z_i}{D_i} + \cdots + (k-1) * \frac{z_i}{D_i} = \frac{k * (k-1)}{2} * \frac{z_i}{D_i}$$

When we include the number of lanes, we get a honeycombing loss of:

$$\frac{q_i}{z_i k} \frac{k(k-1)}{2} \frac{z_i}{D_i} = \frac{(k-1)}{2} * \frac{q_i}{D_i}$$

Each lane is occupied during $k \frac{z_i}{D_i}$ time periods, so the average occupancy for the $\frac{q_i}{k z_i}$ lanes is

$$\frac{\frac{q_i}{z_i k} + 1}{2} \frac{k z_i}{D_i}$$

So the total loss amounts to:

$$\frac{a}{2} * \frac{q_i}{z_i k} * \frac{\frac{q_i}{z_i k} + 1}{2} \frac{k z_i}{D_i} = \frac{a}{2} \frac{\frac{q_i}{z_i k} + 1}{2} \frac{q_i}{D_i}$$

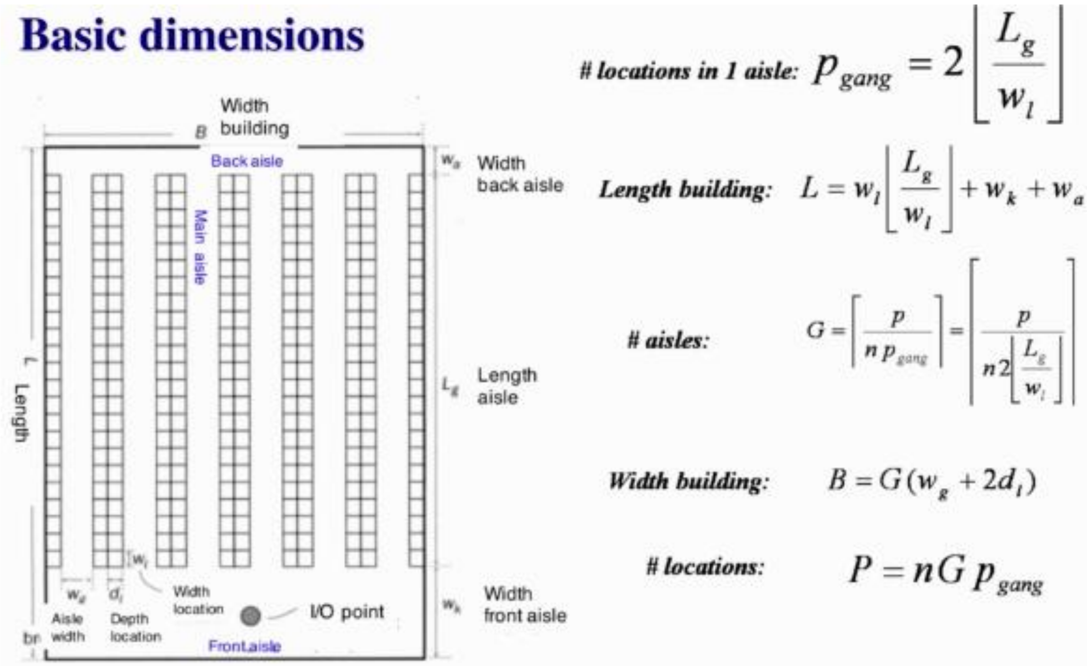
To determine the optimal depth the total cost function is derived with respect to k and set equal to zero. This gives the following result:

$$k_{opt} = \sqrt{\left(\frac{a}{2}\right)\left(\frac{q_i}{z_i}\right)} \quad \text{for one sku} \qquad k_{opt} = \sqrt{\left(\frac{a}{2}\right)\left(\frac{1}{n}\right)\left(\sum_{i=1}^{n} \frac{q_i}{z_i}\right)} \quad \text{for n skus}$$

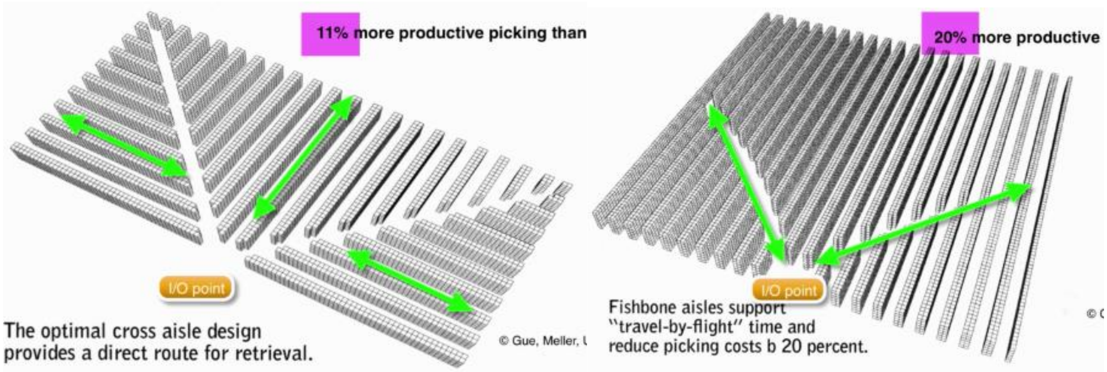
Don't forget, **a is in fractions of pallet depth!!!!**

Dimensions of a warehouse

w_a: width back aisle
w_k: width front aisle
w_g: width aisle
l_g: length aisle
d_l: depth storage location
w_l: width storage location
CAP: central drop-off point



Traditional lay-outs are 23.5% less productive than crow-flight distances in order picking. The optimal cross aisle design results in a 11% more productive picking. The fishbone aisles cause a 20% reduction in picking costs.



Types of storage policies

Storage can take place by sorting the SKU in classes, where the most used classes are put the closest or the most convenient with respect to the I/O-point. SKU's can also be sorted by families: contact-based (frequency that i and j are demanded within the same customer order) or by product characteristics (frozen, cooled, ambient)

3 types of policies:

- Dedicated storage: Every SKU I gets a number of storage locations, N_i, exclusively allocated to it.
- Randomized storage: Each unit from any SKU can be stored anywhere
- Class-based storage: SKU's are grouped into classes. Each class is assigned a dedicated storage area, but SKU's within a class are stored randomly.

Major goal of the policies is to reduce both the travel time and the travel distance by allocating the most *active* units to the most *convenient* locations.
The most convenient locations are the ones with the smallest distance d_j to the I/O-point.

- ➔ $d_j = (|x_j-x_{I/O}|+|y_j-y_{I/O}|)$ (forklifts or similar material handling equipment)(Manhattan metric)
- ➔ $d_j = \max(|x_j-x_{I/O}|,|y_j-y_{I/O}|)$ (AS/RS systems which move simultaneously in both directions)(Tchebychev metric)

The most active SKU's is found by average visits per storage location per unit time = (number of units of i handled per unit of time)/(number of allocated i storage locations).

The popularity of a sku: $P_i = \sum_{order\ j\ in\ period\ T} x_{i,j}$ with $x_{i,j}$ = 1 if the item occurs in order j and otherwise equal to zero. T is a reference period.

Turn index (T) is defined as the ratio of the picked volume during a period T to the average stock volume stored in T. The higher the index, the more important the SKU.

To achieve the goal you will then need an algorithm to match the active SKU's with the convenient locations.

Storage equipment

The basis for selecting storage equipment is the unit load in which products will be stored. (pallets, boxes, product packs,…)

Pallets are standardize for easy use. -> euro pallet

Shelves are most common but are not the most efficient. Certainly for picking, only a limited range of heights is easy accessible. Special racks can increase the space used efficiently.
High shelves with floors on different levels are called **mezzanines**.
Pallet racks are a more rigid and larger version of the normal shelves.

Drive-in pallet racks are specifically designed so forklift trucks can enter the shelf and place the pallet as deep as possible. The FILO principle applies here.

Another option is the roll through or **gravity rack**. The goods are put in on one side and roll through to be picked out on the other side. Here the FIFO principle applies. Loading and unloading happens thus happens in different aisles.
While in a traditional shelve it takes 15% of the time to read the ordersheet, 25% of the time to grasp the item and 60% to travel, it only takes 20% travel time if gravitational racks are used, because more items can be stored in the front. It also reduces the number of aisles, and thus floorspace.

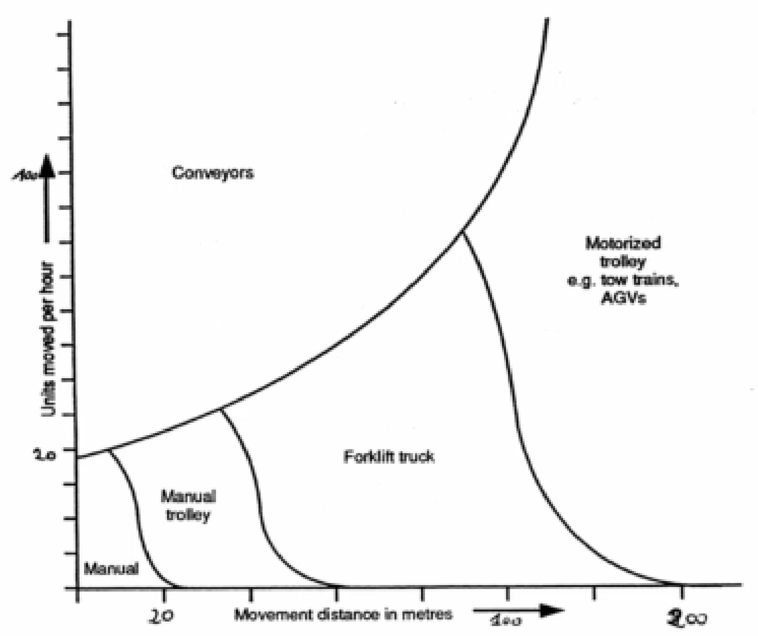
Other special racks: **Cantilever** (or support beam racks: used for long parts), **pigeon holes** (for rolls, eg carpet), **moveable racks** (saves floorspace and protects content, not efficient when racks are often used)

Automatic storage (goods to man):

- Carrousel (old type, commonly used in semi-manual picking stations, long waiting times, modular design)
- Encased carrousel: Vertical lift module (or lean lift) (lot of space for medium to small items, very fast, can contain camera's that allow easy verification of the content)
- Automated Storage & Retrieval system (AS/RS): full automatic cranes (reaches up to 20m, very large warehouses because heavy investment) (input/output systems have very strict control systems because the products needs to fit in the rack)
- Miniload system: AS/RS system but downsized so it can be used for smaller loads. (speed increases too)
- A-frame: special system designed for high speed order picking.

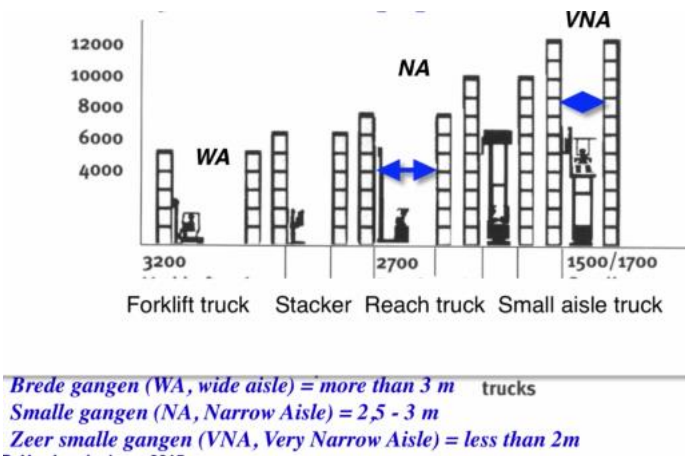
Transport & handling equipment

Selecting material handling equipment:



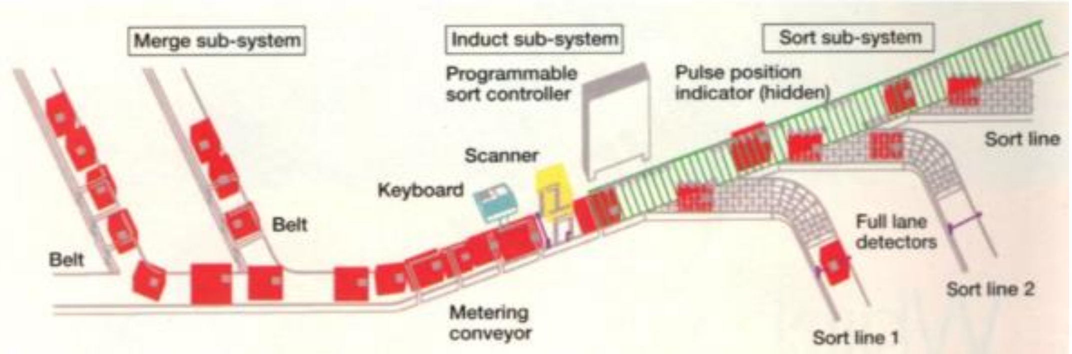
Forklifts have the drawback that they need wide aisles. Therefore the reachtruck was invented. These can operate in smaller aisles, but cannot lift as much weight and do cost more.

For a more efficient use of floorspace one can use automatic shuttle systems in combination with forklifts. These shuttles will move the pallet further in the rack so that a more compact configuration can be realised.

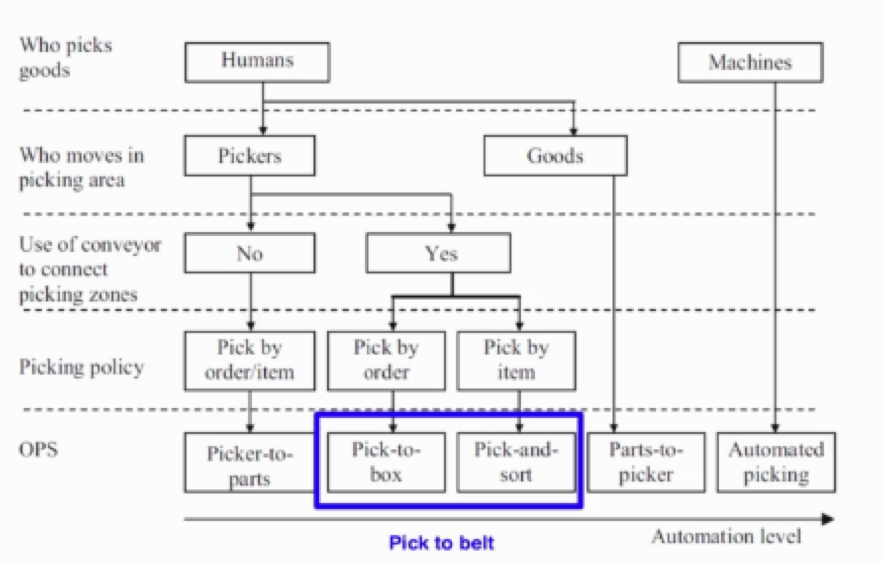


More and more AGV's (automated guided vehicles) can be found in factories. They are guided by indoor GPS or markings on the racks or floor. They can be found in numerous forms: small, large, with forks, as towing truck, …

Parts of a conveyor system:



Order picking classification



Pick-to-box is when a picker picks an entire order and collects it in a box on his cart. Often multiple boxes are on the carts and he picks multiple orders at the same time.
Pick-and-sort is the picking of multiple items which then need to be sorted over the different orders. Both of these systems are also referred to as put systems.

Automated systems can only handle certain volumes, so for bigger volumes more manual picking will be necessary.

