Erasmus Universiteit Rotterdam
Faculteit der Economische Wetenschappen

Maintenance and Service logistics

Rommert Dekker

Erasmus School of Economics, The Netherlands

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Maintenance Education Consortium

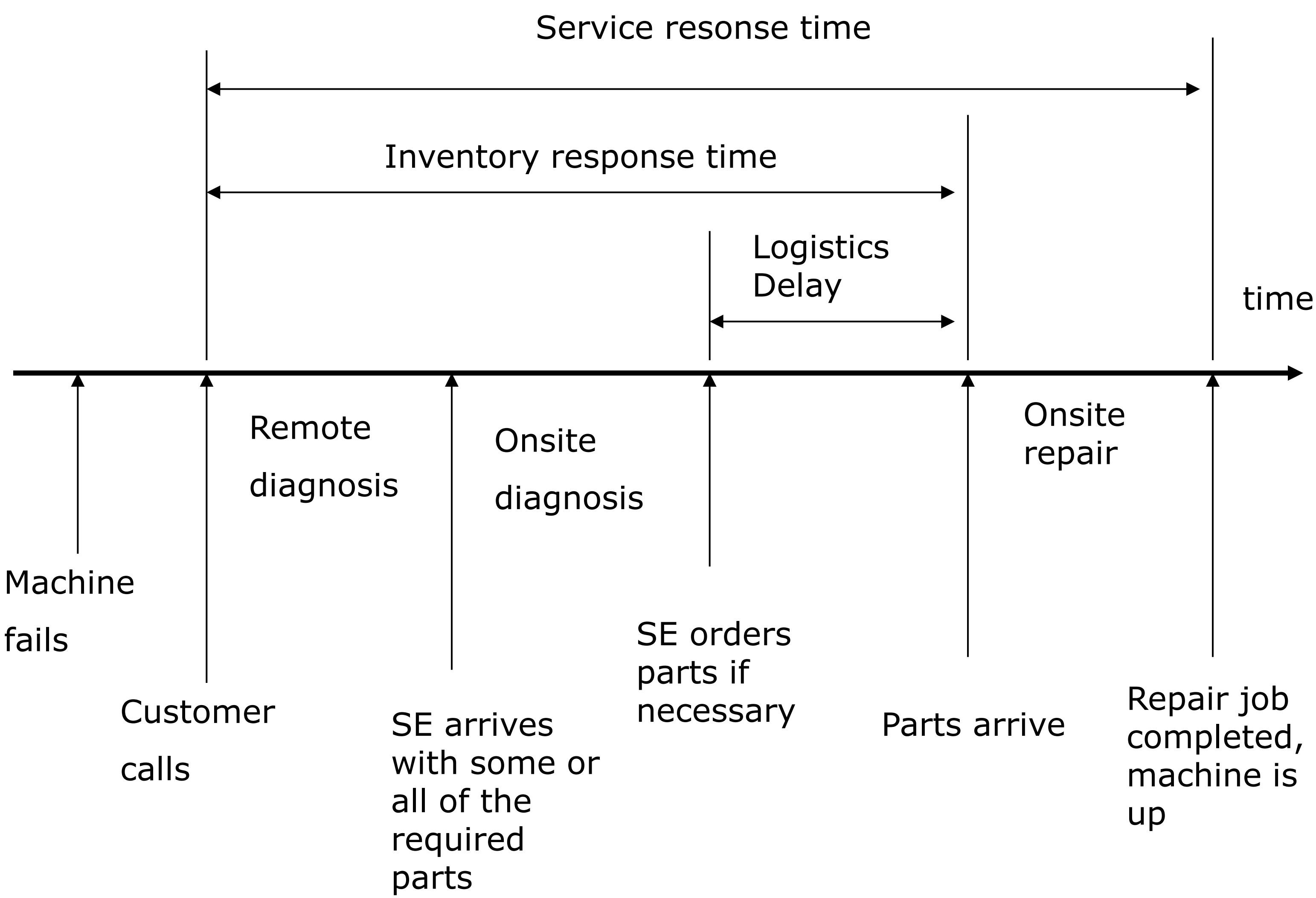
Outline

- Repair shop management
- Stocking calculations and pooling
- Pooling and alternative concepts

Rommert Dekker

- MSc,PhD mathematics ‘85, MSc Industrial Eng. ‘91.
- 85-91: Shell Laboratories & Shell Int.
  decision support systems for maintenance optimization and for opportunity maintenance.
- 92-now full professor of Quantitative Logistics
  - reverse logistics and service logistics
  - maintenance optimization
  - transport optimization
  - port and container logistics
- Projects: ProSelo, SLF Research, Revlog and many companies: Fokker Services, Shell, ECT, A16,

