Stocking strategy for service parts : a case study

Document status and date:
Published: 01/01/1998

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

Download date: 17. Nov. 2023

**Stocking strategy for service
parts : a case study**

René Botter and Leonard
Fortuin
WP ?3

Stocking strategy for service parts – a case study

René Botter[1] and Leonard Fortuin

Eindhoven University of Technology, Faculty for Technology Management, Paviljoen F.18, P.O. Box 513, NL 5600 MB Eindhoven, The Netherlands (e-mail: L. Fortuin@tm.tue.nl)

Abstract – Service part inventories cannot be managed by standard inventory control methods, as conditions for applying the underlying models are not satisfied. Nevertheless, the basic questions of inventory control have to be answered: Which parts should be stocked? Where should they be stocked? How many of them should be stocked? This paper is a case study in which a pragmatic but structured approach is followed: a framework is developed and built into a spreadsheet. The resulting tool has been tested in a real-life situation, indicating that considerable amounts of money can be saved.

Keywords: inventory, service, spare parts

1. Introduction

Service parts are important. Many companies are faced with worldwide competition; customer satisfaction has become crucial. An important means to keep customers satisfied is quick repair of a product or system that failed. To this end enough service parts have to be stocked at appropriate points in the supply chain to guarantee a high service level. As most of these parts are expensive, this requires large amounts of money to be invested.

Three control situations have to be distinguished (Fortuin & Martin [3]):

- service parts to maintain own (production) facilities and systems;
- service parts to service (professional) systems installed at customer sites;
- service parts to repair consumer products, at service workshops.

As in any inventory control situation, some basic questions have to be answered. The follow-ing apply here:

- Which parts have to be stocked?
- Where are the parts to be stocked?
- How much stock has to be kept for each of these parts (reorder level and reorder quantity)?

Service part management means finding feasible and efficient answers to these basic questions. That is a difficult task as standard methods for inventory control fall short: consumption is so erratic and low that there is no demand process that allows forecasting of future demand, parts are expensive and

[1] Andersen Consulting, Apollolaan 150, 1077 BG Amsterdam, e-mail: rene.botter@ac.com.

customers very demanding. Criticality of parts is a useful concept to bring some order in this mess. It expresses the importance of a part in case of system failure. A generally valid definition of "criticality" is hard to find, as local circumstances play an important role.

Service parts can be divided into two categories:

1. Repairables: service parts that are technically and economically repairable. In case of failure, such a part is swapped with a new one and sent to a repair centre.

2. Consumables: service parts that are technically and/or economically not repairable. In case of failure the part is replaced by a new one and scrapped.

This paper is based on a case study. It describes a solution for the second of the three control situations mentioned at the beginning of this section, namely the control of service parts for the repair of professional electronic systems at customer sites. The parts involved are repairable. For obvious reasons, sensitive information about the company, its position in industry, and its operations has been left out. The company is called here EDIAP, which stands for Electronic Devices for Industrial APplications.

The outline of the paper is as follows. First, in Section 2, we pay some attention to related literature. Then we describe the company (Section 3), the problem (Section 4) and the approach followed (Section 5). Application of the model and some results are described in Section 6, and conclusions are drawn in Section 7.

2. Related literature

The area of stock control has received much attention from the scientific community for many decades now. The majority of literature is focused on (re)ordering policies in order to supply production lines with material, and stock control for distribution networks. In this paper, we focus on the special requirements for (re)ordering policies in service parts environments. Thereby we are primarily interested in realistic and tested approaches, rather than in approaches of a purely hypothetical and theoretical nature. From a survey [1] we derive the following observations:

- Most of the professional literature deals with one of four branches: (1) electronic industry, including computers; (2) automotive industry; (3) aviation industry and (4) production companies keeping stock of parts for maintenance.

- The electronic industry, the automotive industry, and the airline operators more and more tend to outsource service parts management.

- In these industries there is also a tendency towards co-operation, e.g. joint exploitation of service parts inventories, for the sake of cost reduction. Joint acquisition of parts and collective maintenance are also examples.

- Investments in automation of administrative processes and warehouse operations are high, in order to reduce time for processing, handling and transport. Stock reduction is the result.

- Classification of service parts by labelling them as 'fast mover' or 'slow mover' is no longer sufficient. Other classification criteria emerge, such as: criticality of the function to be performed by a system that has become defective; price; delivery time; and life cycle phase of the service part.
- Methods to improve productivity of field service are getting ample attention, especially for the electronic industry.

