Spare parts inventory and demand management. Comparing theoretical approaches with managerial practice.

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Abstract
Demand and inventory management for spare parts are different than for components used in assembly of finished products, in reason of lumpy demand, larger variety and risk of stock obsolescence. The paper deals with three aspects: 1) a description of the elements of complexity peculiar to the spare parts supply chain; 2) a framework and a literature review about spare parts demand and inventory management approaches and models; 3) the analysis of five case studies, suggesting a gap between theoretical approaches and the ones adopted in practice by companies.

Keywords: spare parts, demand forecasting, inventory management.

Introduction
The design and management of spare parts demand, inventory and distribution networks encompasses a set of decisions that can be grouped in (Huiskonen, 2001): 1) a strategy/policies/processes level, concerning the definition of objectives (e.g. service level); 2) the definition of the network structure (e.g. number of inventory echelons and locations); 3) the coordination and control mechanisms (inventory control principles, incentive and performance measurement systems, information support tools); 4) the supply chain relationships. The study of real cases (e.g. Persson and Saccani, 2009) show that these decisions are strongly related one another, and impact on the performance of the whole supply chain and its actors. Since after-sales supply managers are faced with trade-offs when making these decisions, mathematical models and decision support systems can be of great help. Nonetheless, in this paper we argue that a gap exists between theory and managerial practice. In fact, models in literature might not be applicable to real life, since they often rely on hypotheses that oversimplify the situation (for instance about demand features, data availability, or information sharing among supply-chain actors). Moreover, they do not adopt an integrated approach towards the set of decisions described above, so they might take only to local optimization. In addition, other practical obstacles exist, such as the different knowledge of the problems treated by the functions involved in the decision-making process (Kerkkanen, 2007), or the availability of the financial and human resources needed to implement complex decision models. Moreover, decision-makers are keen to base their
decisions on experience and common sense (Zsambok, 1997) and they may neglect the recommendations of decision support systems, as argued by Fransoo and Wiers (2008). This paper, after an introductory part that explain the main differences between the management of spare parts for after-sales service and components for first assembly of finished products, presents a framework relating the different decision aspects about the configuration and management of a spare parts inventory and distribution network. Then, the paper proposes a review of research about the main aspects of the framework itself. Finally, five case studies of appliance manufacturers are described, in order to point out the gap that exists between theoretical approaches and the ones adopted in practice, trying to identify causes and levers to use for performance improvement.

Complexity drivers of spare parts demand and inventory management

The inventory and demand management for spare parts is more critical than for components used in assembly of finished products, in reason of three aspects (Persson and Saccani, 2009):

- **Numerousness and Variety.** Technological innovation occurring at an increased pace, time-based competition (Stalk and Hout, 1990), the consequent reduction of time-to-market, the increased renewal rate of the product range by manufacturers, the mass customisation phenomenon for consumer goods (Pine, 1993) as well as the increasing relevance of product customisation, concur in widening the range of spare parts a manufacturer should manage.

- **Time (responsiveness).** A responsive product support process and spare parts availability are critical factors in many contexts. Holding stocks at every customer location would allow to reach this objective, but the variety issue described above often prevent from doing that. Moreover, the time dimension interact with the variety and demand dimension by creating the obsolescence phenomenon. According to Cohen et al. (2006), 23% of spares become obsolete every year.

- **Demand.** The demand for spares tends to show a lumpy pattern. Lumpiness may emerge as a consequence of specific market characteristics, in particular numerousness and heterogeneity of customers in the market, order frequency, variety and correlation of customer requests (Bartezzaghi et al, 1999). Moreover, the consumption rate of a spare part is highly dependent on the number of pieces of equipment where the part is installed, as well as its intrinsic level of reliability.

A framework for spare parts management

In figure 1 we present a framework relating the different decision aspects concerning the configuration and management of a spare parts inventory and distribution network. This framework adopts a supply chain perspective, focusing on managerial aspects rather than on formal analysis or modelling; its objective is to be a guide for both literature review and case-based research, and as a consequence of this, to allow a comparison between theory and practice.
The first factor that influence planning choices is the **spare parts demand**, in particular its volume and variability. This is strongly related to some underlying variables, i.e. the product features, the customers characteristics and the supply chain structure.