Service event timeline



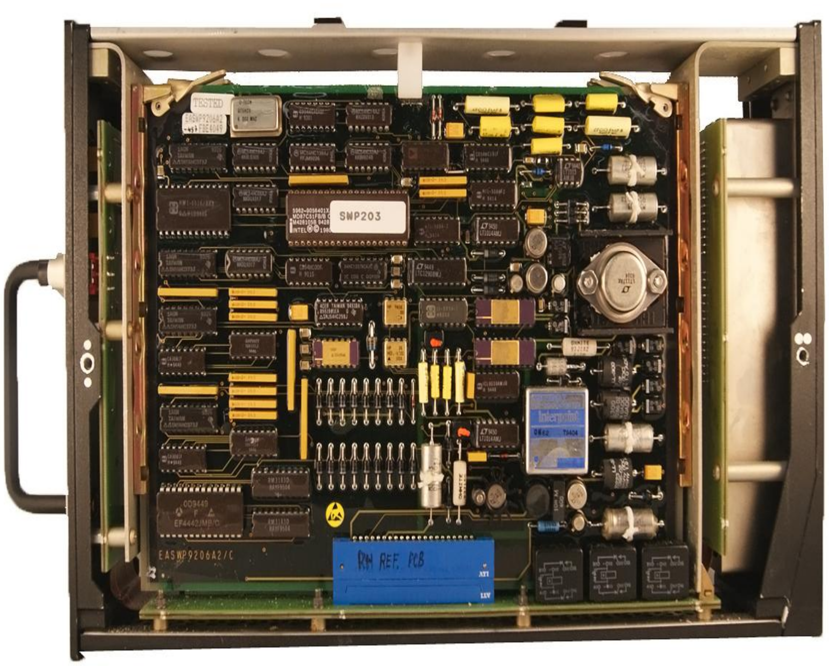
Remote Diagnosis

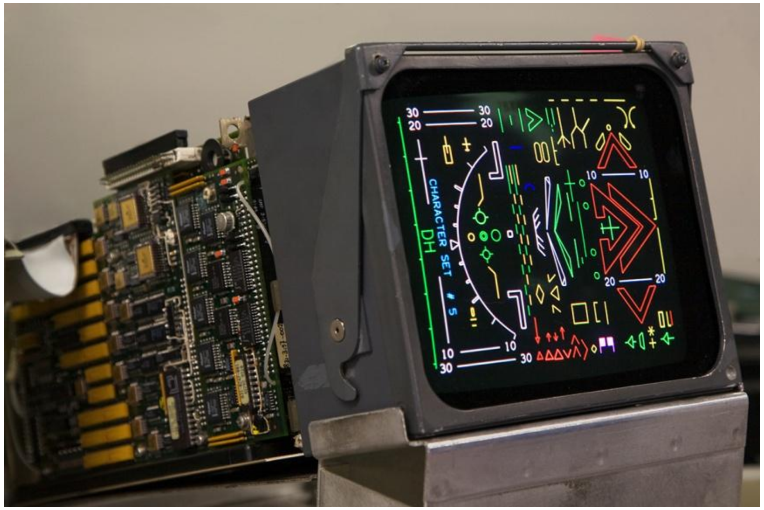
- Possible when system is connected to internet / has gsm function
- Automatic diagnosis function & classification
- Important to determine what should be done and which spare parts likely to be needed. Yet there is no certainty and often more parts are sent.

Repair or Replace?

- Major decision in maintenance
- Depends on costs of repair vs new price: set a price limit for repairs.
- Repair often cheaper, but may take more time
- Hence replacement is better for system uptime
- Replaced components may often be repaired.
- More inventories are needed

Examples aircraft components





Repair of Replaced Component

- Quite often expensive components can be repaired to an as-good-as new situation.

- Specialised repair shops: in aviation interesting business for e.g. KLM, Fokker Services etc.

- Important business sector (worldwide turnover 9 bln USD).

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Performance Repair shops

- Criterion: number of repairs done within certain time.
- Issue: number of repairs and hence workload is varying.
- Amount of work per repair varies: often only visible once repair has started.
- Piece parts needed in the repair may not be on stock and have to be ordered.

How to handle these problems?

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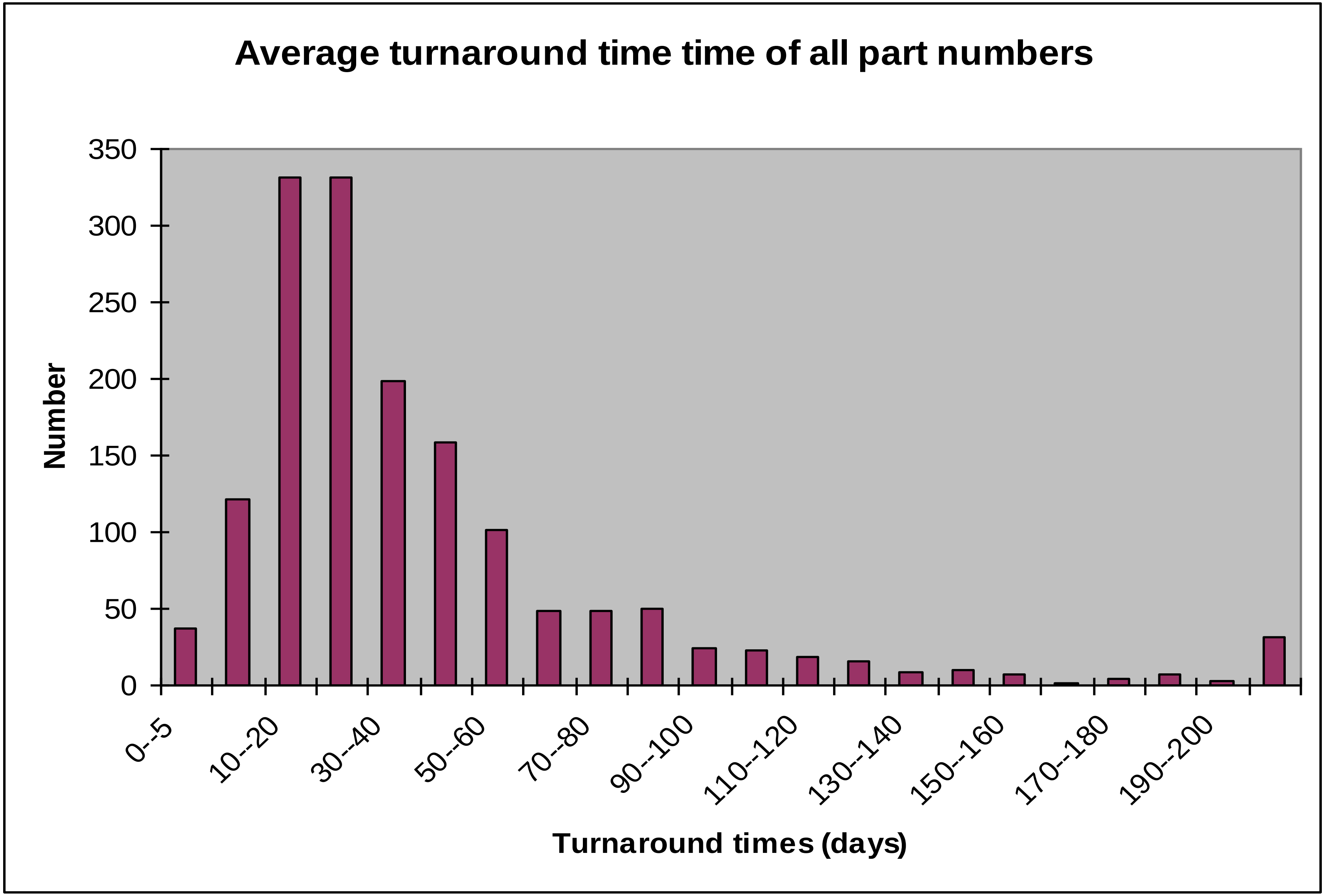
Typical repair turn around time