3. The company

3.1 The logistics organisation

EDIAP is a large multinational company; it develops, manufactures, sells, supports and services electronic devices to be used in industry. In order to support the installed base throughout the product lifecycle, EDIAP has a multi-echelon distribution and repair structure to supply customers with service parts. It operates in a market characterised by:

- growing importance of after sales activities;
- severe competition.

A European Supply Centre (ESC) is the main distribution and repair centre for service parts in Europe, the Middle East and Africa. Its main responsibility is the procurement, warehousing and distribution of service parts for and to the stocking points in the countries. There are 16 countries to be served, with in total 80 National Warehouses. The ESC also serves the National Warehouses with logistical advice in order to achieve a better use of the European stock. Each National Warehouse employs a number of Service Engineers. These engineers visit customers in case of a system failure. The term Installed Base is used to indicate all the systems in use at customers' sites. Figure 1 gives an impression of EDIAP's supply chain for spare parts.

Besides this distribution function, the ESC has three other important functions:

1. Repair of returned defective service parts in the Repair Service Centre (RSC), so they can be used again for maintenance.
2. Disassembly and scrap of defective systems and parts that are technically or economic-ally no longer repairable. Usable parts are stocked or sold to third parties.
3. Refurbishment and upgrading of used systems.

Insert about here

Figure 1 – The supply chain for spare parts of EDIAP

3.2 Products and parts

The product assortment of EDIAP is divided into six categories. Each category consists of several families, each family counts several systems. A system can be equipped with different options. These options are the smallest saleable parts. Systems and built-in options have a modular structure. Modules, here called Field Replaceable Units (FRU), contain several components.

The ESC has to provide maintenance for the products sold to the market, the installed base. This "service after sales" is offered on the basis of service contracts. Hence service engineers must have service parts at their disposal at the right time and at the right place. Here a service part can be a system, an option, or a FRU.

Within the supply chain of the ESC two goods flows can be observed:

- The flow of newly made or repaired service parts towards service engineers. This flow is driven by replenishment and emergency orders from the various stocking points. These stocking points supply service engineers with service parts for repair at customer sites. When the needed parts are on stock, they are allocated to the service engineer requesting them and immediately a replenishment order is generated. Service parts for replenishment are shipped to the lower echelons via a consolidated transport network.

- The flow of defective repairable service parts towards the repair centres. After replacing a defective part by a new one at the customer site, the service engineer takes the part back home, where consumables are destroyed. Depending on the available repair facilities, repairables are repaired at country level or shipped to the ESC.

In each country, management is responsible for service performance and related costs. Stocks for service parts are kept at a recommended (order-up-to) level, called Target Stock Level (TSL). When customer demand appears, the stock level will drop below the TSL and automatically an order is generated and placed for replenishment at the ESC. Prices of service parts are high, and customer demand usually regards one piece at a time of a certain item. Hence the ordering procedure follows the "one-for-one replenishment" rule, or (S-1,S) rule. This is supported by fundamental research by, e.g. Sherbrooke [5]. At European level, at the ESC, inventory control follows the (RsQ) policy: stock levels are reviewed weekly (R), a quantity of service parts (Q) is ordered whenever the stock level has fallen below the reorder point (s). In total there are about 50,000 active part numbers.

4. The problem

The company is operating in a market with severe global competition. Strategic market research has revealed that customers want a wider range of services at lower costs. This means among others that the level of service agreed upon acquisition of a product depends on the *application* of the product, rather than on the product itself. Customers will choose the service level per application, i.e. they desire a high level for critical applications, whereas they try to reduce costs in the less critical areas. A plan to re-engineer the global supply chain was set up; it is aiming at two key goals: better

financial performance and higher customer satisfaction. To achieve these goals, the company defined four key issues to focus on:

- improvement of supplier performance;
- speeding up delivery by the logistics organisation;
- improvement of the field stocking strategy;
- better contract support.

This paper deals with improvement of the field stocking strategy, but it will be clear that in practice none of these subjects can be dealt with in isolation from the others.

A Pareto analysis of service after sales revealed that 90% of the service level is achieved with only 10% of the spare parts assortment. Therefore management wants to concentrate on those 10% of items. An important parameter is the Stock On Hand (SOH), defined as available inventory divided by consumption per week. The new stocking strategy should lead to a low SOH for fast movers, higher SOHs for slow movers, and no stock (SOH=0) for very slow movers.

