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Managing the after-sales logistic network – a simulation study

Fredrik Persson[a]* and Nicola Saccani[b]

[a]*Department of Science and Technology, Linköping University, Norrköping, Sweden;* [b]*Service Management Research Centre – Department of Mechanical and Industrial Engineering, Università degli Studi di Brescia, Brescia, Italy*

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The after-sales business has in recent years acquired a strategic role for firms manufacturing durable or capital goods, as it represents a source of revenue, profit and a means to achieve customer satisfaction and retention. The case study analysed in this article concerns a world player of heavy equipment based in Europe. This article analyses the spare parts classification method adopted by the company, and the allocation decisions concerning a second European warehouse and the transfer to that warehouse of a set of suppliers. A simulation model has been developed in order to support these choices. This study suggests that the support of quantitative methods such as spare part classification models and the use of simulation may be of great help to practitioners, in order to focus their effort on what really matters, to adopt cost-effective decisions and to assess the robustness of their decisions to varying exogenous conditions.

Keywords: after-sales services; simulation; spare parts classification; product lifecycle

1. Introduction

The accelerated pace of change in manufacturing and business, as pointed out by Ansoff and McDonnell (1990), changed the boundaries, the structure and the dynamics of the competitive environment, exposing firms to continuously new and unexpected challenges which were so far reaching that Peter Drucker called the new era 'the age of discontinuity'. In such context, with the pressure of global competition and decreasing margins deriving from product sales in most durable goods industries, companies are forced to seek and exploit new sources of revenue and profit. Therefore, the after-sales services and activities (those taking place after the purchase of the product and devoted to supporting customers in the usage and disposal of goods), once considered just a 'necessary evil' (Lele 1997), have acquired a primary importance (Levitt 1983, Wise and Baumgartner 1999). After-sales services and spare parts provision, in fact, may be relevant sources of revenue, profit, service differentiation and customer retention (Yamashima 1989, Goffin 1999, Cohen *et al*. 2006a, b). A recent survey by Deloitte Research (2006) on a sample of manufacturing companies, for example, found out that service business accounted on average for 25% of revenues and had profitability 75% higher than the overall company profitability.

However, the management of a portfolio of services and an after-sales supply chain requires organisational principles, structures and processes new to product manufacturers (Oliva and Kallenberg 2003, Cohen *et al*. 2006b). The management of spare parts inventory and distribution networks then becomes a critical activity. Indeed, the product lifecycle has considerably shortened in the last decades, with an ever increasing rate of introduction of new products. Furthermore, the market is increasingly demanding unique or customised products (Kumpe and Bolwijn 1994). These phenomena have largely increased the width of the product range managed by most companies: since the product lifetime at the customer is quite long for most durable or capital goods, and they need to be serviced, the manufacturer should manage the spare parts of its present product catalogue as well as for the old ones. Thus, as pointed out by Cohen *et al*. (2006b), the after-sales supply chain involves the management of a number of stock keeping units up to 20 times higher than the corresponding manufacturing supply chain. Moreover, the demand for spare parts tends to be rather low (in relation to the number of products sold) and irregular. Finally, the joint effect of the shortening product lifecycle, the response time requirements and the sporadic nature of demand, make obsolescence a serious threat for spare part inventories: according to Cohen *et al*. (2006b), 23% of spares become obsolete every year. This has to be considered when undertaking inventory decisions (Cobbaert and Van Oudheusden 1996).

*Corresponding author. Email: fredrik.persson@liu.se

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In such a context, manufacturers, when designing their spare parts inventory and distribution systems, are faced with the typical cost *versus* service trade-off. They should act, in fact, in order to satisfy their customers by ensuring spare parts availability at short notice, while on the other hand they should minimise the costs related to inventory holding and obsolescence. Quantitative methods such as simulation are, then, suitable for supporting decision-makers in dealing with the after-sales logistic network complexity.

This article analyses the issues of spare parts classification and logistic network configuration, through the case of a European manufacturer of heavy equipment. In particular, the aim is to evaluate different choices about the location of spare parts inventory through a simulation model. The use of simulation in order to investigate the supply chain cost structure is motivated by the ability of a simulation model to handle the reactive characteristics of the spare part inventory control system.

