Maintenance spare parts logistics: Special characteristics and strategic choices

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Abstract

The diversity of the operational control characteristics of spare parts is taken as a basis for supporting the planning and designing of a spare parts logistics system. Four control characteristics of maintenance spare parts – criticality, specificity, demand pattern, and value of parts – are discussed in terms of their effects on logistics system elements – network structure, positioning of materials, responsibility of control, and control principles. Distinct operating policies for different types of parts in the spare parts supply chain are illustrated. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

The requirements for planning the logistics of spare parts differ from those of other materials in several ways: service requirements are higher as the effects of stockouts may be financially remarkable, the demand for parts may be extremely sporadic and difficult to forecast, and the prices of individual parts may be very high. On the other hand, material and time buffers in production systems and supply chains are decreasing. These characteristics set pressures for streamlining the logistic systems of spare parts.

With such high requirements of material flow, it is natural that spare parts management is an important area of inventory research. Besides a few spares management publications (e.g. [1–5]), spare part research has mostly focused on inventory modelling. During the past decades inventory research has produced a vast amount of theory for modelling different inventory control situations (for state-of-the-art and bibliography see e.g. [6]). The most basic inventory theory and models (such as EOQ, ROP, ABC-analysis, MRP) have been widely applied, in practice, but there is relatively little evidence of the use of more sophisticated applications, such as multi-echelon models. The inventory management practice of spare parts has mostly relied on the basic theories, too [7]. In practice, spare part inventories are often managed by applying general inventory management principles, if any, and not enough attention is paid to control characteristics specific to spare parts only. Furthermore, the control is usually focused on local inventories and not so much on the supply chain as a whole.

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From logistics point of view, even the most sophisticated models have been limited to optimizing the inventories within often very strict assumptions. When these assumptions are relaxed to increase the realism of the models, the complexity of the models increases even faster and makes it difficult for the practitioners to understand and apply them.

The approach chosen in this paper includes two choices. First, supply chain aspects, that is the boundary-spanning role of logistics, are emphasized rather than merely intra-organizational issues. Second, the discussion is directed towards practitioners’ purposes rather than formal analysis or modelling. With these choices, a qualitative approach is chosen to facilitate the wider perspective of analysis needed to incorporate the effects of the actions of different parties in the spare part supply chain. The main objective of this paper is to improve the decision-maker’s understanding of the control requirements of different types of spare parts, and the logistics development opportunities related to them. This is done by studying the effects of various operational control characteristics of spare parts on the logistics system design. Both the user’s and the supplier’s aspects are taken into consideration.

The paper is organized as follows. In the following section, a brief review on the approaches in earlier spare part logistics research is given. Then supply chain aspects related to spare parts management are discussed. The special characteristics of spare parts are analyzed with respect to their requirements for logistics system design and control. Finally, distinct development actions are designed for different control situations using the maintenance of a paper and pulp mill as an illustrative case setting.

2. Research approaches in spare part logistics

The relevant areas of research regarding spare part logistics would, in broad terms, include several different topics, such as maintenance and reliability, production and inventory control, supply chain management, and some strategic management aspects, as well. However, it is beyond the scope of this paper to review all these areas. In the following, we briefly review the research which will be most relevant for our theme.

Spare part logistics research is mostly related to inventory management research. Spare part inventory management is often considered as a special case of general inventory management with some special characteristics, such as very low demand volumes. The principal objective of any inventory management system is to achieve sufficient service level with minimum inventory investment and administrative costs. For this purpose and for numerous specific operational conditions, a vast number of inventory models have been developed during the past decades (see e.g. [6]). Though our purpose is not to discuss all this research here, it is worthwhile to note the increasing interest in research concerning multiechelon inventory systems (e.g. [8]), which are particularly relevant in the supply chain setting and for spare parts management, too.

Mathematical models are usually aimed at optimizing the problem of inventory investment and service levels, while considerations of administrative efficiency have led to different types of classifications of inventory items. While efficient computers make ever more prominent modelling possible, we still have to choose control parameters, allocate control resources, make purchasing decisions, and think about different policies for different types of items. For this purpose, item classification is as important as ever. As this classification approach is relevant for our later discussion about examining the supply chain aspects, a brief literature review is provided here.

The most well known, and perhaps the most commonly used classification scheme in logistics is the ABC-classification according to the Pareto-principle. It is easy to use, and serves well the inventory management of materials that are fairly homogenous in nature and differ from each other mainly by unit price and demand volume. Therefore, ABC-analysis has retained its popularity among the practitioners in directing the control efforts and choosing the sufficient-enough control parameters without the need of item-specific analysis. However, as the variety of control characteristics of items increases, the one-dimensional ABC-classification does not discriminate all the control requirements of different types of items. In
an application of physical distribution, e.g., Fuller et al. [9] have used a six-factor classification of materials to create distinct groups of products in order to differentiate distribution operations.