Now the problem to be solved can simply be stated as follows: create a tool for stock control of spare parts that guarantees a good balance between customer satisfaction and costs. With this tool two questions have to be answered:

1. Which parts have to be stocked?
2. How many items have to be stocked, and where?

5. The approach

5.1 Selection of parts

There are two good reasons to reject the idea of developing *one* optimising mathematical method for *all* spare parts:

- Conventional models for inventory control are hardly suitable for spare parts, especially parts with a low frequency of demand.
- EDIAP wants a tool for the entire supply chain of spare parts, hence a tool to cover the whole spare parts assortment. But not all parts are the same, and so a classification is required.

Instead, a practical method was developed. It gives a performance that satisfies both customers and management. In this method *criticality* is the criterion to distinguish important parts from others, with the VED approach (VED = Vital, Essential, Desirable) as point of departure. Details can be found in Section 5.2.

As there are about 50,000 active parts numbers, from the beginning it was clear that the method had to be based on modern IT techniques, easy to implement and to maintain. Given the limited[Y] amount of time for this job, some more restrictions had to be made:

[Y] The work reported here was done as a project to obtain a M.Sc. degree in Industrial Engineering. At the Eindhoven University of Technology such a project takes 8-9 months.

- No changes in the existing distribution network are allowed. This means that no attempts will be made to define new locations for stocking parts.

- Only two echelons of the distribution network are to be considered: the ESC and the National Warehouses. Stocks in branches, in technician's cars, and at customer sites remain out of the scope.

- The tool to be developed has to be simple to implement and use. As we will see in Section 6, this has resulted in a spread sheet application.

5.2 The VED approach

According to the VED method, there are three types of parts:

- *Vital* parts: Items that cause high losses due to non-availability of equipment, in case they are needed while not on stock.

- *Essential* parts: Items that cause moderate losses due to non-availability of equipment, in case they are needed while not on stock.

- *Desirable* parts: Items that cause minor disruptions, in case they are needed while not on stock.

Criticality is here the ruling criterion. From the point of view of its functional necessity in production or service operations, criticality of a spare part has many faces. EDIAP distinguishes those listed in Table 1. However, evaluating the criticality of parts is a difficult task that is often accomplished by using subjective judgements. A systematic procedure that could be helpful here is the Analytic Hierarchy Process (AHP). This multi-criteria decision-making tool was developed by Saaty [6] to find out the relative priorities or weights to be assigned to different criteria and alternatives which characterise a decision. The decision model is based on the idea of structuring the problem into a hierarchy with three levels: the overall objective is at the apex, criteria characterising the objective are placed in the middle, whereas the decision alternatives can be found at the bottom. Criteria and alternatives have to be determined by management. In case of EDIAP the overall objective is "Evaluation of the criticality of spare parts". Criteria at middle level and their alternatives are those collected in Table 2.

After a thorough explanation of this method, management of EDIAP rejected it as a way to classify spare parts. The main reason was this: one of the most important criteria, response time agreed upon in service contracts, can vary for the same part from one customer to the other. Consequently, such a spare part cannot uniquely be assigned to a class. Moreover, management found the proposed method "too theoretical". Then it was decided to modify the VED method in such a

way as to accommodate local knowledge.

Table 1 – The many faces of criticality

Name	Comment
Response time	Maximum time between a call for help and restoration of the system's functionality, as agreed by contract
Functionality	Effect of the failure of a part on the system's availability: a part is functional if the system cannot function without it, or merely cosmetic if the system can continue to run without it, possibly with some minor restrictions
Consumption	Total demand for a part, per unit of time, expressed in number of pieces or in financial units
Stage of the life cycle	Newly developed, established and to be continued, or soon to be phased out
Price	A part can be (relatively) cheap or expensive
Purchase lead time	Time between placing an order at the supplier of a part and the moment the part is available for use
Reparability	The possibility to restore a part's functionality after failure

Table 2 – Criteria and alternatives for spare parts

Criteria	Alternatives
Response time agreed upon in service contracts	• 2-4 hours • next business day • later than next business day
Life cycle	• introduction • maturity • decline
Demand (AMC = Average Monthly Consumption)	• $AMC \leq 5$ • $5 < AMC \leq 100$ • $AMC > 100$
Purchase lead time (LT in weeks)	• $LT \leq 1$ • $1 < LT \leq 3$ • $LT > 3$
Price (P in $)	• $P \leq 100$ • $100 < P \leq 1000$ • $P > 1000$

5.3 Which parts have to be stocked?

The next item on the list of factors influencing criticality is *functionality* (see Table 1). There are two possibilities: a spare part is either *functional* or *cosmetic*. According to the VED analysis, we also have to look at the notions vital, essential and desirable. However, a functional part can be vital as well as essential, as can be seen from the definitions of these terms in Section 5.2. But the distinction between *huge* loss and *moderate* loss is hard to make. For practical reasons we therefore assign all functional parts to class E (Essential). Because failure of a cosmetic part does not cause failure of the whole system, cosmetic parts can be assigned to a less important class. In terms of the VED analysis this class is called D (Desirable). So along the dimension functionality we now have two possibilities: cosmetic (Class D) and functional (Class E).