Approaches Repair shops

- Check every repair directly upon entry
  Identify NFF (No Fault Found) cases
  Identify piece parts needed for repair and order them
  Give feedback on repair time needed.

- Set work priorities according to earliest deadline.
  Delay work for parts with high inventories.

- Predict workload. Use flexible workforce and subcontracting to handle workload fluctuations.

- Possibly maintain own stocks for very frequent repairable components.

Research done for Fokker repair shops (Willem van Jaarsveld)

- Other major issue:
  often multiple piece parts are needed in a repair.

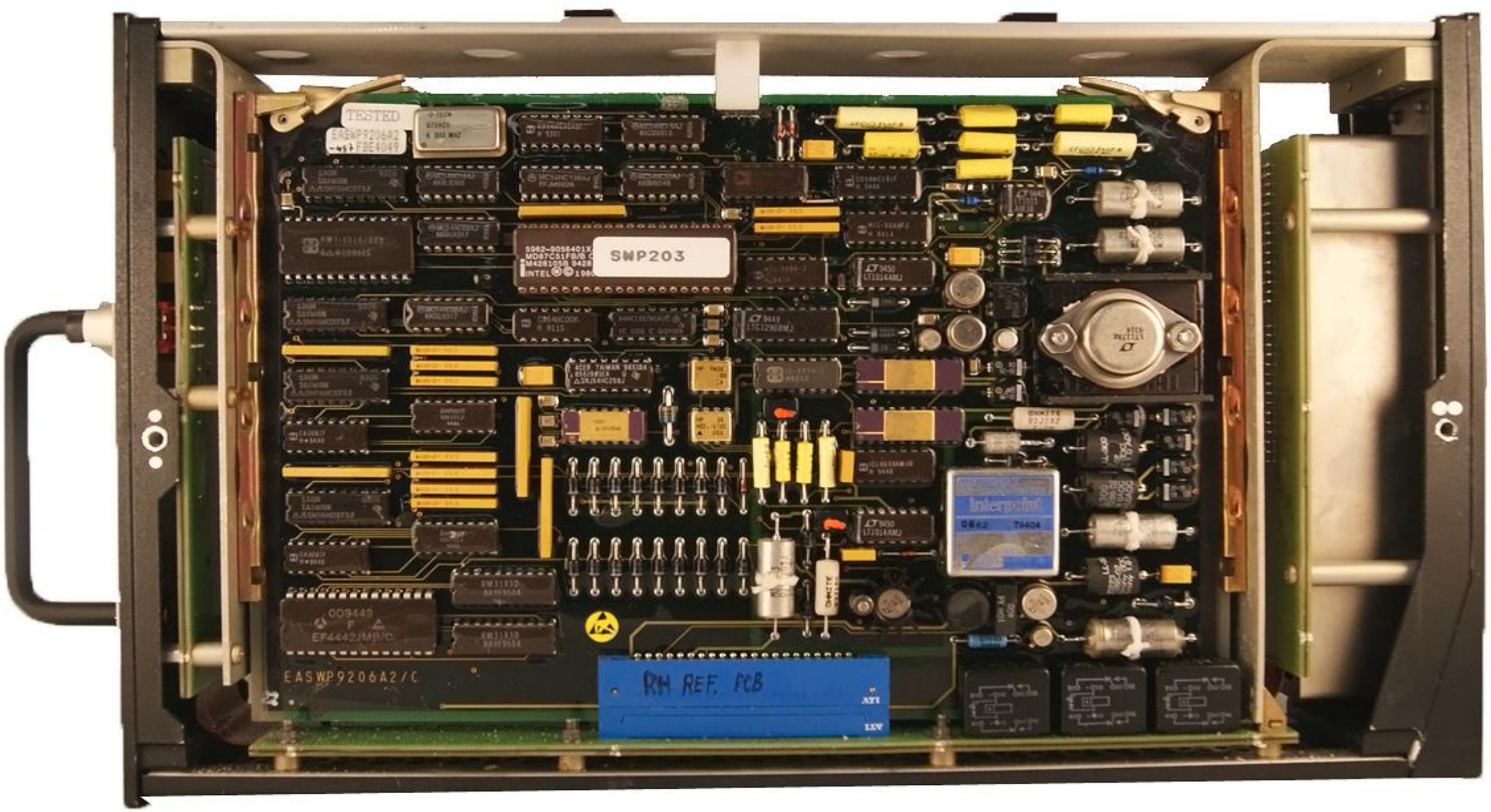
- Keep track of the (stochastic) bill of materials needed in repair, e.g.