The **product features** influencing spare parts demand are a). **specificity**, in order to discriminate spares which are widely used and are also readily available, from others used only in few and specific models of finished products, b). **criticality**, in particular process criticality, related to the consequences caused by the failure when a replacement is not readily available, and control criticality, related to the possibility of predicting and controlling unexpected situations such as failure, existence of spare part suppliers, etc. (Cavalieri et al., 2003), c). **value** of the part and d). **life cycle phase** of the related finished products (Persson and Saccani, 2009).

In addition, the most relevant among the **customers characteristics** are a). the **numerousness** of potential customers, b). the **heterogeneity** of customers (for instance in some markets where few large customers coexist with a large number of small customers), c) the **frequency** of customer requests, d) the **variety** of customers requests (measurable by the coefficient of variation of the demand of a single customer) and e). the **correlation** between customers requests, for example due to imitation which induce similar behaviours in customers (Bartezzaghi et al., 1999). The **supply chain structure**, finally, influences demand through a). the **number and type** of different actors involved and b). the **level of vertical integration**.

The second block of the framework consists of the Objects and Internal Organization of the company. It includes **structural and organizational aspects**, such as company size, sector and the functions involved in the spare parts management, and the **company operations strategy**, which includes the relationship among demand forecasting, inventory management and company competitive priorities, such as costs, quality, delivery performance or flexibility (Leang et al., 1990).

The framework suggests that these factors impact on the planning choices, in particular on spare parts demand and inventory management, the focus of this paper. Our objective is to investigate the relationships that exist between demand management (planning and forecasting) and inventory management (when to place an order, how many units to order and, in a multi-echelon and multi-location system, where to place spare parts inventories) in different environments.
Last item of our framework is the Performance Assessment of the demand & inventory management process. Performance management should be carried out with an integrated perspective, focusing on the trade-off between inventory and service level, in relation with the customer service objectives (Zotteri and Kalchschmidt, 2007). Indeed, in multi-echelon systems, it is useful to assess economics and service performances, on both the single node and whole logistic chain (Cavallieri et al., 2003). Obviously, the output of performance assessment leads firms to make, in the long term, aware decisions about the configuration of the logistic network that govern the overall described process.

Demand management

Literature has deeply focused on demand uncertainty and its effects on business performances. When dealing with uncertain demand, there are 3 possible approaches that can be developed. First of all, one can redefine the decisional problem in order to eliminate (or reduce) the source of uncertainty. For example, at the product design level, it is possible to reduce the number of sub-assemblies by leveraging on common components. In this way, the requests for a single component rise, thus reducing the uncertainty effects. Secondly, it is possible to influence demand so to better manage it, for example by means of marketing campaigns and partnerships with important customers. Finally, efforts can be made to reduce the effects of uncertainty by means of flexibility, slack capacity or inventories. This action is usually not effective when dealing with extremely variable situations; in these conditions, variability must be anticipated by improving forecasts (Kalchschmidt, 2002). Today in fact, especially in complex supply chains, the importance of forecasting is higher than in the past, since high inventory levels are not acceptable any more, as they carry heavy holding and obsolescence cost. To cope with this ever more relevant issue, literature has provided two basic approaches: judgmental and quantitative forecasting.

Judgmental forecasting is based on the knowledge developed by people over time and so their experience play a primary role. This methodology, typically based on an implicit model, allows exploiting all types of information available, in particular the unstructured one, but it is difficult to apply to a large number of items. The most known techniques are Delphi Method, Lifecycle Analogy, Expert Judgment and Building Scenario (for more details, see Makridakis et al, 1983).