Using several criteria as a basis for classification is especially useful for spare parts that do possess several distinctive characteristics other than price and demand volume. This has led researchers to suggest different types of multi-dimensional classifications for spare part inventory management. Duchessi et al. [10] used a two-dimensional classification scheme combining inventory cost and part criticality as criteria. Flores and Whybark [11] also used multiple criteria classification in maintenance inventory control. Cohen and Ernst [12] introduced a general grouping method that can be used to define group-based operational control policies. Petrovic et al. [13] designed an expert system model for advising on spare part inventory control. The heuristic decision rules used in the model were based on several operational characteristics of spare parts: availability of required system, essentiality, price, weight, and volume of the part, availability of spares in the market, and efficiency of repair. Gajpal et al. [14] elaborated the criticality analysis of spare parts by using the analytic hierarchy process (AHP) for classifying the spare parts.

Our purpose is not to create another new classification scheme as a management tool, but to analyze the different development requirements and opportunities for the logistics management of a large variety of maintenance spare parts. For this purpose, it is necessary to analyze the different control characteristics of spare parts and categorize the control situations with similar development strategies. As the problems are discussed in the supply chain setting, special attention is paid on the user–supplier interface.

3. Supply chain considerations

The process of a logistics system design cannot, of course, be done in isolation, without taking into account the numerous links with the other processes of a company or, indeed, with the other parties in the supply chain (e.g. [15]). For the purpose of this paper we, however, only discuss some aspects of logistics system design without going into the higher levels of strategic planning.

There are several possible ways of describing the logistics system design process, and different approaches may be used, depending on the emphasis and the purposes of the study (see e.g. [16]). One rather simple and general approach is used here to provide the basis for discussion in this particular study. Fig. 1 illustrates what can be considered as the basic constituting elements of any logistics system study.

The four elements – strategy/policies/processes, structure, relationships, and coordination/control – have to be considered during the analysis, and decisions about them have to be made as a result of planning. Traditionally, customers’ and suppliers’ views of the desirable logistics system have been very different. However, the logistics system’s role as a link between the parties in the supply chain emphasizes the need of collaborative planning. Hence we should be able to use the same framework for studying both the customer’s and the supplier’s requirements for the system. For this reason a very general framework is used here.

From the supplier’s point of view the strategy/policies/processes element describes e.g. what levels of service are to be offered, and whether customers are segmented and prioritized in terms of service. For example, promising deliveries within 24 hours or providing emergency services could be considered. Hence, the question is about the role of...
the distribution system to support the possible strategies, such as differentiation of service to each customer segment.

The customer’s (i.e. part user’s) main concern in maintenance is assured availability of parts and the quality service with reasonable costs. This includes the processes of comparing and selecting the supplier(s) and deciding on the supply strategies.

The network structure – element defines the number of inventory echelons and locations used in the system. Structural issues are typically considered only by one party of the chain (usually the supplier, or a third party service provider). However, as the locations concerned may be owned, managed or controlled by either the customer or the supplier, a collaborative planning of their use should be done. For example, management practices such as vendor managed inventory (VMI) or just-in-time II (JIT II) are based on co-operative use of the other party’s facilities and/or other resources. The decision of parts deployment in the network is closely connected to the structure itself, and they should be considered together.

Management of relationships between the parties in the supply chain is becoming a more and more important aspect of supply chain planning. It considers such aspects as degree of co-operation, responsibility of control, as well as sharing the risks between the parties. Instead of distant arm’s length relations, a variety of cooperative relationships can be employed (e.g. [17]).

Finally, all the three elements have an effect on what types of coordination and control mechanisms would best support the ultimate objectives of the logistics system. The coordination/control – element includes decisions about inventory control principles, performance measurement and incentive systems, and also information systems used to implement the control procedures. For example, it is well known that in multiechelon inventory systems, information should be made readily available to the upstream parties of the chain. Furthermore, control and coordination in inter-organizational setting need not always be based on hard formal systems, but are often achieved by “soft” means through trust and commitment between the parties.

From what has been said, a few points are worth emphasizing. The elements discussed are strongly interrelated with each other and should be considered simultaneously in strategic logistics planning. Collaboration between the customer and the supplier (and possible other parties) is needed while designing the system, and the importance of open information sharing is crucial for managing the inter-company supply chain effectively.