The next section provides a review of spare parts classification and the relation with inventory decisions; the third section describes the methodological approach adopted. The case study is presented in Section 4, which also describes the simulation model designed. Section 5 provides the main simulation findings, and Section 6 discusses the results and the managerial implications of this research. Finally, some concluding remarks are drawn in the last section.

2. Background

2.1. *Spare parts distribution and inventory decisions*

Due to the spare parts business peculiarity, e.g. the need to ensure a high service level coupled with sporadic demand, the configuration of logistic systems for spare parts needs special attention. According to Huiskonen (2001), when designing and managing a logistic system there are four decision levels to be considered:

- The strategy/policies/processes level concerns the objectives to be pursued by one actor or by the entire supply chain (e.g. in terms of service level or response time);
- The network structure defines the number of inventory echelons and locations in the supply chain;
- The coordination and control mechanisms include decisions about the inventory control principles, the incentive and performance measurement systems, and about the information support tools or systems to be used;
- The supply chain relationships, finally, consist of the degree of cooperation or reciprocal influence among supply chain actors that may impact on the achievement of the objectives through the implementation of the control and coordination activities.

The choice of the network structure includes decisions, among others, about vertical integration, transport systems and number of echelons. Moreover, warehouse localisation, stock allocation and inventory control policies are of the foremost importance. Cohen *et al.* (2006a), for instance, focus on the interplay of spare parts allocation decisions. Decisions should be taken in order to optimise the cost–service trade-off related, as shown in Figure 1, to the product and the geographic hierarchy. For example, a company may decide to replace a failed product with a standby end product stocked at the customer's premises. This solution provides the fastest response time, but it is much more costly than deciding to replace only the broken parts with spares stocked at the company central warehouse.

Decisions on what product level to stock and where the stock should be kept might influence the design of the logistic and distribution network. Moreover, as

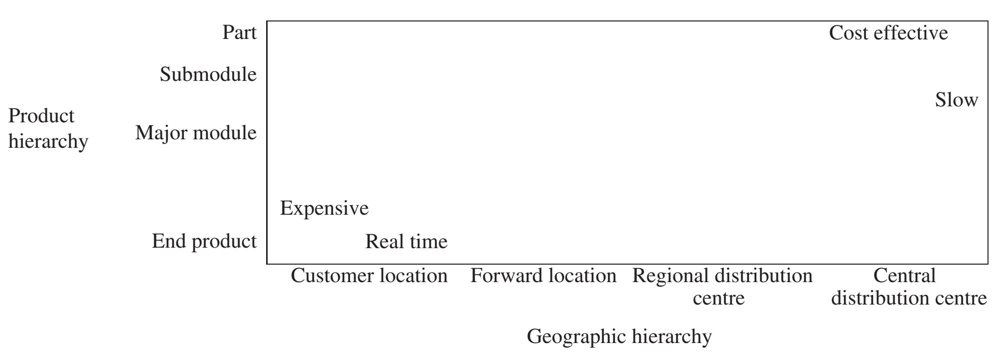

Figure 1. The product and geography hierarchy for allocation decisions (from Cohen *et al.* 2006a).

pointed out by Kalchschmidt *et al.* (2006), the complexity of a company's supply chain (i.e. the network structure itself) influences the level of irregularity and heterogeneity of demand, especially when multiple types of distribution channels are managed at the same time.

2.2. *Spare parts classification*

Some authors have treated the classification of spare parts as a way to provide inventory management guidelines. Huiskonen (2001) classifies spare parts according to four dimensions: (i) *criticality*, (ii) *specificity*, (iii) *demand pattern* and (iv) *value*. Analysing a case company, he finds out five spare part classes, for which suggestions for inventory control policies are provided. Williams (1984), and later Eaves and Kingsman (2004), build their classifications on the variability of spare parts demand. In particular, the lead time variance is decomposed into the contribution of: the number of orders during the lead time, the size of orders and the lead time duration. Eaves and Kingsman (2004) identify five groups of parts in reason of their demand pattern: *smooth*, *irregular*, *slow moving*, *mildly intermittent* and *highly intermittent*. Gajpal *et al.* (1994) and Braglia *et al.* (2004) use the AHP methodology (Saaty 1990) for spare parts classification. Gajpal *et al.* (1994) aim at assessing the spare part criticality, through a weighted measure of the stock out implications, the type of spares required (level of standardisation) and of the lead time. Braglia *et al.* (2004), instead, develop a multi-attribute spare tree analysis. The classification of a spare part according to one criterion (e.g. *spare part plant criticality*) may lead to different decision diagrams, that lead to a classification according to another criterion. The other criteria proposed are *spare supply characteristics*, *inventory problems* and *usage rate*. Each classification is made through the AHP technique, and finally parts are grouped in four classes, to which inventory management guidelines are associated.