Insert about here

Figure 2 – Framework 1 for the stocking strategy – Which parts on stock?

Consumption of spare parts is another important item in Table 1. Two versions can be met in practice: consumption expressed in money and consumption in pieces. EDIAP holds the latter for the most important, because also a cheap spare part might cause a serious breakdown at a customer. Via the well-known Pareto analysis of cumulative demand in pieces, we distinguish three classes of spare parts: fast moving parts (class X), slow moving parts (Class Z), and parts of Class Y in between. Combining these two dimensions, we get a framework for answering the first question: Which parts have to be stocked? It consists of 6 segments, as is shown in Figure 2. Each segment represents a particular group of spare parts. The segment EX, for instance, contains all fast moving essential parts; DZ contains all slow moving cosmetic parts. The size of a group depends on the definition of fast moving, etc. It is common practice to take 90 % and 99 % as boundaries.

Each segment requires a different stocking strategy. For the major part these are based on decisions made by EDIAP management. As an example we mention the possibility that management decides not to stock cosmetic parts. From a systems point of view this is acceptable, because failures of cosmetic parts will not immediately influence operations of the system. Then only the parts in segments EX, EY and EZ are left as candidates to be stocked. If next the decision is taken to cover 90 % of cumulative consumption, only the parts in segment EX have to be stocked.

5.4 How many items have to be stocked, and where?

Framework 1 of Section 5.3 enables us to answer the first question posed in Section 4: Which parts have to be stocked? For the parts selected for stocking, we will now address the second question: How much stock has to be maintained of those parts, and where do they have to be stocked? The answer strongly depends on the desired Level Of Service (LOS). Conventional inventory theory is not applicable here, as demand frequency is far too low. Sophisticated mathematical models, with complex distribution functions to approximate low demand levels, have to

be rejected also. The reason for this rejection is simple: management finds them too difficult to implement and too hard to maintain.

In Section 5.3 it was stated that consumption in pieces is regarded as more important than consumption expressed in money. However, when deciding about how much and where to stock parts, price is important too. After all, it is undesirable to stock very expensive spare parts in every local warehouse. So if possible such parts will be stored only centrally in the countries or even only at the European Supply Centre, and the number of pieces to be stocked will be kept to a minimum. On the other hand, logistics managers will have few objections when cheap parts such as nuts and bolts are stored locally, even in large quantities.

After applying Framework 1 of Section 5.3, still a majority of the parts to be stocked will be characterised by low consumption. Therefore, usage in pieces will also be relevant when deciding about where to stock parts and how many. It is likely that fast moving spare parts are stocked in local warehouses, as large(r) quantities can be shipped by cheap(er) means of transport. On the other hand, slow movers will be stocked only centrally, to decrease inventory costs. If demand occurs, such parts will be shipped to the customer, if necessary by courier or taxi.

Although both factors, i.e. consumption in pieces and price, are very important, again the most important factor is the time that is allowed to provide customers with spare parts. After all, one of the functions of stock is to decouple successive processes in such a way that these processes can be executed independently. In our case the successive processes are replenishment and repair. If the repair process allows spare parts to arrive within a day after a call, the stocking strategy will differ from the strategy when parts have to be available within a few hours. Obviously, this time depends on the service contracts in which service response times are defined.

Insert about here

Figure 3 – Framework 2 for the stocking strategy – How many parts and where?

The three dimensions described above can be depicted in another framework: see Figure 3. Along each axis two general classes are defined. This choice is arbitrary: it is up to management to decide upon the number of classes for each of the dimensions. We suggest taking no more than two. Then the number of different segments becomes eight, which is manageable. Each segment represents a particular group of spare parts, each with its own approach. We briefly describe the segments of Figure 3:

1. *Low price, short response time, high usage*: These fast moving parts have to be stocked in large quantities in local warehouses, i.e. close to the market.
2. *Low price, short response time, low usage*: Also these cheap slow moving parts have to be stocked close to the market, but in lower quantities.
3. *Low price, long response time, high usage*: For these parts inventory costs and transport costs should be investigated, in order to determine whether or not local stocking is better than central

stocking. Local stocking of fast moving parts could decrease transport costs, as larger quantities can be shipped by cheaper means of transport.

