SPARE PARTS CLASSIFICATION AND INVENTORY MANAGEMENT: A CASE STUDY

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Spare parts classification and inventory management: a case study

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Abstract

The aim of this paper is to propose and discuss a hierarchical multi-criteria spare parts classification method developed for inventory management purposes and tested through an intensive case study in an Italian household appliances manufacturing company. In particular, the classification scheme under concern is built on the basis of several key dimensions in an almost hierarchical fashion, resulting in 12 different classes of spare parts, for which varying forecasting and inventory methods are proposed and tested. The results of our simulation study demonstrate the reduction of the total logistics costs by about 20% whilst the service target level is achieved for each of the classes. Even more importantly, the proposed approach is simple and straightforward enough to be understood by company managers, thus increasing the probability of its adoption (in the same or similar form) in other real world settings.

Keywords. Spare parts management; Classification methods; Demand management; Inventory management, Case study.

Acknowledgments

1. Introduction

Trade of service parts for products like household appliances, automobiles and copy machines has grown into a business worth more than $200 billion worldwide (Gallagher et al., 2005). Spare parts inventories are required to be available at appropriate points within a supply chain, in order to provide after-sales services and to guarantee the achievement of pre-specified service targets (Botter and Fortuin, 2000). However, several factors render demand and inventory management for spare parts a very complex matter; among them: a) the high number of parts managed (Cohen and Agrawal, 2006); b) the presence of intermittent or lumpy demand patterns (Boylan and Syntetos, 2010); c) the high responsiveness required due to downtime costs by customers (Murthy et al., 2004); d) the risk of stock obsolescence (Cohen and Agrawal, 2006).

Research on spare parts demand and inventory management has developed rapidly in the recent years with new results implemented into software solutions because of the importance in practice. However, practical applications lag considerably behind the relevant theoretical propositions in this area. In particular, after-sales service and spare parts management in the context of durable consumer products (both as far as manufacturing and selling are concerned) is an area that has been traditionally overlooked (Cohen et al., 1997; Farris et al., 2005; Cavalieri et al., 2006; Cavalieri et al., 2008). As a result, the management techniques adopted are often not differentiated form the ones used for finished products or components used in production (Boylan and Syntetos, 2008).

Currently, companies' investments on spare parts management are tremendous indeed. For example, the Aberdeen Research group estimated the total market size for service parts management software at over $100 million in 2005 (Aberdeen Group, September 2005). However, still much needs to be done in this area. As pointed out by Boone et al. (2008), for instance, companies lack a system perspective and they suffer the weakness of supply chain relationships and the inaccuracy of demand forecasts.

The fact that a gap might exist in the domains of demand forecasting and inventory management between research and practice has been suggested also by other researches (Van Donk, 2001; Wagner, 2002; Sanders and Manrodt, 2003 and Perona et al., 2009). Wagner (2002) pointed out that "*despite half a century of impressive research on inventory modeling … companies have poor customer service despite excessive inventories,* p. 217" and that "*incremental mathematical inventory research is not likely to enhance practice,* p. 223". Such a gap exemplifies the need for case study research. However, the majority of contributions continue to focus on the development of new methods or techniques for spare parts management with little or no attention towards implementation related issues and empirical implications.

In particular, an important operational issue involved in the management of spare parts is that of categorising the relevant Stock Keeping Units (SKUs) in order to facilitate decision-making, i.e. select appropriate forecasting and stock control methods and set appropriate targets. This issue has been overlooked in the

academic literature although it constitutes a significant opportunity for increasing spare parts availability and/or reducing inventory costs. In a recent investigation that deals with inventory control related issues for spare parts, Dekker and Bayindir (2004) noticed that despite the huge literature, developed since the 1970s, dealing with this problem, very few studies are actually considering solution implementation and with few exceptions (Ashayeri et al., 1996; Botter and Fortuin, 2000; Boylan et al., 2008; Porras and Dekker, 2008) case studies are lacking.

In this paper, we are concerned with the design and testing of a simple hierarchical multi-criteria spare parts classification method the purpose of which is to facilitate inventory management and to enable the differentiation between planning choices according to spare parts specificities. The classification method is developed through an intensive case study of a European white goods manufacturer. Our contribution is two-fold: first we discuss in detail the construction of the classification framework and the process of spare parts management re-engineering allowing insights to be gained into pertinent managerial factors. Second, we evaluate the implications of such a framework in the same case study organisation enabling the linkage between process performance and process development.

The remainder of our paper is structured as follows: in the next Section the guidelines offered in the literature on spare parts classification are reviewed along with the few contributions in which industrial case studies are conducted. Section 3 describes the case study organisation and Section 4 outlines the development of the multi-criteria classification method. The utility of the proposed solution is empirically assessed in Section 5 while in Section 6 we point out the implications of this work for the Operations Management (OM) theory and practice. Conclusions are offered in Section 7 along with the natural next steps of research in this area.

2. Research background

In this section we first provide a critical review of the literature on issues related to spare parts classification (sub-section 2.1) followed by a review of empirical studies in this area (sub-section 2.2).

2.1. Spare parts classification: literature overview

Spare parts tend to be highly varied, with different costs, service requirements and demand patterns (Boylan and Syntetos (2007). Since most manufacturing organisations carry a large amount of items in stock (Cohen and Agrawal, 2006), a categorisation of spare parts stock keeping units (SKUs) should be performed to determine service requirements for different classes and for facilitating the allocation of the most appropriate forecasting methods and stock control policies.

Table 1 summarizes the academic literature concerned with classification related issues for spare parts management (see Bacchetti and Saccani, 2011). In total 25 papers were analysed, 18 of which have proposed

classification methods specifically developed for, or at least applied to, spare parts. The remaining papers (Williams, 1984; Flores and Whybark, 1988; Partovi and Anandarajan, 2002; Ramanathan, 2006; Chen et al., 2006; Zhou and Fan, 2006 and Ng, 2007) deal with intermittent demand items in general. (At this point we should note that spare parts are known to be characterised by slow or intermittent demand structures, thus the relevance of this latter part of studies to our research.)

