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Single echelon inventory strategies in spare parts supply chains

(Estrategias de nivel simple en cadenas de suministro de repuestos)

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Abstract:
Inventory Management in Spare Parts Supply Chains (IMSPSC) plays an important role for both the Customer Company who wants to remain operational despite flaws in its machinery or equipment and the Supplier Company or Producer that want to improve their post sales service processes. The increasing importance of IMSPSC for the performance of companies calls for improved and innovative strategies in this area. This paper describes Single Echelon Inventory Strategies in Spare Parts management practices and serves as a source for deciding on the best strategy depending on the type of business and application. Nowadays these practices are not only a legal obligation of an organization but an opportunity to increase profits and to build long term commercial relationships and loyalty with customers.

Keywords: Spare parts inventory management; supply chain; single echelon strategies.

Resumen:
La Gestión de Inventarios en Cadenas de Suministro de Repuestos (GICSR) juega un rol importante tanto para la Compañía Cliente que desea mantenerse operativa a pesar de fallas en la maquinaria o equipos y la Compañía Proveedora o Productora que desea mejorar sus procesos de servicios de post venta. El incremento en la importancia de GICSR requiere la búsqueda de la mejora e innovación de las estrategias en esta área. Este artículo describe estrategias de Nivel Simple de gestión de inventarios en prácticas de administración de repuestos y sirve como una fuente para decidir sobre la mejor estrategia en función del tipo de negocio y la aplicación. Hoy en día estas prácticas no son solo una obligación legal de una organización sino también una oportunidad de construir lealtad y relaciones comerciales a largo plazo con los clientes.

Palabras clave: Gestión de inventarios de repuestos; cadena de suministro; estrategias de nivel simple.

1. Introduction

1.1. Motivation

Nowadays Inventory Management in Spare Parts Supply Chains (IMSPSC) plays an important role for both the Customer Company who wants to remain operational despite flaws in its machinery or equipment and the Supplier Company or Producer that want to improve their Post Sales Service processes. The increasing importance of IMSPSC for the performance of companies calls for improved and innovative strategies in this area. Ensuring minimum down time is the key factor that

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drives the processes in an IMSPSC (ManagementStudyGuide, 2012). This involves different actors as logistics service providers, warehouses, customer service teams and technical teams working together to ensure customer satisfaction while at the same time increasing their profit and revenue. (Wagner & Eisingerich, 2012). A key issue that managers face is the decision to store or not store spare parts (Rego & Mesquita, 2011).

Companies these days see Spare Parts management not only as a legal obligation but as an opportunity to increase profits and to build long term relationships and loyalty with their customers. Therefore it is important to take a proactive role by undertaking preventive maintenance instead of taking a reactive role when a problem occurs. (Kumar & Kumar, 2004)

1.2. Goals of the paper

This paper attempts to review "Single-Echelon-Inventory-Strategies" in spare parts supply chains. Therefore a distinction will be made between Classical Inventory Management and Spare Parts Inventory Management. Additionally an overview of different inventory strategies in single-echelon spare parts SC and identification of special requirements will be done. Furthermore the aim of this paper is to analyze in detail a specific single-echelon inventory strategy which can prove to be efficient for gaining improvements and cost savings.

Another important goal of the paper is to give guidelines for researchers and companies that will like to follow one of the listed strategies and show in which cases a certain strategy can be applied.

1.3. Structure of the paper

The structure of this paper is as follows. Section 2 describes important definitions which are relevant to Inventory Management in Spare Parts Supply Chains. This section also presents the differences between Classical Supply Chains and Spare Parts Supply Chains. Section 3 presents an overview of different types of Single-Echelon Inventory Strategies. In the same chapter an analysis of Partial Pooling strategy is made with the presentation of a case example. Finally, in Section 4 conclusions are drawn.

2. Inventory Management

There are two situations in which Inventory Management in a Supply Chain can be analyzed. The first situation is inventory management in the Supply Side of the Chain, in this case the analysis will be made to the Manufacturer who provides a Machine or Equipment, the Manufacturer then has to provide post-sales support for their customers by assuring the availability of the spare parts. On the other hand the second situation is inventory management in the Demand Side of the Chain, the Retailer who wants to offer superior service levels or the Producer who wants to increase its productivity by maximizing the asset uptime (Saccani, Johansson, & Perona, 2007).