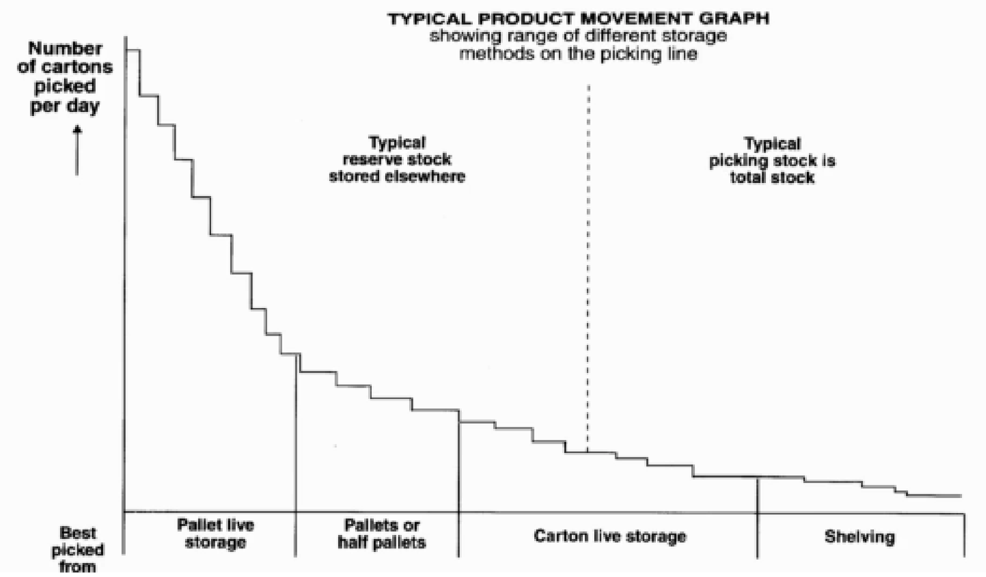
Batch picking is when multiple orders are picked on the same route. Discrete picking is picking only one order, multiple items in one route. Zone picking is when items need to be picked in different zones to fulfil one order. Multiple routes will be necessary as the picker are ought to stay in their own zone.

Forward pick area

Products can be stored in a forward pick area closer to the point where it is needed. The advantage is that the pick becomes less expensive, but the restock of that area also needs to be organised.

Possible decisions include which items to put there and how much of those items, also the size of such an area is an unknown.

Picking strategies vs volume



For high volumes it is suitable to foresee a forward picking area because the sheer size of the central storage will slow down the picking.

Picker routing

Usually a stow trip is combined with a retrieval trip to a dual trip so that deadheading (=idle walking) is prevented as much as possible.

To calculate the most efficient route, routing algorithms are used. But there are also some easy picking heuristics:

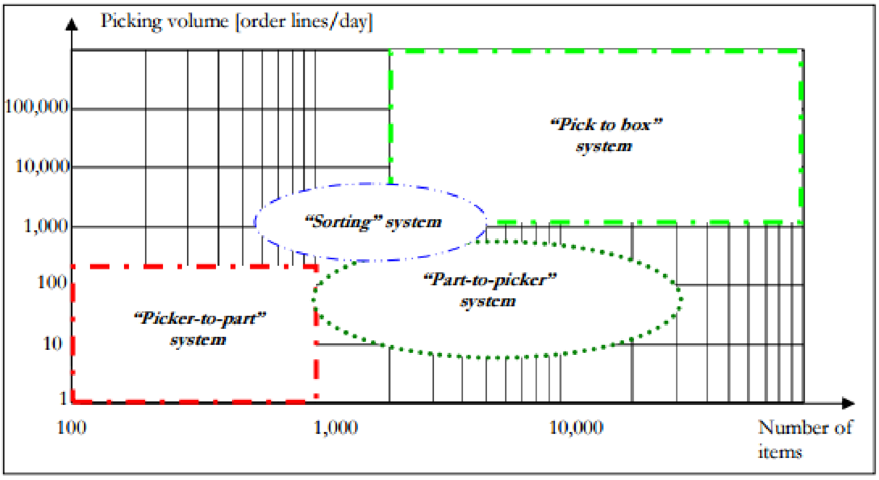
- S-shape: go through every aisle with at least one pick
- Largest gap: go through every aisle with at least one pick, but turn back before the largest gap between two picks in the same aisle.
- Combined: Go through every aisle once, from left to right, and turn back when last pick before halfway in the aisle.

Common sense rules

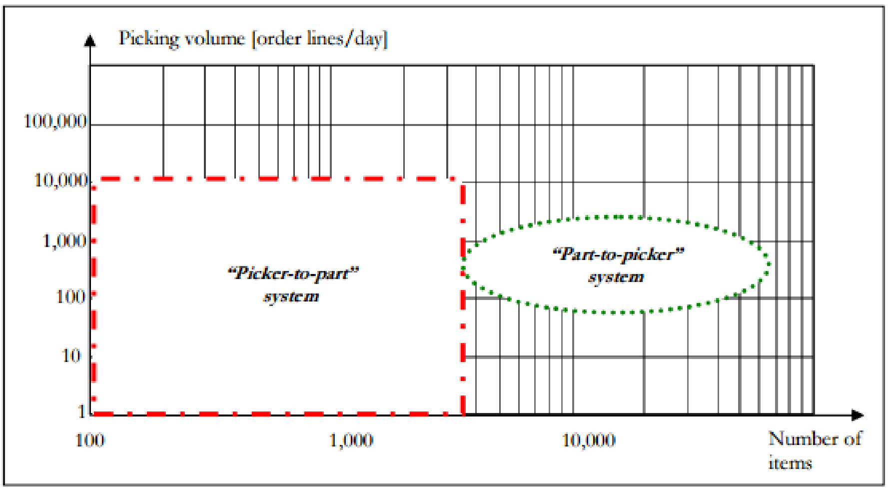
1) Reduce picking errors: put similar products far apart, lighting should not hinder identification (glossy labels, …)
2) Increase productivity: example: forklifts take 2 pallets per trip, customer order odd number of pallets -> agree to order by 2 pallets.
   Also never return empty.
3) Spreading of deliveries: reduce waiting time for trucks

Notes from the text about order picking systems

When order size < 0.5 m³:



When order size > 0.5 m³:



The design of an order picking system is also dependent from other factors that are hard to generalize like the cost of labour in the country and the risk attitude of the company. It is possible that the best solution is not the most convenient but the cheapest because of the short life of outsourcing contracts.

Chapter 3: Design of plant logistics

Most manufacturing operations require a complex supply system to make sure that the correct parts are available at the correct workplace at the correct moment. These logistic systems are quite different in objectives and scope from warehouses, yet use many of the same technology and design methods. This section will describe how the methods can be adapted for these kinds of systems.

Challenges:

- Constraints on available space on border of line
- Cost effective resupply
- The impact of logistics on production process
- Right materials, at the right time, to the right place and In the exact amount.

Resupply strategies

Line stocking

Line stocking, sometimes also referred to as bulk feeding, continuous replenishment or point-of-use storage, is the most straightforward method of replenishment. Parts are supplied directly to the assembly line in quantities larger than one, within a dedicated container.

For the replenishment, two systems are possible. The first possibility is a 2-bin system in which there are 2 bins placed at the border of line. When the first one is used up, a signal for replenishment is given. In the meantime the second bin should cover the time until the next bin is delivered. It should also provide a safety stock.
The second possibility is a reorder point. As soon as the stocklevel in the border of line reaches that point, a signal for replenishment is given. The remaining stock should be enough to cover the delivery time of the replenishment. (+ safety stock)

Downsizing

Parts are first repackaged from the large containers they arrive in and are then supplied to the line.

Sequencing

Parts are not stored in bulk at the line but are only supplied to the line at the moment and in the quantity they are needed according to the production schedule.

Kitting

Parts are grouped together in a kit so that one kit can support one or more assembly operations for one given end product. The kits are then sequenced and brought to the assembly line with a schedule based on the takt time.

General remarks

Downsizing, sequencing and kitting induce additional material handling activities. These can happen at the supplier, but also in between the point of arrival and the point of use, in so called supermarkets. These activities can of course also be done by a third party logistics provider.

Advantages and disadvantages

The advantage of kitting is the reduced stock of parts at the border of line. Certainly in situations with mass customization this is an important advantage because stocking an amount of every possible part at the assembly plant would increase the size of the border of line and would thus result in a unnecessary large plant.

The reduction of WIP also leads to better parts visibility and accountability, resulting in an improved control over the WIP. Moreover, the majority of the material is stored centrally which increases security in the control of physical inventory.

The biggest drawback from kitting is when a part in the kit is wrong or damaged, the production will be disrupted and a replacements has to be brought from central storage. Unlike in the case of line stocking where another substitute can be directly taken out of the box. Solutions are to include a spare part or place a container of parts sensitive to failure in the border of line.
Cannibalisation of kits happens when the operator takes a part from the next kit to replace the missing part from the current kit.

Kitting also reduces material handling and walking distances at the assembly line. It is therefore advised under a lean philosophy. It also translates into shorter lead times.

Because materials in a kit are placed in a way to support the assemblers work, they are also very convenient to be used as a work instruction and this will ease education of new staff. Consequently training costs will be reduced.

Controlling the exact quantity, position and orientation of individual parts in a kit also allow the use of robotics.

Quality also increases if parts are placed in exact positions in a kit because a missing part will be noticed early in the chain. In the case of line-stocking the risk of picking a wrong part will reduce in a lower quality.

Ergonomics also benefit from kitting.

Besides the benefits of kitting, kitting also brings a lot of extra handling of parts. It also takes quite some space in stock room. In addition, more handling means more risk of damaging parts.

Transports for kits can be easily timed since kits are in sync with the takt time.

Kitting decreases the flexibility of the production schedule because the schedule must be known well in advance to make the kit and bring it to the point of use. Rescheduling causes kits to be brought back to the supermarket and to be dekitted again.
The advantage of knowing the schedule is that you can detect shortages in stock early and place order at the suppliers before the parts are needed or change the sequence till the right parts are back in stock again.

Line-stock has the advantage of having denser packages because the parts are not prepositioned or in an exact position as in kitting.

Downsizing is a form of line-stocking, but since the stock at the bol is smaller, some advantages of kitting are also valid here: better control over WIP, less walking, …

Sequencing also combines some of the advantages and disadvantages of line-stocking and kitting.

Summary of the advantages of kitting:

- Reduction in stock at the border of line
- Better overview and control over WIP
- Reduction in material handling and walking during assembling
- Possibilities for robotic handling
- Increase in quality

- Easy transport planning
- Ergonomically better
- Better control of central stock because schedule is known

Summary of the disadvantages of kitting:

- More material handling in advance
- More chance of damaging parts
- Less flexibility
- Errors can interrupt production

Cost-model

There are four kinds of costs:

Picking cost

Composed of the cost of time it takes for an operator to walk to the necessary part and pick it. In case of kitting the time for picking the part is zero.

Transport cost

The cost for transporting parts from the warehouse to the bol in case of line-stock or the cost of transporting kits from the supermarket to the bol. The cost is dependent from:

- the distance from warehouse/supermarket to the bol
- in case of line-stocking: box or pallet
- Velocity of forklift or tugger train
- The usage rate (both for boxes and kits)
- The number of items per package
- Capacity of the tugger train (only for boxes)
- Utilization of the tugger train (only for boxes)

Kit assembly

The labour cost of the kit assembly. The average time to pick a part depends on the opportunity to pick multiple parts at once, which depends on the batch size in which kits are assembled. It also depends on the usage frequency of the part as well as the number of units of the part used at the workstation. The physical limit of the number of parts that can be picked at once (because of weight or size) also plays a role.

Replenishment of the supermarket

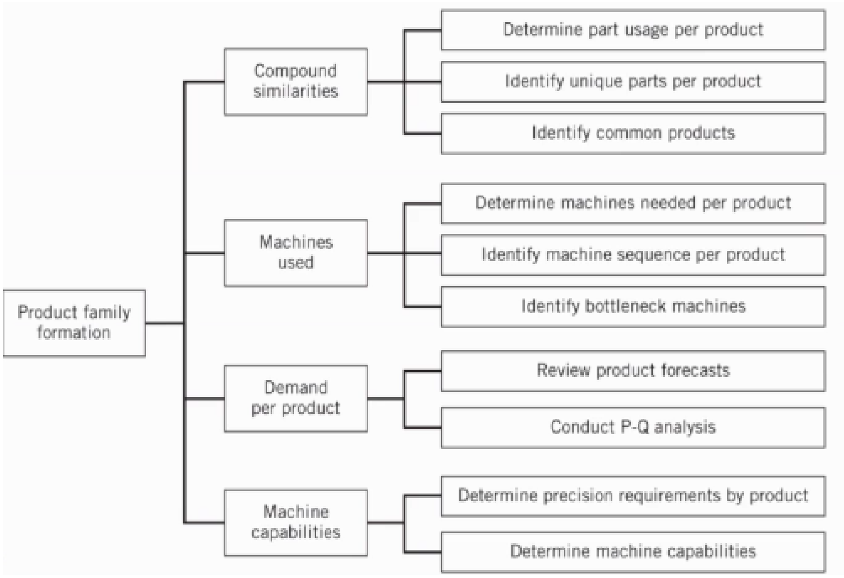
Similar to the transport cost, but is only present when kitting takes place and the parts need to be transported from the warehouse to the supermarket.

Chapter 4: Micro-design of cells and lines

Production systems are composed of work units that may be single workplaces with one machine or work table, or cells comprised of multiple units. This section teaches methods to distinguish cells and units out of the material flow information (such as volume, part characteristics, specific processes).

How to form cells?

In order to form cells it is important to group parts into families that are then used in one or a few cells. Families can be formed according to similarities in different categories:



Once the families are formed, one can assign the families to manufacturing cells. Once cells are formed, raw materials can be assigned to their point of use and incoming and outgoing flows of the cell can be determined.

Systematic Layout planning

In the planning of the layout the following data are important (PQRST):

- Product: Types of products to be produced
- Quantity: Volume of each part type
- Routing: Operation sequence for each part type
- Services needed: support services, locker rooms, inspection stations, …
- Timing: When are the part types to be produced? What machines will be used this time period. Important for example when products are seasonal.

Other factors that influence the flow pattern are: number of parts in each product, number of operations on each part, sequence of operations in each part, number of subassemblies, number of units to be produced, product vs process type layout, desired flexibility, locations of service areas, the building, …

This data can be gathered from: exploded view, assembly chart, operations process chart, flow process chart, multi-product process chart, flow diagram, from-to chart

How to classify products?

Intuitive charting/grouping

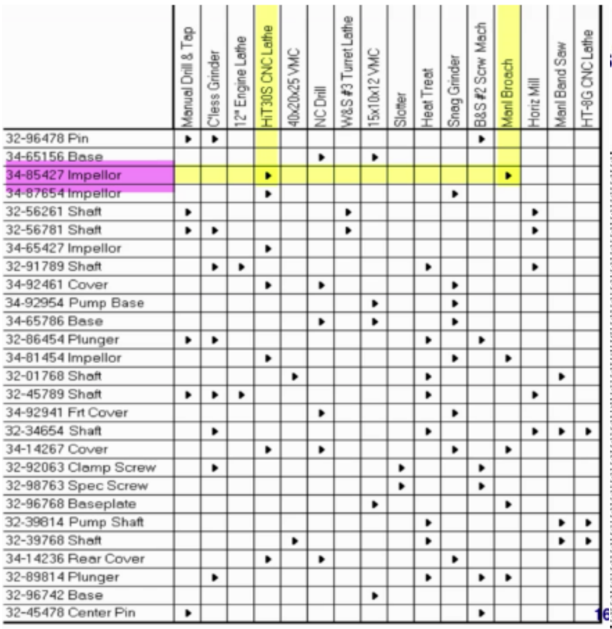
Looks at the type of parts, but also the processes. The disadvantage is that it is not easy to replicate across different people.