Author(s)	Year	Mono criteria	Multi criteria	Criterion						Methodology			
										Quantitative		Qualitative	
				Part cost / value	Part criticality	Supply characteristics / uncertainty	Demand volume / value	Demand variability	Others	ABC	Other	AHP	Other
Gelders and Van Looy	1978	X					X			X			
Williams	1984	X						X			X		
Duchessi et al.	1988		X	X	X					X			
Flores and Whybark	1988		X		X		X			X			
Yamashina	1989		X					X	X Part reliability, Life cycle phase		X		
Ernst and Cohen	1990		X	X	X	X		X			X		
Petrovic and Petrovic	1992		X	X	X		X		X Part weight, Repair efficiency		X		
Gajpal et al.	1994	X			X							X	
Nagarur et al.	1994		X	X		X					X		
Huiskonen	2001		X	X	X			X	X Part specificity				X
Sharaf and Helmy	2001		X	X	X	X	X		X Life cycle phase			X	
Partovi and Anandarajan	2002		X	X		X	X			X			
Braglia et al.	2004		X	X	X	X	X					X	
Eaves and Kingsman	2004		X			X		X			X		
Syntetos et al.	2005		X					X			X		
Ramanathan	2006		X	X	X	X	X			X			
Zhou and Fan	2006		X	X	X	X	X			X			
Ng	2007		X	X		X	X			X			
Boylan et al.	2008		X					X			X		

Cavalieri et al.	2008		X	X	X	X		X	X Part specificity				X
Chen et al.	2008		X		X	X	X			X			
Chu et al.	2008		X	X	X					X			
Porras and Dekker	2008		X	X	X		X					X	
Persson and Saccani	2009		X	X	X	X	X		X Life cycle phase				X
Syntetos et al.	2009	X					X			X			

Table 1. Overview of the main contributions in the area of spare parts classification (from Bacchetti and Saccani, 2011)

From Table 1 is possible to notice that among the proposed criteria, the most popular ones are the part cost (unit cost or inventory cost) and the part criticality, both reported in 15 contributions. Other proposed criteria relate to supply characteristics such as the replenishment lead time, supplier availability and risk of non-supply (12 references), demand volumes or value (13 references) and demand variability (8 references). Finally, some more criteria identified in our literature review are: the part life cycle phase, reliability and specificity.

Table 1 also reports the classification techniques proposed by the reviewed studies. Such techniques may be categorised as either quantitative or qualitative in nature. With regards to the former category, item classifications based on traditional ABC approaches are suggested by 10 contributions. In addition, some papers propose a purely demand-based classification (Williams, 1984; Eaves and Kingsman, 2004; Syntetos et al., 2005; Boylan et al., 2008). Yamashina (1989) proposes the definition of product-still-in-use quantity curves and service part demand curves as inputs for spare parts classification. Nagarur et al. (1994) and Porras and Dekker (2008) propose a hierarchical 2 - (or 3 -) dimensional quali-quantitative classification. Finally, Ernst and Cohen (1990) apply the Operation Related Groups methodology, based on a clustering technique, while Petrovic et al. (1990) and Petrovic and Petrovic (1992) propose an expert system combining the determination of failure rates and fuzzy logic. In contrast with quantitative techniques, qualitative methods attempt to assess the importance of keeping spare parts in stock, based on information related to the specific usage of spares and to factors influencing their management (costs, downtime, storage considerations, etc.). Gajpal et al. (1994) propose a VED (vital, essential, important, desirable) classification model based on the use of the Analytic Hierarchic Process (AHP) procedure. Similar, although more articulated, are the approaches proposed by Sharaf and Helmy (2001) and Braglia et al. (2004). Finally, Huiskonen (2001) and Cavalieri et al. (2008), although they do define classification criteria, do not propose a specific technique for classifying spare parts according to the criteria under concern. They rather analyse, qualitatively, various requirements for the effective logistics management of a large variety of spare parts.

Bacchetti and Saccani (2011) observe that little attention has been paid to identifying the context in which one criterion may be preferable to others. This is a very important issue and one that has been under-exposed

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in the academic literature. (Boylan and Syntetos, 2008, for instance, suggest that part criticality seems more appropriate for technical systems rather than end-products used by customers.) In addition, studies that consider the comparative benefits of various approaches to classification (e.g. ABC vs. other techniques) are also lacking.

2.2.   Spare parts classification: industrial case studies

As pointed out in other academic contributions (Dekker and Bayindir, 2004; Nenes et al., 2010; Syntetos et al., 2010), very few papers propose and discuss the operationalisation of classification methods and offer managerial guidelines through industrial case studies. In fact, many among the papers analysed in Table 1 do not pay any attention to the practical applicability of the proposed classification techniques; aspects such as data availability, implementation algorithms, computational expense, classification update, solution sensitivity to threshold values or judgmental aspects are treated by a few papers only (Huiskonen, 2001; Boylan et al., 2008 and Syntetos et al., 2009). Moreover, only Gelders and Van Looy (1978), Nagarur et al. (1994), Eaves and Kingsman (2004), Boylan et al. (2008), Porras and Dekker (2008), Persson and Saccani (2009) and Syntetos et al. (2009) report classification solutions that have actually been adopted by companies. This shortage of empirical papers reflects a gap between theory and practice in the area of spare parts management, as discussed in Section 1.

In the remainder of this sub-section, we discuss in more detail some case studies selected due to the fact that they represent situations similar to the one addressed by this paper. Indeed, they deal with spare parts management in manufacturing companies servicing directly, or through a third party network, an installed base of durable products geographically dispersed (Nagarur et al., 1994; Kalchschmidt et al., 2003; Persson and Saccani, 2009; Syntetos et al., 2009), or wholesalers or distributors selling a large amount of items with irregular or lumpy demand to a large customer base (Nenes et al., 2010; Syntetos et al., 2010). Therefore, cases reporting spare parts and MROs (maintenance, repair and operations) materials management methodologies in a single company for its own production systems (e.g. Gelders and Van Looy, 1978; Gajpal et al., 1994; Porras and Dekker, 2008; Cavalieri et al, 2008) are not considered since they do not match the scope of this study. In fact, these cases refer to technical systems (rather than end-user products), and also to situations in which spare parts customers are internal to the studied organization (plants, production lines or equipment). In this kind of situations, spare parts management may rely on a very large amount of information available within the organization (e.g. fault history, equipment usage data) on the planning of maintenance activities and on a greater coordination and information sharing between the internal customers and the spare parts inventory managers. This situation is very different from the one related to the case study organisation that will be presented in section 3, dealing with durable consumer goods and a multi-echelon supply chain, as discussed above. The cases are summarized in Table 2.

Paper	Company	Classification	Demand and inventory management	Implementation effect
Nagarur et al. (1994)	Mainframe and PC distributor	Based on supplier criticality and part value (4 classes)	Fitting of three demand forecasting models Re-order point, economic order quantity for all classes	Inventory cost reduction
Kalchschmidt et al. (2003)	White goods manufacturer	No SKU classification, but demand filtering	SES for regular series and modified Croston (1972) for irregular ones Order-up-to levels	No actual implementation. Simulation showed reduced inventory levels
Persson and Saccani (2009)	Construction equipment manufacturer	Multi-criteria: lifecycle phase, criticality, demand volumes, competition	Differentiated for the various classes Vendor Managed Inventory (VMI) with European dealers	It was being implemented at the time of the study
Syntetos et al. (2009)	Consumer electronics manufacturer	ABC based on demand value	Differentiated forecasting and inventory management for the three classes	Improved order fill rate with significantly reduced inventory costs
Nenes et al. (2010)	Distributor of castors and wheels	No SKU classification, but demand distribution fitting	Forecasting according to a Gamma or Poisson demand distribution Periodic review inventory policy with order-up-to levels	Lower inventory costs. Obsolescence phenomenon addressed Higher visibility and awareness about the management process
Syntetos et al. (2010)	Industrial valves wholesalers	ABC SKU classification based on profit contribution	Syntetos-Boylan Approximation (2005) Reorder point, economic order quantity policy, with periodic review	Inventory cost savings of about 40% Aggressive write-off strategy for obsolete items

Table 2. Overview of the case study contributions

The papers in Table 2 report actual implementations of the described methods, with the exception of Kalchschmidt et al. (2003). This paper was nonetheless included in this review because it reports a case from the same industry we refer to (white goods), presenting the same supply chain characteristics (number of echelons, type and numerousness of customers and information-sharing problems).