The scope of this paper is to focus on the Supply Side of the Chain. Therefore some important definitions will be drawn in this context for IMSPSC. These definitions are intended to clarify the post sales processes in a company which aims to improve the following objectives: customer service, efficiency of purchasing and production, minimize inventory investment and maximizing profit (Viale, 1996).

2.1. Spare Parts Management

2.1.1. Spare Parts

Spare Parts also known as Service Parts are described by (Patton, 1984) as “Components, assemblies, and equipment that are completely interchangeable with like items installed or in use, which are used, or can be used, to replace items removed during maintenance and overhaul”.

The objective of Spare Parts management is to satisfy customers by providing the necessary parts, at the right location, for a reasonable price, in usable condition, at the proper time. This process support the customer to improve their operations and can be referred as the five rights of parts: item, place, price, quality, and time (Patton, 1984).

Spare Parts can be classified in different ways (Bachetti, Plebani, Saccani, & Syntetos, 2010). A typical classification of spare parts is done in two general groups: repairable and non-repairable parts also called discardables or consumables parts (Muhaxheri, 2010).

2.1.2. Non-Repairable

This group of spare parts is subcategorized in disposable items or consumable items. Both categories do not follow a repair procedure. When disposable parts fail these are disposed while on the other hand consumable parts are replaced on a regular basis because they have a limited life cycle. Non-Repairable Spare Parts tend to be lower cost items and are characterized by having low prices and high demand.

2.1.3. Repairable

Repairable spare parts in contrast follow several failure-repair cycles. Rather than bear the cost of completely replacing a finished product, repairable parts typically are designed to enable more affordable maintenance by being more modular. This allows components to be more easily removed and repaired enabling less expensive replacement.

This failure – repair cycle is illustrated in an example in the aircraft industry in Figure 1. Items that need to be repaired are sent to the Maintenance Repair and Overhaul (MRO) Company. Once they are repaired they are returned to the customer stock and used to supply the damaged items.

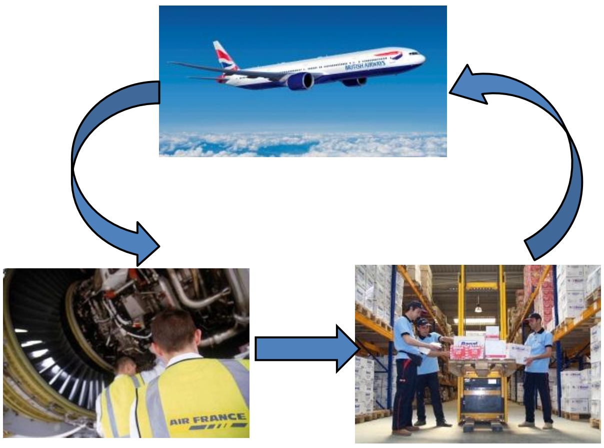

Figure 1. Repairable Items in a Failure – Repair Cycle in the Aircraft Industry
Based on: (Muhaxheri, 2010)

All possible types of spare parts in a Supply Chain will be taken into account when presenting the different inventory management strategies that can be applied in this field of studies. For a better understanding of the final outcome of this paper it is considered important as well to show the differences between classical inventory systems in a SC and spare parts inventory systems in a SC. Therefore the next section will review these topics.

2.2. Differences between Classical Supply Chains and Spare Parts Supply Chains

Inventory Management in a Classical Supply Chain and in a Spare Parts Supply Chain do not work in the same way. There are specific characteristics that are applicable for each approach.

2.2.1. Inventory management in Classical Supply Chains

In Classical Supply Chains there are different systems to maintain inventory levels and to ensure on time supply in the right quantity. In the following paragraphs three systems in a classical supply chain will be presented (Bijvank, 2009).

2.2.1.1. Order Rhythm Systems

Every period t_B an order is issued with a certain order quantity Q (see Figure 2) or an amount of the difference to certain order level S (see Figure 3).