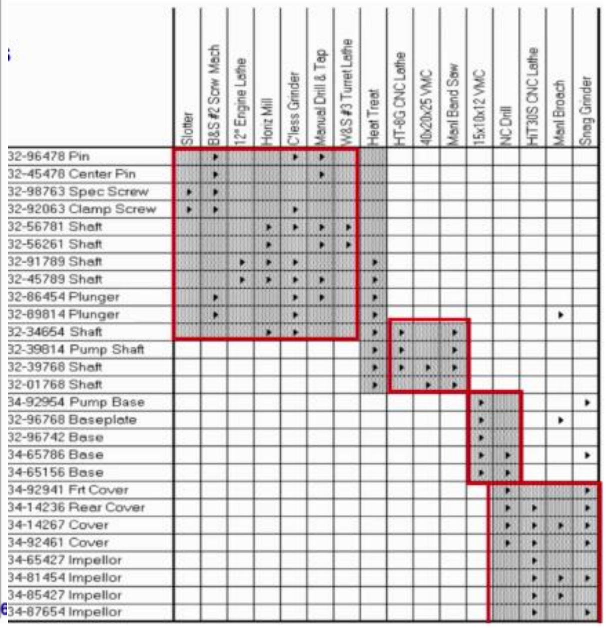
Coding & classification

The most used type of coding is the group technology code. It is a standard codification that tries to describe the characteristics of a product by using codes. Different products have different code systems.

Production flow analysis

PFA looks at the flow pattern that emerges from the production sequence or the machines that are used and will try to group them into homogenous cells. Basis for this procedure is the incidence matrix or product-machine matrix. When the rows and columns are regrouped we get the matrix on the right and we see cells appearing.





Some machines are not assignable to one specific cell (eg heat treat). In that case there are two options, creating a separate cell for the machine or duplicating the machine.

Determining the capacity of a cell

Once we've determined which cells to use, we have to determine the capacity of the cells. The capacity should be able to cover the anticipated evolution. So cells need to have some spare capacity if you are for example in a growing market, to prevent having to reorganise the entire plant.

The batch size used in a cell is an important factor in determining the capacity of cell:

$$CAP[B] = \frac{B}{S + p * B}$$

With setup time S, cycle time p and batch size B.

Quantifying flow characteristics: Flow dominance measure

Measures how common the different routings are, and thus anticipates the success of the PFA analysis.

Notations:
M: number of acitivities, MxM matrix is solution space
N_{ij}: number of different types of tiems moved between activities i and j, index k
f_{ijk}: flow volume between i and j for item k (in volume units/time period)
h_{ijk}: equivalence factor for moving item k with respect to other items moved between i and j (dimensionless, indicates relative weight, bulkiness, …)
w_{ij}: equivalent (total) flow volume specified in from-to chart (in volume units/time)
$\overline{w}$: the average flow between any activity pair
f': is the coefficient of variation (CV=std dev/average)
f_L and f_U are lower and upper bounds on f' (the upper bound is only guaranteed to work when each process plan includes all acitivities, otherwise f>1 is possible).
f: Flow dominance measure

$$w_{ij} = \sum_{k=1}^{N_{ij}} f_{ijk} h_{ijk}$$

$$\overline{w} = \frac{\sum_{i=1}^{M} \sum_{j=1}^{M} w_{ij}}{M^2}$$

$$f' = \frac{\left[\frac{\sum_{i=1}^{M} \sum_{j=1}^{M} w_{ij}^2 - M^2 \overline{w}^2}{M^2 - 1}\right]^{1/2}}{\overline{w}}$$

$$f_U = M \left[\frac{M^2 - M + 1}{(M-1)(M^2-1)}\right]^{1/2}$$

$$f_L = M \left[\frac{1}{(M-1)(M^2-1)}\right]^{1/2}$$

$$f = \frac{f_U - f'}{f_U - f_L}$$

The flow dominance measures results in three cases:

- f ≈ 0: A few dominant flows exist, so a product lay-out is best suitable. A process chart will be a good starting point to develop a layout.
- f ≈ 1: Many nearly equal flows, so any layout equally good with respect to flows. Qualitative measures will be the principal sources of activity relationship.
- 0<<f<<1: no dominant flows, difficult to develop layout, both quantitative and qualitative measures are important.

Cell formation algorithms

The basis is the part/machine incidence matrix:

		M_1	M_2	M_3	M_4	M_5	M_6	M_7
$[a_{ij}] =$	P_1	1			1		1	
	P_2		1	1		1		
	P_3				1		1	
	P_4		1	1				
	P_5			1				1
	P_6		1			1		1

$a_{ij} = 1$ if part P_i is processed on Machine M_j

c_{ij} = cost = a_{ij} (or in some cases = f_{ij})

Rank order clustering algorithm (ROC)

1) Assign binary weight $BW_j = 2^{m-j}$ to each column j of the part-machine processing indicator matrix.
2) Determine the decimal equivalent DE_i of the binary value of each row i using the formula:

$$DE_i = \sum_{j=1}^{m} 2^{m-j} a_{ij}$$

3) Rank the rows in decreasing order of their DE values. Break ties arbitrarily. Rearrange the rows based on this ranking. If no rearrangement is necessary, stop; otherwise go to step 4.
4) For each rearranged row of the matrix, assign binary weight $BW_i = 2^{n-i}$.
5) Determine the decimal equivalent of the binary value of each column j using a similar formula as in step 2.
6) Rank the columns in decreasing order of their DE values. Break ties arbitrarily. If no rearrangement is necessary, stop; otherwise go to step 1.

Step 1 and 2

		M_1	M_2	M_3	M_4	M_5	M_6	M_7	
Binary weight		64	32	16	8	4	2	1	Binary value
$[a_{ij}] =$	P_1	1			1		1		74
	P_2		1	1		1			52
	P_3				1		1		10
	P_4		1	1					48
	P_5			1				1	17
	P_6		1			1		1	37

Step 3 and 4 and 5

		M_1	M_2	M_3	M_4	M_5	M_6	M_7	
Binary value		32	28	26	33	20	33	6	Binary weight
$[a_{ij}] =$	P_1	1			1		1		32
	P_2		1	1		1			16
	P_4		1	1					8
	P_6		1			1		1	4
	P_5			1				1	2
	P_3				1		1		1

Step 6 and 1 and 2

		M_4	M_6	M_1	M_2	M_3	M_5	M_7	
Binary weight		64	32	16	8	4	2	1	Binary value
$[a_{ij}] =$	P_1	1	1	1					112
	P_2				1	1	1		14
	P_4				1	1			12
	P_6				1		1	1	11
	P_5					1		1	5
	P_3	1	1						96

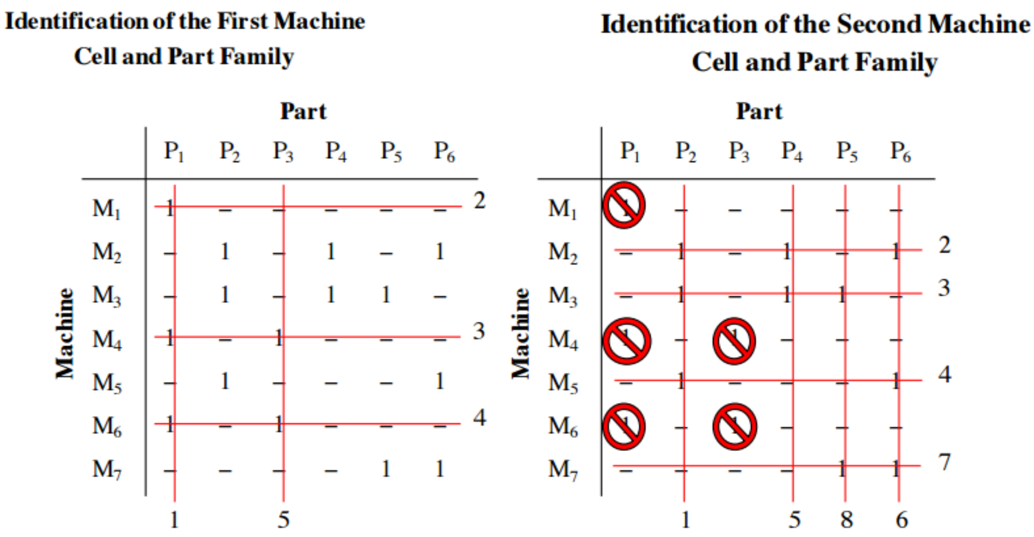
		M_4	M_6	M_1	M_2	M_3	M_5	M_7	
Binary value		48	48	32	14	12	10	3	Binary weight
$[a_{ij}] =$	P_1	1	1	1					32
	P_3	1	1						16
	P_2				1	1	1		8
	P_4				1	1			4
	P_6				1		1	1	2
	P_5							1	1

Direct clustering algorithm (DCA) – Chan & Milner

1) Sum 1's in each row and each column. Order rows top to bottom in descending order of #1's. Order columns in ascending order of #1's from left to right. Break ties in descending numerical sequence.
2) Take each row in turn from first one and
   1) shift columns to left if they have 1 in the row
   2) stop if no opportunities are left
3) Take each column left to right and
   1) shift row up when opportunities exist to form block of 1's.
4) Form cells such that all processing of one part occurs in one cell.

Row and column masking algorithm (R&CM)

1) Draw a horizontal line through the first row. Select any 1 entry in the matrix through which there is only one line.
2) If the entry has a horizontal line, go to step 2a. If the entry has a vertical line, go to step 2b.
   2a) Draw a vertical line through the column in which this 1 entry appears. Go to step 3.
   2b) Draw a horizontal line through the row in which this 1 entry appears. Go to step 3.
3) If there is any 1 entries with only one line through them, select any one and go to step 2. Repeat until there are no such entries left. Identify the corresponding machine cell and part family. Go to step 4.
4) Select any row through which there is no line. If there are no such rows, stop. Otherwise, draw a horizontal line through this row, select any 1 entry in the matrix through which there is only one line, and go to step 2.



Single linkage (S-link) clustering algorithm

S-Link is the simplest of all clustering algorithms based on the similarity coefficient method.
The similarity coefficient between two machines is defined as the number of parts visiting both the two machines divided by the number of parts visiting either of the two machines. Suppose we have m parts.

$$S_{A,B} = \frac{\sum_{j=1}^{m} a_{A,j} a_{B,j}}{\sum_{j=1}^{m} (a_{A,j} + a_{B,j} - a_{A,j} a_{B,j})}$$

Algorithm:

1) Pairwise similarity coefficients between machines are calculated and stored in the similarity matrix.
2) The two most similar machines join to form the first machine cell.
3) The threshold value (the similarity at which two or more machine cells join together) is lowered in predetermined steps and all machine/machine cells with the similarity coefficient greater than the threshold value are grouped into larger cells.
4) Step 3 is repeated until all machines are grouped into a single machine cell.

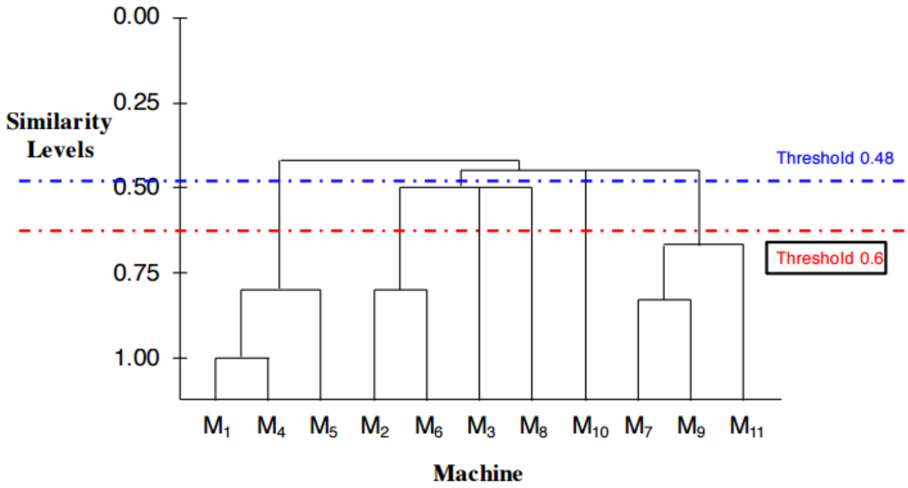
Example 4: Initial Similarity Coefficient Matrix

Machine (columns) / **Machine** (rows)

	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}	M_{11}
M_1	–										
M_2	0.08	–									
M_3	0.00	0.43	–								
M_4	1.00	0.08		0.00	–						
M_5	0.80	0.00	0.00	0.80	–						
M_6	0.00	0.80	0.50	0.00	0.00	–					
M_7	0.00	0.00	0.10	0.00	0.00	0.00	–				
M_8	0.00	0.25	0.50	0.00	0.00	0.27	0.45	–			
M_9	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.36	–		
M_{10}	0.43	0.45	0.23	0.43	0.43	0.36	0.00	0.17	0.00	–	
M_{11}	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.37	0.67	0.00	–

Cluster	Threshold
M1-M4	1
M7-M9	0.83
M2-M6	0.8
M5-[M1-M4]	0.8

Example 4: Dendrogram Based on S-Link



Example 4: Machine Part Groups using S-Link (TH=0.6)

Part (columns) / **Machine** (rows)

	P_1	P_3	P_{16}	P_2	P_{15}	P_{22}	P_{20}	P_{21}	P_7	P_{11}	P_8	P_{19}	P_5	P_{12}	P_{13}	P_6	P_{14}	P_{18}	P_9	P_{10}	P_{17}	P_4
M_5	1	1	1	1	1	1	1	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–
M_1	1	1	1	1	1	1	1	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–
M_4	1	1	1	1	1	1	1	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–
M_{10}	1	1	1	1	1	–	–	–	1	1	1	1	1	1	–	–	–	–	–	–	–	–
M_2	–	–	–	–	–	–	–	–	–	1	1	1	1	1	–	–	–	–	–	–	–	–
M_6	–	–	–	–	–	–	–	–	–	–	1	1	1	1	–	–	–	–	–	–	–	–
M_3	–	–	–	–	–	–	–	–	–	–	–	1	1	1	1	1	–	–	–	–	–	–
M_8	–	–	–	–	–	–	–	–	–	–	–	1	1	1	1	1	1	1	1	1	1	–
M_7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	1	1	–	1	1
M_9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	1	–	1	1
M_{11}	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	1	1	1

Average linkage (A-link) clustering algorithm

The average similarity coefficient between two machine cell is defined as the average of pairwise similarity coefficients between all members of the two cells.

$$AS_{cell1,cell2} = \frac{1}{K}\sum_{K} S_{A,B}$$

For all K (A,B) combinations where A ∈ Cell 1, B ∈ cell 2

Algorithm:

1) Compute pairwise similarity coefficients between machines and construct the similarity coefficient matrix.
2) Merge the two most similar machines into a single machine cell.
3) Compute the similarity coefficients between the newly formed machine cell and the remaining cells. Revise the similarity coefficient matrix.
4) The threshold value (the similarity level at which two or more machine cells join together) is lowered in predetermined steps and all machine/machine cells with the similarity coefficient greater than the threshold value are grouped into larger cells. Repeat steps 3 and 4 until all machines are grouped into a single machine cell.

Example 4: Revised Similarity Coefficient Matrix I

Machine Cell	(M_1,M_4)	(M_2,M_6)	M_3	M_5	(M_7,M_9)	M_8	M_{10}	M_{11}
(M_1,M_4)	–							
(M_2,M_6)	0.04	–						
M_3	0.00	0.47	–					
M_5	0.80	0.00	0.00	–				
(M_7,M_9)	0.00	0.00	0.05	0.00	–			
M_8	0.00	0.26	0.50	0.00	0.41	–		
M_{10}	0.43	0.41	0.23	0.43	0.00	0.17	–	
M_{11}	0.00	0.00	0.00	0.00	0.62	0.36	0.00	–

Comparison

- R&CM is the simplest clustering algorithm
- A major dis advantage of R&CM is that when the machine part matrix contains one or more bottleneck machines (machines that belong to more than one cell) or exceptional parts (parts that are processed in more than one cell), the algorithm may provide a solution with all machines in a cell and all parts in a corresponding part family.
- S-link is quite simple and has minimal computational requirements. It also possible to construct the dendrogram which gives cells for different threshold values.
- The disadvantage of S-link is the chaining problem. Two cells may join just because two of their members are similar while the others may remain far apart.
- A-link solves this chaining problem. Therefore the A-link method is the best!