The reviewed classification methods present common elements such as the attention to criticality aspects and to the demand pattern of spare parts, although with different degrees of importance and different evaluation procedures. It is possible to point out the fact that none among the classifications described above considers directly the product and part or component lifecycle. These, on the contrary, are suggested as relevant elements by Yamashima (1989), and strongly influence the demand for spares. For example, products in the early life cycle stages tend to be less reliable than mature products, and may be subject to substitution also due to the technological innovation (e.g. CD or DVD players). Therefore, they have a demand pattern for spare parts different from mature products. The study in Yamashima (1989) helps to point out the complex relationships between the product lifecycle characteristics, the product life probability, the parts reliability and the demand for spare parts.

3. Methodology

This article develops a case-based simulation research. Due to the descriptive purpose of the research, a case study seems a suitable methodology (Yin 1994). Moreover, the case study allows a richer knowledge of the issues treated in this article to be reached than would have been possible through a quantitative approach alone (Nordin 2005). On the other hand, through the case study it was possible to gather all the quantitative data needed to build a simulation model in order to support decision-making on spare parts allocation.

3.1. *Case study*

The case study in this article was carried out through interviews and data collection. Several interviews were held with the person responsible for the spare parts supply chain, addressing the following topics: general information about the company, the spare parts logistic network, spare parts classification, spare parts demand and inventory management practices and spare parts supply process. Interviews were aimed at collecting data, as well as understanding the qualitative aspects related with each topic treated. Secondary sources as well were consulted (website, company documentation). The information gathered through the case study allowed the simulation model to be built.

3.2. *Simulation methodology*

Simchi-Levi *et al.* (2000) include simulation in their list of useful analytical tools for decision support in supply chain management. Simulation of supply chains incorporates the use of the simulation methodology, in this case discrete event simulation, to analyse and solve supply chain management problems. The main reasons to use discrete event simulation in this field are (i) the possibility to include dynamics and (ii) the simplicity of modelling, e.g. bottom-up or top-down approaches. Discrete event simulation is well suited for these kinds of studies where time-dependent relations are analysed. Simulation also has a capability of capturing the uncertainty and complexity that are common in supply chains (Jain *et al.* 2001).

The used simulation methodology follows the steps described in Persson (2003). The first step (i) is the project planning or problem formulation where the outline of the study is determined. The next step (ii) is the conceptual modelling. The conceptual model describes the system under investigation. The conceptual model is validated as the next step (iii). The computer-based model is created as step (iv). This model must be verified (v) and validated (vi). Model verification aims at estimating if the simulation model is a valid representation of the conceptual model while model validation aims at estimating if the model is a valid representation of the system. The experimentation step (vii) consists of experimental runs with the simulation model. The results of these runs are then analysed (viii) and the result of that analysis is the base for the recommended decision or implementation (ix).

4. The case study

4.1. *The case company*

The case company is one of the world's leading manufacturers of heavy equipment. Production plants are located in Northern and Western Europe, North and South America and South-eastern Asia. To obtain maximum profitability from the equipment and to respect scheduled activities, uptime is a critical performance for the company's customers. Therefore, great effort is devoted to the after-sales service, managed by a service division. Among the services offered to customers are: (i) tailored customer support agreements with different contents, ranging from inspections of the machine to the full responsibility for maintenance and repairs at a fixed cost; (ii) spare parts availability, offered through a global distribution network and a wide number of dealers (company-owned or, in most cases, third party) in Europe and outside; (iii) a reserved website in which customers find both general and detailed information about their machines' service history, as well as service reminders.