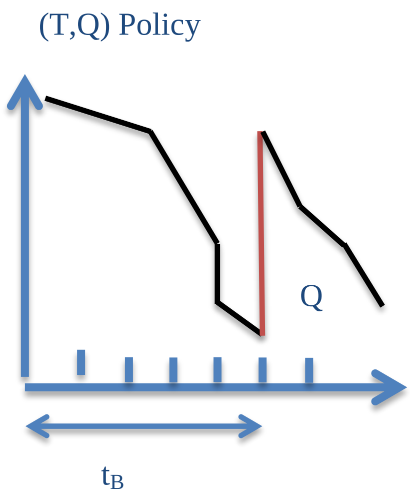

Figure 2. Order Rhythm System (T,Q) Policy
Based on: (Bijvank, 2009)

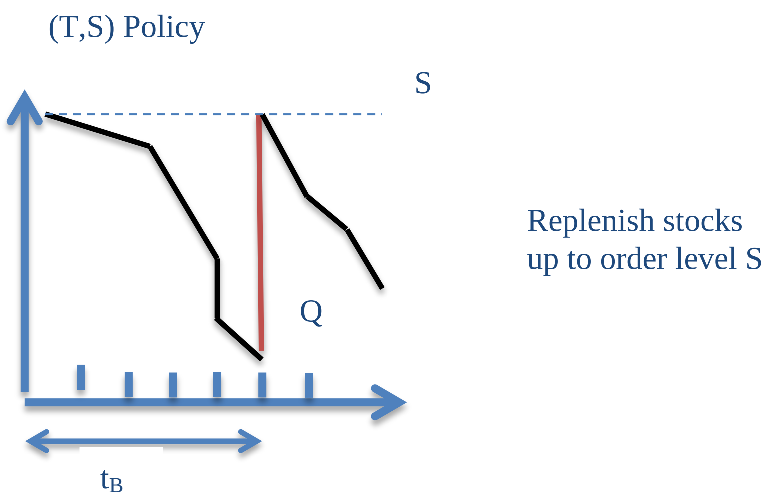

Figure 3. Order Rhythm System (T,S) Policy
Based on: (Bijvank, 2009)

2.2.1.2. Order Point Systems

If an order point has been reached or if the stock level falls under a certain level "ss" an order is issued with a certain order quantity Q (see Figure 4) or with an amount of the difference to certain required order level. This check is done in a continuous way (see Figure 5).

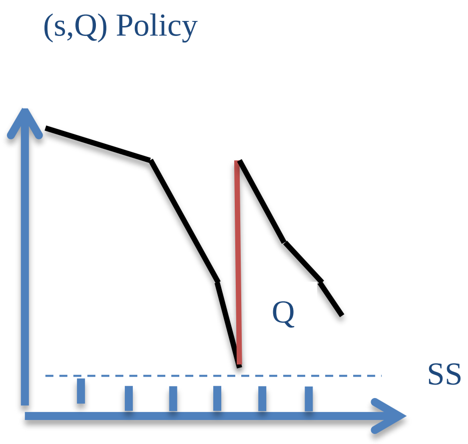

Figure 4. Order Point System (s,Q) Policy
Based on: (Bijvank, 2009)

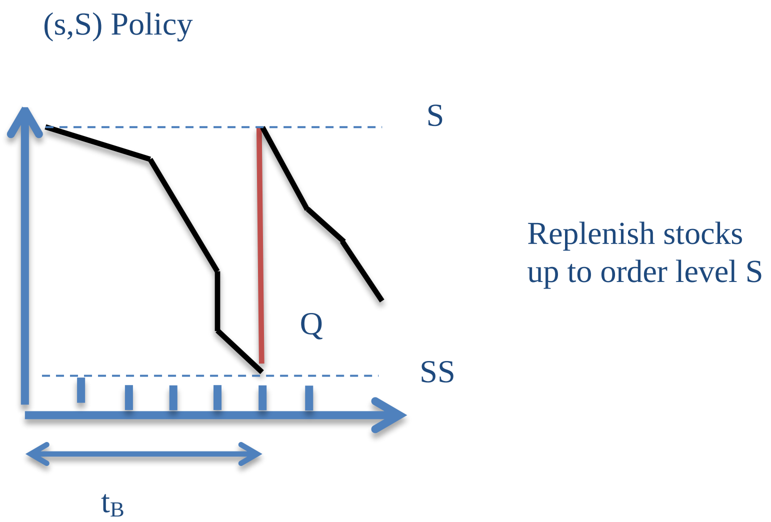

Figure 5. Order Point System (s,S) Policy
Based on: (Bijvank, 2009)

2.2.1.3. Control Rhythm System

This Control System is similar to order point with the difference that a verification is done only every certain fixed periods T (see Figure 6 and Figure 7).