There are several factors that affect the outcome of the logistics system design. For example, in a distribution system study of exhaust pipes de Leeuw [18] used product, process, and market characteristics as inputs for system design. In general terms, while designing a logistics system, usually, at least the following factors have to be considered: product-specific characteristics, competitive situation in the market, customers’ special requirements, and supplier’s resources and commitments. In this paper we mainly study the effects of product-specific characteristics of maintenance spare parts on logistics system design. This is done by analyzing generic operational characteristics of spare parts in terms of their effect on service strategy and related policies, supply/delivery structure, supply chain relationships and inventory control systems. These observations have to be supplemented by context-specific information when applied to a real-life planning situation.

4. Operational control characteristics of maintenance spare parts

As discussed above, the need for more specific categorization of items originates in their more varied control requirements, that is, their different effects on the characteristics of the logistics system. In the following, based on our expression of the general elements of logistics system design (Fig. 1), a logistics system of spare parts is characterized with respect to the following elements: network structure of inventories in the supply chain, positioning of materials in this network, responsibility of control in the system, and control principles used for managing the materials flow (Fig. 2).

To find out the most relevant control characteristics, we have to analyze the effects of different
control characteristics on the different elements in the supply system, and find the most distinctive features between the items. Then, we can design the operating policies for the relevant combinations of control characteristics. To keep the development work manageable, the number of item categories is reduced to the most relevant ones. We shall start by analyzing the most relevant control characteristics: criticality, specificity, demand and value.

The criticality of an item is probably the first feature that is pronounced by the spare part logistics practitioners, while enquired about specific item characteristics. The criticality of a part is related to the consequences caused by the failure of a part on the process in case a replacement is not readily available, and hence it could be called as process criticality. The impact of a shortage of a critical part may be a multiple of its commercial value, which makes e.g. an ordinary ABC-analysis an insufficient control tool. There is a substantive amount of subjective criteria used in assessing the criticality of parts in practice ([7]). Theoretically, it can be evaluated by the downtime costs of the process, although it is often very difficult to determine in practice. However, an exact determination is not needed, as for practical purposes it is sufficient to determine a few degrees of criticality (see e.g. [1]). One practical approach is to relate the criticality to the time in which the failure has to be corrected. For example, three degrees of process criticality could be determined on this basis: (1) The failure has to be corrected and the spares should be supplied immediately, (2) The failure can be tolerated with temporary arrangements for a short period of time, during which the spare can be supplied, (3) The failure is not critical for the process, and can be corrected and spares can be supplied after a longer period of time. Using time dimension as a measure of criticality makes it easier to consider control systems, e.g. choosing between material and time buffers to control the system. It also provides both the user and the supplier with a common means for setting the objectives and for controlling the performance of operations.

The other aspects of criticality are not related to the consequences of a failure and shortage, but rather to the possibilities to control the situation, and hence they could be called control criticality. These include predictability of failure, availability of spare part suppliers, lead-times, etc. They can be taken into account in the analysis when found to be of exceptional importance in a particular control situation.

From the logistics control point of view, it is most essential to know how much time there is to react to the demand need, that is, whether the need is immediate or whether there is some time to operate. This dichotomy dictates the positioning of stock, that is, whether to use a time buffer or a material buffer against variations in demand. In case of immediate need e.g. local safety stocks are usually the only way of provisioning, but with more time to operate a centralized structure with direct deliveries also becomes an option. Hence, process criticality is a very strong factor in classifying the control situations of spare parts.

The specificity of a part is another control characteristic specific to maintenance spare parts. Among the wide spectrum of maintenance spare parts there are typically both standard parts, which are widely used by many users and hence also readily available from several suppliers, and a certain amount of parts specifically tailored for and used by a particular user only. For standard parts the availability is usually good, there are stocks of these parts at different levels of the supply chain, and the suppliers are willing to cooperate with the users, as the volumes are high and offer economies of scale. For the user-specific parts quite the opposite is true: suppliers are unwilling to stock the special, low volume parts and the responsibility of availability and control remains with the user himself.

The demand pattern of parts includes the aspects of volume and predictability. Volume of demand as
a control characteristic is related to the economies of scale of operations, and is common to all materials in the logistics chain. What is special to spare parts is that among them there is typically a large amount of parts with very low and irregular demand. This feature makes the control more difficult and combined with other characteristics – e.g. high criticality and high price – it lends itself to increase the amount of safety stocks needed to cover unpredictable situations. Furthermore, low volumes as such do not attract suppliers to offer any special services, but the responsibility of control may remain mainly with the end-user. This is, however, in contrast to the logistics theories, which say that low volume items should be held back in the chain, that is, they should be more centrally located.