4.2. *Spare parts classification and inventory management policies*

The company has recently adopted a new, sophisticated method to classify spare parts. These are the main classification dimensions considered:

(1) *Lifecycle phase* of the related final product. Parts are clustered in four main groups: *launch*, *prime*, *decline* and *phase out*. Boundaries between these classes are set by the number of years from which the heavy equipment is being manufactured, or by the time passed since the production ended.
(2) *Volumes*. Parts belonging to the prime, decline or phase out categories are classified as fast moving, medium, or slow moving. In the decline phases other classes apply, such as medium-high, medium-low and extra-slow moving. The classification is based on the demand of the previous year.
(3) *Criticality*. During the whole lifecycle, critical items are identified among low-volume parts in order to guarantee an adequate service level, although their demand is low. Critical items include main components/subsystems, subcomponents and remanufacturable parts.
(4) *Competition*. This dimension holds only for the 'launch' lifecycle phase, in which volumes are generally low. Parts are differentiated according to their availability in the independent market or from competitors (competitive parts). If so, a high service level is needed to compete in the market.

The classification is then built composing the dimensions in an almost hierarchical fashion. Interrelating these dimensions, 26 classes are obtained, as shown in Figure 2.

The classification is used by managers to define the required service level of the parts (availability at the warehouse) and the inventory management policies and parameters. In the *launch* phase of the product lifecycle, parts availability is considered critical to keep the machines' uptime very high. Safety stocks and a re-order point policy are thus defined for parts in this area. The same policy, although with different parameters, is kept for non-fast-moving parts in the *prime* and *decline* phases. In the decline phase, nonetheless, back-orders are tolerated. For fast-moving parts, instead, a continuous review policy with safety stock and re-order point is kept along the whole lifecycle. Finally, parts in the *phase out* stage have two distinct policies: the 'moving' ones are managed in an MTO or PTO policy, with no safety stock and re-order point equal to zero (nonetheless, those parts may have high availability if large inventories were accumulated in previous phases). Non-moving phase out parts, finally, are simply not serviced by the company.

4.3. *After-sales logistic network and spare parts allocation*

The logistics network of spare parts is depicted in Figure 3. The company's suppliers are located in all different parts of the world, shipping spare parts to the

Part criticality \ Lifecycle phase	Launch	Prime	Decline	Phase out
Low	(1) Competitive (2) Non-competitive	(6) Fast moving (7) Medium (8) Slow moving	(12) Fast moving (13) Medium-high (14) Medium-low (15) Slow moving (16) Extra-slow moving	(20) Fast moving (21) Medium-high (22) Medium-low (23) Slow moving
High	(3) High 1 (4) High 2 (5) High 3	(9) High 1 (10) High 2 (11) High 3	(17) High 1 (18) High 2 (19) High 3	(24) High 1 (25) High 2 (26) High 3

Figure 2. Spare parts classification in the case company.

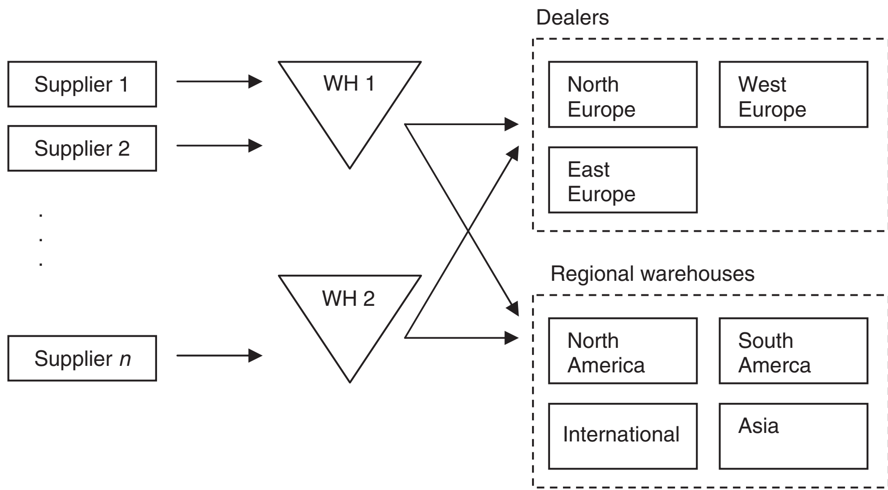

Figure 3. Spare parts logistics network of the case company.

two warehouses located in Europe, of which the main warehouse (WH 1) is located in Northern Europe.

Spare parts inventory levels and shipments to regional warehouses and dealers are controlled by re-order point systems. If the inventory level of any spare part in the two warehouses or at the regional warehouses is below the safety stock level, an express freight is utilised. That accounts for about 10% of all freights; otherwise ordinary transports are used.