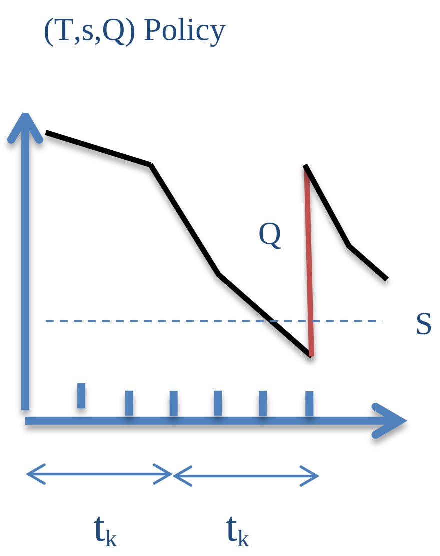

Figure 6. Control Rhytm System (T,s,Q) Policy
Source: (Bijvank, 2009)

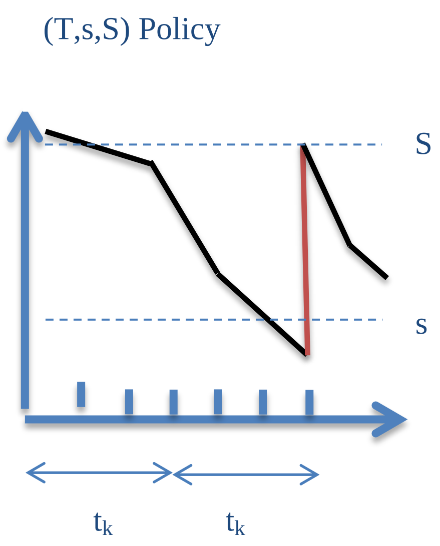

Figure 7. Control Rhytm System (T,s,S) Policy
Based on: (Bijvank, 2009)

2.2.2. Inventory management in Spare Parts Supply Chains

Inventory management in Spare Parts SCs is quite different than Inventory management in Classical SCs. In order to analyze these differences, important facts of a Spare Parts SC are presented in the following list.

- Demand for spare parts depends on the output of preventive and predictive maintenance activities (consumption predictions) and considers both the cost of lack and the cost of stock of a part due to the intermittent characteristic of the demand.

- The existence of part alternates and common parts makes inventory management more complex, having consumable and repairable items.

- Inventory Stock levels should be directly linked to costs of system failure or “down time”
- Work with vendors for cost-reduction and in-stock improvement (spare parts in consignment, pay only for parts consumed).

Some important characteristics of both types of Supply Chains are shown in Table 1. One of the characteristics that will influence inventory management and which is useful for the scope of this paper is the Demand. In both SC we can forecast the demand using different techniques. In one hand in a Classical SC the demand can be determined by simply analizing the flow of materials or the consumption in the market. In the other hand in Spare Parts SCs the demand is determined by consumption rates but also by the fact that a breakdown could lead to major losses and diminish the profits of the business(Callegaro, 2010).

Another characteristic which is worth mentioning are products, in a Classical SC products are used for production and sales. This type of products are classified as raw materials or final products and are clustered as high, medium and low value (Softwork, 2010). While in Spare Parts SCs products are used for Equipment Support, Maintenance and Repair Operations. These products are classified as repairable and non-repairable and are clustered by criticality as Vital, Essential and Desirable (Syntetos, Keyes, & Babai, 2009).

Table 1. Characteristics of a Classical and a Spare Parts Supply Chain.

Characteristic	Classical Supply Chain	Spare Parts Supply Chain
Use	Availability of products for sales and production	Equipment Support, Maintenance Repair and Operations (MRO)
Importance	Reduce Costs, Increase Sales	Ensure minimum down time and remain operational despite flaws
Demand	Forecast Depends on consumption of products (Demand tends to be stable)	Forecast depends on the output of maintenance activities and considers cost of lack and cost of stock(Demand is intermittent)
Demand Techniques	Qualitative (Delphi Method, Market Survey) Quantitative (Time Series Forecast)	Single Exponential Smoothing, Binomial Method, Syntetos-Boylan Approximation, Box Jenkin Methods, Neural Network …
Type of Products	Raw Materials and Final Products	Repairable and Non-Repairable Spare Parts
Classification of Products	Paretos (High, medium and low values)	By Criticality (Vital, Essential, Desirable) or By Paretos

Consequences of Stock outs	Miss opportunities of maximizing profits and poor Customer Service	Stock out Costs can stop the production of a machinery and increase operating costs
Inventory	Single - Echelon, Multi – Echelon	Single - Echelon, Multi - Echelon

3. Single-echelon inventory strategies applied in spare parts supply chains

Inventory strategies can be classified into single-echelon and multi-echelon. The scope of this paper is to describe single-echelon inventory strategies; therefore just a brief introduction of multi-echelon inventory will be made.