Bond energy algorithm

1) Set i=1. Arbitrarily select any row and place it.
2) Place each of the remaining n-i rows in each of the i+1 positions (i.e. above and below the previously placed i rows) and determine the row bond energy for each placement using the

formula: $\sum_{i=1}^{i+1}\sum_{j=1}^{m} a_{ij}(a_{i-1,j} + a_{i+1,j})$
Select the row that increases the bond energy the most and place it in the corresponding position.

3) Set i=i+1. If i<n, go to step 2; otherwise go to step 4.
4) Set j=1. Arbitrarily select any column and place it.
5) Place each of the remaining m-j rows in each of the j+1 positions (i.e. to the left and right of the previously placed j columns) and determine the column bond energy for each placement using the formula: $\sum_{i=1}^{n}\sum_{j=1}^{j+1} a_{ij}(a_{i,j-1} + a_{i,j+1})$
6) Set j=j+1. If j<m, go to step 5; otherwise stop.

P-median model using the weighted Minkowski metric

The absolute Minkowski metric measures the dissimilarity between part pairs.

$$d_{ij} = \left[\sum_{k=1}^{n} w_k * |a_{ki} - a_{kj}|^r\right]^{1/r}$$

With r being a positive integer, w_k the weight of part k and d_{ij} instead of s_{ij} to indicate that this is a dissimilarity coefficient.

This is then used to construct an upper triangular matrix with at most P clusters by minimizing $\sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}x_{ij}$ and is subjected to:

$$\sum_{j=1}^{n} x_{ij} = 1 \qquad i = 1,2,\dots,n$$ Each part i belongs to 1 cluster

$$\sum_{j=1}^{n} x_{jj} = P$$ There are at most P clusters

$$x_{ij} \le x_{jj} \qquad i, j = 1,2,\dots,n$$ x_{ij}=1 if part i is joined to part j

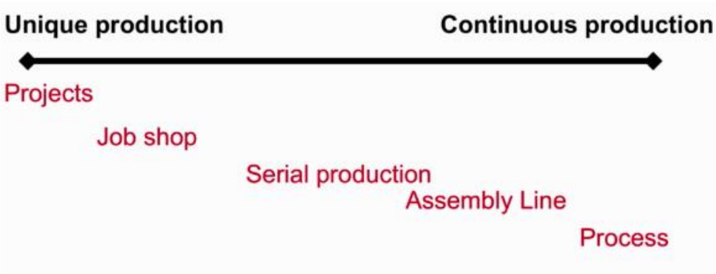
$$x_{ij} = 0 \text{ or } 1 \qquad i, j = 1,2,\dots,n$$ x_{jj}=1 if part j represents a cluster

Chapter 5: Macro-design of facilities

The performance of facilities such as plants and warehouses is largely determined by their internal layout. This layout of workplaces, cells and equipment determines the internal flow of goods and people, which is a considerable part of the cost structure. This section will provide manual and computer based algorithms to design a layout within a new or existing building.

Layout basic forms

There are a few basic forms of layout that are linked with production strategy.



Projects

- Product is large and/or unique
- Production is relative complex
- Takes a long time to achieve
- Examples: bridges, ships, large machines, industrial buildings, …

Advantages:

- Material movement is reduced
- Promotes job enlargement by allowing people to perform the whole job
- Continuity of operations and responsibility results from team
- Highly flexible in terms of product design, product mix and product volume
- Independence of production centres allowing scheduling to achieve minimum total production time.

Disadvantages:

- Increased movement of personnel and equipment
- Equipment duplication may occur
- Higher skill requirements
- General supervision required
- Cumbersome and costly positioning of material and machinery
- Low equipment utilization

Job shop production

- Volume of produced products is limited
- Process layout
- Nature, time and sequence of production activities is specific for each product
- Production resources are permanently organised
- Examples: classical restaurant, car repair, machine building, hospital, …

Advantages:

- Better utilization of machines can result, thus fewer machines needed

- High degree of flexibility in allocation of people or equipment for specific tasks
- Comparatively low investment in machines required
- Diversity of tasks offers a more interesting and satisfying job for the operator
- Specialized supervision is possible

Disadvantages:

- Due to longer flowlines, material handling is more expensive
- Production planning and control system are more involved
- Total production time is usually longer
- Comparatively large amounts of in-process inventory
- Lots of WIP
- Higher grades of skill required

Serial production

- Batch production
- Group layout (cell layout)
- Limited range of relatively similar products
- Nature, time and sequence of operations are similar
- Examples: pint shop, garment sewing, configurated PC assembly

Advantages:

- Increased machine utilization
- Team attitude and job enlargement tend to occur
- Supports the use of general purpose equipment
- Shorter travel distances and smoother flow lines than for process layout

Disadvantages:

- General supervision required
- Higher skill levels required of employees than for product layout
- Depending on balancing of material flow possible WIP and buffers
- Lower machine utilization than for process layout

Continuous production

- Assembly line (discrete products) or process production (bulk products)
- Product layout
- High volume
- Limited range of products
- Examples: fast food restaurants, automobile assembly, chemical processing, breweries, …

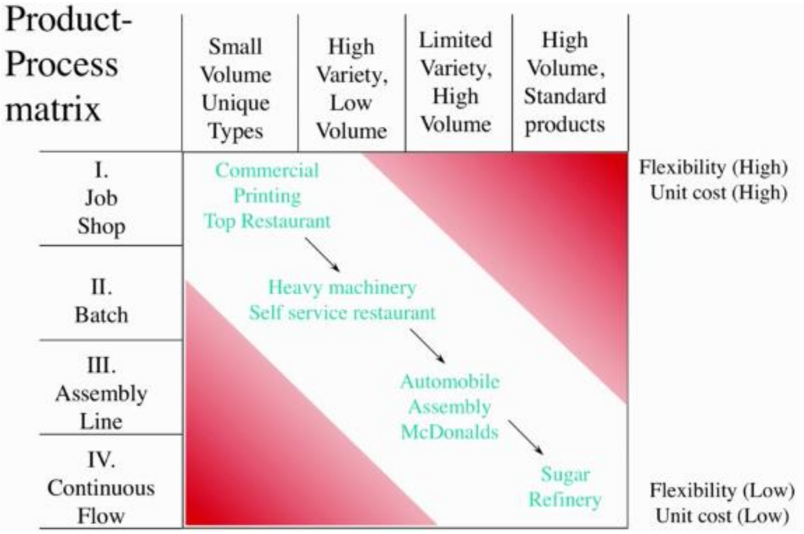
Advantages:

- Layout matches sequence of operations, resulting in smooth and logical flow lines
- Small in-process inventory
- Total production time per unit is short
- Material handling is reduced
- Little skill is required, leading to short and inexpensive training
- Simple production planning control systems are possible
- Less space is occupied by work in transit

Disadvantages:

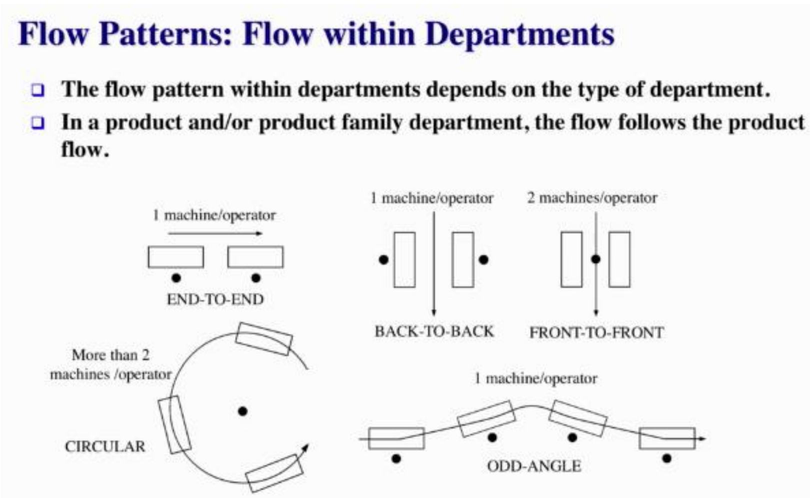
- A breakdown in one machine may lead to a complete stoppage of the line
- Change in product design may require major changes in the layout
- Pace is determined by the slowest machine
- Supervision is general, rather than specialized
- High investment is needed, as identical machines are sometimes distributed along the line.

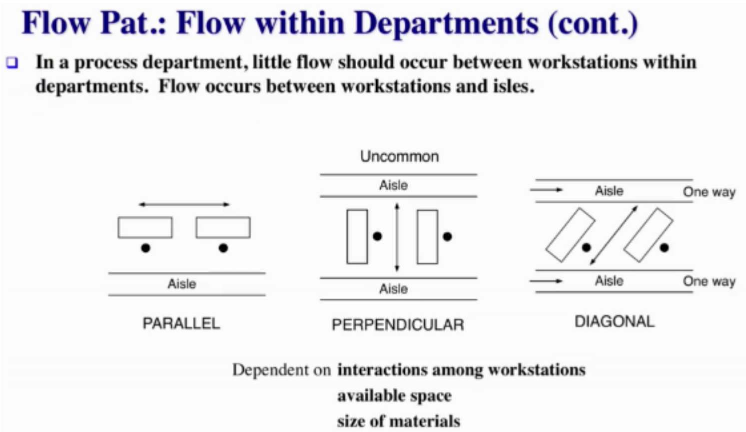
Product-process matrix



Basic flow patterns

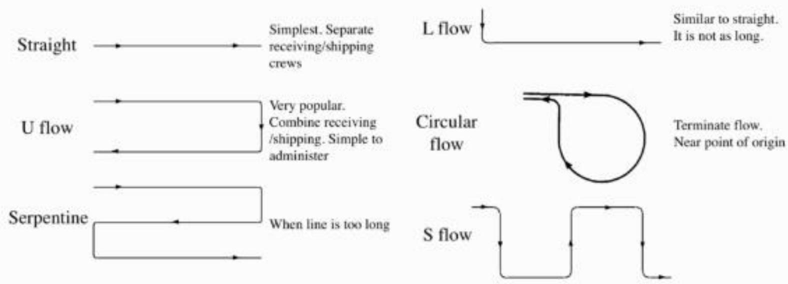
There are 3 kinds of flows: within workstations, within departments and between departments.





Flow between Departments

- Flow between departments is a criterion often used to evaluate flow within a facility.
- Flow typically is a combination of the basic horizontal flow patterns shown below. An important consideration in combining the flow patterns is the location of the entrance (receiving department) and exit (shipping department).



Make sure to use the right aisle width!

ACTIVITY RELATIONSHIPS AND SPACE REQUIREMENTS

Table 16 Recommended Aisle Widths for Various Types of Flow

Type of Flow	Aisle Width (feet)
Tractors	12
3-ton Forklift	11
2-ton Forklift	10
1-ton Forklift	9
Narrow aisle truck	6
Manual platform truck	5
Personnel	3
Personnel with doors opening into the aisle from one side	6
Personnel with doors opening into the aisle from two sides	8

Factory building design rules

Design in standard modules. This facilitates changes in layout when the building has already been established.

Design the plant so that extension is always possible. Make sure to put the fixed structures not in the way of expansions possibilities.

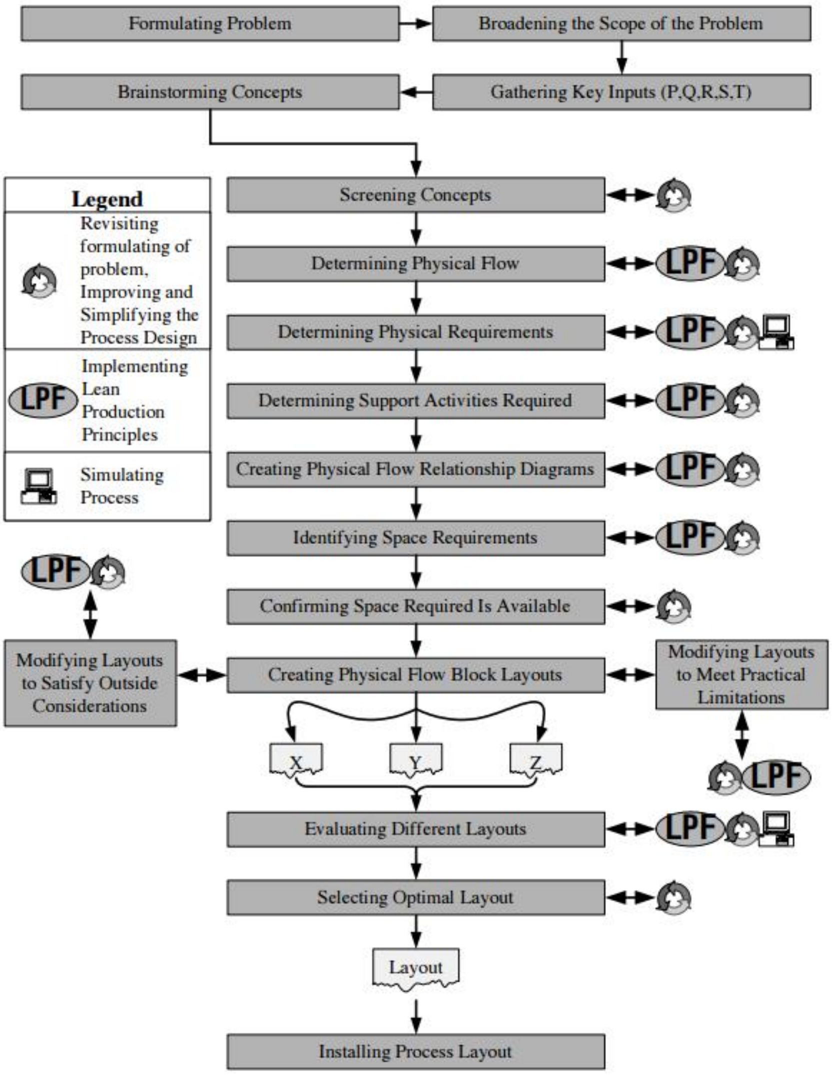
The systematic Layout Planning (SLP) design process

Step 1: Gathering key inputs (PQRST)
Step 2: Determining physical flow (constructing the **physical flow chart**) (multiple process technologies and types of processes are possible, the team should select all the feasible ones)
Step 3: Determining physical requirements: determining the numbers of equipment and operators
Step 4: Determining Support Activities required
Step 5: Creating **physical flow relationship charts** (representing the desirability to place pairs of operations next to each other)
Step 6: Identifying physical space requirements (including future expansion and changes)
Step 7: Confirming space required is available (if not, abandon current process design concept)
Step 8: Creating **physical flow block layout diagrams**
Step 9: Modifying layouts to satisfy outside considerations (issues like access for maintenance, limited supply of utilities, building constraints like support columns, …)

Step 10: Modifying layouts to meet practical limitations (considers impact of moving costs of equipment, need for larger aisles, fewer operators/m² for safety, …)
Step 11: Evaluating different layouts
Step 12: Selecting the optimal layout (using concept scoring, with weighted criteria)
Step 13: Installing process layout

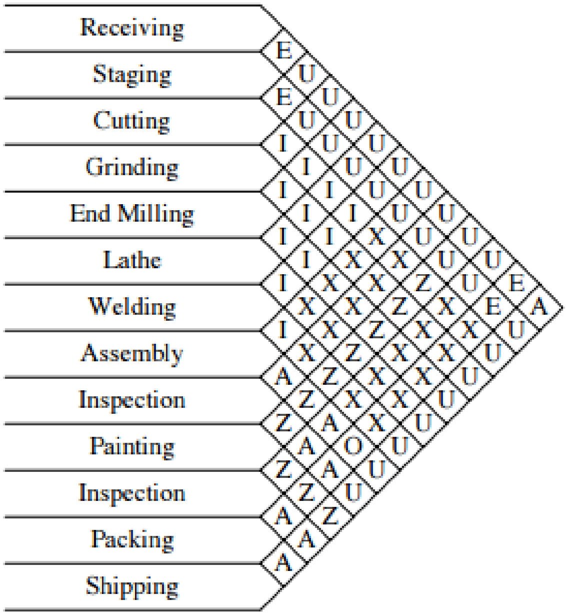
Additional steps:

1) Formulating the problem (make sure that the root causes are tackled)
2) Broadening the scope of the problem (Imagine the project like a black box, you don't know what's going on inside and you only look at the inputs and outputs and think of different solutions for the inside of the box.)
3) Brainstorming concepts
4) Screening design concepts (remove non-feasible concepts)
5) Improving and simplifying the process design (make sure to not have an optimal layout of a suboptimal process)
6) Implementing Lean production principles
7) Simulating the process
8) Confirming performance (checking the realised output versus the ultimate output to check whether the made assumptions were correct)



Physical flow relationship chart

An example of such a chart:



Proximity Rating	Description
A	**Absolutely necessary**: There is a high rate of material transfer, materials transferred are cumbersome to handle, or other reasons make the close proximity of the two process elements absolutely necessary.
E	**Extremely important**: There is a moderate rate of material transfer, materials transferred are somewhat cumbersome to handle, or other reasons make the close proximity of the two process elements extremely important.
I	**Important**: There are regular situations where it would be nice if the two process elements were close together, but proximity is not vital.
O	**Ordinary**: There are occasional situations where it would be handy if the two process elements were close together, but proximity is not vital.
U	**Unimportant**: It does not matter if the process elements are located close together or not. The entities are unrelated.
X	**Undesirable**: It would be better if the process elements could be kept separated.
Z	**Extremely undesirable**: It is dangerous if the process elements are near to each other. Or, it is likely to be highly disruptive to one or both of the process elements if they are located close together.