4. *Low price, long response time, low usage*: These parts are only to be stocked centrally, at the European Supply Centre (ESC).

5. *High price, short response time, high usage*: These parts require firm management, as stocking is expensive. Owing to the short response time, parts primarily have to be stocked in local warehouses. The quantities should be as low as possible, and depend on the desired customer service level.

6. *High price, short response time, low usage*: Again firm management is needed. It may be worthwhile to consider fast means of transport , even if they are expensive (e.g. taxi). In this case stocking centrally in the countries becomes possible, thus reducing inventory costs.

7. *High price, long response time, high usage*: For these parts a trade-off has to be made to choose between central stocking in the countries and at the ESC.

8. *High price, long response time, low usage*: Owing to the long response time these parts can be stocked centrally, at the ESC, and shipped by regular means of transport when needed.

In this way we obtain an integrated stocking strategy for all segments. A complication, however, may arise if a spare part belongs to two different systems, each with its own response time. In fact, this happens often at EDIAP. Nevertheless, in this paper we will not consider this possibility.

5.5 Quantitative analysis

In the previous section we dealt with the question of how many parts should be stocked and where. Framework 2 only provides an answer in a qualitative sense. When stock levels have to be quantified, the desired Level Of Service (LOS) plays an important role. For this parameter we have a straightforward definition: it is the percentage of demand delivered directly from the shelf, as experienced by the customers. Because of the last part, *as experienced by the customers,* we may regard the LOS as a measure for the final customer service.

Suppose that for a certain segment of Framework 2 we have to stock N different spare parts (items). Consumption per item and total consumption are given, both in pieces. For each item p (p = 1,2,…,N) we determine two quantities:

- The consumption rate, C_p ($0 \leq C_p \leq 1$), i.e. consumption for item p divided by total consump-tion.

- The fill rate, F_p ($0 \leq F_p \leq 1$), i.e. the fraction of demand that is met from stock on the shelf.

Then the LOS for the segment can be computed from:

(1) $$LOS = \left(\sum C_p * F_p \right) * 100\ \%.$$

Formula (1) indicates that the pre-specified overall LOS as required by EDIAP, depends on the fill-rate of the individual spare parts multiplied by their share in the total consumption in pieces. We call this the "weighted fill-rate". What we have to do now is (1) to determine for each spare part the stock level needed to realise a sufficient fill-rate for that part, in such a way that (2) the sum of all weighted fill-rates is equal to or larger than the wanted LOS.

Sherbrooke [5] defines the stock level s as:

(2) $s = OH + DI - BO,$

where

OH = number of pieces of stock on hand

DI = number of pieces of stock due in from repair or resupply

BO = number of pieces being back ordered.

The stock level s is a constant, the other variables are non-negative random numbers. Any change in one of them causes a change in another. For example, when one item is demanded, one item is reordered (one-for-one replenishment) and DI increases by one. If at that moment OH is positive, demand is followed by delivery and OH decreases by one. However, if OH = 0, delivery is impossible and BO increases by one. In either case, (2) remains valid. When a repair is completed or a new part arrives from resupply, DI is reduced by one. Then BO decreases by one if it was positive, or, if there are no backorders OH increases by one. Again the equality is preserved. The simplicity of (2) is caused by the fact that the batch sizes for ordering, repair, resupply and demand are all equal to one.

If DI # s-1 demand will be followed by a fill, because OH > 0. For DI ∃ s, there is no stock on hand. So, the expected fill rate, $F_p(s)$, follows from the formula:

(3) $F_p(s) = Prob\{DI = 0\} + Prob\{DI = 1\} + ... Prob\{DI = s-1\} = Prob\{ DI \# s-1 \},$

where Prob{DI=i} is the steady-state probability of having i units of stock due in. According to Sherbrook [5] this is a Poisson probability with mean mT, where mT follows from Palm's theorem:

If demand for an item is a Poisson process with annual mean m and if the time for repair or resupply for each failed unit is independently and identically distributed according to any distribution with mean of T years, then the steady-state probability distribution for the number of units in repair or resupply is a Poisson distribution with mean mT.