Nagarur et al. (1994) designed a computer-based information system for spare parts inventory management purposes in a company selling mainframe and personal computers and their accessories. The company was also undertaking repairs and replacement of components (directly or through third parties), handling in inventory more than 20,000 SKUs. Prior to the solution development and implementation, inventory management was carried out manually, based on experience.

The researchers developed a SKU classification based on supply criticality and cost, resulting in four classes: A) parts procured overseas only, with high unit cost; B) parts procured overseas only, with medium-low unit cost; C) parts available locally, with high unit cost; D) parts available locally, with medium-low unit cost. The choice of the forecasting method for each SKU was performed by the system after testing the accuracy of three alternative methods, over past demand data. The methods were: i) a reliability-based forecasting method (based on reliability information of each SKUs, in-use quantities and age of items in use); ii) a regression method, that forecasts the demand of each SKU by regressing the demand on the number of finished product units in the market; iii) a moving average time-series method.

Subsequently, for each SKU, the system determines a re-order point and a re-order quantity. The re-order point is calculated by adjusting the average lead-time demand by factors related to the part value and criticality, the demand variability and supply uncertainty, according to a methodology termed as Business Factor Index (Hoyt, 1973). The re-order quantity is calculated based on the classical Economic Order Quantity (EOQ) model. The implementation of the information-based system in the company resulted in a significant reduction of inventory costs and in the improvement of the timeliness and quality of inventory-related information that facilitated improved management procedures.

Kalchschmidt et al. (2003) present a case study of a spare parts business unit of a major white goods manufacturer located in Italy. The case involves a multi-echelon supply chain, in which the direct company customers are not the final product users, but rather repair shops, importers, wholesalers and subsidiaries of the case company. Kalchschmidt et al. (op. cit.) emphasise the importance of customers' differences as a source of lumpiness. In fact, the different roles and sizes of the customers deeply affect the size and frequency of orders. The researchers suggest the disaggregation of the overall demand into two components: a stable component of demand, generated by many small orders which are continuous in time, and an irregular component, generated by few large orders that create sporadic peaks, as shown in Figure 1.

For the purpose of separating the two components of demand, they use a filtering system. Then, for the stable component of demand the use of Single Exponential Smoothing (SES) is proposed along with an order-up-to policy for inventory management. For the irregular part, instead, the authors develop an ad-hoc forecasting method based on Croston's method (Croston, 1972). In this case, the forecasts feed into an inventory control system, where a replenishment order is placed according to the forecast and to the probability of demand occurrence (i.e.. a replenishment order equal to the forecasted quantity is issued if the estimated probability of a demand peak occurrence in the lead time is higher than a threshold value).
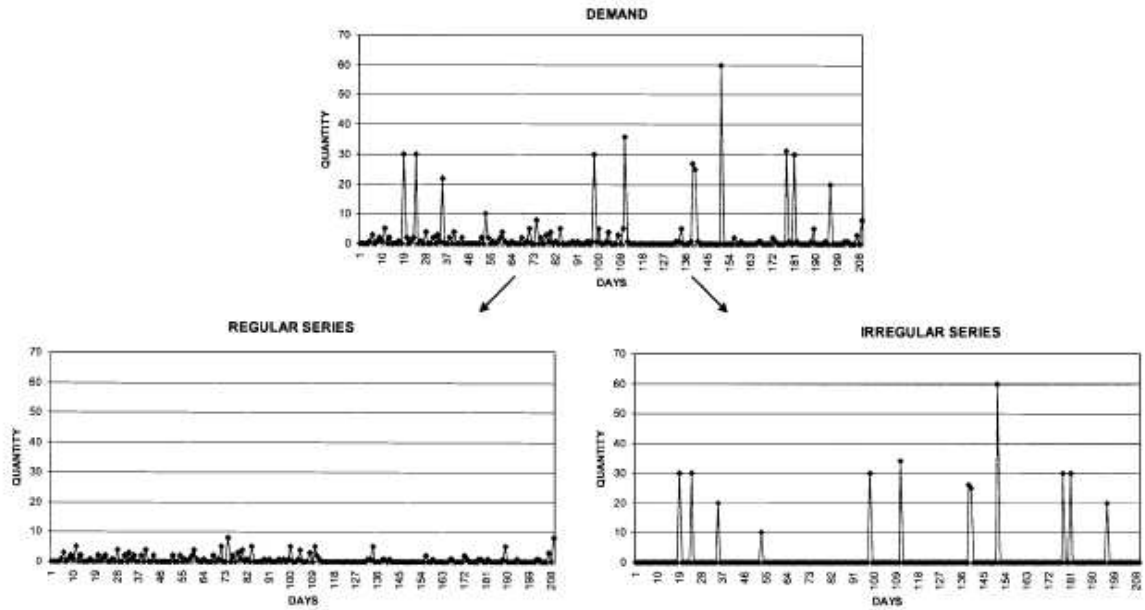
Figure 1. Disaggregation of demand components (adopted from Kalchschmidt et al., 2003)

Subsequently, a simulation study was performed comparing the new solution against the current situation in the company for two different service level targets. The simulation that was carried out over 1,214 SKUs, showed a reduction of the inventory levels by almost 75% and 69.5% for a target service level of 83% and 95% respectively. Finally, the authors also evaluated the possible benefits of advance demand information provided by the few large customers (mainly) responsible for generating the irregular part of the demand.

Syntetos et al. (2009) present a case study of the European spare parts logistics operations of a big Japanese electronics manufacturer. The firm distributes spare parts to the European market, supplying 13 European local warehouses. Each warehouse kept in stock 2-3 months of average demand and classification was taking place according to an ABC method by volume. Starting form this situation the company set up a project for the centralisation of stocks along with the reconfiguration of the demand management processes (focusing mainly on demand classifications related issues). The overall objective was to reduce logistics costs by 50% and increase considerably the hit-ratio (order fill rate) across Europe.

The proposed solution is implemented in 3 steps. The first step relates to spare parts classification. The proposed solution is very simple, performed essentially through a Pareto evaluation of the demand value, obtained as a combination of SKU cost and demand volume. The second step relates to the proposal of appropriate forecasting and inventory control methods. Before the project, the firm replenished spares using re-order points, supported by a 6-month moving average forecasting technique with judgmental adjustments. In order to differentiate the approach according to parts classification, in the new solution different review periods and forecasting models were defined, as shown in Table 3. For B items the forecasting method was selected by the information system based on a set of methods available and according to the minimisation of the MAD (mean absolute deviation). For C items a six-month moving average was selected.