Manual layout procedures

Simple from-to network (Buffa)

Starting from the part-machine matrix we form a graph in which we try to move the nodes around to place nodes with big flows as adjacent as possible. For example:

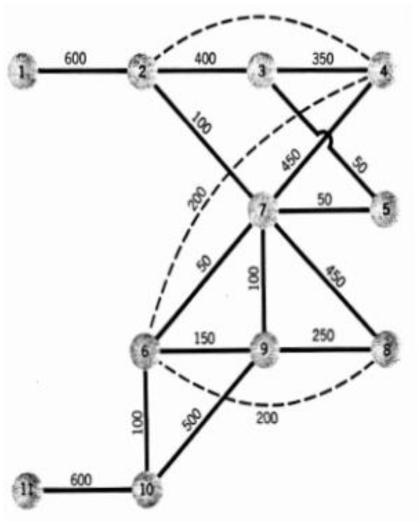


FIGURE 18. Initial graphic solution developed from load summary of Table I. It can be seen by inspection that 4 can be moved to the position between 2 and 6 to eliminate 300 nonadjacent loads. The positions of 8 and 9 are improved by replacing 9 by 8 and moving 9 to the position just below 8. (From Buffa [5].)

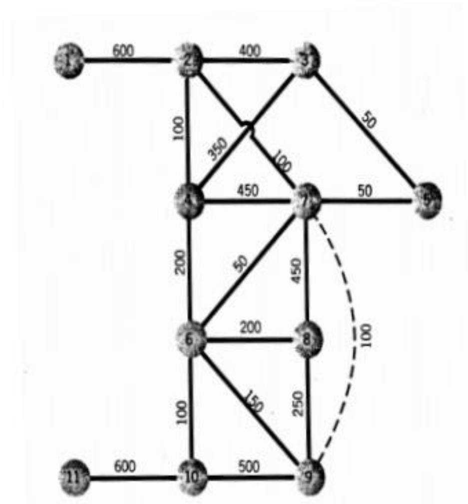


FIGURE 19. Ideal schematic diagram incorporating changes suggested by Figure 4. Solution is not necessarily optimal but no further location changes seem to yield improvement. (Based on Buffa [5].)

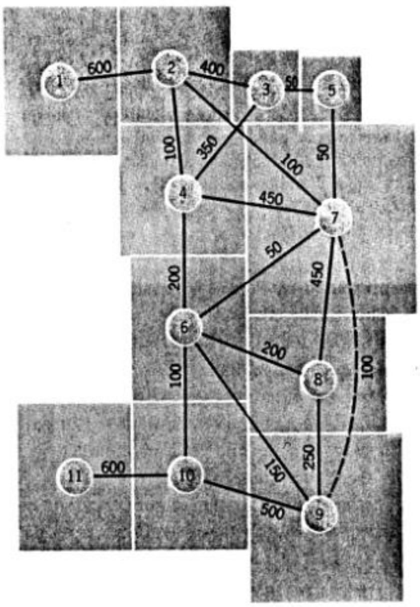


FIGURE 20. Initial block diagram. Estimated work center areas are substituted for circles in the ideal schematic diagram of Figure 5. Block templates are used for estimated area requirements for the various work centers. (Based on Buffa, [5].)

Buffa

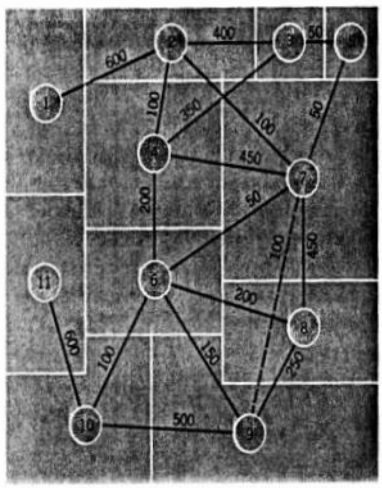
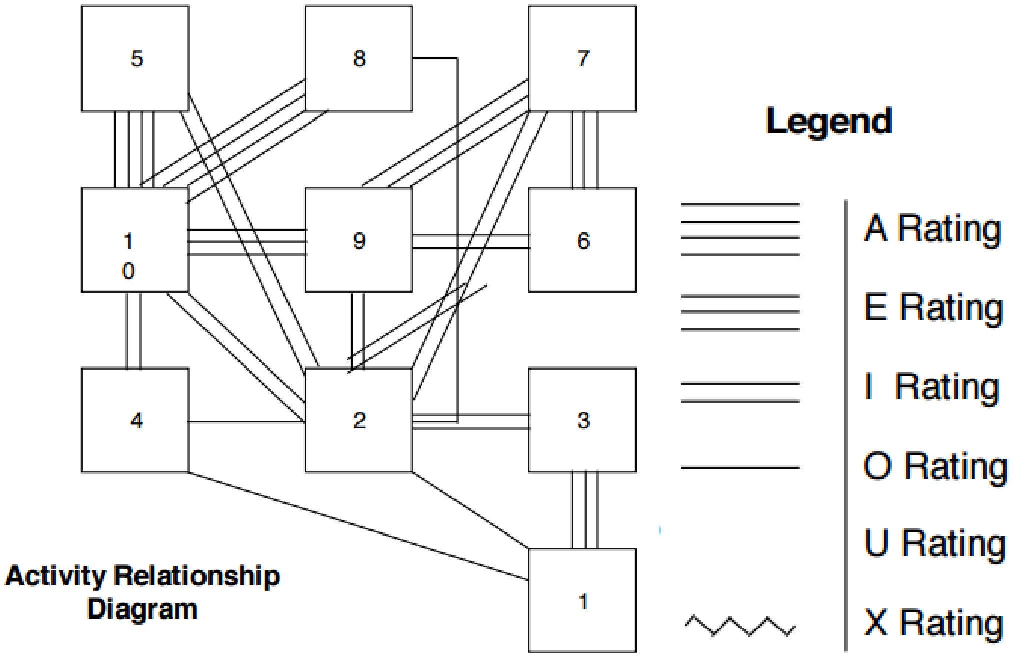


FIGURE 21. Block diagram which takes account of rectangular building shape and other possible restrictions of shape and dimension imposed by site but still retains approximate work center area requirements and idealized flow pattern. (Based on Buffa [5].)

Systematic layout procedure (SLP)

An activity relationship diagram is developed from information in the activity relationship chart (see above). An example of a relationship diagram can be seen below.



Dominant flow

When a dominant flow is present this method (greedy algorithm) can be used:

1) Start at first or last department
2) From all unplaced departments with direct flows with the last placed department, choose the one with the largest flow
3) Continue until you reach the last department in the flow
4) Go back to step 1 and repeat with nest higher flow remaining
5) Stop when all departments are placed

Manual CORELAP algorithm

CORELAP is a construction algorithm to create an activity relationship diagram or block layout from a relationship chart. Each department (activity) is represented by a unit square and numeric values are assigned to the relationships, so called CV values, for example:
V(A) = 10000; V(E) = 1000; V(I) = 100; V(O) = 10; V(U) = 1; V(X) = -10 000

For each department, the total closeness rating (TCR) is the sum of the absolute values of the relationships with other departments.

Procedure to **select** departments:

1) The first department placed in the layout is the one with the greatest TCR value. If a tie exists, choose the one with more A's.
2) If a department has an X relationship with the first one, it is placed last in the layout. If a tie exists, choose the one with smallest TCR value.
3) The second department is the one with an A relationship with the first one. If a tie exists, choose the one with the greatest TCR value.
4) If a department has an X relationship with the second one, it is placed next-to-the last or last in the layout. If a tie exists, choose the one with the smallest TCR value.
5) The third department is the one with an A relationship with one of the placed departments. If a tie exists, choose the one with the greatest TCR value.
6) The procedure continues until all departments have been placed.

Weighted placement (WP) is the sum of the numerical values $V(r_{ij})$ for all pairs of adjacent departments. For partial adjacency there is a factor alpha to consider. (0<alpha<1)

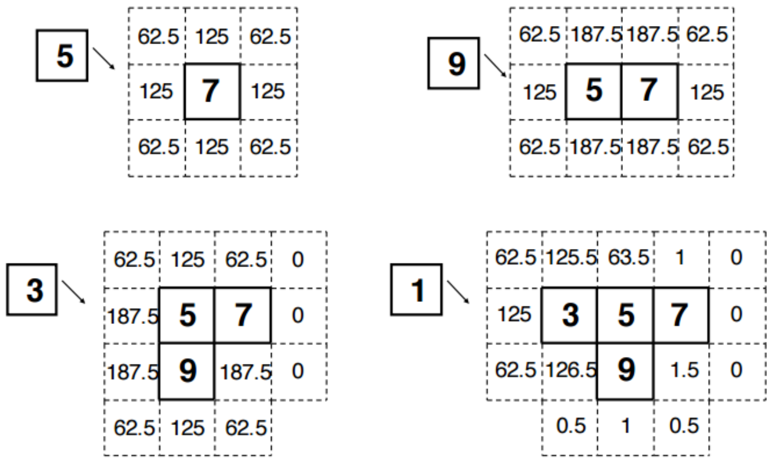
Procedure to **place** departments:

1) The first department selected is placed in the middle.
2) The placement of a department is determined by evaluating all possible locations around the current layout in counter clockwise order beginning at the "western edge".
3) The new department is located based in the greatest WP value.

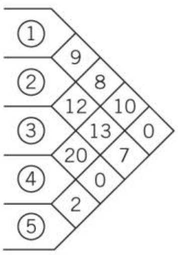
Example:

3x125 + 1x25 + 2x1 = 402

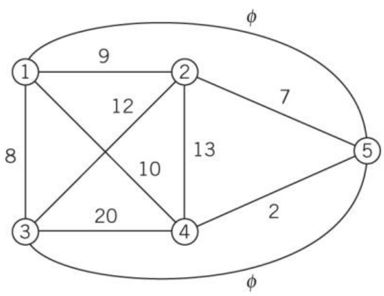
Dept.	Department									Summary						TCR	Order
	1	2	3	4	5	6	7	8	9	A	E	I	O	U	X		
1	-	A	A	E	O	U	U	A	O	3	1	0	2	2	0	402	(5)
2	A	-	E	A	U	O	U	E	A	2	2	0	1	3	0	301	(7)
3	A	E	-	E	A	U	U	E	A	3	3	0	0	2	0	450	(4)
4	E	A	E	-	E	O	A	E	U	2	4	0	1	1	0	351	(6)
5	U	O	A	E	-	A	A	O	A	4	1	0	2	1	0	527	(2)
6	U	O	U	O	A	-	A	O	O	2	0	0	4	2	0	254	(8)
7	U	U	U	A	A	A	-	X	A	4	0	0	0	3	1	625	(1)
8	A	E	E	E	O	O	X	-	X	1	3	0	2	0	2	452	(9)
9	O	U	A	U	A	O	A	X	-	3	0	0	2	2	1	502	(3)



Manual planar graph method

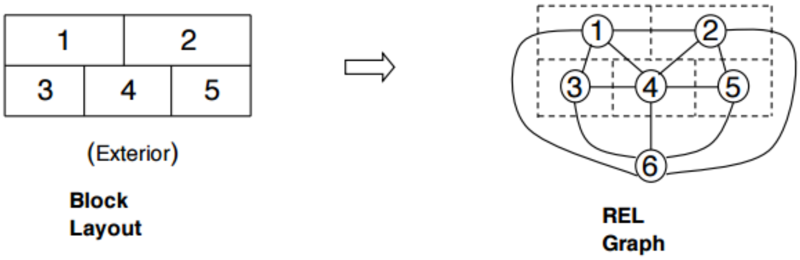


a) Relationship chart



(b) Relationship diagram

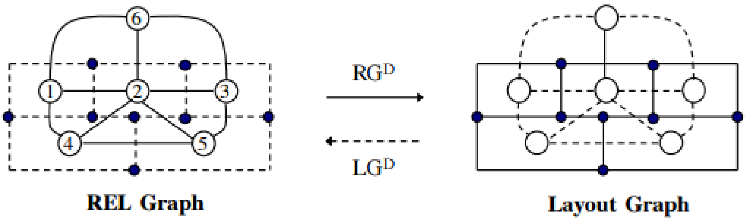
Given a (block) layout with M activities, a corresponding planar undirected graph, called the relationship (REL) graph, can always be constructed. A REL graph has M+1 nodes (one extra for the exterior). A REL graph corresponding to a layout is planar because the arcs connecting two adjacent activities can always be drawn passing through their common border of positive length.



But since the REL diagram is often constructed from the REL chart, it is in general non-planar. A REL diagram has M*(M-1)/2 arcs, while a planar graph can have at most 3M-6 arcs. A REL graph is therefore a subset from the REL diagram.

The number of nodes in a primal graph is the same as the number of faces in the dual graph, and vice versa. Even more, if a primal graph is planar, so is the dual graph.

Given a REL graph (RG), it's corresponding layout graph ($LG = RG^D$) is the dual of the REL graph:



So if the REL graph is planar, it means that the layout graph is also planar and thus a solution satisfying all adjacency requirements exists.

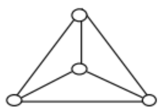
Procedure to construct a relationship graph:

1. **Rank activities in non-increasing order of TCR_k, k = 1,…,M, where**

$$TCR_k = \sum_{i=1}^{k-1} \max(0, V(r_{ik})) + \sum_{j=k+1}^{M} max\left(0, V(r_{kj})\right)$$

(Note that the negative values of $V(r_{ik})$ and $V(r_{kj})$ are not included in TCR_k).