So for DI we have (i = 0,1,...):

(4) $Prob\{DI = i\} = (mT)^i \exp(-mT)/i!$

This formula into (3) enables us to calculate the expected fill rate of a spare part, if stock level, average monthly demand, and average resupply time (in months) are given.

If the number of spare parts is very high and consumption per part is low, it makes sense to combine the parts into a *group* and base the analysis on the demand of the group, rather than on each of the parts. Then the formula for the LOS becomes:

(5) $LOS = \left(\sum CG_g * FG_g \right) * 100\%,$

where

LOS =   Overall Level of Service (0# LOS # 100)

g =   group number

CG_g =   Consumption rate ($0 \leq CG_g \leq 1$), i.e. consumption for Group G divided by total consumption.

FG_g =   Fill rate, ($0 \leq FG_g \leq 1$), i.e. the fraction of demand that is met from stock on the shelf.

6. Application of the model

The foregoing model has been applied to the assortment of spare parts for a certain family of products. European consumption was given over a period of six months. In Europe there are 80 National Warehouses. The assortment consists of approximately 50,000 different spare parts. Application of Framework 1 divided them in about 30,000 functional parts (Class E) and 20,000 cosmetic parts (Class D). Then management decided that all functional parts have to be stocked, a simple and straightforward answer the first basic question: Which parts have to be stocked?

How many items have to be stocked, and where? was the second question posed. Treating each of the 30,000 functional parts in the way outlined in Section 5.4 would be very time-consuming. Moreover, it would produce a tool that is hard to implement and support. Hence, the following procedure was adopted:

- Division of the assortment into eleven groups, on the basis of demand frequency. This resulted in Table 3.
- Analysis of each spare part in Group 1 and Group 2 in the way outlined in Section 5.4, via formula (1). These parts are the so-called fast movers.

- Analysis of the parts in Group 3-11, per group, on the basis of equation (5). These are the so-called slow movers.

Table 3 – Grouping of spare parts for Europe

Group	Consumption in 6 months (pieces)	# of items in a group	Total consumption in 6 months (pieces)	Average price ($)
1	more than 1000	69	125,885	140
2	501 – 1000	104	71,211	231
3	401 – 500	52	23,497	240
4	301 – 400	85	28,961	231
5	201 – 300	194	46,711	271
6	101 – 200	470	65,594	322
7	51 – 100	777	53,780	310
8	11 – 50	3,613	78,088	312
9	4 – 10	5,407	27,199	407
10	1 – 3	2,719	3,742	407
11	0	15,562	0	493
Total		29,052	524,668	

6.1 Stocking individual parts in every National Warehouse

We illustrate the calculation of the LOS for each of the fast-moving parts, i.e. those in Group 1 and 2, by looking at the spare part with the highest consumption. We label it with p=1. Its consumption in 6 months equals 5410 pieces. As there are 80 National Warehouses (NW) in Europe, this means an average of about 12 pieces per month per NW. The consumption rate, C_1, for this part is 5410/524,668 = 0.0103. The replenishment time from the ESC to each of the NWs is assumed to be distributed with a mean value of 3 days, or 0.1 month. Hence in equation (4) we can substitute mT=12*0.1=1.2 and so we get for the number of units due in:

(6) $\text{Prob}\{DI = i\} = (1.2)^i \exp(-1.2)/i!$

Next we have to look at the fill rate for a given value of the stock level s. With equation (6) we can calculate $F_p(s)$ as given in (3). Some results are listed in Table 4, for s=0,1,...,7.

Table 4 – Expected fill rate and LOS for a single part (part number 1)

Stock level (s)	$F_1(s)$ in formula	$F_1(s)$ numerical value	Contribution to LOS
0		0	0

1	Prob{DI=0}	0.301	0.0031
2	Prob{DI=0} + ... + Prob{DI=1}	0.662	0.0068
3	Prob{DI=0} + ... + Prob{DI=2}	0.879	0.0091
4	Prob{DI=0} + ... + Prob{DI=3}	0.966	0.0099
5	Prob{DI=0} + ... + Prob{DI=4}	0.992	0.0102
6	Prob{DI=0} + ... + Prob{DI=5}	0.998	0.0103
7	Prob{DI=0} + ... + Prob{DI=6}	0.999	0.0103

This table shows that in order to acquire an expected fill rate of at least 0.99, a stock level of five units in each of the 80 NWs is needed. As the price of this part is $ 35, the total investment in stock for this part will be 5*80*$35 = $ 14,000. Then the part is expected to contribute approximately 0.992*0.0103*100% = 1.02 % to the *overall* LOS. The foregoing calculation has to be done for all the 173 parts in Group 1 and 2.