On the other hand, when the quantity of items that need to be forecasted grows, quantitative techniques are preferable; these techniques aim at identifying some kind of link between past and future behaviour, or relationship among observable variables and the spare parts demand. First, we can classify forecasting approaches according to the aspect of the forecasting process they focus on: on one side there are Time Series Methods, that rely on past demand data, and, on the other side, methods that leverage on the information retrieval process regarding how demand is generated. Within Time Series Methods, it is possible to separate techniques used for stable demand from those expressly studied to be applied to highly variable or uncertain demand, in particular lumpy demand. For what deals with stable demand, literature considers Smoothing and Average based techniques, that include simple averages, simple moving averages, weighted moving averages (Makridakis et al, 1983) and exponential smoothing (Brown, 1959; Winters, 1960), Bivariate and Multivariate models (Makridakis et al, 1983) and ARIMA methods, developed by Box and Jenkins (1976), all suitable for regular patterns of demand or in case of systematic variability, such as trends and seasonality. When demand is lumpy, these techniques tend to perform poorly (Bartezzaghi et al, 1999), and so the suggestion is to consider different techniques, studied specifically for variable
and uncertain demand. The first approach was developed by Croston (1972), who introduced a new specific method; according to this method, separate exponential smoothing estimates of the average size of the demand and the average time interval between demand occurrences are made. If demand occurs in the following period, estimates are updated, otherwise they remain the same. Other authors have provided other similar approaches that modify this method to reduce sources of bias (Syntetos and Boylan, 2001; Leven and Segerstedt, 2004). Another approach is Wright’s method (1986), that is a modification of Holt’s method in which a trend line is calculated and updated using exponential smoothing. Another promising technique is Bootstrapping, developed by Willemen et al. (2004) to forecast intermittent demand, especially when a poor series of past data are available. However, the major criticality related with time series methods is that they are more focused on the demanded quantity than on when demand will occur. This can be a relevant problem when demand shows a very sporadic pattern or when lumpiness is very high, since these systems tend to increase inventories even if demand will occur very far in time.

These problems can be reduced by adopting different techniques based not on past demand data (or at least not only), but that focus on the demand generation process and that try to estimate future market requirements by looking at information linked to demand variability. We can classify these kinds of techniques according to the perspective they adopt in the information retrieval process. A first group of methods has a product-oriented focus; these techniques, in fact, pay attention to product characteristics and commonalities and they are known as Analysis of Reliability (Yamashina, 1989). This technique is studied to deal with spare parts markets, since it links the failure probability for a component to its requirements. The most known model in this area was developed by Yamashina (1989), and focuses on reliability of components in order to derive the number of parts that will be requested during a certain period of time. The main problem of this kind of approach is that some kind of technical analysis on parts has to be conducted and this operation is often complex and costly, moreover when items are many. A different perspective is adopted by other techniques that focus directly on customers; among these techniques there is Order Overplanning (Bartezzaghi et al., 1999). By focusing on the purchasing process of each customer, the functions involved in the sales process try to capture subjective information on possible requirements that will occur in a given time period $t$. This early information can be used to separate customers in two groups: those customers that are expected to place an order (likely buyers) and those that seem not intended to place any request (unlikely buyers). According to Bartezzaghi et al. (1999), this method is suitable in cases of significant interactions between buyers and sellers before the order is placed, a case not very common for spare parts.

Indeed, there are some other approaches that use at the same time demand data and information related with the demand generation process (mixed methods). Into this family we can find the techniques called Early Sales (Kalchschmidt, 2002), that evaluate forecasts of total demand during a certain period by means of a partial observation of demand. Typically these techniques use data as pattern of demand in analogous period (of very similar products) during past years an orders that have been already received. Obviously, in order to apply these methods a high correlation between the different products considered and, especially, customers, because the orders achieved by first (early) buyers could well represent purchase intentions of the late buyers. This approach should be used to predict the demand for spare parts when new product models are offered on the market. An innovative approach, belonging to the mixed methods family, applies neural network modelling in forecasting lumpy demand.
Flexibility and nonlinearity are the two most powerful aspects of neural networks; these models are also designed to learn the relationship between independent and dependent variables incrementally when new information is available. Gutierrez et al. (2008), in their paper, demonstrate that neural network models are generally superior to the traditional time-series models in forecasting lumpy demand. One important aspect is that neural network can be combined with both time series method and demand generation models, in order to build effective hybrid models.