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Category	Review period	Forecasting	Control method	Control processing
A	Week	Judgmental	Re-order point	Manual
B	Two weeks	System	Re-order point	Automatic
C	Month	Manually set	Re-order point	Automatic

Table 3. Forecasting & stock control for the spare parts classes discussed by Syntetos et al. (2009)

Although very simple in nature, the new spare parts classification scheme allowed the company to focus managerial attention to the new A class SKUs (reduced from more than 1,000 in the previous classification to 108) accounting for almost 80% of demand value. The implementation of the new method resulted in dramatic decrease of the inventory costs whilst service levels targets were met.

Persson and Saccani (2009) describe the case of one of the world's leading manufacturers of heavy equipment. A hierarchical multi-criteria spare parts classification method has been adopted by the company, based on:

- *Life-cycle phase of the related final product*: parts are grouped in four categories (*launch*, *prime*, *decline* and *phase out*) according to the number of years for which the final product is being manufactured, or the time passed since its production ended.
- *Volumes*: parts belonging to the prime, decline or phase out categories are classified as fast moving, medium, or slow moving, based on the demand of the previous year.
- *Criticality (high or low)* determining the required service level: three classes of critical parts exist (main components/subsystems, subcomponents and remanufacturable parts).
- *Competition*: this dimension is used only in the 'launch' lifecycle phase, in which volumes are generally low. 'Competitive' parts are the ones available also in the independent market or from competitors, for which a high service level is needed to compete in the market.

Lifecycle phase	LAUNCH	PRIME	DECLINE	PHASE OUT
Inventory policy	Re-order point (s) policy with safety stocks (s, Q): Q = the order quantity	Fast-movers: continuous review policy with safety stock and re-order point (96% to 99% target service level) Medium and slow movers: re-order point policy with safety stocks (90% - 94% target service level)	Medium and slow movers: re-order point policy with no safety stocks (back-orders are tolerated)	'Moving' Parts: Make-to-order or purchase-to-order policy, with no safety stock and re-order point equal to zero No-movers: not serviced

Table 4. Inventory management policies for the different spare parts classes in the case described by Persson and Saccani (2009)

The hierarchical combination of these criteria leads to 26 different classes (see Persson and Saccani, op. cit.). This 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, as summarized in Table 4.

The customers of the central warehouse(s) are some regional warehouses and the European dealers. The company decided that fast-moving parts with medium-to-low-value should be kept in stock at the dealers' premises or at the regional warehouses. For these parts, the replenishment is managed directly by the company through vendor managed inventory (VMI). For slow moving parts, dealers do not hold stock, thus urgent deliveries are required.

Nenes at al. (2010) present a case of a small Greek distributor of castors and wheels with a range of about 3,000 components, bought from 28 different suppliers. Nenes et al. (op. cit.) develop and apply an easy-to-use inventory control system for lumpy demand items. The authors move from the observation that, even if researchers may propose sophisticated methods to forecast or manage demand, in real contexts the methods utilised are limited to the implementation of a few basic and generic tools, such as traditional forecasting techniques or the computation of the economic order quantity. The inventory control system is based on a periodic review order-up-to level (S) inventory policy (R, S), the review period R depending on the supplier characteristics. The authors implement a decision support system based on the following steps:

1. Selection of data input for each SKU (review period, lead time, target fill rate, demand history);
2. Check for sufficiency of demand data: simple policies are proposed for SKUs with insufficient demand data;
3. Demand analysis: checking the goodness-of-fit of the Gamma and Poisson distributions (the former for faster-moving items and the latter for the slower-moving ones);
4. Search for demand data outliers;
5. Computation of base stock levels for each SKU policy and other characteristics (expected demand, coefficient of variation, average stock-on-hand).

The proposed decision support system is integrated within the company's information system. The effects of the project acknowledged by the company managers are:

- The rationalisation of the procurement procedures and a more systematic, objective and transparent stock management process;
- A better understanding of demand characteristics and relative importance of different SKUs;
- The identification of obsolete SKUs;
- The reduction of inventories, for a given service level;
- The reduction of urgent orders to suppliers and transportation costs.

Syntetos et al. (2010) address the case of a wholesaler of industrial valves. The company sells more than 2,000 SKUs which are primarily stored in the warehouse ready for dispatch. The company's supply base is

quite vast, given the wide range of items available in its catalogue. The planning system prior to the project was based on manual stock control, with a periodic re-order point type system. This procedure was not formalised and relied on the skills of one single person. For instance, the order quantity corresponded to the average demand over a number of weeks – the number not being readily available; similarly, the re-order points were arbitrarily specified, with new SKUs not even having a suggested re-order point. The new implemented solution described in the paper did include demand classification but only for the purpose of demonstrating to management the distribution of SKUs with regards to their contribution to profit as well as the tremendous opportunities that existed for scrapping a large number of obsolete SKUs. Since a considerable proportion of SKUs showed intermittent demand, the Syntetos-Boylan Approximation (Syntetos and Boylan, 2005) was used for demand forecasting; this was in conjunction with a periodic re-order point (s) order quantity (Q) (s, Q) policy that matched, conceptually, what was previously in place, but obviously through a rigorous and much more formal application. The application of the new methodology (for a target service level of 95%) led to expected inventory-related cost savings of about 40%. That beneficial performance was accompanied by the introduction of an aggressive write-off strategy for obsolete SKUs that was perceived of equal importance by the management of the company to the very new procedures.

In summary, the literature review presented above indicates that simple but carefully designed and well-informed solutions for spare parts may offer substantial benefits in terms of cost reduction, service level improvement and increased transparency of the inventory management methods. This further demonstrates the previously discussed discrepancy between theory and practice of spare parts management according to which the latter follows considerably behind the former.

3. The case study organisation

The case study presented in this paper refers to the spare parts business unit of one of the main European white goods manufacturers, whose headquarters are in Italy. The company sells and delivers white goods appliances and spare parts all over the world, and the business unit provides after-sales services, warranty management, spare parts distribution and repair services, through several external repair centres.

Prior to this project the company was not adopting a structured approach to spare parts management and most planning activities were executed in a non-formalised fashion. Therefore, the aim of our intervention was to evaluate a wide range of potential improvements in spare parts management through:

- The development of a sound methodology specifically related to spare parts but that would be easy enough to be understood and implemented by management;
- The measurement of the benefits achieved through the potential adoption of the new methodology.

The expected outcome of the intervention was the identification of a practical and cost-effective way of managing spare parts, for the case company considered. The re-engineering of the current management process may be divided in three different phases: i) spare parts classification; ii) demand forecasting, and iii) inventory management.