Predictability of demand is related to the failure process of a part and the possibilities to estimate failure patterns and rates by statistical means. From a control point of view, it is useful to divide the parts in terms of predictability into at least two categories: parts with random failures and parts with a predictable wearing pattern. The predictability of demand has an effect on the choice of the control principle between provisioning and time-phased service and maintenance. Especially, postponing the movement of stocks to the downstream locations makes it possible to consolidate the demand and reduce its variability.

The value of a part is a common control characteristic to all materials, and high value makes stocking a non-attractive solution for any party in the logistics chain. High value forces the different parties in the chain to seek solutions other than stock holding. However, if it is not a question of a make-to-order item, stocks have to be held and then it is a complicated matter of objectives, negotiation power and cooperation of the parties in the supply chain and also an issue of incentives, how the supplies are organized. On the other hand, with low price items, the replenishment arrangements have to be efficient so that the administrative costs do not increase unreasonably in proportion to the value of the items themselves. In general, a high value of a part favors positioning materials backward in the supply chain.

5. Strategies for developing maintenance spare part logistics

As described above, there are several criteria according to which different control situations may arise, and combining them all would produce an unmanageable amount of different classes of items. This would not serve the original purpose of the analysis, which is to clarify the different control requirements and reveal the development opportunities related to them. Therefore, in the following we will discuss the most important combinations of control characteristics which offer the most distinctive and practical opportunities for development actions. As an example for implementing the outcomes of this analysis in real life situations, the maintenance parts of a paper and pulp mill are used to illustrate different control situations and the development strategies related to them.

From the criteria discussed above, the criticality and specificity of parts are dichotomous by nature. Therefore, they are suggested to have only two possible outcomes each. With respect to criticality, parts are either highly critical or of medium criticality. High criticality means operationally that their need in case of failure is immediate, and parts of medium criticality allow some lead time to correct the failure. The parts of lower criticality, that is, having no specific time restrictions for corrective operations in case of failure, have been left out of the examination. They do not need any specific attention, but can be controlled by “standard” logistics methods. In terms of specificity, parts are classified either as standard or user-specific.

The other two criteria, i.e. the demand volume and value of parts, are considered to be more continuous by nature and their effects are handled within the categories determined by criticality and specificity. Although continuous, volume and value are also referred to by discrete expressions, such as low and high, in this qualitative discussion.

Considering parts of high specificity, these special parts are usually ordered by the make-to-order principle, and therefore the leadtimes for them are lengthy. Furthermore, their prices tend to be relatively high and volumes low and sporadic. As an illustrative case, in a paper and pulp mill, gears belong to this category. In these conditions
suppliers are not willing to hold any stocks for the special purposes of one user only. Therefore, the basic alternatives for the user are either to accept the stockout situation or to rely on own safety stocking, even though this incurs considerable inventory holding costs. Safety stocking becomes necessary for all the parts for which leadtimes are longer than the time to tolerate a stockout situation in case of failure.

In this control situation, the main goal for development is to find a solution that would reduce leadtimes and make replenishment more dependable. A possible development strategy is to search for a reliable supplier who could specialize in fabricating the special parts for the user. By having drawings and tools available for the user’s purposes, the supplier could fabricate and deliver the special parts with shorter leadtimes when necessary, and could give some priorities for the orders of the volume customer. This would decrease the user’s need for holding expensive safety stocks. This kind of subcontracting partnership may develop in a supply chain between a bigger user company and a smaller local machine shop, which would get a considerably large part of its orders from this one company.

The situation concerning standard parts is different. This business is more attractive to suppliers and third-party companies, and therefore there are usually several suppliers and users for those parts meaning that availability is better, and leadtimes shorter. As compared with special parts there are more strategic options available for developing the logistics process. In case of standard parts, different logistics control situations arise with regard to the criticality of the parts for the process (that is, time to tolerate the stockout situation in case of failure). For high criticality parts (an immediate need in our terminology) the user must typically hold a small local safety stock to guarantee the availability. However, as the parts are more or less standard, i.e. used by several other customers, suppliers are more ready to hold stocks, and offer special services, such as 24-hour or faster deliveries, to gain customers. This time-guaranteed delivery is an alternative strategy in this control situation, which can considerably reduce the user’s need for holding safety stocks even if the criticality is high. This strategy can be implemented typically by using a specialized spare part service company that has well established procedures and reputation to guarantee the service needed. It is especially tempting for high value parts with a low and irregular demand pattern. In the paper and pulp mill case, powerful electric motors could be this kind of parts.