2. **2. Form a tetrahedron using activities 1 to 4 (i.e., the activities with the four largest TCRk's).**



3. **For k = 5, …, M, insert activity k into the face with the maximum sum of weights ($V(r_{ij})$) of k with the three nodes defining the face (where "insert" refers to connecting the inserted node to the three nodes forming the face with arcs).**
4. **Insert (M+1)th node into the exterior face of the REL graph.**

General procedure for graph based layout construction

1) Given the REL chart, use the Heuristic procedure to construct the REL graph.

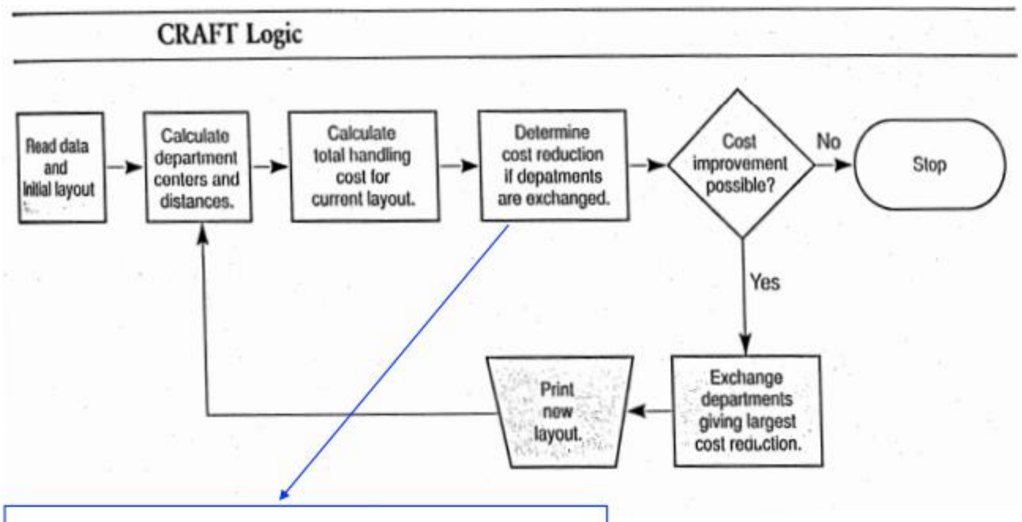
2) Construct the layout graph by taking the dual of the REL graph, letting the facility exterior node of the REL graph be in the exterior face of the layout graph.
3) Convert the layout graph into an initial layout taking into consideration the space requirement of each activity.

Graph theoretic method:

1. **Identify the department-pair in the flow matrix with the maximum flow. Place the corresponding nodes in a new planar acyclic graph (PAG) and connect them.**
2. **From the rows corresponding to the connected nodes in the flow matrix, select the node which is not yet in the PAG and has the largest flows with the connected nodes.**
3. **Update PAG by connecting the selected node to those in Step 2. This forms a triangular face in the PAG.**
4. **For each column of the flow matrix corresponding to a node not present in the PAG, examine the sum of flow entries in the rows corresponding to the nodes of the triangular face selected in step 3. Select the column for which this sum is the largest. Update PAG by placing the corresponding node within the selected face and connect it to nodes of the face. This forms three new triangular faces.**
5. **Arbitrarily select one of the faces formed and go to Step 4. Repeat Step 5 until all the nodes have been included in the PAG.**

Computerized layout method

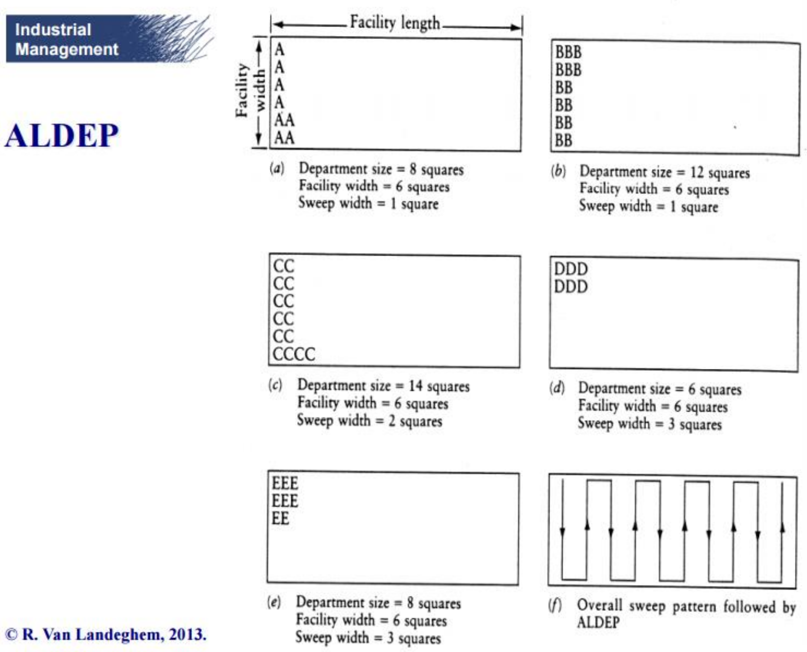
CRAFT algorithm



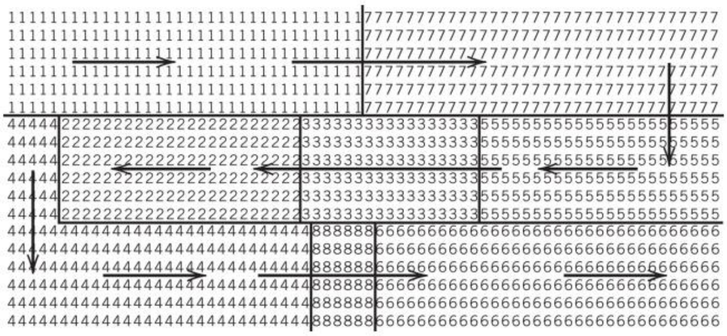
1. Pair-wise interchanges.
2. Three-way interchanges.
3. Pair-wise followed by three-way interchanges.
4. Three-way followed by pair-wise interchanges.
5. The best of pair-wise or three-way interchanges.

Dummy departments can be implemented to fill building irregularities, represent fixed areas (stairways, elevators, restrooms, …) or aid in evaluating aisle locations in the final layout.

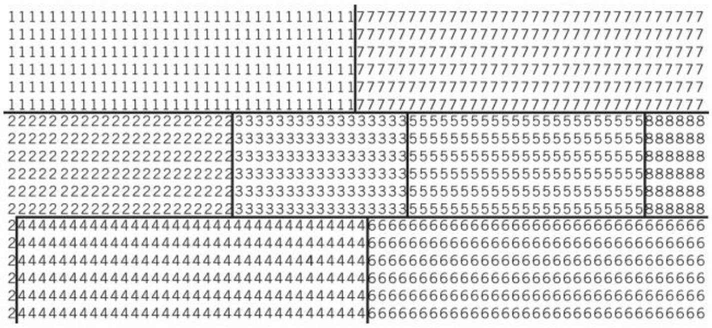
Other methods



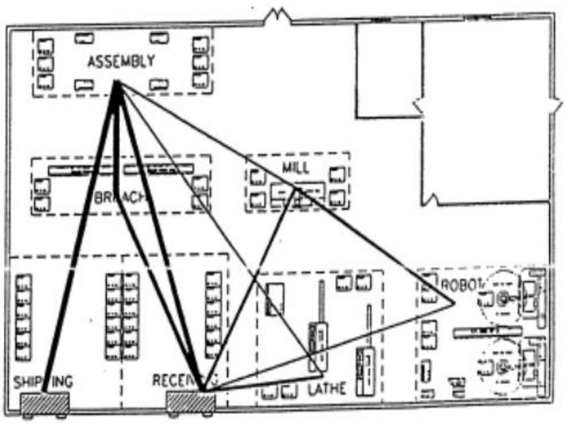
MCRAFT



MCRAFT after 4 two-opt exchanges



CAD based flow analysis (AutoCad + FlowPlan)



Chapter 6: Lean management

Since 1995 the Toyota Production System has taken western companies by storm, under the label "Lean Management". The method has taken Toyota to be the number 1 car manufacturer and proved to be extremely effective in driving operational improvement across a wide range of organizations. Lean has found its way into manufacturing, health care, public services, service industry, offices, construction engineering and ICT development. The foundation of the method is the "socio-technical" system and lean is one of the first methods to truly address both aspects of it.

History

Craft manufacturing: Late 1800’s, built by craftsmen, everything hand-crafted, excellent quality, very expensive, few produced -> now found in supersportscar

Mass manufacturing: low skilled labour, simple jobs, no pride in work, interchangeable parts, lower quality, affordably priced, billions identical cars produced, example: Ford’s assembly line

The modern corporation: Ford cannot cape with increasing number of car models, the centralized micro-management style is overwhelmed by the growth of Ford Company. Sloan structures GM according to Military hierarchy: business units, organograms, division of authority and reporting lines. Served as a blueprint for companies until today.

Lean manufacturing: Cells or flexible assembly lines, broader jobs, highly skilled workers, proud of product, interchangeable parts, even more variety, excellent quality mandatory, costs decrease through improvement, example: Toyota Production Process (TPS)

Flexible means that operators have to be able to do multiple jobs and also needs to be capable of doing so.

Definition of lean

- Lean is a management method
- Aimed at improving the customer experience
- By pursuing excellent internal processes (so NOT best products, organisation, … this follows from excellent internal processes)
- Through empowerment of the employees (operators have authority on deciding how to organize the work on the shopfloor)
- Supported by a specific management style (coaching, consensus, avoiding to force solutions)
- And a whole array of simple, very effective techniques (“lean tools”)

Excellent processes yield excellent results. Therefore standard processes have to be used.

Lean aims to eliminate Muda(waste), MURA(unevenness, variation) and MURI(overburden, of machines and people).

7 types of waste: overproduction (to large quantities or to fast), internal transportation, rework, excess movement, waiting (both operator and machines), process work that is not needed, and inventory. Inventory is the worst kind of waste because it hides other problems.

Lean thinking in 5 steps:

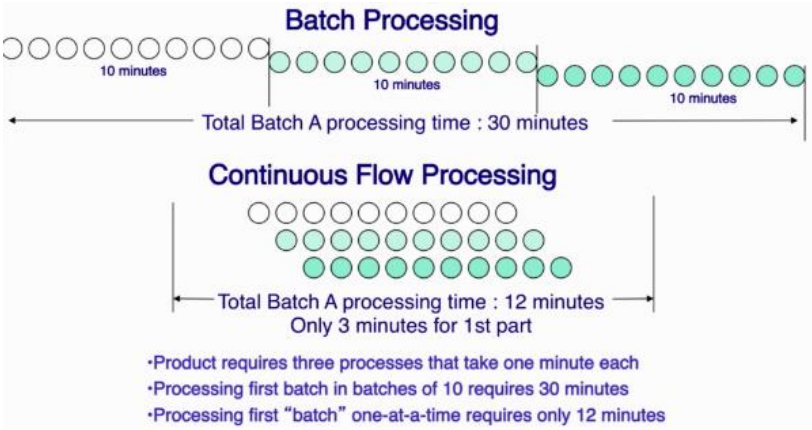
1) Specify the **value** that the customer wants
2) Identify the **value stream** & eliminate **waste** in it
3) Make the product **flow**
4) Let the customer **pull**
5) And strive for **perfection** every day!

Value is what the customer is willing to pay for. Value = perception – expectation. Many opportunities to improve the value: reduce delivery time, improve robustness and interoperability, reduce complexity, improve productivity of services, …

Three types of activities:

- Value adding activity: Makes a service or product more valuable
- Non value adding activity: Do not add value and are not necessary -> Eliminate!
- Necessary non value adding activity: Do not add value but are necessary at the moment, but should be eliminated on the long term

Make the product flow:



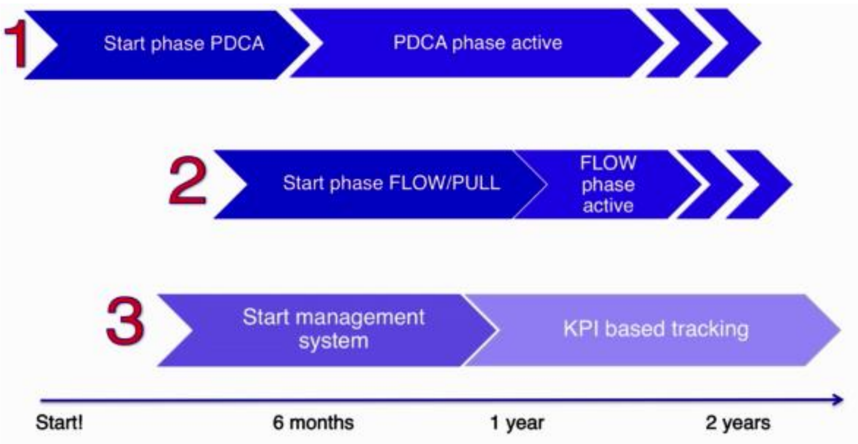
In pull systems only one process needs to be told what we need and it will pull from the rest of the processes. This process is called the pacemaker.

5S: Sort, Set in order, Shine, Standardize, Sustain

Lean implementation problems

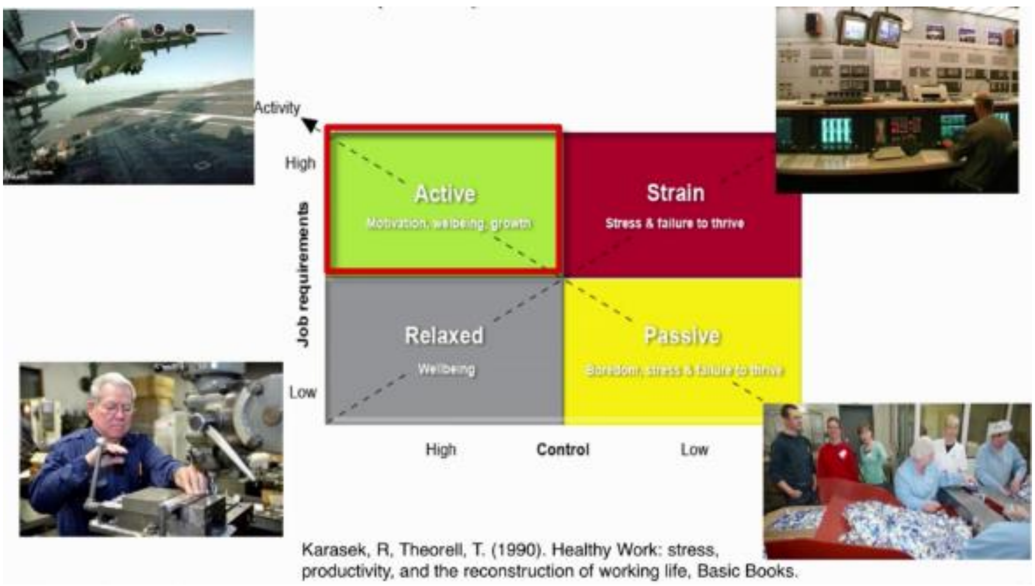
Lean implementation needs 3 phases. One of them is PDCA (plan, do, control, act) in which teams of operators try to improve the processes.

The management system is a system to monitor improvements.



Most popular obstacles: middle management system, lack of implementation know-how, employee resistance, supervisor resistance, … So mostly people are the problem because they have the change the way they work. ("Before making things, you first have to make people" – Toyota saying)

Model of Karasek:



Lean aims to achieve active jobs.