3.1. Current scenario

The spare parts distribution logistic network of the company is arranged on two levels, as shown in Figure 2. The main spare parts warehouse is located near Milan, next to the company's headquarters. It supplies parts to all over the world, through a complex network of subsidiaries, importers, wholesalers, and repair centres located close to end customers in the different markets. The central warehouse supplies directly 3 different kind of customers: i) three subsidiaries located in Spain, France and UK; ii) importers and wholesalers all over the world (more than 700 during the last 5 years); iii) repair centres all over the world (more than 3,500 during the last 5 years). Our study focuses on the main warehouse, since the long term objective of the company is the centralisation of the spare parts' distribution. At that location the company manages about 90,000 different SKUs. However, during the last 5 years only about 40,000 SKUs were sold.
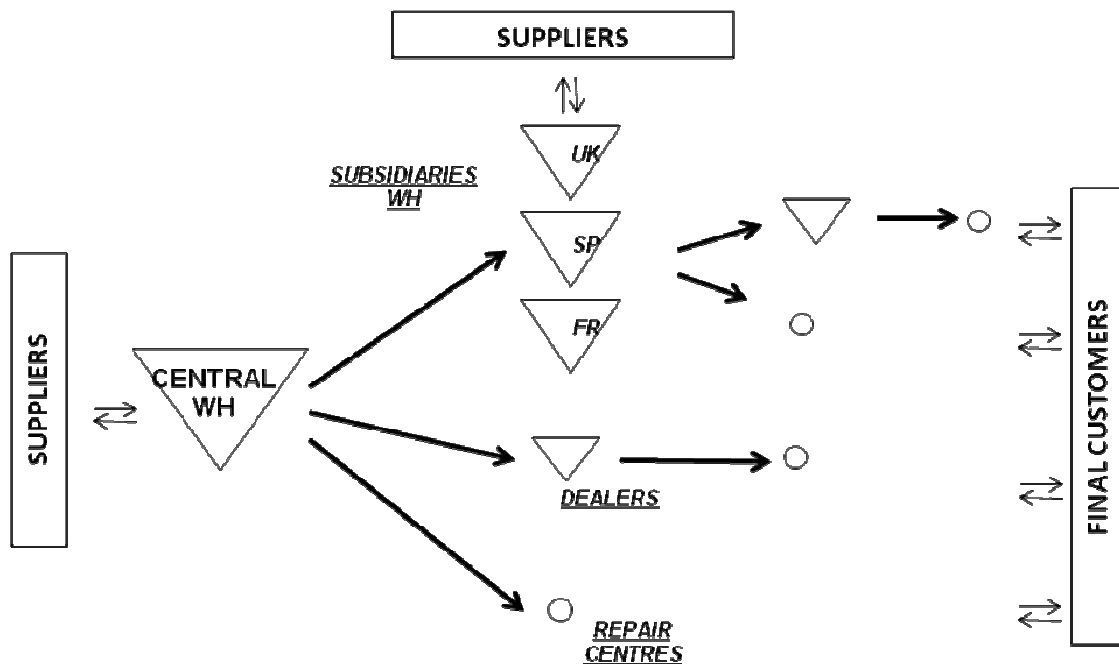

Figure 2. The service network of the case study organization

The planning mechanism before the implementation of this project was the following. Parts' planning was carried out twice a month, through the support of a software solution that is not integrated with the Enterprise Resource Planning (ERP) system utilised by the company. All the parts were managed in the same fashion (i.e. no classification modelling was in place). The only differentiation criterion was technology oriented and

grouped together all the components with the same functionality. However, this clustering bears only a little relevance to logistics priorities and requirements. As a consequence, forecasting approaches were also non-differentiated; they were based on Single Exponential Smoothing (SES) that nevertheless is known to suffer from bias related problems in the context of intermittent demands (Croston, 1972) such as those underlying the spare parts considered in our case. With regards to stock control, demand data and current stock levels were utilised (in a black box fashion as far as the inventory managers were concerned) for the purpose of proposing purchasing quantities. Table 5 summarises the main aspects of the pre-project management process, in order to underline possible opportunities for improvement.

INVENTORY RELATED ISSUES	DESCRIPTION
Classification	Undifferentiated approach to demand forecasting and inventory management. Planning through manual controls
Target / performance assessment	Not formalised
Information sharing	Absent, both with subsidiaries and customers
Information management	Manual control of data

Table 5. Main inventory management characteristics before the development of the case study

4. Solution development

In this section we discuss the development of our proposed solution. First, we elaborate on the methodology utilised for the purposes of our research. Subsequently, issues related to SKU classification are discussed and a relevant scheme is developed that captures a number of important criteria. This is followed by the selection of appropriate forecasting and stock control methods for each of the resulting categories.

4.1. Working framework

The proposed approach constitutes a multi-criteria classification scheme that suggests how to forecast demand and how to manage inventories for each of the resulting categories. First an appropriate framework is developed that provides a range of options in terms of forecasting and stock control for each of the resulting categories. This is followed by a simulation study that aims at the formal comparison of possible candidate solutions for each class for the purpose of selecting one. This is linked to performance measurement for each of the classes expressed in a number of Key Performance Indicators (KPIs). Finally, another simulation exercise is performed that assesses the empirical utility of the proposed solution and analyses its comparative benefits with regards to the current practices employed by the case study organisation. In this section we solely focus on the construction of our solution whereas its empirical performance is analysed in the next section. In some more detail our methodological approach is as follows:

I. Framework development

- *Specification of a hierarchical multi-criteria classification model for spare parts management*. It is necessary to identify and select all the dimensions/criteria that may influence logistics-related choices about forecasting and inventory management. The hierarchical combination of these dimensions constitutes the classification method. The application of the classification method allows parts to be clustered in homogeneous classes of items.

- *Specification of the forecasting method – inventory policy combination*. For each class it is possible to select from more than one possible approach that, from a theoretical point of view, should be expected to lead to a good stock control performance.

II. Simulation study

- *Selection of the best suited policy for each class according to a simulation of different alternatives*. When many policies are theoretically viable, a choice is being made by means of simulation that compares performance for various KPIs as well as the costs and benefits associated with each policy.

- *PART→CLASS→POLICY association*. This phase addresses the association of each spare part with one specific class and subsequently a specific forecasting method and inventory policy, both in terms of model and parameters setting.

III. Analysis of performance

- The last part of our project (outlined in the next section) consists of a comparison, conducted through simulation, between the current performance and the one resulting from the proposed approach; this allows the quantification of the overall expected benefits.