Data analysis on completed repairs of components of a given type:

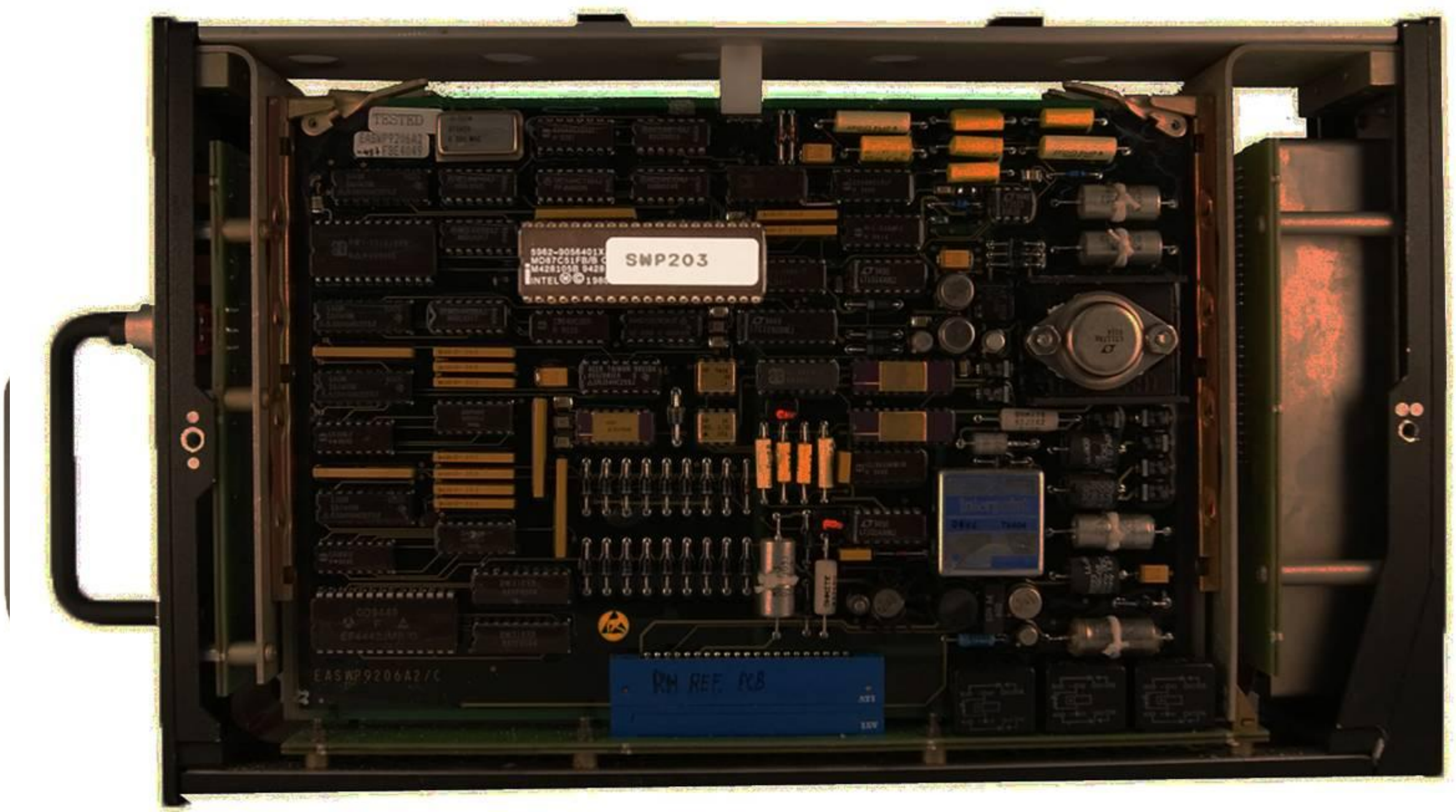
P/N	Usage prob.	Quantity
MA9541	31.30%	1 (31.30%)
40-882-208	17.39%	1 (15.65%), 2 (1.74%)
...		
40-693-518	4.35%	2 (4.35 %)
...		
KIP1012	0.87%	1(0.87%)
KIP1060	0.87%	1(0.87%)
...		

Excerpt of statistical BOM for component type P0KK-1010-021 (based on 115 repairs).