6.2 Stocking groups of parts in every National Warehouse

This type of calculation will be illustrated by means of Group 3 in Table 3. This group contains 52 spare parts with a demand between 401 and 500 pieces during the period of six months. The average price per part is $ 240. Total consumption equals 23,497 pieces. Hence, the average demand per month and per NW is m=0.94 pieces (23,497/(52*6*80)). Once again we assume that demand is a Poisson process and the replenishment time from the ESC to the NWs is on the average 3 days, i.e. T=0.1 month. Consequently, the number of units due in has a steady-state Poisson probability distribution with mean mT = 0.094.

Table 5 – Expected fill rate for Group 3

Stock level (s)		FG_3
	0	0.000
	1	0.910
	2	0.996
	3	0.998

Table 5 shows the expected fill rate for s = 0,1,2 and 3 pieces. If management decides that an expected fill rate of 0.910 is sufficient for this group, each NW should keep one item in stock. Roughly, this will require an investment of 1*52*80*$240 = $ 998,400. As CG_3 = 23,497/524,668 = 0,045, the contribution by this group to the overall LOS amounts 0.910*0.045*100% = 4.1 %.

6.3 Stocking groups of parts in a *central* National Warehouse

So far the focus has been on stocking parts in every NW. However, many times the Average Monthly Consumption (AMC) per NW per spare part is far less than 1. In that case, stocking parts in just one central warehouse in a country rather than in each NW, is preferable.

Table 6 – Expected fill-rate for Group 7

Stock level (s)	$FG_7(s)$
0	0.000
1	0.931
2	0.998

For example, in Group 7 the AMC per country per spare part is 0.72. The average replenishment time from the ESC to a *central* NW is 3 days, or 0.1 month. So the number of units due in has a steady-state Poisson probability distribution with mean value 0.072. Table 6 shows the fill-rate for stock levels s=0, 1 and 2 units. A (central) stock level of 1 unit in every country for every part in this group will result in an expected fill-rate of 0.931. This requires an investment of (1x777x16x\$310 = \$ 3,900,000. As the CG_7 = 53,780/524,668 = 0.103, the contribution of this group to the overall LOS is 0.931x0.103x100% = 9,54 %. The feasibility of this mode of stocking parts depends on the time that is allowed for spare parts to arrive at the customer. Usually, this allowed time is stated in the contract with the customer.

6.4 Stocking groups of parts only in the ESC

For many spare parts demand is so low that even central stocking in the countries is not acceptable. For these parts, stocking at the ESC or not stocking at all, are the only possibilities. Parts of Group 9, e.g., have a European AMC of 27,199/(5407x6) = 0.84. It is important to note that in this case the average replenishment time from vendors to ESC is crucial. It is assumed to be equal to 0.5 months. Consequently, the number of units due in has a Poisson distribution with mean value 0.5x0.84 = 0.42.

Table 7 shows the fill-rate at the ESC for stock levels from 0 to 3 units. A stock level of 2 units calls for an investment of around 2x5407x\$407 = \$ 4,400,000; it results in an expected fill-rate of 0.933, a CG_9 = 0.052 (27,199/524,668) and an overall contribution to the LOS equal to 0.933x0.052x100 % = 4.9 %. The impact of the accepted service response time is even stronger than in the previous case. Despite a very low demand, some parts do have to be stocked in the countries, or even in local warehouses. Information on response time, however, was not available during our investigation.

Table 7 – Expected fill-rate for Group 9

Stock level (s)	FG$_7$(s)
0	0.000
1	0.657
2	0.933
3	0.991

6.5 A spreadsheet for the whole assortment

In the foregoing sections we have shown how the model has to be applied in various cases, corresponding to the intensity of the demand process. In this way it becomes clear where the spare parts have to be stocked and in what quantity, the second basic question. The cases treated correspond to the boxes of the framework drawn in Figure 3. To facilitate the calculations needed for the whole assortment, i.e. the 11 groups with in total 524,668 parts, a spreadsheet has been developed. It enables EDIAP to calculate the investments in stock and consequently the interest costs of stock keeping, necessary to acquire a pre-specified Level Of Service. Thereby transport, warehousing and handling costs are not taken into account. As a matter of fact these costs are not negligible, but it can be shown (Van Goor *et al.* [4]) that for spare part distribution by EDIAP interest costs are most important.