Our approach is graphically depicted in Figure 3. The (sub)section where each of the phases of our project is explicitly considered is also indicated.
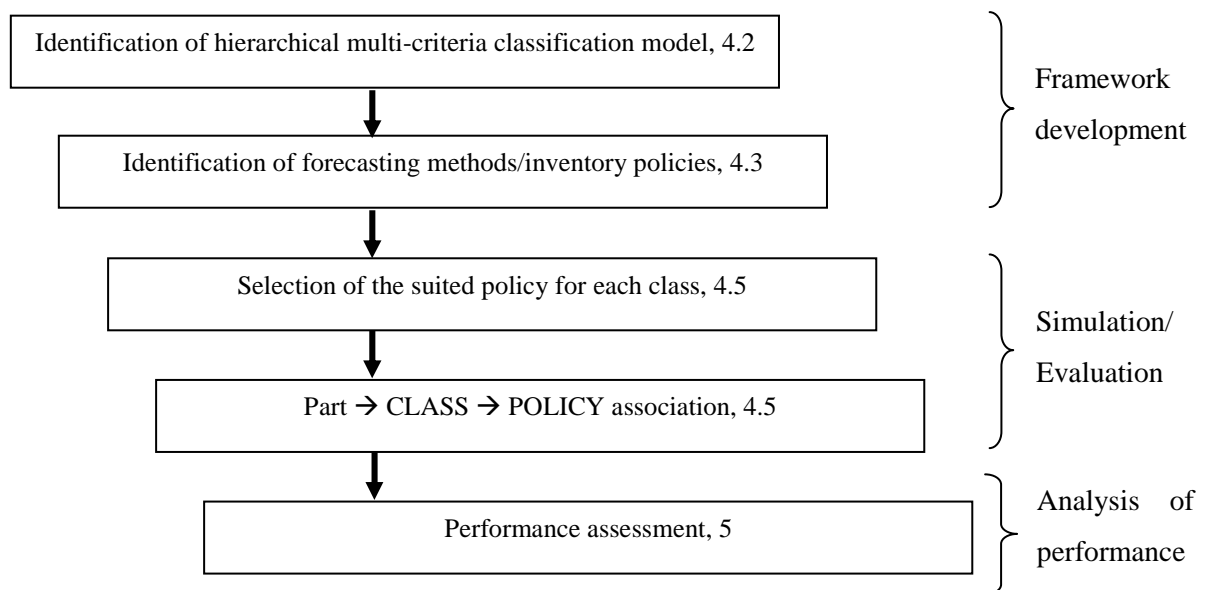

Figure 3. Working framework

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4.2. SKU classification

The proposed classification method originates on the premise that the underlying demand pattern is a major determinant of the logistics requirements of a spare part. Demand classification has been shown to link directly to forecasting and stock control decision making; in particular the average inter-demand interval (or correspondingly the frequency of demand occurrence) and the variability of the demand sizes (when demand occurs) – typically expressed through the squared coefficient of variation of the sizes – have been shown to be important from a theoretical point of view (Syntetos et al., 2005). However, Boylan et al. (2007) showed by means of experimentation on a large empirical database of a software manufacturer that the latter criterion may not necessarily be important in an empirical setting. On the contrary, the average inter-demand interval not only is relevant in real world practices but is also a very insensitive criterion with regards to the cut-off value assigned to it.

Following discussions with the company the demand pattern analysis relied on a 2-year history and the consideration of weekly and monthly time buckets as an alternative to the currently employed bi-weekly reviews. With regards to the length of the series that became available to us, two years was judged to be long enough to appreciate variability related issues while taking into account the fast changing environment of the Industry under concern. However, for several parts the analysis of the corresponding demand patterns cannot be carried out since there is not sufficient history. This may be due to several reasons such as the recent introduction of an item, its dismissal or a very few number of overall orders received. In this last case (and as it will be discussed later in more detail) we adopt a purely reactive approach without parts demand forecasting. Moreover, further discussions with the company's managers revealed, as expected, that other factors (such as the target service levels or the safety stocks) may considerably influence logistics decisions. Consequently, the demand pattern analysis need be supplemented by other criteria. Such criteria, along with their cut-off values (where applicable) have been decided after consultation with the company's management and they are outlined in Table 6.

CRITERION	LOGISTIC CONSEQUENCES / EFFECTS	ALTERNATIVES	THRESOLD VALUES
Sales cycle phase	Demand forecasting; Inventory management	Three phases: *Introduction*; *In-use*; *Dismissed*	6 months from the first order -18months from the last orders.
Response lead time to customers	Stock – Non stock decision making	> or < replenishment LT	Variable
Number of orders	Stock levels	They may be deemed as: *Sufficient*; *Not sufficient* for the purpose of evaluating a pattern in terms of demand frequency	3 orders received during the last 2 years
Demand	Demand forecasting;	*High frequency* (fast);	Average Demand Interval

frequency	Inventory management	*Low frequency* (intermittent)	(ADI) value according to Syntetos et al (2005) (ADI = 1.32) evaluated during the 2-years demand history.
Part critically	Service level → Safety stocks	*Aesthetic*; *Functional*	Classification based on company's input. Data available to us allows the separation of the parts according to their relevance in the finished product's functionality.
Part value	Stock levels; dimensioning of purchasing and inventory management parameters (e.g. order-up-to level quantities)	*Low*; *High*	5 €

Table 6. Criteria employed in the proposed classification scheme

These criteria are subsequently discussed in more detail.

1. Sales cycle phase. Sometimes the evaluation of the underlying demand pattern is not possible or is not useful. In the presence of a new spare part (spares for recently introduced products or new spares for existent products), historical information is obviously not available and this suggests the utilisation of a forecasting approach that is not based upon a time series model but rather on causal techniques. Similarly, when the demand series consists only of zero demands, demand pattern analysis is not relevant. In terms of the sales cycle phase (Figure 4) an item is considered to be in the *Introduction* phase when the interval between the moment of evaluation and the moment in which the first customer order was received is shorter than 6 months. On the other hand, when the time between the evaluation instance and the receipt of the very last order is larger than 18 months the spare part is classified as *Dismissed* (since demand in the last 18 months or more has been zero). All the other parts are classified as *In-use*. The criterion of sales cycle phase is relevant (as it will be discussed later) both in terms of demand forecasting and purchasing /inventory management.
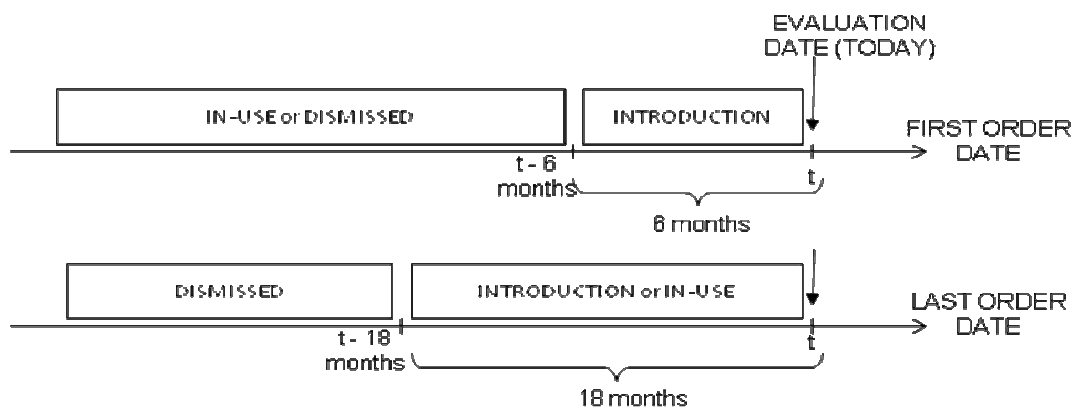

Figure 4. Sales cycle phase considerations

2. Response lead time to customers. This criterion affects the decision of keeping or not inventory for a particular spare part. That is to say, the main component of delivery lead time (LT) is represented by the replenishment LT (lead time of receiving an order placed to the suppliers). As such, when the response LT is larger or equal to the replenishment LT it is not necessary to keep inventories. The company's suppliers are located all over the world and the replenishment LTs are on average 1 month for Italian suppliers and 3 months for other non-European suppliers. Because on average the response lead times are less than 3 days for repair centres and about one week for subsidiaries, it is evident that is necessary to respond to demand from what is available in stock. For these reasons it is only for some dismissed parts that the company suggests the possibility of satisfying demand from order; in these cases the quantification of the customer service level is not relevant. As it will be discussed later in this paper, these items are very few indeed. In the remainder of the paper, when we refer to service level requirements for dismissed spare parts we imply that demand is to be satisfied from stock.