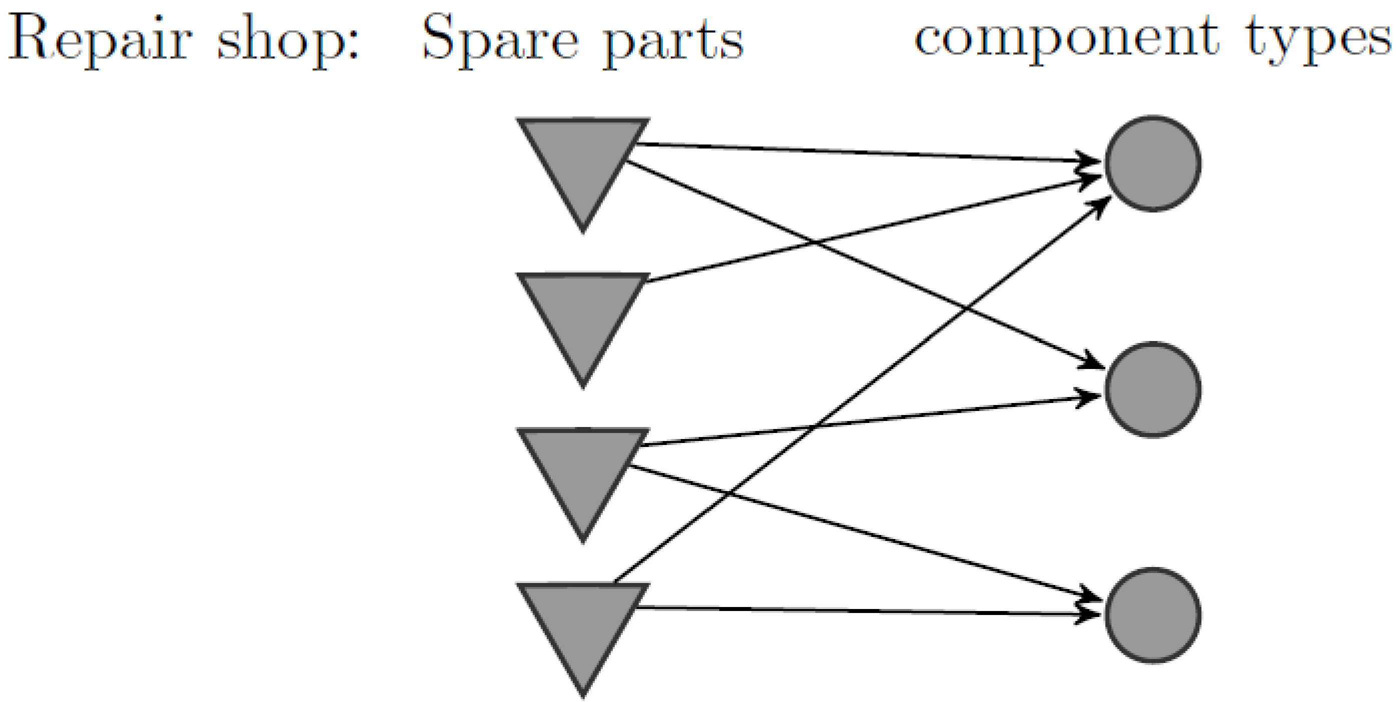
Component



Component and piece part



Complex structure



Problem

- Customers' expectations of repair turnaround times differ according to the type of component that is repaired.
- In the model, repair shop managers set performance targets for each individual component type:
  - i.e. in 90% of the repairs of a component of type 212-121-441, all spare parts needed in the repair should be available 0 days after initial inspection (i.e. fillrate for component 212-121-441).
  - and in 95% of the repairs of that component type, all spare parts needed in the repair should be available 20 days after initial inspection.

Stock Control Parameters

- Statistical based:
  use parameters to trigger replenishments
  Reorder Point s (also called min level)
  Order quantity Q (s+Q called max stock level)

- Forecast – MRP based
  forecast demand over leadtime. If remaining stock is below safety stock level ss, then order Q.

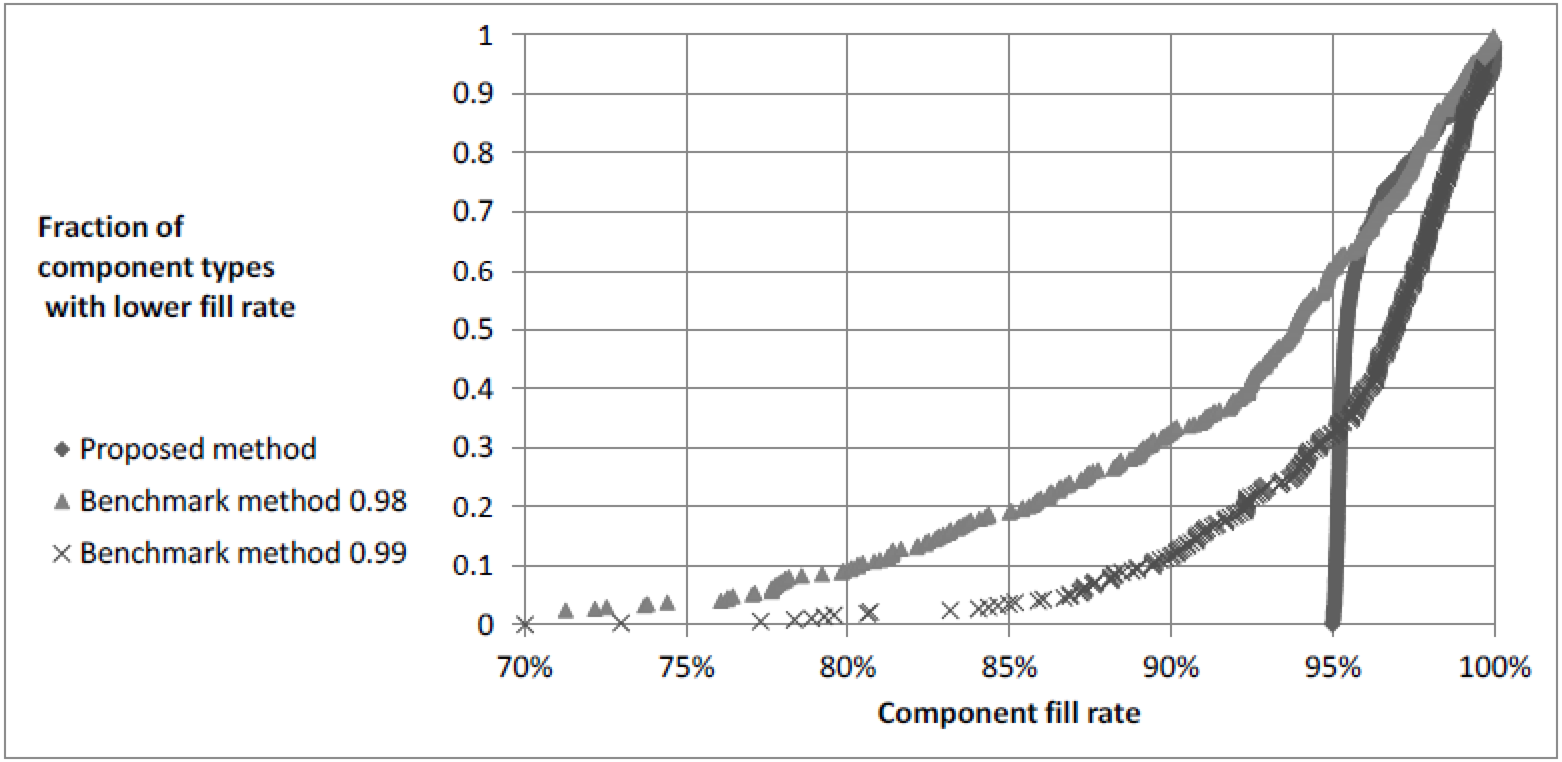
- s,ss and Q can be set manually, but also using stock control methods (better), assuming statistical distributions of demand over leadtime.