The customers of the central warehouse(s) are of two kinds: the regional warehouses and the European dealers. The company decided that fast-moving, medium-to-low-value parts should be kept in stock at the dealers' or at the regional warehouses. For these parts, the replenishment is managed directly by the company through a vendor managed inventory (VMI) programme. The case company defines the safety stock, the re-order point and re-order quantity; orders are proposed by the manufacturer's information system and approved in an automatic, semi-automatic or manual fashion by dealers (i.e. dealers can modify quantities and dates). The other spares (slow-moving and/or high value parts), are kept in stock at the central warehouse, and shipped to order (generally through an express freight) to the dealer or to the regional warehouse.

From the description above, it follows that fast-moving parts are generally managed on a continuous review policy with safety stocks at the dealers. This way, orders are planned in advance and the normal transportation (the cheapest) is the most used. For slow moving parts, dealers do not hold stock, thus urgent deliveries are required. The company acknowledges that around 75% of deliveries of fast-moving parts (or critical) parts are made through regular shipments, while around 25% are express ones. On the other hand, slow-moving parts present a share of urgent deliveries much higher than 50%.

4.4. *Problem formulation: spare parts supply*

Today some of the suppliers of spare parts are dedicated to either the main warehouse (WH 1) located in Northern Europe or to warehouse WH 2 in Western Europe. In the near future, the capacity needs to increase in WH 1 due to new forecasted higher sales volumes. One way to solve the problem would be to transfer some of the suppliers to WH 2, thereby reducing the number of suppliers storing their spare parts in Northern Europe and thus making storage capacity available. One restriction to the problem is that if a supplier is moved, all spare parts supplied by that supplier must be moved.

The purpose of the case study is to investigate this transfer of suppliers from WH 1 to WH 2. This is done given the existing structure of the supply chain and taking all relevant costs and part criticality into consideration. Simulation is chosen to investigate the supply chain cost structure. There are two reasons for that: (i) the ability to handle stock outs and delays in transportations, and (ii) the reactive characteristics of the inventory control system that, among other things, determines if transportation should take place with ordinary transportation or with express freight.

The supply chain, as depicted in the previous section, is modelled in the simulation software Arena. The model contains 20 suppliers (out of over 800 suppliers in total). These 20 suppliers are chosen because they stand for 88.1% of the total weight shipped, 89.7% of total purchasing cost and 92.5% of total number of order lines. All internal suppliers (suppliers owned by the same company) are not considered in this study. The model still covers approximately 4400 different parts and several thousand order lines per year. The spare parts of the 20 suppliers are positioned in all classes of the spare part classification with a majority of parts at the low-criticality level and in prime lifecycle phase, see Figure 4.

5. Experiments and results

The simulation model in Arena was used to calculate the transportation cost for the two different cases of localisation, WH 1 or WH 2. Transportation cost is calculated as the sum of all transports (from the supplier to the warehouse and from the warehouse to the customer), taking the cost for weight, the weight of the parts and the order class into consideration. The order class is the type of transport that the part utilises. An express transport is more expensive than an ordinary transport.

The case company presented four different scenarios of future market growth to be analysed with the simulation model. The future growth is represented by percentage increase in the demand year by year in each geographical market served by the company. The differences between scenarios represent alternative changes in the European market, where different parts of the European market get different impact on total sales. Each scenario contains sales data for the years 2008, 2010, 2012 and 2014.

5.1. *Cost structure*

The first simulation used the demand for 2006 and the results of this experiment were used as a base case to compare to the rest of the simulations. Each experiment was run twice, one run considering the cost matrix of WH 1, the other time considering the cost matrix of WH 2.

For each future scenario the costs for each supplier were calculated through the simulation model. The difference between placing the supplier in WH 1 compared to placing the supplier in WH 2 was calculated as the main result variable. If this difference is positive it means that the cost is lower when the supplier is moved from WH 1 to WH 2. The higher the positive value is in the calculations, the higher the cost savings when the supplier is moved to WH 2. In the cost calculations, the costs are split between inbound costs (transports from suppliers to WH 1 and WH 2) and outbound costs (transports from WH1 or WH2 to regional warehouses and dealers in Europe). In some cases, both the inbound cost and the outbound cost differences are negative (indicating the spare part to stay at WH 1) and the conclusion to keep the supplier in WH 1 is unambiguous. In other cases, both cost differences are positive (indicating the part to be moved to WH 2) and here as well, the conclusion to move the supplier is clear. In the rest of the cases, the inbound and outbound costs differ and the cost levels decide the conclusion, as illustrated in Table 1. This indicates that if a supplier is closer to a warehouse, it does not directly follow that the costs will decrease if it is moved to that warehouse. If the outbound costs become very high, they will surpass the benefits obtained in the inbound cost. Therefore, the location of a supplier with respect to the