3. Number of orders. For some items customer requirements arrive very sporadically. Consequently, it is possible that some spare parts are demanded only once or twice over the period of several years. In these cases a time series forecasting method may not be used and only a totally reactive approach is possible. The threshold value for this criterion is set to 3 orders during the demand history; this follows from the minimum number of demand occasions required to calculate an Average Demand Interval (ADI).

4. Demand frequency. Boylan et al. (2007) showed by means of experimentation on the system employed by a software manufacturer that the ADI criterion is a very robust one for differentiating between alternative demand patterns. The researchers demonstrated, empirically, the insensitivity of the ADI cut-off value, for demand classification purposes, in the approximate range 1.18–1.86. In this work the ADI cut-off value is set to 1.32 review periods following the work conducted by Syntetos et al. (2005). For each eligible item the ADI value is calculated considering the last 2-years of the demand history. This criterion has important implications both for forecasting and stock control.

5. Part criticality. The functionality of a spare part determines its criticality and this affects the service levels offered to customers. In particular, the company makes a distinction between aesthetic and functional parts (more critical), and asks for different service levels and safety stocks for the two categories.

	INTRODUCTION		IN – USE		DISMISSED (CLASS 11)	
	Functional	Aesthetic	Functional	Aesthetic	Functional	Aesthetic
Target service level (service hit ratio)	95%	95%	95%	90%	90%	90%

Table 7. Parts' criticality related targets in relation to the sales cycle phase

This criterion affects the setting of a target service level expressed, following the company's suggestions, in terms of the *service hit ratio*; that is the percentage of orders satisfied directly from stock in hand. As it is shown in Table 7, the company wants to assure different hit ratios for differing functional purposes and life cycle phases. Also, and as discussed above, the application of a target does not concern all the dismissed items.

6. Part value. The cost of an SKU influences the overall inventory holding cost. The unit part value is used in order to dimension the parameters of order-up-to (OUT) level policies: for high value parts the OUT level is lower than that set for low value parts.

No other criteria are explicitly considered at this stage for classification related purposes. Such a decision reflects the number (and nature) of criteria that management would feel comfortable with. Other important factors such as the supply lead time and its variability and the demand variability will be further considered in the calculation of safety stocks, when such an exercise is required.

Having selected the criteria that collectively (between the company's management and the researchers) are judged to be the most appropriate for the purpose of classifying spare parts, those are then applied hierarchically in order to define homogeneous classes of items. The result is a hierarchical multi-criteria classification model; in particular the model presents the combination of the six relevant dimensions, allowing the identification of 12 spare parts management classes, as it is shown in Figure 5.
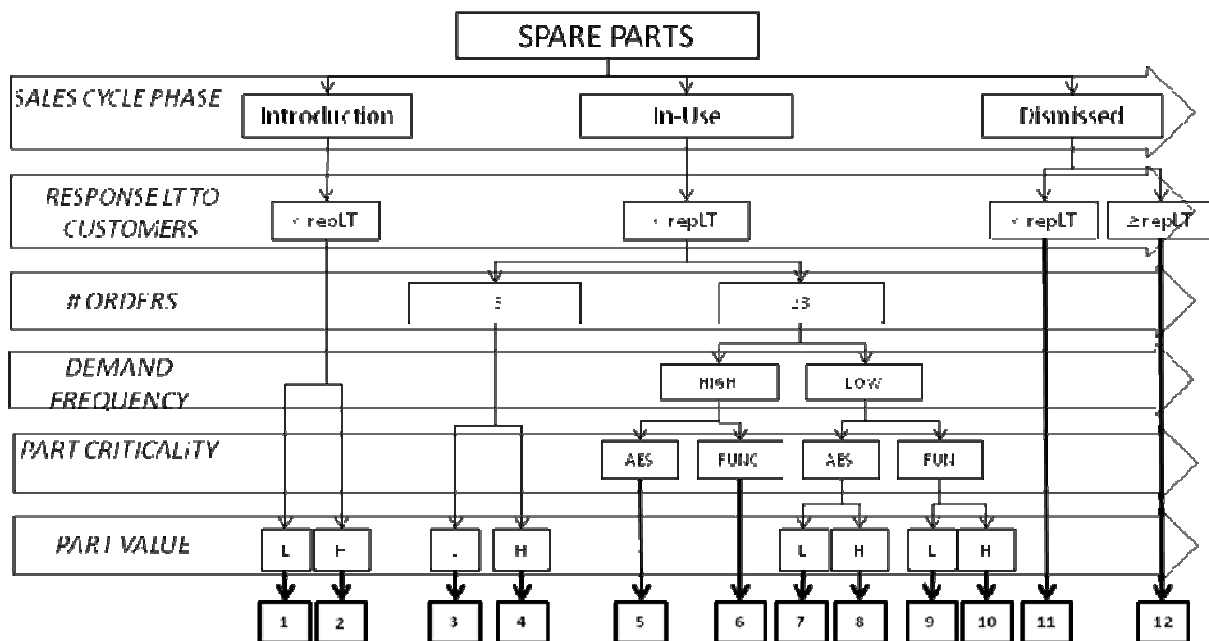

Figure 5. The proposed classification model

Looking at the classification solution, it is possible to notice that not all criteria affect necessarily the final proposed classes. For instance *Introduction* codes are characterised by definition by a very low number of orders. Therefore, neither the number of orders nor the demand frequency is considered. Similarly the part criticality is also not taken into account since the company opted for a set target service level of 95% for every SKU in this category regardless of its *aesthetic* or *functional* usage (see also Table 6).

For *In-use* spare parts with an overall number of orders lower than 3, the suggested management policy is based on a reactive dimensioning of the inventory and does not consider the use of safety stock that could not be dimensioned because of the data shortage; subsequently part criticality (that affects decisions on safety stock dimensioning) becomes also irrelevant. For *In-use* high demand frequency parts it is shown later in the paper that the preferred way of managing orders is the fixed EOQ model; in that respect the impact of the *part value* is not further considered.

For the *Dismissed* spare parts, as for the *Introduction* ones, is not feasible to analyse the demand pattern, since no demand has been recorded in, at least, the last 18 months. Moreover, and as it will be discussed later in the paper, the OUT level of these items is not influenced by the part value and the target service level is set to 90% for every SKU regardless of its functional usage.