Research
Willem van Jaarsveld

- Developed a new method to determine the best spare parts control parameters (min, max stock levels – or reorder point s and order up to level S) that have lowest inventory costs while meeting specific availability targets.

- Implemented in a decision support system, presently in use.

Performance algorithm



Relation component repair and inventory control

- Upon use of a replacement component the available stock is decreased by one.
- This may trigger a replenishment order in the ERP system.
- Yet as the repaired component comes back from the repair shop, the inventory is increased by one, perhaps exceeding the max inventory level!

Outline

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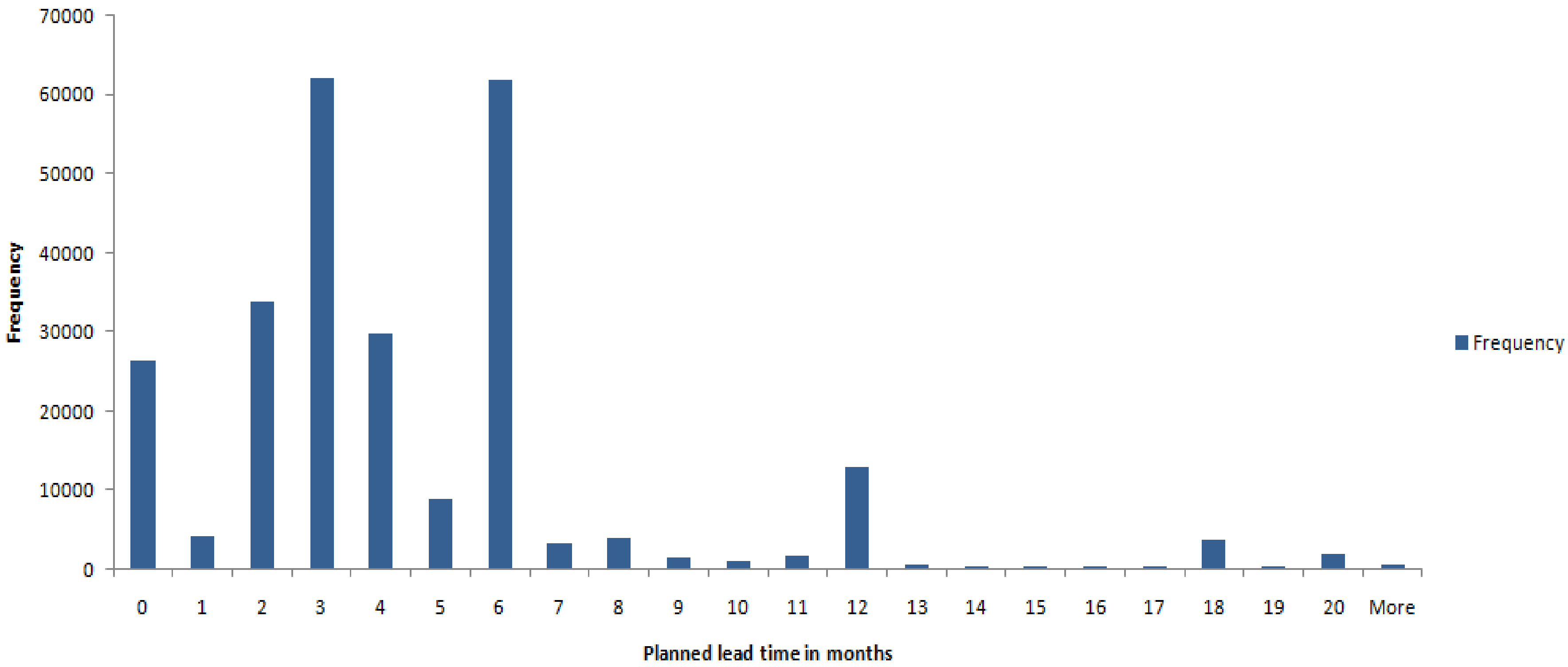
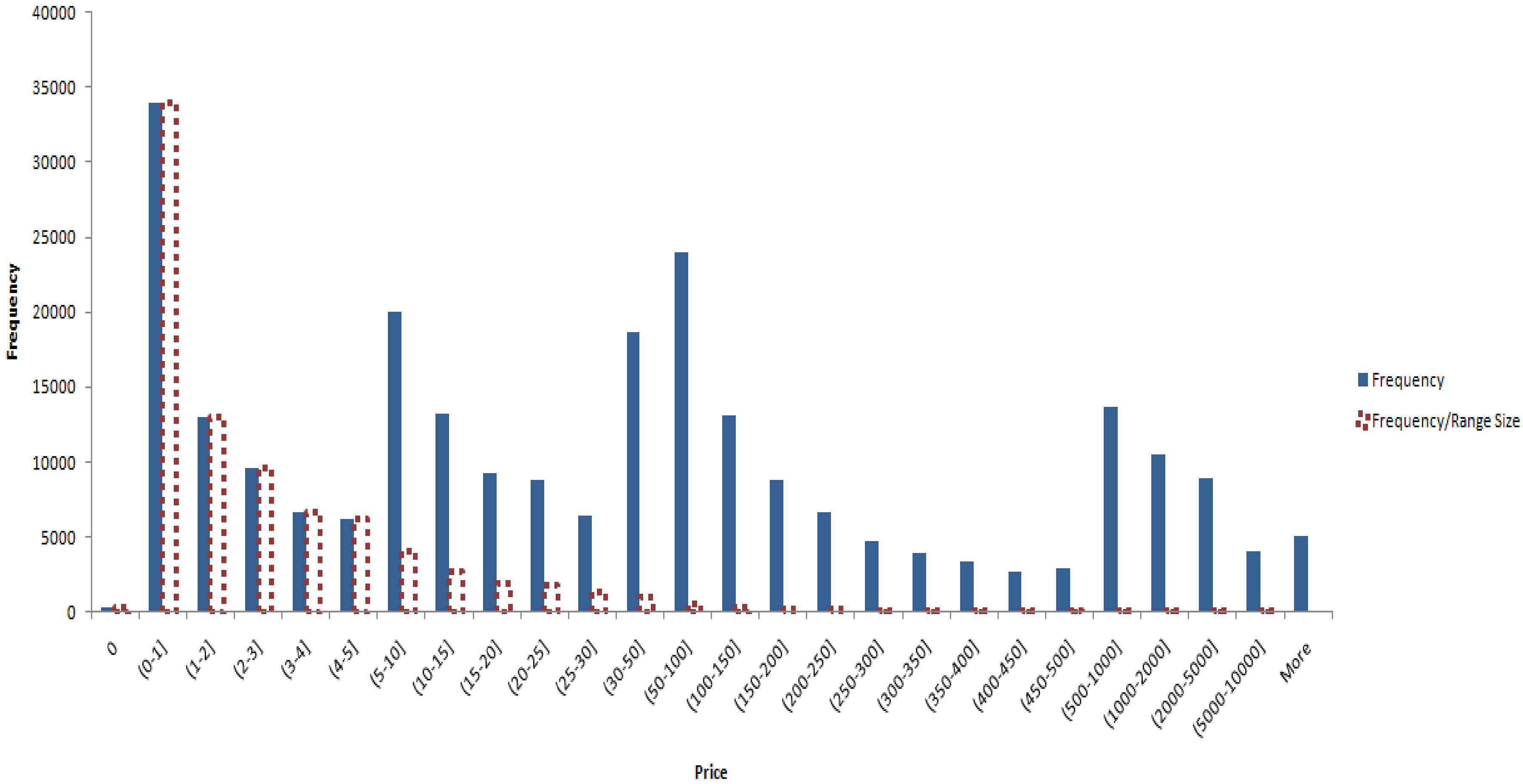
Leadtimes spare parts Naval Maint. Company
(according to Basten & van Wingerden(2012)