<table>
<tr><td>Part criticality</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Low</td><td>5.7%</td><td>62.3%</td><td>20.3%</td><td>8.3%</td></tr>
<tr><td>High</td><td colspan="3">3.2%</td><td>0.2%</td></tr>
<tr><td>Lifecycle phase</td><td>Launch</td><td>Prime</td><td>Decline</td><td>Phase out</td></tr>
</table>

Figure 4. Classification of spare parts supplied by the 20 suppliers considered in the model.

warehouse is not a decisive factor in finding the lowest total cost.

Considering the results obtained in the first scenario, described in Table 2, it is clear that costs can be saved if two suppliers (out of the total 20) are moved to WH 2.

Analysing the other scenarios, we find out that the same two suppliers are suitable to be moved in every scenario. As the demand increases according to the sales forecasts there are two developments worth noting: (i) for the first supplier (supplier 7) the cost savings decrease as the demand increases, and (ii) for the second supplier (supplier 13) the cost savings increase as the demand increases. This means that for supplier 13 it becomes more and more profitable to move the supplier, while for supplier 7 the profitability of movement will decrease but still be positive. Thus, the solution is stable over the scenarios that were tested.

Table 1. Cost relations.

Inbound cost [difference WH1 – WH2]	Outbound cost [difference WH1 – WH2]	Total cost [difference WH1 – WH2]	Consequence
<0	<0	<0	Stay in WH 1
<0	>0	?	?
>0	<0	?	?
>0	>0	>0	Move to WH 2

Table 2. Total cost difference in base case [Euro].

WH 1–WH 2	Inbound*	Outbound*	Total cost*	Suggestion
Supplier 1	−4	−14	−18	Stay in WH 1
Supplier 2	−4	−4	−8	Stay in WH 1
Supplier 3	−1	−4	−5	Stay in WH 1
Supplier 4	−13	−11	−24	Stay in WH 1
Supplier 5	−2	−4	−6	Stay in WH 1
Supplier 6	−3	−2	−5	Stay in WH 1
Supplier 7	**4**	**−3**	**1**	**Move to WH 2**
Supplier 8	2	−7	−5	Stay in WH 1
Supplier 9	0	−11	−11	Stay in WH 1
Supplier 10	1	−1	0	Stay in WH 1
Supplier 11	−6	−3	−9	Stay in WH 1
Supplier 12	−43	−48	−90	Stay in WH 1
Supplier 13	**110**	**−10**	**100**	**Move to WH 2**
Supplier 14	3	−14	−11	Stay in WH 1
Supplier 15	3	−11	−8	Stay in WH 1
Supplier 16	−18	−1	−19	Stay in WH 1
Supplier 17	−2	−5	−7	Stay in WH 1
Supplier 18	−17	−8	−25	Stay in WH 1
Supplier 19	7	−10	−3	Stay in WH 1
Supplier 20	1	−10	−9	Stay in WH 1

Note: *Numbers are indexed to hide real value.

5.2. *Spare parts classification*

The second analysis aims at locating suppliers that are critical. In total, the critical spare parts constitute 3.4% of the ~4400 items supplied by the 20 suppliers in the analysis (Figure 4).

To be classified as a critical supplier, the supplier needs to provide many critical items or sell a high volume of critical spare parts to the company. A critical supplier is a supplier that provides at least 20% highly critical parts (Figure 4) out of the total of parts provided or that has a total sales volumes of critical parts above a certain amount.

Table 3 lists all 20 suppliers and the relative amount of critical parts supplied by each, in number of items (on total parts supplied by the supplier) and sales volumes (on total sales of critical parts).