3.1. Single-Echelon Inventory System

The word echelon describes each level in the SC. Single-Echelon inventory in the SC is equal to the sum of the inventory in all locations in the same level (Muckstadt, 2005), Figure 8 depicts an example of a single-echelon system.

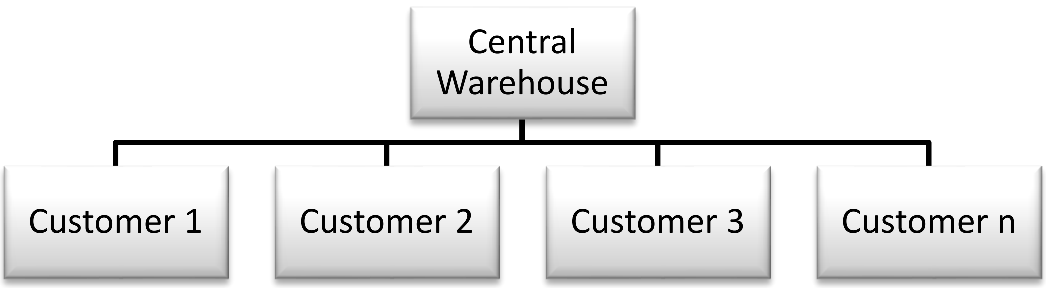

Figure 8. Single – Echelon System
Based On: (Ranga & Rama, 2007)

3.2. Multi-Echelon Inventory System

Similarly to single-echelon, a multi-echelon inventory system comprehends the local inventory at a level plus all the stock of products that have left the level or node and that have not reached the final customer, an example of a multi-echelon system is depicted in Figure 9, total inventory in this example is the sum of the inventory in the central warehouse plus the entire inventory available in the regional facilities (RF) that has not been delivered yet to the customer depicted in the figure with a “C”. In this figure there are not lateral shipments among the RF (Ranga & Rama, 2007).

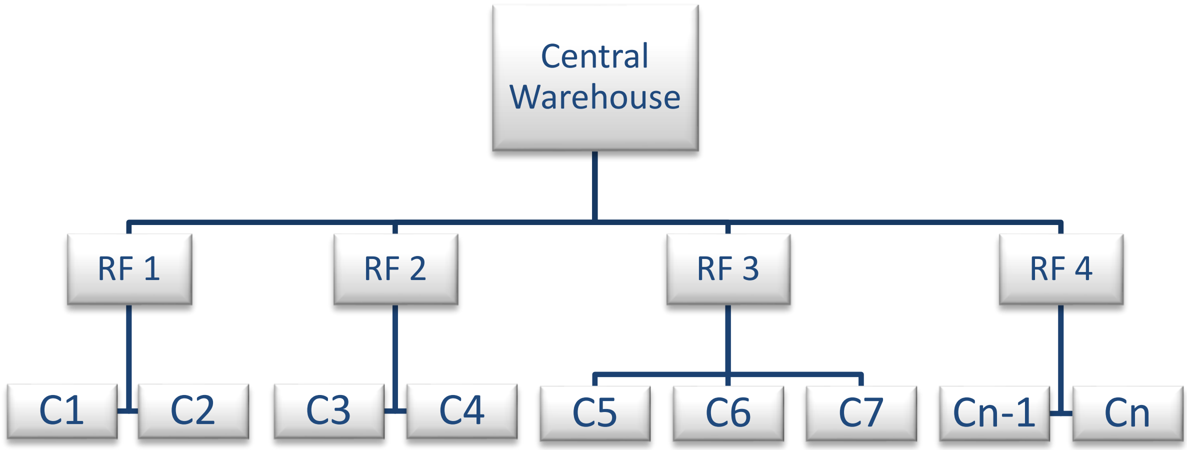

Figure 9. Multi – Echelon System
Based On: (Ranga & Rama, 2007)

3.3. Overview of spare parts inventory strategies and application

Seven single-echelon inventory strategies are presented in the following paragraphs, the purpose of this section is to characterize each strategy, determine the type of products that are applicable to each strategy and what are their requirements and application. The selected strategies are shown in Table 2; this table presents an overview of the strategies and shows which industry is using them and when it could be applicable. To have a better understanding of each of the strategies a brief description is presented afterwards.