A prerequisite for self-empowered teams to work (determining their own work schedule, plan holidays, plan for absence, quality of production issues) is that management creates a culture where:

- Problems are recognized as opportunities
- It's okay to make legitimate mistakes
- Problems are exposed because of increased trust
- People are not problems, they are problem solvers
- Emphasis is placed on finding solutions instead of "who did it"

In a lean management, the number of layers will also be reduced. Preferably to only two: operations manager team and self directed work teams. Management gets a more coaching function and should visit the workfloor from time to time and ask the right questions.

Tools of lean management

Target costing

Target cost = market price – target profit

Instead of price = cost + profit, were cost is determined by engineers you look at what the customers want to pay and build a product that has a cost that is suitable.

Design for manufacture (DFM)

- easy and fast assembly
- machining for low volumes (low investment, high product unit cost), pressing for middle volumes and moulding for high volumes (highest investment, low product unit cost)
- Insert variety options as late as possible in the process
- Lower the number of parts: Does the part need tom move to the rest of the assembly? Must the part be made of a different material? Does the part have to be physically separated for access, replacement, or repair?
- Maximize ease of assembly: Insert part from the top of the assembly; make part self-aligning, avoid having to orient part; …

Production contribution analysis

Or Pareto analysis, is used to rationalise the product portfolio or to help keeping the portfolio on track.

The muda map

Ask operators, managers and planners to give points to the seven types of waist on importance and on performance and plot it in a chart. The types of waist in the zone of high importance and low performance should be tackled first.

Value stream mapping

Track how and when value is added to the product or service in an attempt to identify unnecessary non value adding activities.

Process flow chart

Used by both study officers as supervisors and operators. Even if present at the work station, reality often differs from the official version.

Product variety funnel

Useful in understanding where variety is added along a supply chain. The principle is that variety should be added as late as possible. Adding variety too early cuts responsiveness, adds inventory, and reduces flexibility.

5S

5S is about changing the mindset and about making orderly and standardised operations the norm. It has a direct impact on safety, cost, quality, delivery, and on OEE.
The 5S's stem form 5 Japanese words, so the S is lost in translation:

- Cleanup: remove everything (dirt, inventory, paper, furniture, tools, memos, manuals, …) that is not necessary now or for a certain period ahead. Also look at the use of aisles and floor paint colours. Don't forget windows, walls, lighting and roof.
- Aranging: Everything has its own optimal location. Preventing people from reaching, bending, and walking. Also includes instructions and standards being up to date.
- Neatness: Keep the workstation tidy, it makes it easy to see missing parts or oil leaks indicating problems. It is a good practice to make the operators clean for 5 minutes after their shift.

- Discipline: It is easier to keep things going, than to reintroduce them every month. Therefore it is important to get into the routine of keeping up the standards. Possibly using some kind of reward system.
- Ongoing improvement: We should not only be concerned in cleaning up the oil spillage, but also look at where it comes from and tackle the root cause. This asks for keeping records of problems.

Kaikaku

Blitz krieg kind of approach, where in a focussed area problems are solved without much planning and without asking permission for every change made. (also known as kaizen blitz)
Results are obtained very quickly (e.g. a week).

Standards

Help keeping up improvements. There is however more than one way to do something and the best way is found by using the operators experience. Also helps in keeping knowledge of leaving operators in the company.
Standards also lead to less variation which improves the quality.

String diagrams

Trace product flows and material handling but also the movement of people in a cell, in changeover and in maintenance.

Kaizen

Continuous improvement, in small increments, at all levels, forever!

Total productive maintenance (TPM)

TPM aims at zero breakdowns and at zero defects. It evolved out of preventive maintenance, and has much in common with total quality. It includes the operator, material, process, environment, … in the maintenance of a machine.
Try to prevent the Six big losses:

1) Breakdown losses
2) Setup and adjustment losses (delaying the start of work)
3) Idling and minor stoppages
4) Reduced speed losses
5) Start-up losses (pre-production)
6) Quality defects (as a result of imperfect equipment)

Overall equipment efficiency (OEE)

OEE = availability x performance rate x quality rate

Little's law

WIP = production rate x lead time

Kanban

The classic signalling system for production pull systems. CONWIP and POLCA are also such systems.

Batch sizing

Continuous flow is not possible in every process, for example in processes where changeover times exceed the manufacturing takt time. (And if SMED – single minute exchange of dies – did not help)
In those cases an economic batch size needs to be determined.

Changeover reduction (SMED)

Separate internal form external activities during changeover in an attempt to make the changeover happen as fast as possible.

Mixed model production

It is better to minimize the maximum time between any two similar units of production, thus instead of AAAABBBB use ABABABAB. Because it is easier to balance a mixed model and customer service levels rises while inventory drops.

Group technology and cellular manufacturing

Is the production of a part family, of products or services, in one area, compromising all the necessary machines and processes, thereby enabling one-piece flow.

Point of production control (PoP control)

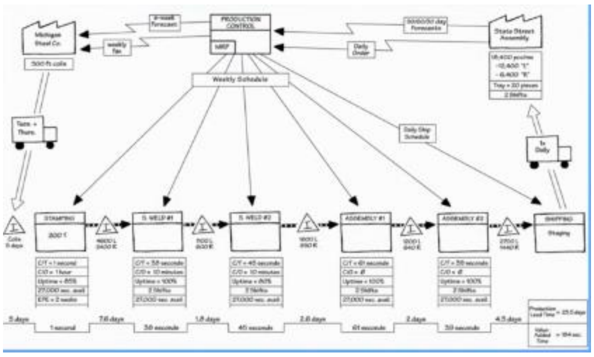
A pop system is usually an electronic display board linked to a production process that provides continuous, automatic, and real-time monitoring.

Value Steam Mapping (VSM)

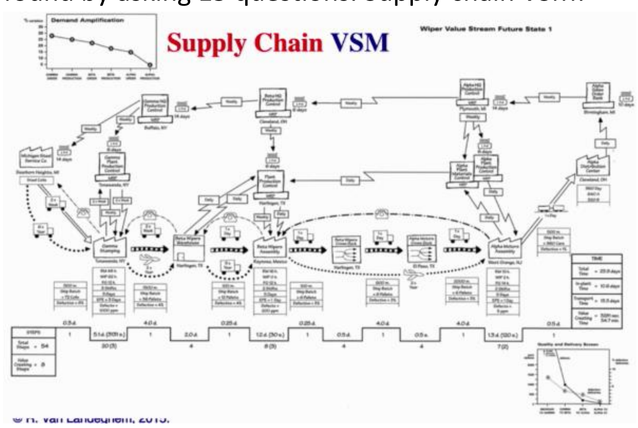
Value stream: It is all the actions (both value added and non-value added) currently required to bring a product through the main flows essential to every product.

There are three levels of VSM

1) The level of the workstation: usually a flow process chart
2) Starts with the raw material entering the plant and ends with the finished product leaving the plant. The unit is a process, the current state is found by walking the line of the process and the future stat is found by asking 8 questions. This is called a door-to-door map:



3) The third level links multiple companies over the supply chain. Every rectangle now represents a plant, the current state is found by asking 12 questions and the future state is found by asking 15 questions. Supply chain VSM:

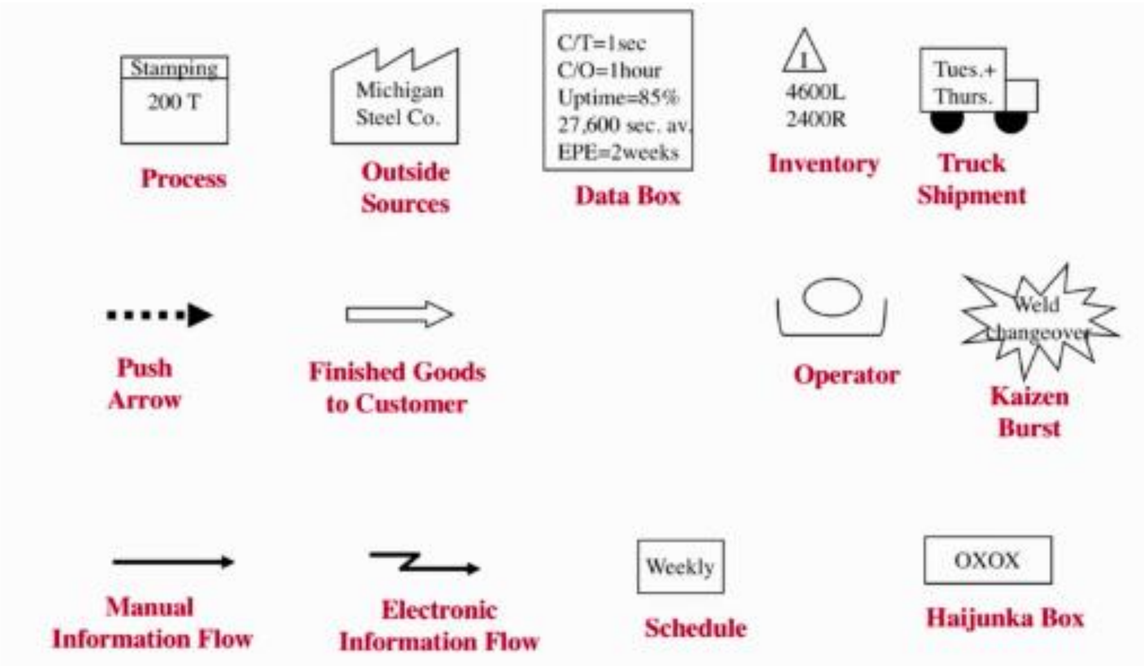


Typical steps to complete a current state drawing:

1) Document customer information
2) Complete a quick walk through to identify the main processes (i.e. how many process boxes)
3) Fill in data boxes, draw inventory triangles, and count inventory
4) Document supplier information
5) Establish information flow: how does each process know what to make next?
6) Identify where material is being pushed
7) Quantify production lead time vs. processing time

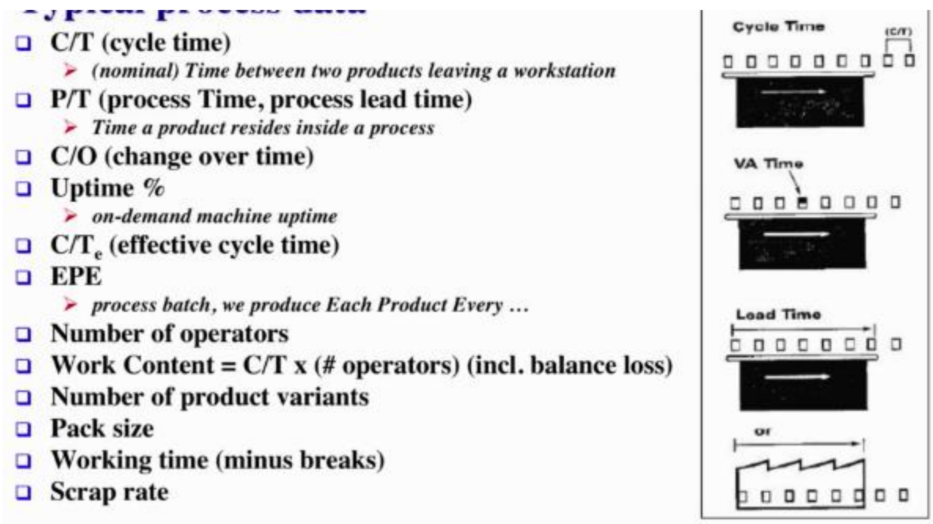
A process starts and ends where the flow stops and material accumulates.

Standard icons:



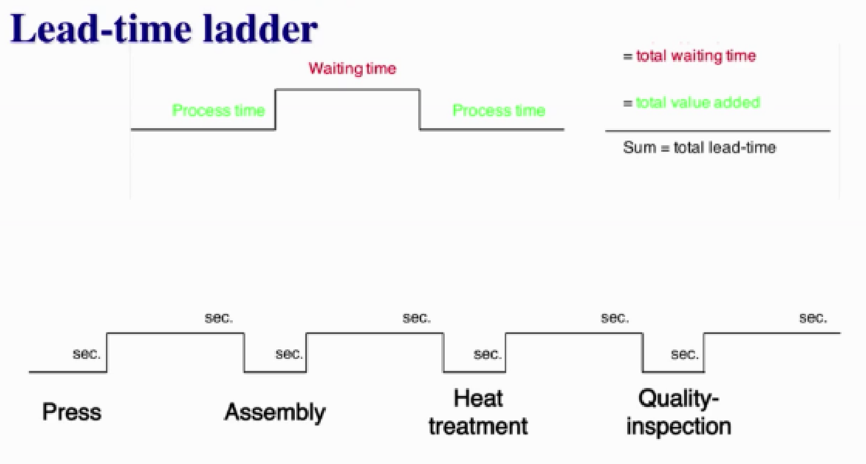
(*Haijunka is reducing variability or mura)

Useful process data:



EPEI = Every product every interval: Every product is produced on average after an interval of time, so the EPEI says how long one batch will last till it's sold out and we have to produce another batch. Small EPEI's for small production batch (eg 2 days) and big EPEI for big batches (eg one month) no matter the industry segment.

Lead-time ladder is the final part of the VSM. Important here is to add the ratio of the value added time to the total lead time.



Future state VSM

How?

- By eliminating or combining process steps, increase flow between steps and introduce pull
- And dividing into phases that can be introduced and stabilized in a 3 to 6 month timeframe
- Short time future vs long time future state

Guideline 1

Produce to your takt time.

Guideline 2

Develop continuous flow wherever possible. This means that you have to remove intermediate inventory as much as possible.

One solution is a FIFO buffer. A simple way to tune the buffer is to look at which positions of the buffer are not used during for example a week.

Guideline 3

All the remaining gaps between two processes should be filled with supermarkets where continuous flow is not possible. Thus no uncontrolled inventories remain.

Guideline 4

Try to send the customer schedule to only one production process (pacemaker). The pacemaker is also known as the decoupling point and is the most downstream continuous flow process in the door-to-door stream.

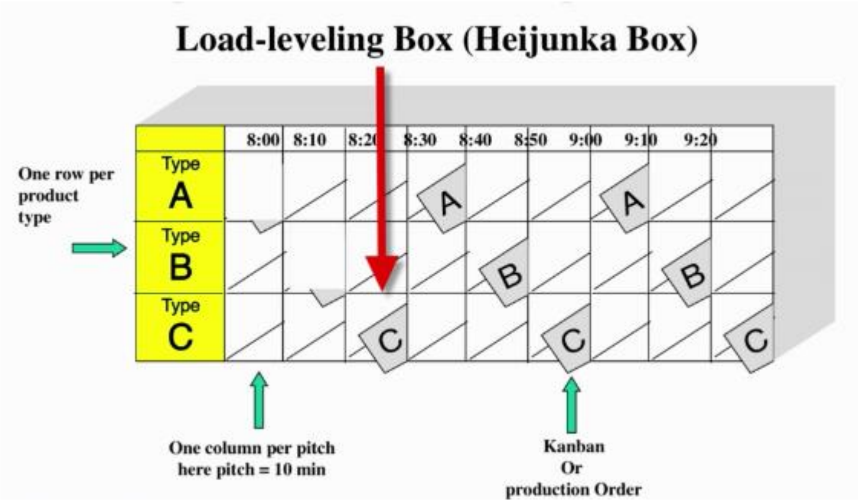
Guideline 5

Pursue mixed model production taking in account the batch sizes and setup times.