With the spreadsheet three scenarios have been investigated:

- Scenario 80-0-20: The overall LOS has to be at least 95%, approximately 80% of total customer demand has to be met instantaneously by the National Warehouses and 20% by the ESC.
- Scenario 50-0-50: The overall LOS has to be at least 95%, approximately 50% of total customer demand has to be met instantaneously by the National Warehouses and 50% by the ESC.
- Scenario 100-0-0: The overall LOS has to be at least 95%, approximately 100% of total customer demand has to be met instantaneously by the National Warehouses.

Table 8 shows the most important results.

Table 8 – Overview of results for three scenarios

(LOS = Level Of Service)

Description	Scenario 80-0-20	Scenario 50-0-50	Scenario 100-0-0
Investment in fast movers	9,148,200	9,148,200	7,226,800
Investment in slow movers	64,842,000	40,129,100	420,732,300
Total investment	73,990,200	49,277,300	427,959,100
Average lead time of fast movers to customers (days)	0.54	0.54	0.66
Average lead time of slow movers to customers (days)	1.22	1.90	0.56
LOS for parts delivered by the National Warehouses (%)	96,7	98.5	95,1
LOS for parts delivered by the ESC (%)	90.2	90.5	---
Overall LOS (%)	95.4	95.1	95,1

We note some interesting effects:

- As the actual total investment in stocks was $ 107.3 million, the model shows that a reduction of about $ 33 million is possible in case of Scenario 80-0-20.

- For Scenario 50-0-50 total investment in stock is much lower than for Scenario 80-0-20. This can be understood by realising that central stocking is cheaper than stocking in National Warehouses. Compared with the actual investments, a decrease of $ 58 million seems possible. The 'price' to be paid for this saving is the longer average lead-time of slow movers.

- Delivering all parts from NW (Scenario 100-0-0) requires a large amount of stock. The average lead-time for fast movers increases somewhat, but for the slow movers the average lead-time reduces to half the value that holds for Scenario 80-0-20.

7. Conclusions

A pragmatic framework has been presented by means of which we answered the three basic questions for spare parts inventory control for a two-echelon network of warehouses with some 50,000 items. The framework has been implemented into a spreadsheet programme. Three scenarios have been analysed; they differ in the degree in which spare parts are to be delivered directly from local warehouses: 50, 80 and 100%. In all scenarios the required customer service level is 95%. Some interesting conclusions can be drawn:

1. The best solution to a logistics problem, here the Analytic Hierarchy Process, is not always acceptable to management.

2.   For spare parts management, consumption expressed in *pieces* is more important than consumption expressed in *money*.

3.   The answer to the first basic question: Which parts have to be stocked? depends on the criticality of the part, i.e. the consequences to the customer if a part is needed and not available. This leads to the distinction between Vital, Essential and Desirable parts.

4.   Service response time and functionality primarily determine criticality.

5.   Service response time is not a suitable criterion for classifying parts as vital, essential or desirable, because an item can be part of different systems each with its own contracted response time.

6.   If the assortment of spare parts to be managed is large, it is recommended to limit the number of classes to two, namely functional parts and cosmetic parts.

7.   The decision not to stock cosmetic parts can reduce investments in stock considerably.

8.   In order to answer the second basic question: How many items have to be stocked and where? we have used two factors: usage in pieces, and price. Service response time is important too. But for the same reasons as mentioned in 5, this factor cannot be included.

9.   Service response time has a huge impact on required investments in stock.

10. Analysis of three scenarios reveals that the developed tool is capable of reaching a desired service level at much lower inventory costs.

8. References

1. R. Botter, "Spare parts: run or brake down!" Report of a special assignment, Eindhoven University of Technology (December 1996), in Dutch.

2. R. Botter, "An integrated European stocking strategy for spare parts", Eindhoven University of Technology, thesis M.Sc. (May 1997).

3. L. Fortuin and H. Martin, "On the logistics of service parts," Eindhoven University of Technology, Research Report TUE/TM/LBS/96-12 (December 1996).

4. A.R. van Goor, M.J. Ploos van Amstel & W. Ploos van Amstel, *Physical distribution: thinking in added value* (Stenfert Kroese, Leiden, 1994), in Dutch.

5. C.C. Sherbrooke, *Optimal inventory modeling of systems* (Wiley, New York, 1992).

6. T.L. Saaty, *The Analytic Hierarchy Process* (McGraw-Hill, New York, 1980).