**Inventory management**

In this paper we focus on the major contributions specifically related to *spare parts inventories* in multi-echelon system, updating the work by Kennedy et al. (2002). From one side there are papers that adopt an *Integrated approach*, that offer a systematic view of spares inventory management, often proposing a specific framework and which do not necessarily develop analytical models or methods, but might propose only managerial guidelines. On the other side, there are some contributions that show a specific *Modelling approach*; it means that they focus on a specific context and problem, and develop *ad hoc* models in order to find the optimal solution.

Among the *Integrated Approach* class, we can include the works by Petrovic et al. (1990), Gajpal et al. (1994), Huiskonen (2001), Diaz (2003), Braglia et al. (2004), Niemi and Huiskonen (2006) and Cavalieri et al. (2008).

In the *Modelling* class, focusing only on multi-echelon systems, we can identify three different class of papers: a). *multi-echelon system*, including Muckstadt et al. (1973), Rosenbaum (1981), Cohen et al. (1986 and 1992), Sherbrooke (1992), Shtub and Simon (1994), Hopp et al. (1999), Chang et al. (2004) and Al-Rifai and Rossetti (2007); b). *multi-echelon system with repairable items*, including Gross and Pinkus (1979), Kohlas and Pasquier (1981), Singh and Vrat (1984), Moinzadeh and Lee (1986), Allbright and Gupta (1993), Papadopoulos (1996), Diaz and Fu (1997), Sleptchenko et al. (2002 and 2005) and Wong et al. (2005); c). *multi-echelon system with repairable items considering obsolescence*, including Dhakar et al. (1994), Cobbaert and Van Oudheusden (1996), Kim et al. (1996) and Walker (1996). Spare parts obsolescence is indeed a relevant factor in some industries, like electronics, computer and household appliances, where product models are continuously changing and so the ability to deliver spare parts quickly is a key aspect of after sales service (Cohen and Lee, 1990). Most of the Modelling class contributions adopt a cost minimization approach: customer service aspects are considered as constraints just in few papers among them (e.g. Gross and Pinkus, 1979; Cohen et al., 1986; Kim et al., 1996; Walker, 1996; Hopp et al., 1999; Wong et al., 2005). Instead, there is another category of specific contributions that contain papers that try to optimize the stock level, with a fixed budget as constraints (Rosenbaum, 1981; Kohlas and Pasquier, 1981).

All these approaches tend to share a common factor: they consider the distribution function of demand as known and they derive optimal inventory management policies given the environmental conditions. Especially for irregular series, to apply an inventory management policy that fully exploits the probabilistic information produced by the forecasting system, can deeply raise the process performances. For example, in a household appliance context, Kalchschmidt (2002) proposes an order management system that binds the emission of a replenishment order to the minimum probability of occurrence estimated by the forecasting system. If the probability of occurrence of demand peaks over the planning horizon is lower than a minimum probability of occurrence, no orders are placed; otherwise the system releases an order for a quantity equal to the average peak, estimated by the forecasting system.
A different kind of approach for spare parts management is proposed by the Continuous Replenishment Planning (CRP) (Cavalieri et al., 2003) and the Vendor Managed Inventory (VMI) (Persson and Saccani, 2009) policies, that modify the traditional procedure of order generation, introducing replenishment models managed by the supplier and based on data of actual and forecasted demand. These techniques forecast the control, by the manufacturer, of the entire downstream logistic process, including the control on stock in the wholesalers’ and distributors’ warehouses. Cavalieri et al. (2003) demonstrate that CRP, applied to a real two-level distribution system of an Italian household appliances company, outperforms both in terms of economic and service level performances, a traditional multi-echelon inventory model.

**Empirical research**

**Methodology**

The adopted methodology consists in five case studies, characterized by six main steps: a). a preliminary interview with managers involved in spare parts management b). a detailed questionnaire was sent to the companies in order to collect data, c). the questionnaire was reviewed by the authors in order to identify the main point to focus on in the d). full day interview. After this phase of data collection, e). there is the data elaboration of each case study and a cross case comparison, in order to identify common criticalities and try to develop strategies for a consistent improvement, illustrated to companies in f). the final discussion workshop, now still ongoing.

**Sample description**

The sample is composed of five manufacturers, operating in the heating, air conditioning and white goods sectors, with headquarters in Italy (table 1).