In case of extremely low volume parts, another strategy may be more feasible. When there are a few relatively closely located users of a high-value part, a cooperative stocking pool can be created which holds the necessary safety stock (maybe one unit) in one user’s premises for common purposes. With this arrangement, sporadic demands of individual users are consolidated into more smooth one and the holding of safety stock is more justified. To be operative, such a practice needs fast and reliable means for transmitting information. For this kind of virtually centralized, but physically decentralized inventory holding, internet-based applications provide viable solutions. For example, paper manufacturing industry in Finland has started using internet-based systems for running cooperative, regional stock pools for low volume and high value parts. For low value parts, provisioning with own safety stocks may prove more desirable as they do not tie capital significantly.

In case of parts of only medium criticality (time to operate in our terminology), the user’s need for holding local stocks for provisioning purposes is reduced. Hence, the criterion becomes one of economic efficiency of replenishment operations in the supply chain. This brings about an option of pushing all the user’s stock backward in the chain to the supplier or service provider. This strategy is based on economies of the scale achieved in consolidation of low volumes in the supply chain, and postponing the replenishments of high value items until needed. Therefore, for a user, this strategy is especially tempting with the high value and low volume parts. For example in a paper and pulp mill, equipment for wastewater and wood chips belong to this category.

As the value of parts becomes lower, the need for simple replenishment practices is emphasized. Because the capital committed is not significant as a whole, replenishment lots can be relatively big. Orders can be automatically generated by a computer, based on pre-determined order signals.
Table 1
Categorization of control situations and respective strategies/policies

<table>
<thead>
<tr>
<th>Criticality</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard parts Value</td>
<td>Order processing simplified e.g. by automated orders or Outsourcing of inventory control to a supplier</td>
<td>User's decentralized safety stocks and generous replenishment lot-sizes</td>
</tr>
<tr>
<td>High</td>
<td>Stock pushed back to the supplier</td>
<td>Optimized user's safety stock (with high and smooth demand) Time-guaranteed supplies from established service company (for lower and irregular demand) Several users' co-operative stock pools (for very low demand)</td>
</tr>
<tr>
<td>User-specific parts</td>
<td>User's own safety stock + partnership with local supplier to shorten leadtimes, to increase dependability and get priorities in emergency situations. In the long run, standardization of parts when possible.</td>
<td></td>
</tr>
</tbody>
</table>

In some situations, a supplier may take the responsibility of controlling the whole process of replenishments (e.g. VMI, vendor managed inventory practices).

The categories of distinct control situations and the related strategies and policies that could be used in a paper and pulp mill case setting are summarized in Table 1.

The above-mentioned development strategies serve as guidelines in the defined control situations and have to be adjusted to the special conditions of a particular case in question. In the long run continuous development efforts have to be made to decrease the specificity and criticality of parts, and to intensify coordination in the supply chain to decrease the need for excessive local safety stocks.

As guidelines for implementing the presented approach in real life situations, the following points are emphasized:

- The interconnectedness of the basic elements in a logistics system (as presented in Fig. 1 and discussed in Section 3) should be understood and addressed explicitly to achieve a proper supply chain approach in the planning.
- A few most relevant control characteristics of the parts should be selected, and their effects on the relevant logistics system elements analyzed (as presented in Fig. 2 and discussed in Sections 4 and 5).
- As an outcome, while taking into consideration the situation-specific conditions, a few distinct categories of control situations should be formed, and related strategies and operational policies for them derived (as discussed in Section 5 and summarized in Table 1).
- Continuous efforts should be made to release the most restrictive characteristics of the system (e.g. criticality and specificity of parts, old-fashioned information systems, undeveloped cooperation relationships, etc.) and adjusting the strategies, policies and processes to correspond with the changed conditions.

6. Concluding remarks

The advances in inventory research have made it possible to take more realistic assumptions into consideration in inventory modelling. However, surveys have shown that it has not been easy to transfer these results into managerial practice. Even though the complications of models have been hidden in the computer software, most managers...
do not feel comfortable if they do not understand on what the specific results of models are based. This may be one important reason why different rules-of-thumbs are so popular in managerial practice. The qualitative approach chosen here relates to this practice and has tried to increase the understanding of the problem situation rather than the specific solutions given.

This paper addressed the question of managing spare part logistics by discussing the basic principles affecting the strategic choices and related policies in this area. While some specific observations were made in terms of the illustrative case context, the main objective was to emphasize the need of differentiating the policies between different types of spare parts as well as revealing the links between the part characteristics and logistics system elements. Another objective was to emphasize the need to include the aspects of the whole supply chain in the analysis and to increase the collaboration between the parties at planning stages.

References