Three suppliers are identified as critical in Table 3. Supplier 1 has a high percentage of critical parts and a moderate sales volume. Supplier 15 has a high sales volume but a low percentage of critical parts. Supplier 20 has both a high sales volume and a high number of critical parts. The two suppliers that were suitable for movement to the other warehouse (from WH 1 to WH 2), supplier 7 and supplier 13, however, are low on both of the two measurements (number of critical items and sales volumes of critical spare parts). Suppliers 7 and 13 are thus not critical and could be moved without further analysis. However, this would not be the case with critical suppliers: if any among suppliers 1, 15 and 20

Table 3. Criticality of suppliers.

Supplier #	Critical parts %	Sales volumes
Supplier 1	**28.3**	**5.6%**
Supplier 2	5.9	5.0%
Supplier 3	6.2	0.7%
Supplier 4	0.0	0.0%
Supplier 5	0.4	0.1%
Supplier 6	0.0	0.0%
Supplier 7	3.1	0.4%
Supplier 8	0.0	0.0%
Supplier 9	0.9	0.4%
Supplier 10	0.0	0.0%
Supplier 11	0.0	0.0%
Supplier 12	0.0	0.0%
Supplier 13	1.1	0.1%
Supplier 14	2.5	8.2%
Supplier 15	**3.0**	**49.1%**
Supplier 16	8.3	0.1%
Supplier 17	0.0	0.0%
Supplier 18	0.0	0.0%
Supplier 19	0.0	0.0%
Supplier 20	**23.7**	**30.4%**
Total		100%

Note: *Numbers are recalculated as percentages to hide real value.

were to be moved according to the simulation output, in fact, an evaluation of the service level variation (for instance based on lead times or delivery performance) should be undertaken before making the final decision.

6. Discussion

As the previous sections show, there were two main issues concurring in the decision of spare parts allocation in the case study addressed: the spare parts classification (and subsequent inventory management policy) defined through a classification model, and the total transportation cost, investigated through the simulation model developed in this research.

Concerning the first aspect, the spare parts classification method developed by the case company offers the opportunity for some considerations. First of all, the relevance of the spare parts business at the company seems to justify the adoption of a sophisticated classification methodology, based on multiple criteria. This supports the statement by Huiskonen (2001) about the need for multi-dimensional classifications for spare parts, differently from other materials. Second, the case study points out the relevance of two classification criteria, often overlooked or only implicitly considered in literature. One is the lifecycle phase: not only does it influence the volumes, but also the regularity and predictability of demand (in relation to the underlying product and components reliability) as well as supply-related factors such as supplier availability, supply lead times and supply lead times stability. The other one, instead, is the competition-related dimension included in the classification method, namely the availability of spare parts from competitors in the after-market. Inventory-related costs, then, should also be traded off with lost sales opportunities.

Concerning the second aspect treated in this article, the simulation model applied to different demand scenarios showed that moving a supplier from one warehouse to another is not a straightforward decision. In this case, it turns out that there need to be costs savings in both the inbound and outbound transportation or that the cost saving in one of the two needs to be large to overshadow the other. A supplier that has a positive cost structure (lower cost after the move) is suitable for movement, but this should be subject to a sensitivity analysis of demand, as the scenarios allowed to be done in this case. It can also be argued that critical suppliers must undergo a more detailed analysis before the decision can be made, assessing the impact on service level, for instance based on lead times or delivery performance.

Some managerial implications can also be drawn from the research presented in this article. The main problem for a manager in the after-market services and spare parts distribution, who deals with a very large number of SKUs, stands in the trade-off between keeping the cost for inventory management low while providing a high customer service. This article highlights two ways that concurrently might be adopted to reach the objective. First of all, a thorough classification of spare parts allows the service level requirements to be differentiated, so that, for instance, slow and fast movers are treated in different ways and with the effort actually needed. This article also suggests, through the literature review and the case discussion, possible dimensions for an effective spare parts classification. Second, it is important to keep the right product (spare part) at the right location so that total transport costs are minimised: the research shows that the simulation methodology is helpful in supporting this kind of decision, taking into account the dynamic aspects of inventory control, and easy enough to apply even in a complex manufacturing context.

For the specific case analysed, the company managers found the simulation results helpful in suggesting which choice to undertake (suppliers to move), and in focusing on the demand sensitivity analysis as a way to support the sustainability of the choice in the long run.