<table>
<thead>
<tr>
<th>Company</th>
<th>Business area</th>
<th>Size</th>
<th>Turnover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>White goods</td>
<td></td>
<td>Overall turnover [K€]</td>
</tr>
<tr>
<td>A</td>
<td>x</td>
<td>250</td>
<td>39.000</td>
</tr>
<tr>
<td>B</td>
<td>x</td>
<td>135</td>
<td>54.000</td>
</tr>
<tr>
<td>C</td>
<td>x</td>
<td>250</td>
<td>65.000</td>
</tr>
<tr>
<td>D</td>
<td>x</td>
<td>7.610</td>
<td>1.107.000</td>
</tr>
<tr>
<td>E</td>
<td>x</td>
<td>7.200</td>
<td>1.200.000</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>3.090</td>
<td>493.000</td>
</tr>
</tbody>
</table>

For the sample firms, 56% of the total customers are small repair shops, followed at distance by wholesalers, foreign importers, foreign branches and regional warehouses. In almost any analyzed case, customers are very numerous and with very different sizes. The effects on the spare parts demand is relevant, because it is deeply influenced by the heterogeneity of customers, that tends to create a very high number of order lines for
very different amounts (for the same SKU, the order size ranges from a few units up to thousands). The root causes of this phenomenon can be traced back to the existence at the same level of the supply chain of many heterogeneous customers; in particular four firms have a supply chain composed by two levels, while only one company in the sample has a single-level supply chain.

**Main findings**

**Spares analysis and classification**

The case companies manage on average about 48,000 spare parts SKUs in Italy, ranging from 1,600 to 145,000, not perfectly according to company size; in fact, the largest company of the sample (case E) manages only 60,000 SKUs, against 145,000 SKUs of the second largest one (case D), partially due to the different business area where they are involved. On average, around 14,400 items (35% of managed SKUs) are kept on stock, while 9,500 (20%) are sold in a year, and only 2% are fast movers, ranging from a maximum value of 46% (case A) and a minimum value of case D (0.7%). This means that, on average, there are a lot of SKUs to manage, but just few of them are characterized by an high turnover index during a single year. Concerning spares classification, every company except one defines different classes of spare parts. The classification is generally technology-driven, separating mechanical parts from electrical ones, hydraulic ones, and so on. Only one firm (company D) adopts a specific classification linked with planning choices: the classification criteria used are volume, value and turnover index of spare parts, through a simple ABC methodology.

**Demand management**

For all the sample companies, demand is considered an external variable, that is possible to forecast, but not to influence. As a matter of fact, marketing campaigns, partnerships with important customers and some other kind of collaborative practices are not used in order to regulate demand, making forecasting easier. In order to forecast demand, time series methods are used by four companies out of five; in particular simple average (case C), weighted moving average (case B) and single exponential smoothing (case D, E) are the adopted techniques, with a relevant contribution of human experience. Experience is the only one adopted method for company A, that manages a demand apparently without lumpiness. Two firms (case A and E) forecast demand only for fast moving codes, adopting a reactive approach (inventories) for slow movers, while the other three companies forecast demand for each defined class of spares. In particular, company A forecasts demand for expensive fast moving codes, without a quantitative assessment of them. The forecasting horizon is rolling and ranges from a minimum of three (case E) to a maximum of twelve months (cases A, B, D). As for the IT support, companies B, C and E use a specific forecasting tool of ERP, while company D adopt an external forecasting software, also integrated in the ERP. In none of the analyzed companies it is possible to underline a specific approach for irregular demand forecasting, even if, for all the analyzed companies, demand forecasting is the most difficult phase of spare parts management process.

**Inventory management**

Four companies out of five (companies A, B, D, E) adopt a quantitative inventory planning policy; in particular MRP and EOQ are the specific models used by firms.
Experience is the only one method for company C. Companies B and C use described inventory methods for every codes, while the other three companies (A, D, E) try to adopt a specific approach for different classes of spares, even if company A, that does not adopt any spares classification, defines the more critical codes in a not-structured way.

All the case companies except one (case B) hold safety stocks, especially for the more critical spare parts, in most cases resorting to experience.

In two cases (D, E) IT support is provided by the company ERP, while company A uses office automation systems and company B adopts a specific software for inventory management.