Table 2 . Single-Echelon Inventory Strategies in Spare Parts Supply Chains

Strategy	Characteristics	Type of Products	Industry	Requirements	Application
Min - max (s,S) policy with service level constraint	Service level constraint by running 5 demand models.	Critical parts. High value items and consumable tools	Energy, Oil and Gas Sector	Production Equipment and SLA	Large companies with service level agreements
Base Stock	For each withdrawal of inventory an order is placed	Repairable and non-repairable items	Automotive and Industrial	Items with low demand	Companies with intermittent demand

Combined Forecast Inventory (s,Q) with control procedure	Order quantity Q placed, considering variable intervals and improved by simulation	Spare parts in for Machinery	Confectionery Producer	Highly Automated Machines	Companies with open storage and closed storage section
Critical Level Policy (c,s,Q), "c" denotes critical levels	Inventory reserved for high priority demand	Repairable items	Aircraft	Different demand and priorities for Customers	Companies with different levels of demand from their customers
Integrated Inventory and Transportation mode selection Policy (S-1,S)	Minimize the inventory and transport costs while ensuring that service constraints are met	Parts for Critical Equipment and Technically advanced systems	Health Care, Military, Industrial	Multi-facility, time-based service level constraints. Different transportation modes	Companies with service level agreements to their customers,
Partial Pooling with base stock control	Lateral transshipment between main warehouses	Multi item, expensive capital goods	Equipment Manufacturer in Semiconductor Supplier Industry	Multi-location, base stock and aggregate mean waiting time constraints	Companies that design, build parts with multiple warehouses
Cycle Time Reduction with (S-1, S) Policy using models	Reduce production cycle times to meet short lead times	Expensive and Critically important items	Manufacture	Multi item, multi machine	Manufacture firms

3.3.1. Min - max (s,S) Policy with service level constraints

This strategy is studied in a large energy company by paper (Guajardo, Rönnqvist, & Halvorsen, 2012). The inventory in place corresponds to a min-max strategie (s,S) with control parameters decided based on expert judgement. The strategy presented in the paper shows methods on how to establish the parameters by using different demand models for different service level agreements (SLA) in different locations. Its application is in large companies (Energy, Oil and Gas Sector) with service level constraints that use high value and critical spare parts and that have differents locations to hold inventory; each with different control parameters and constraints.

3.3.2. Base Stock

The paper by (Rego & Mesquita, 2011) describes classical inventory policies used in Classical SCs and also describes Base Stock as one of the most used strategies for spare parts inventory management. The strategy works in the following way: for each withdrawal of inventory an order of the same amount is placed. This strategy is suitable for items with low demand including spare parts. Base Stock can be used for both repairable and non repairable items. Their application can be in industries with intermittent demand particularly in the Automotive and Industrial sector.

3.3.3. Combined Forecast Inventory (s,Q) with control procedure

This strategy is studied by (Heuts, Strijbosch, & van der Shoot, 1999) in a company that has two sections for storing inventory. An open section for not expensive parts and a closed section for expensive and critical parts with low demand. In both sections the control parameters for the (s,Q) policy can be set by experience. The main difference of managing the inventories is that in open inventories transactions are not registered while in the close section they are. In this paper an analysis of different control procedures is made by using simulations to determine the best values for control parameters.

3.3.4. Critical Level Policy (c,s,Q)

(Kleijn & Dekker, 1998) discussed in their paper the critical level policy for inventory management. This strategy analyzes companies in which the demand is classified into different levels of priority and in which their customers have higher stock out costs or require minimum service levels than others. The main idea of this strategy is that some inventory is reserved for high priority demand using the (c,s,Q) system, in which "c" denotes critical levels. Products within this strategy are rotable or repairable products. The main application of this strategy is in companies that have different levels of demand from different customers an example of this could be the Aircraft Industry.

3.3.5. Integrated Inventory and Transportation mode selection Policy (S-1,S)

(Kutanoglu & Lohiya, 2008) considered Integrated Inventory with transportation mode selection in their paper and presented a multi-facility service part system that minimizes inventory and transportation costs while ensuring that service constraints are met. The model used in this study is based on a Base Stock stochastic model. The tradeoff between saving costs using slower transportation modes and responsiveness achieved using faster modes is analyzed. This strategy can be applied to critical equipments and technically advanced systems in companies with different stock facilities that offer service level agreements to their customers. The demand in this strategy is satisfied directly from stock from facilities or emergency shipments from the central warehouse. Exemplary industries that may use this strategy are Health Care and Military.