Moreover, considerations about the limitations of the classification model adopted by the company were also discussed. The classification method, in fact, does not take two relevant aspects into consideration: (i) the product variety *versus* component commonality issue and (ii) the relation between the component lifecycle and the final product lifecycle. The method considers the components' lifecycle as coinciding with the product one; different lifecycle instead (e.g. consumable parts that wear out in the early life of the product) may influence the demand for spares. Moreover, the level of commonality of components across the product range may also influence the demand: for instance, a component common to many final products at the launch lifecycle stage may present a higher and more regular demand pattern than a component specific to a single product in the prime or decline phase. Finally, it should be noted that the company has moved very recently to this new classification method and to the related inventory decision-making process. Therefore, this period will also help to test the validity of the model and to fine-tune the classification and decision rules. As a final general consideration for managers, we may say that fine-tuning and threshold definition in the classification method is a rather critical activity, since close to the 'thresholds' may stand the areas presenting the risk of poor service or, conversely, excess cost.

7. Conclusions

Managing an after-sales logistic network is a critical activity for durable goods manufacturers or distributors. From one side, the provision of spare parts may be a relevant source of profit for companies, and for that reason, an area of competition (for instance about service level performance). On the other hand, as described in the first section of this article, the variety of items and the sporadic nature of demand make the management of the after-sales logistic network a very complex activity, which needs to be supported by quantitative methods in order to obtain the highest customer satisfaction at a reasonable cost.

This article addresses two main issues, resorting to a case study of a heavy equipment manufacturer: (1) to evaluate different choices about the location of spare parts inventory through a simulation model; (2) to analyse the spare parts classification criteria, that lead to the definition of inventory policy.

The results of this research study, described in Sections 4 and 5 and thoroughly discussed in the previous section may be summarised as follows.

First of all the classification of spare parts is a very important lever for an effective management of the after-sales logistic network, and thus critical from a managerial standpoint, and at the same time an area that has not been thoroughly investigated from the research standpoint. The case company classification model, in fact, provides useful insight for research. For instance, the competition dimension shows how the business opportunities related to spare parts availability (i.e. increased market share), should be taken into consideration as a strategic input when making inventory decisions. Although previous research addressed the issue of spare parts classification, a comprehensive analysis of the topic has still to be drawn. An objective for future research, therefore, should be the definition of a general framework, listing and analysing the characteristics of different classification dimensions. This would allow the relevance of different classification criteria in different contexts to be assessed, by relating them to drivers such as the industry, lifecycle duration, product value and so forth.

Second, the use of a simulation model proved helpful as decision support tool in order to perform supplier (and thus parts) allocation decisions in the logistic network, allowing costs to be minimised. A preliminary analysis about the supplied weight, order lines and value allowed the most relevant suppliers to be pointed out. Through the simulation model, then, it was possible to highlight the mechanisms underlying the evaluation of transportation costs, and (i) the possible trade-offs between inbound and outbound costs; (ii) the relevance of supplier criticality as a driver of the allocation decision; (iii) the relevance of the expected demand evolution (analysed through scenario) to the allocation decision. When the complexity of the business context increases, in conclusion, simulation proves an effective methodology since it allows several variables to be taken into account at the same time (and their possible evolution in the future) without explicitly assessing all the causal relations among variables.

Finally, as discussed in the previous section, the support of quantitative methods such as spare parts classification models and the use of simulation models may be of great help to practitioners, in order to focus their effort on what really matters, to adopt cost-effective decisions and to assess the robustness of their decisions to varying exogenous conditions.

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Notes on contributors

Fredrik Persson is an Assistant Professor in Quantitative Logistics at the Department of Science and Technology at Linköping University, Sweden. His research interest includes modelling and simulation of manufacturing systems and supply chains in industry and especially in the construction industry. Of special interest are simulation methodology and validation methods. He is currently head of the quantitative logistics group in Brains and Bricks – a research consortium focusing on construction industry related topics.

Nicola Saccani (Department of Mechanical Engineering, University of Brescia, Nicola.saccani@ing.unibs.it) is an Assistant Professor at the University of Brescia (Italy). He graduated in industrial engineering at the Politecnico di Milano (Italy) and at the Ecole Centrale de Lille (France), and he holds a PhD in Operations Management from the University of Brescia. His research and publications concern inventory management, buyer–supplier relationships and services operations management. He is member of the Research Centre on Service Management at the University of Brescia, and of the ASAP Service Management Forum initiative (www.progettoapsap.org).

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