Why are these leadtimes that long?

Prices Parts Naval Maint. Company



some parts are cheap,
some are expensive!

Overall statistics spare parts NMC

	Price[a]	Planned LT[bc]	Planned - realised LT[bd]	Number of demands	Demand size
Number of values	5,191	5,191	25,890	5,191	39,408
Minimum	0.01	0	-1,265	2	1.00
10^{th} percentile	2.28	2	-8	2	1.00
Average	4,723.65	4	47	8	19.25
90^{th} percentile	6, 498.18	8	122	16	24.00
Maximum	2,697,070.10	37	1,100	182	15,000.00
Standard deviation	43,379.69	3	85	11	151.20

Table 3: Characteristics of parts at the Naval Maintenance Company

[a] In euros [b] LT = lead time [c] In months [d] In calendar days

Cf Basten et al (2012)

Slow moving spares?

- Several parts have very long leadtimes – evidently suppliers do not have them on stock. User needs to keep stocks to care of risk during leadtime.
- There can be quite some deviations from the planned leadtime: how to manage that risk?
- Many dead parts – should they ever have been stocked?
- There is scope for improvement.

Basic stocking considerations – supplier

- Typically: sales price = costs + margin (25%?)

- Profit per year: *Demand x margin*

- Stock holding costs:

  parts costs x holding cost rate (typically 25%/yr)

- Hence if demand < 1 / year a supplier should not stock parts, but assemble / make it on demand.

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Stocking considerations – user 1

- Stock holding costs:
  part's costs x holding cost rate (often 25%)

- Savings by having parts:

  Demand x leadtime reduction x downtime penalty costs

  leadtime reduction = reduction in time to obtain part by having it on stock

- Downtime cost penalty – production loss by delaying repair for waiting for parts

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Stocking considerations – user 2

- If stockout penalty is high enough, we will stock:
- Example: demand: 1 / 20 year
  part costs 50.000 €
  holding cost rate 25% / year
  extra leadtime: 30 days
  production loss per day: 10.000 €
- Stocking costs: 12.500 € / year
- Expected losses by not stocking:
  1/20 x 30 days x 10.000 € / day= 15.000 €/yr

  So we need to stock the part!