3.3.6. Partial Pooling with base stock control

This strategy is presented by (Kranenburg & van Houtum, 2009), the main idea of this strategy is to use lateral transhipments between warehouses when stock can not be supplied by one specific location. This strategy is applicable in companies where the opportunity cost in case of lost production when an equipment is down is very high and where SLA have to be met. This strategy will be explained in detail in section 3.2 to show the benefits of using.

3.3.7. Cycle Time Reduction (S-1, S) Policy and models that predict average cycle times.

In this paper (Schultz, 2004) describes the benefits of reducing the production cycle times to meet short lead times by maintaining an inventory of spare part components. This strategy is suitable when dealing with multiple spare parts, expensive capital goods and waiting time constraints. Cycle Time Reduction is applicable in manufacturing firms that want to reduce machine downtime and support a bottleneck or capacity constrained workstation without excesive inventories.

3.4. Partial Pooling with base stock control a detailed analysis

This analysis shows the reader advantages of using pooling in inventory management for single-echelon scenarios. The analysis builds on “A new partial pooling structure for spare parts networks” of (Kranenburg & van Houtum, 2009)

This strategy requires a multi-item, multi-location, single-echelon system with base stock control and aggregate mean waiting time constraints. There are two types of warehouses in this scenario: main and regular local warehouses. Lateral transshipment is made only from main warehouses as shown in Figure 10. An advantage of this setting is that only a limited number of warehouses have to be equipped to fulfil this capability. An evaluation method is used for the base stock level determination. The strategy in the paper shows how to manage inventory with lateral transhipments when a demand occurs in a warehouse that is out of stock.

There is not inventory kept in the production sites, but the warehouses are in close distance to the customer. If a customer needs a spare part it will be delivered from the local warehouse. The stock in local warehouses is replenished from the central warehouse which takes 2 weeks of replenishment. If a customer wants a spare part that is not available from the local warehouse it would take too long to wait for the part. Therefore an emergency delivery can be done that will take 48 hours, which is still long to fulfill the waiting time expected of few hours. A better option to handle this issue is lateral transshipment between warehouses that are located in the same region. This will take from 10 to 20 hours which improves the waiting time. The network for this strategy consists in local warehouses that are close to airports with many flights in order to achieve the expected delivery times.

The evaluation method used is based on the following idea: Divide the network into local warehouses, and then assume that the demand in main local warehouses due to requests for lateral transshipment is variable. Therefore each warehouse can be analysed independently, and an iterative algorithm is needed to determine the demand rates for lateral transshipment. The method presented in the paper shows to be accurate and fast.

(Kranenburg & van Houtum, 2009) show that only a few warehouses can be chosen to provide lateral transshipment in order to obtain a major part of the full pooling benefits. Figure 10 illustrates the network structure with main and regular local warehouses.

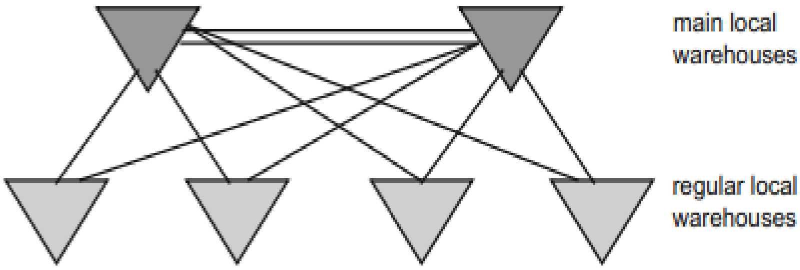

Figure 10. Pooling structure with main and regular warehouses
Source: (Kranenburg & van Houtum, 2009)

Model Description

The model is based on multiple machines with multiple items (or Stock Keeping Units SKU) at the side of the customer. The Machines can have an outage derived from a defective item. This defective item has to be replaced by a new SKU. Demand is assumed to follow a Poisson process. A Poisson process is a stochastic process for modelling the time of arrivals in a system. Arrivals in this process occur at arbitrary positive times (Daniel, 2008).