Finally, no case company adopt any kind of collaborative practices along the supply chain, either with suppliers or customers. Manufactures should manage stocks along the overall supply chain, but the picture that comes out from these cases suggests that manufacturers control only their warehouses, while from the other nodes of the supply chain only few piece of information come back.

**Comparison between theory and practice**

Literature review from one side, and case-based research from the other side, suggest a gap between the way companies actually perform spare parts demand and inventory management and the approaches proposed in literature. Table 2 summarizes the main elements of this gap.

<table>
<thead>
<tr>
<th>Process phase</th>
<th>Theory</th>
<th>Practice</th>
<th>Reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spare analysis and classification</td>
<td>Multicriteria approaches, linked with planning choices</td>
<td>Few criteria are used, with classes not strictly related with planning choices</td>
<td>• Wide range of managed SKUs • Inadequate IT support</td>
</tr>
<tr>
<td>Planning choices</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand planning</td>
<td>Demand regulation through specific actions and clustering approaches for demand forecasting</td>
<td>Demand as an external variables forecasted with simple time series method without a clustering approach</td>
<td>• Culture • Lack of specific skills • Complexity of theoretical models • Data unavailability • Inadequate IT support • Complexity of supply chain governance</td>
</tr>
<tr>
<td>Inventory planning</td>
<td>Collaborative inventory management with global information and centralized control of the supply chain</td>
<td>Simple inventory policy (EOQ, MRP), without any kind of collaborative approach with the other actors of the supply chain</td>
<td></td>
</tr>
<tr>
<td>Performance assessment</td>
<td>Integrated approach for demand and inventory management process, linked with general company objectives</td>
<td>Few indexes are assessed with a non-integrated approach and with a low level of formalization</td>
<td>• Inadequate IT support • Limited perceptions of possible benefits</td>
</tr>
</tbody>
</table>
Which are the main reasons of the gap between practical approaches and theoretical ones emerging from the case studies? From our point of view, it is possible to point out: a). **External reasons**, that include the complexity of theoretical models proposed in literature and the **supply chain fragmentation**, difficult to manage for manufacturers that are really far from their final customers; b). **Internal reasons**, which include a cultural problem (traditionally after-sales and spare parts logistics in the companies analyzed were less important functions and had less talented managers), deficiency of specific planning skills, directly related with models complexity, data unavailability, often linked with an inadequate IT support, and, as a last point, the wide range of SKUs to manage.

**Conclusion**

Inventory and demand management for spare parts is different than for components used in assembly of finished products, in reason of a larger variety (Cohen et al., 2006), an irregular or lumpy demand (Ward, 1978), a high responsiveness required, related to the cost of downtime (Lele, 1997), and, finally, a significant risk of stock obsolescence (Cohen et al., 2006). Although the subject of spare parts demand and inventory management is widely treated by scientific literature, which proposes several approaches and mathematical models, the managerial practice observed in the analyzed case studies (summarized in the discussion above), seems not to “keep the pace” with theory, lacking: i.) an integrated approach to demand and inventory planning; ii.) the use of sophisticated techniques and iii.) a supply chain information sharing approach and the related tools. Starting from this scenario, which are the possible levers that firms may adopt in order to improve the spare parts management process? The empirical research presented in this paper leads to some preliminary suggestions. First of all companies may work on the internal reasons highlighted above, focusing on a). specific training of human resources involved in the process, in order to bottom out culture and skills problems, b). the improvement of IT support, in order to collect and elaborate more data that come from field (i.e. installed base, reliability index), and finally c). the reduction of spare parts specificity through standardization of codes, in order to have more commonalities of codes in the range of models of finished products proposed in the market. In this way the complexity of management inventory process reduces and becomes lower also the risk of obsolescence.

A second major issue seems to be harder to overcome. Companies can reduce the problem related with supply chain fragmentation, trying to focus on collaborative practices with the other actors of the chain, with the objectives of a). improving information feedback from the field, and b). improving materials control along the supply chain, managing slow moving codes with a pooling policy supported by lateral transshipments and fast movers with a continuous replenishment approach, taking the full control of the overall spare parts management process.
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