Guideline 6

Create an initial pull by releasing and withdrawing small, consistent increments of work at the pacemaker process (instead of releasing large batches).
Pitch = takt time * Kanban size

The pitch time should be small to increase flexibility and increase control of the workspace. Pitch is implemented through a heijunka box:



Guideline 7

Develop the ability to make "every part every day" in the processes upstream of the pacemaker process. Thus shorten changeover times, run smaller batches, …

Key questions

Demand

1. **What is the takt time for the chosen product family?**
2. **Will you build to a finished goods supermarket from which the customer pulls, or directly to shipping?**

Material Flow

3. **Where can you use continuous flow processing?**
4. **Where will you need to use supermarket pull systems in order to control production of upstream processes?**

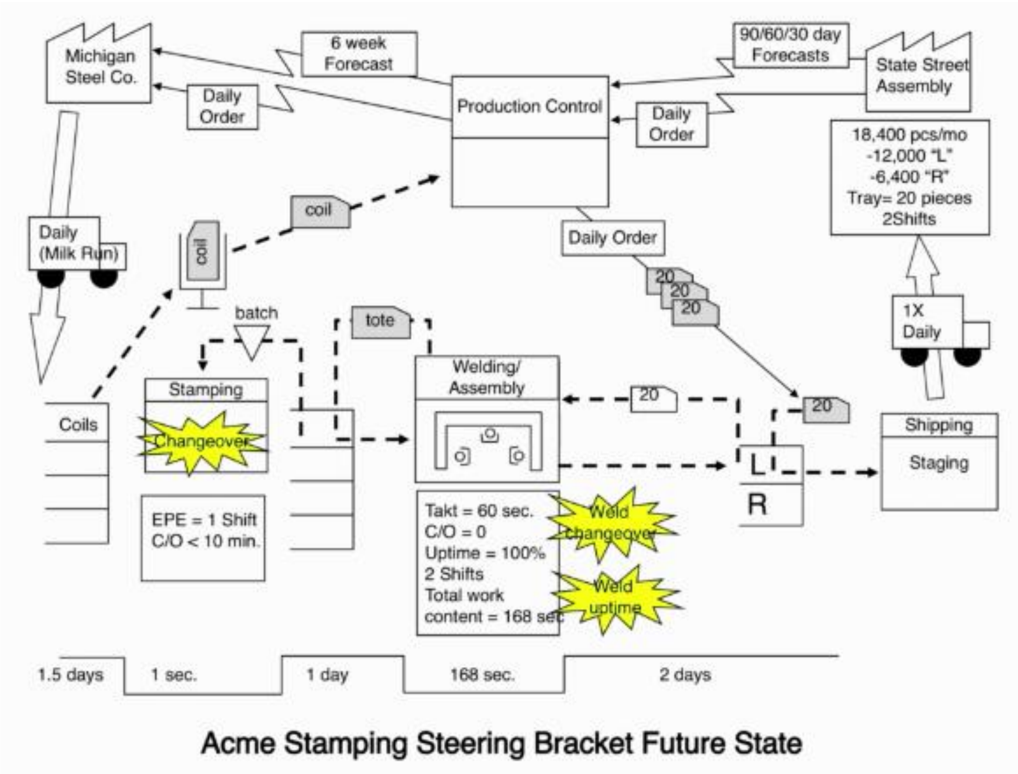
Information Flow

5. **What single point in the production chain (pacemaker process) should you schedule?**
6. **How should you level the production mix at the pacemaker process?**
7. **What consistent increment of work should you release and take away at the pacemaker process?**

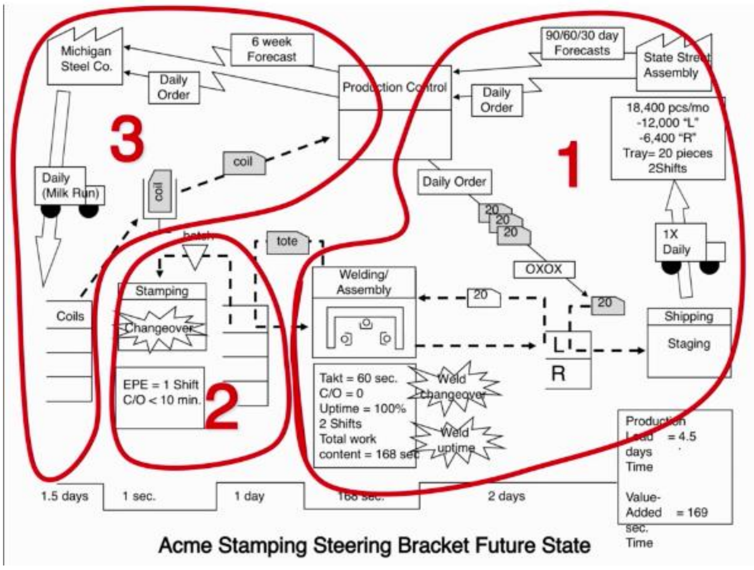
Work plan

8. **What process improvements will be necessary for the value stream to flow as your future-state design specifies?**

End result



Implementation is done in steps with the size of a loop:



Chapter 7: design of service operations

Service systems "process" people, so they have some peculiar characteristics that pose challenges to use the operational design techniques that were discussed previously. We will analyse these differences and explore how we use the design methods to improve customer service and reliability of service systems, while keeping the costs in balance.

Characterisation of a “service”

- Simultaneous production and consumption: customer is part of the production system
- Intangible: service cannot be taken home, only the effects
- Perishable: service has a limited life span, it cannot be stored
- Heterogeneous: each time a service is rendered it is different from the previous time

The service package

- Supporting facility: the physical resources that must be in place before a service can be sold. Examples: golf course, ski lift, hospital, ….
- Facilitating goods: material consumed by the buyer or items provided by the consumer. Examples: food items, legal documents, golf clubs, …
- Information: Operations data or information that is provided by the customer to enable efficient and customize service. Examples: medical records, seats available on a flight, …
- Explicit services: Benefits readily observable by the senses. Examples: quality of meal, attitude of the waiter, on-time departure, …
- Implicit services: psychological benefits or extrinsic features which the consumer may sense only vaguely. Examples: privacy of loan office, security of parking lot, …

Taxonomy of service processes

		Low divergence (standardized service)			High divergence (customized service)		
		Processing of goods	Processing Information	Processing of people	Processing of goods	Processing Information	Processing of people
No Customer Contact		Dry Cleaning Restocking a vending machine	Check processing Billing for a credit card		Auto repair Tailoring a suit	Computer programming Designing a building	
Indirect customer contact			Ordering groceries from a home computer			Supervision of a landing by an air controller	
Direct Customer Contact	No customer-service worker interaction (self-service)	Operating a vending machine Assembling premade furniture	Withdrawing cash from an ATM	Operating an elevator Riding an escalator	Sampling food at a buffet dinner Bagging of groceries	Documenting medical history Searching for information in a library	Driving a rental car Using a health club facility
	Customer service worker interaction	Food service in a restaurant Hand car washing	Giving a lecture Handling routine bank transactions	Providing public transport-a tion Providing mass vaccination	Home carpet cleaning Landscaping service	Portrait painting Counseling	Haircutting Performing a surgical operation

Service profit chain

The chain starts with the employees which have to be motivated, well trained, and carefully selected. These employees should also have access to a supportive work environment. From this they will be able to support a qualitative service which will result in a positive service value and will give the customers satisfaction and resulting in loyalty.

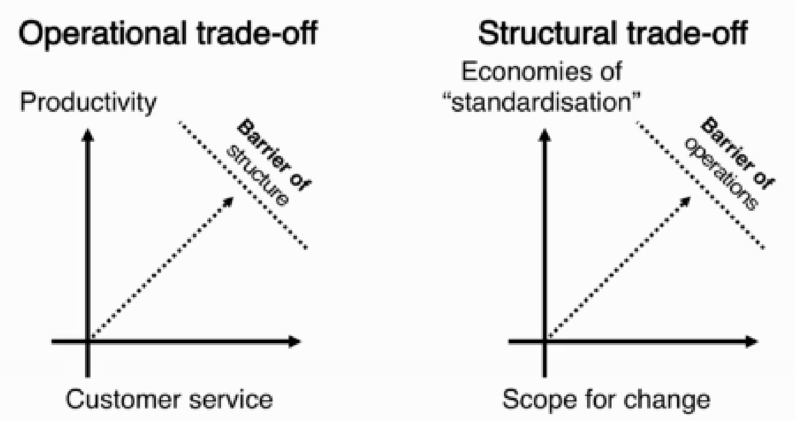
Implications from nature of service

- Production planning:
  - no buffering via storage
  - capacity planning subject to peak demands
  - no accurate standard service times
- Job design:
  - less structured and optimized in detail
  - requires creativity and initiative from the individual worker
- Quality control: solely based on training and motivation of personnel
- Remuneration: cannot be output-based, but can be quality-based
- Location of service site: close to customer
- Economies of scale:
  - less opportunities, because of geographical spread
  - less prone to automation
- Organization of production process:
  - subject to physiological and psychological needs of client
  - mostly suboptimal for the production worker
- Product innovation: difficult to protect (good ideas are copied fast), short lifecycle, customer oriented

Generic approaches to service design

- Production-line
  - limit discretion of personnel
  - division of labour
  - substitute technology for people
  - standardize the service
- Customer as co-producer
  - substitution of customer labour for provider
  - smoothing service demand in case of peaks
- Customer contact:
  - degree of customer contact
  - separation of high and low contact operations
- Information empowerment: Employee and customer

Service system works within two trade-offs:



Organizing for service in 8 steps

1) Detail the process steps (flow chart)
2) Analyse and clearly define the service components
3) Differentiate between back office and front office activities
4) Reduce customer contact, improve remainder
5) Introduce technology to improve efficiency were possible
6) Organize quality control
7) Use industrial engineering techniques (material management, forecasting, …)
8) Put it all together and make sure it works like it should.

Service design elements

- Structural:
  - delivery system (front & back office)
  - facility design (aesthetics, layout)
  - location (competition, site characteristics)
  - capacity planning (number of servers)
- Managerial:
  - service encounter (culture, empowerment)
  - quality (measurement, guarantee)
  - managing capacity and demand (queues)
  - information (data collection, resource)

Leveraging value over cost

There is little control over the cost of a service, therefore we have to maximize the perceived value and keep costs as low as possible so the difference between cost and value becomes big enough. A few techniques:

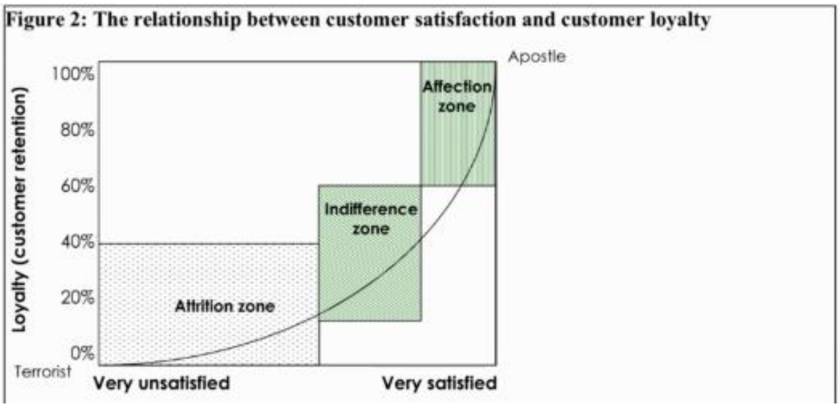
- standardize certain elements of the service
- include service elements that bind clients
- promote easy to leverage service components
- control quality through incentives, pride in workmanship, visibility, peer pressure
- include the customer in the service process
- reconfigure the value chain
- maximize the entry barrier for competitors

Service quality

Value = perception – expectation
Expectations come from word of mouth, personal needs and past experience.

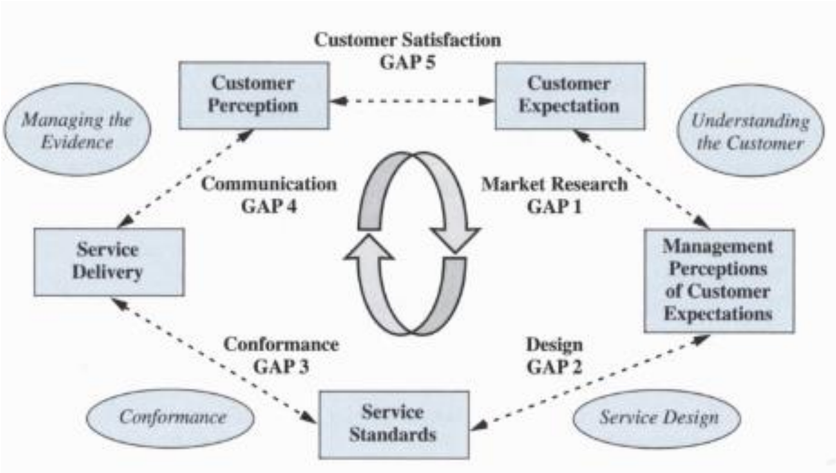
Customer loyalty is due to the lack of a better alternative. Giving customers some extra value will delight them by exceeding their expectations and insure their return.

Dissatisfied customers will express dissatisfaction differently. 96% takes no action, 4% does:
Public action: Seek redress directly from the firm, take legal action, complaint to business, private or governmental agencies
Private action: Stop buying the product or boycott the seller, warn friends about the product and/or seller (the more dissatisfied, the more people he/she will warn)



Customer criteria: availability, convenience, dependability, personalization, price, quality, reputation, safety, speed, …

Possible gaps in the service provided:



Gap 1: misunderstanding of what the customer needs -> wrong marketresearch, …
Gap 2: wrong design -> poor design
Gap 3: service processes have insufficiently quality built in guarantees
Gap 4: the customers perceives the service as not meeting his expectations (false promises)
Gap 5: no direct control over this gap

Solutions:

- Fail-safe devices to prevent errors (eg. Indented trays for surgical instruments, …)
- Process visibility (eg. Open kitchen, show cooking, call centre recording)
- Control customer behaviour (waiting time, self-service)
- Plan for right amount of employee latitude

Approaches to service recovery:

- Case-by-case: addresses each complaint individually, but could lead to perception of unfairness.
- Systematic response: according to protocol but needs prior identification of critical failure points
- Early intervention: try to fix the problem before customer is affected
- Substitute service: allow rival firm to provide service, cold cost loyalty of customer

Capacity management

Managing capacity is very difficult because production and consumption happen simultaneously. Therefore capacity should be flexible or there should be a surplus.
It's possible to manage demand by segmentation of the market; price incentives, linked to timing; develop complementing services; reservation system (overbooking necessary for full use of capacity).
It's also possible to manage supply: fluctuating personnel levels or vary customer participation.

Yield management: getting as much profit as you can from a fixed level of capacity by setting prices for different segments in different times.

How much capacity is needed?

- Based on strategic service level
- Limit maximum waiting times: using simulation or waiting models
- Use newsboy formula:

$$P(demand < capacity) = C_u/(C_u + C_o)$$

- C_o = opportunity cost of 1 capacity unit too much
- C_u = opportunity cost of 1 capacity unit short

Managing waiting lines

Characteristics of queues:

- **Single queue**
  - *Guarantees fairness (FCFS)*
  - *Everyone moves at same speed*
  - *Cutting-in or reneging is almost impossible*
  - *Privacy is better (no one behind you at the service counter)*
  - *Has less average waiting time than multiple queues*
- **Take a number**
  - *Requires attention of customer to hear/see its number*
  - *Increases impulse sales (waiting time spent browsing)*
- **Virtual queue (call center hold)**
  - *Frustrating: no feedback on position or movement ahead*
- **Hidden queue at theme parks (staging area's)**

- **Multiple queues**
  - *Permits jockeying (switching between lines)*
  - *Allows service differentiation*
    - express line in supermarket
    - different functions at bank tellers
  - *Allows division of labour*
  - *Total waiting time seems shorter compared to very long single queue, which reduces chance of balking (check-in line at airport)*
  - *Frustration if other line than yours moves faster*

Approaches to controlling customer waiting:

- Animate, eg themeparks
- Discriminate, eg business class check in
- Automate, use scripts to address 75% of the questions
- Obfuscate (hide), eg in theme parks
- Obliterate, eg hotel bill under your room door at 5am of checkout day