OEM has to meet a target mean aggregate demand per group and a waiting time constraint per group. Two types of local warehouses are presented: main local warehouses and regional local warehouses. Only mains can be suppliers of a lateral transhipment. If a group needs a spare part it will submit the request to their local warehouse and it will be provided immediately if the part is available, the waiting time and cost for this transaction is zero. If the local warehouse does not have stock it tries to obtain the stock from the other main local warehouses via lateral transshipment. This movement of inventory has a corresponding transportation time and cost

Each regional warehouse has a main warehouse. This main warehouse is checked first and then all the other main warehouses in a sequential order are checked until one has stock in hand to proceed to deliver the desired part via lateral transhipment. If neither the local warehouse nor one of the main warehouses has stock at hand and emergency replenishment from a central warehouse can be made.

The stock in all warehouses is controlled with a base stock policy. The base stock levels for SKU's is denoted independently. Once a part is needed to satisfy demand, a new part is requested from the central warehouse, no cost is involved for transportation and replenishment lead times are assumed to be exponentially distributed. An assumption is made in the paper that transportation cost and transportation time does not differ.

The objective of the OEM is to minimize the expected cost for all SKU's under the condition that expected waiting time for a request for each group does not exceed the target total waiting time. Since the expected waiting time for an arbitrary request from a group is a demand-weighted average of the expected waiting times of all SKU-s at local warehouses.

An approximate evaluation method for evaluating a base stock policy is introduced in the paper which proves to be more efficient than an exact evaluation method when the number of warehouses is large. The method starts by decoupling the network into existing warehouses; first it decouples the regular from the mains and then the mains. Then an assumption is made that extra demand processes due to requests for lateral transhipment are Poisson processes. At the end of the model (Kranenburg & van Houtum, 2009) prove the efficiency of the method and show that only a few warehouses selected for lateral transshipment is needed to obtain most of the pooling benefits.

3.5. Case Example

A case study was performed with data obtained from the company ASML, an original equipment manufacturer (OEM) in the semiconductor supplier industry. This data set constitutes data for 19 local warehouses in the United States of America. The evaluation method presented in the paper is used to show potential savings of pooling spare parts inventory at ASML (Kranenburg & van Houtum, 2009) .

The data set is described first and then the total cost is compared for cases with different numbers of mains. At the end an analysis is made for the savings compared to the old system at ASML.

The data set comprehends 1451 SKU-s, 27 groups. In the case study each of the 19 local warehouses serves one or two groups. At local warehouses that serve two groups, there is some SKU-s in common. For each of the groups the target waiting time is set equal to 0.15 days and the demand rates are low.

In the ASML data set, four local warehouses are identified by ASML as candidates to be mains. To compare the total yearly cost at different numbers of main local warehouses, the case study analyses 0, 4, and 19 main local warehouses | K |. When 19 warehouses are studied there is an assumption that 4 warehouses are mains and the others are locals. Results are shown in table 3.

Table 3. Results for the case study ASML in different main local warehouses | K |

|K|	Total yearly cost (normalized)	Cost savings compared to no pooling (%)	Computation time (seconds)
0	100		71
4	51.82	49.18	57
9	49.81	50.19	132

In a no pooling situation the normalized total yearly cost is 100. Table 3 shows that in the full pooling case with 19 main local warehouses more than 50% of cost can be saved. In the partial pooling with four mains the potential savings can be 49.81%. It can be observed that the saving with more warehouses compared to the 4 warehouses situation is very small. In table 4 a comparison is made between the old and the new system with 4 main local warehouses | K |. The saving in yearly costs are 31.49%.

Table 4. Results for case study at ASML. Comparison between old and new model at | K | = 4

Model	Target waiting tim in days (avg)	Realized waiting time in days (avg.)	Total yearly cost (normalized)
Old Model	0.1500	0.1007	100
New Model	0.1007	0.0975	68.51

4. Conclusion

The chosen strategy in spare parts inventory management for a particular company depends in a big extent in the type of industry, the demand, the service level constraints and the type of spare part that is needed for the machinery. Therefore the selection of a good Inventory strategy can support companies to ensure premium service levels and customer satisfaction while at the same time increase their profit and revenue.

Inventory Management has to be managed in a different way in Spare Parts SC than classical SC. The most important difference is that the forecast of demand in a classical SC depends on product consumption while in a spare parts SC depends on the output of maintenance activities and considers the cost of lack and the cost of stock due to the intermittence of the demand.

In this paper different strategies for single-echelon spare parts SC have been presented, and a detailed analysis has been made of Partial Pooling strategy. This strategy has demonstrated that can improve the management of the spare parts inventories using lateral transshipments between few selected warehouses. This setting allows gaining a major part of the full pooling benefits.

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