Stocking Advice table: take sum of indices: if >0 stock else, do not stock

Consumption Rate		CsI
12 or more	per year	5
6 to 11	per year	4
3 to 5	per year	3
1.5 to 3	per year	2
1 per	8-15 months	1
1 per	15-30 months	0
1 per	2.5-5 yrs	-1
1 per	5-10 yrs	-2
1 per	10-20 yrs	-3
less than 1 per	20 yrs	-4

Purchase Cost ($)	PrI
< 250	6
250 - 500	5
500 - 1,000	4
1,000 - 2,000	3
2,000 - 4,000	2
4,000 - 8,000	1
8,000 - 15,000	0
15,000 - 30,000	-1
30,000 - 65,000	-2
65,000 - 125,000	-3
> 125,000	-4

Penalty Cost ($ per day)	PenI
0 – 1,000	-2
1,000 – 7,500	1
7,500 – 30,000	4
30,000 – 60,000	5
> 60,000	6

Lead time			LtI
No lead time			-10
	<=1.5	day	-2
>1.5	<=3	days	-1
>3	<=6	days	0
>6	<=12	days	1
>12	<=21	days	2
>21	<=42	days	3
>1.5	<=3	months	4
>3	<=6	months	5
>6		months	6

Stocking considerations – user 3

- Users have problems in doing these calculations (we have a spreadsheet available)

  they do not know the failure rate at the moment of purchase: (we would like to know the uncertainty)

  production losses can vary widely: hence uncertain.
  redundancy complicates problem (vJaarsveld 2010)
  quite often categories are used: H, M, L.

- Hence many parts are stocked as insurance next to redundancy!

Sharing stocks

- Yet if the extra leadtime by sharing is small, e.g. 1 day, then we can save money by sharing stocks with other parties!

  Example revisited: production loss for 1 day:
  1/20 yr x *1 day* x 10.000 € / day = 500 €/year

- Sharing a stock with one other player halves the stocking costs: saving: 6250 € / year

- It will be clear that sharing is most cost effective for expensive, slow moving parts

Variable Leadtimes (example)

- Price: 1000 €
  demand: 2 / yr
  planned leadtime 2 months
  downtime penalty: 100 € / day,
  target service level: 90%
  exceptional leadtime 6 months

  advice: stock 2 parts -> 95% service level (L = 2)

  what to do against exceptional lead time?

  Use a pool of stock: 3 items -> 92% (L=6).

Consumption Uncertainty

- New users do not know demand, and make conservative estimates.

  E.g.
  demand: real 1/10 year, estimate 1/3 year
  price 10.000 euro
  leadtime 1 months
  down time penalty: 400 € / day

- Comparison
  stocking: 2500 €/yr
  no stocking: Costs: 4.000 €/yr (conserv. Demand)
  1.200 €/yr (real demand)

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Consumption Uncertainty

- Using a pool would reduce holding costs and still take care of stockout risk.
- Through a pool a (and information sharing) a company could much quicker learn real failure rates.
- Information asymmetry: companies with a lot of experience have an advantage. (quantification by Yang & Gabor (2012)).

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Pooling Concepts

- Pooling = sharing parts between different companies.

  Options:

- Sharing parts between user companies
- A pool managed by a third party
- A pool managed by a OEM.

Which parts to share?

- Consumables – parts with a predictable demand: NO usually cheap.
- Insurance parts – expensive parts with low, unpredictable demand: YES
- Repairables – parts which may be repaired upon failure, usually expensive: YES
- Rotables – parts for which a predictable refurbishment to an as good as new condition is possible, e.g. aircraft engines: YES.

How to allocate costs between parties?

- Research by Frank Karsten (TUE)

  A stable cost allocation (= one in which no party is better off by defecting) is obtained if cost are allocated proportional to average usage

- Yet it assumes that demand information is known, and correctly revealed.

- Extensions are needed to determine location of stocks and to take care of dynamic situations

Other concepts

- Exchange scheme – an alternative part is supplied when a part is undergoing a repair.
- Pay per use: supplier provides stocks and user pay a fixed fee per use of system (pay per hour)
- Return schemes – parts can be returned after x years in case of no demand
- Parts supply contracts – users pay for repair and parts supply services with a guaranteed availability.

Observed pools

- ProRail's RailstockForum
  Pool of rail parts kept by RailPro, availability is paid by ProRail
- Fokker's Abacus scheme
  focus on repairables and rotables
  pool + exchange scheme
- AF/KLM component pool for other airlines
  as Fokker's, but limited in set-up.

Which type of pool is best - user?

- Users do not trust each other in the exceptional case parts are needed.
- How to avoid over usage and to allocate costs?
- Users may have different systems, allowing only few parts to be pooled. Hence much overhead for a partial solution.
- What to do if some users abandon systems?
- In case of large industrial complexes where some factories are sold to 3rd parties it is interesting to try out a pool concept.

Which type of pool is best – 3rd party / OEM?

- A third party may provide guarantees in case of part shortage – yet faces high financial costs for setting up a pool and in case companies withdraw.

- The OEM has most experience with parts, knows and wants to learn failure rate and has most opportunity to supply part.

- Yet the OEM often wants to supply new systems rather than providing parts!

- Combination with repairable pool is successful!

Statements

- OEMs should offer more parts pools or parts supply contracts to reduce costs for users and to maintain a long-term relation ship.

- This relationship may also lead to selling upgrades packages.

- Users: do not buy parts, but the right to get delivered on time.
  Acknowledge that this costs money.

  Certainly avoid unique systems with unique parts, because pooling these is not attractive for OEMs.

OEM dilemma

- Keeping stocks becomes problematic if parts are out of production, or produced rarely.

  Offering a pool is then beneficial for users, but how to differentiate service to non-participants?

  E.g. stocks are held for a group of companies. Next another company comes in with an urgent demand, what to do?

- Charge higher price?
  Deliver only if enough stock (customer differentiation)?
  Charge entrance fee for entering pool?

Conclusions

- There are quite some inefficiencies in parts inventories
- Most problems start at the purchase, as then contracts need to be arranged.
- It seems that new contract forms are attractive, however, introduction depends on power positions in supply chains.
- Knowledge and tools are needed to make good assessments, hence the need for a control tower!