4.3. Demand and inventory management related issues

The application of the criteria presented in Figure 5 leads to the identification of twelve SKU classes. Subsequently, forecasting and stock control related issues are addressed for each of the resulting categories. At this point it is important to note the following. It has been argued (Syntetos et al., 2005) that SKU classifications for forecasting and stock control purposes are often conducted in a non-intuitively appealing way. That is to say, if the purpose of the classification exercise is to select appropriate policies then the proposed categories should be the outcome of a formal comparison between the candidate policies as opposed to first classifying SKUs and then selecting policies per category. Although this is methodologically a valid argument in the context of a few classification criteria and resulting categories it obviously becomes an infeasible task in contexts similar to the one analysed in this work.

For *Introduction* items (classes 1 and 2) the absence of demand history prevents us from adopting time series forecasting methods. Moreover, the fact that new spare parts are most probably needed for recently introduced products a high service level is required, necessitating the satisfaction of customers from stock, even if the demand may be particularly low and sporadic. Consequently, the suggested approach consists of satisfying demand from stock dimensioned by the use of a causal forecasting method which is based on the demand rate (calculated as the rate between spare parts demand and finished products' demand) of a similar

component, employed on similar product models with a longer demand history[1]. For purchasing and inventory management purposes a periodic re-order point (*s*) OUT level (*S*) (*s*, *S*) policy has been proposed with a 2-week review period[2]. *S* is differentiated according to the unit value of the part (expected demand during one year for low value parts and during 6-months for high value parts; the selected time period was the outcome of preliminary simulations not reported here). For these items is very important to assure a high service level; at the same time, data shortage does not allow the calculation of an effective safety stock so our proposition was to set the re-order point *s* as the double of the expected demand during the replenishment LT.

For all the parts classified as *In-use* (classes 3 to 10), high target service levels and the relationship between replenishment and delivery lead time necessitate the satisfaction of demand from stock. For *In-use* codes with insufficient demand data (classes 3 and 4), the proposed solution consists of a periodic (*T*, *S*) policy, with *T* being 1 month and *S* being set as the average required quantity (calculated during the last 2 years) for high value spares and the maximum demand over the same time period for the low value items. For these codes no safety stock is proposed since this is viewed as not necessary considering the very low number of demand orders.

For *In-use* codes characterised by high demand frequency (classes 5 and 6) there are 3 possible approaches:

1. Demand satisfied from stock with an inventory management policy of the (*T*, *S*) form (monthly updates) where *S* is calculated based on SES (monthly updated) forecasts and the safety stock is determined based on the forecasting error variability and the target service level. Demand was assumed to be normally distributed – no other distributions were considered and we return to this issue in the last section of our paper where the limitations of this work are discussed;

2. Demand satisfied from stock with an inventory management policy of the (*T*, *S*) form (monthly updates) where *S* is calculated based on the average monthly demand over the previous 2 years and the safety stock is determined based on the demand quantity variability and the target service level;

3. Demand satisfied from stock with an inventory management policy of the periodic (s, Q) form based on a weekly review period and a fixed *s* specified based on the demand variability over the last 2 years and the target service level. The long term (annual) demand for calculating the Economic Order Quantity (EOQ) is forecasted through a moving six-month aggregate demand estimate. In

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[1] These are components with the same functionality, employed on similar finished product models with a longer demand history. The company's dataset available for our research purposes contains information that allows to group together all the spare parts with the same function for the household appliances (for instance there is a code that identifies all the dishwasher timers).

[2] Before the development of this project, and as it was discussed in section 3, the company planned all the replenishments periodically twice a month. Our intervention took this factor into account planning for the minimum possible disruption into current operations, i.e. we have opted for not altering the review period unless this was judged to be particularly important, as in the case of In-use codes for example. Moreover, continuous review systems have not been considered as possible candidates at all.

calculating the EOQ quantity for each part, it became evident that for very low unit value parts the economic order quantity could be considerably larger than (by approximately 4 or 5 times) the annual average demand. In a variable context as is the spare parts one, keeping in stock a high quantity of a particular spare increases the risk of obsolescence. In order to minimize this risk, and following the company's suggestions, we decided to use as the OUT level the maximum value between the EOQ and the average demand during the last 18 months.

For *In-use* codes characterised by low demand frequency, i.e. high intermittence (classes 7, 8, 9 and 10), the three following approaches have been considered:

1. Demand satisfied from stock with an inventory management policy of the (*T*, *S*) form (monthly updates) where *S* is calculated based on Croston's method (monthly reviewed) forecasts and the safety stock is determined based on the forecasting error variability and the target service level assuming normally distributed demand;

2. Demand satisfied from stock with an inventory management policy of the (*T*, *S*) form (monthly updates) where *S* is determined based on the assumption that demand is Poisson distributed (with a rate being equal to the average demand over the last 2 years);

3. Demand satisfied from stock with an inventory management policy of the (*T*, *s*, *S*) form (monthly updates) where *S* are calculated in a different way for low and high value parts. Following the results of some simulations not reported here, *S* is set for the high value parts as the average demand during the last 4 months; for the low value parts the average yearly demand is used instead. In both cases the safety stock is calculated according to the demand variability and the target service levels.

Finally, for *Dismissed* parts, the service level target is universally set to 90%, i.e. is generally lower than that considered for the classes discussed above and as such we evaluate the possibility of satisfying demand from order (class 12). Class 12 groups all the spare parts that presumably are not necessary to keep in stock; in these cases the company assumes that it is possible to satisfy demand from order without evaluating any service level targets. For *Dismissed* parts belonging to class 11 instead, the company sets target service levels, so the proposed solution consists of a (*T*, *S*) policy: *T* being set to one month and *S* being calculated based on the assumption of Poisson distributed demand.

As it was previously discussed in this sub-section one of the main problems characterising spare parts management is the issue of obsolescence; consequently the related costs constitute a major determinant of the total logistics costs in this context. Unfortunately, in this project the issue of obsolescence has not been explicitly addressed. It was implicitly taken into account when suggesting the calculation of the various inventory parameters (e.g. for the *In-use* codes of classes 5 and 6 we decided to introduce as the OUT level the maximum value between the EOQ and the average demand during the last 18 months) but explicit consideration of such issues was left as an area for further research (next steps of intervention) and this is further discussed in the last section of the paper.

4.4. The distribution of the spare parts among the classes

The data that became available to us constitute the demand history of approximately 26,000 SKUs. The data available cover the period June 2006 – June 2009. The first 2 years was utilised, as previously discussed, for obtaining the series descriptive statistics and initial analysis purposes whereas the remaining year was used as the out-of-sample period for simulation purposes (see sub-section 4.5 and section 5). The distribution of our sample SKUs among the different classes is outlined in Table 8. The distribution of the parts among the classes is presented by the number of the relevant codes, their sales value [€] and volume [units].

SALES CYLCE PHASE	INTRODUCTION		IN-USE								DISMISSED		TOTAL
CLASS	1	2	3	4	5	6	7	8	9	10	11	12	
Number of spare parts	1,570	827	4,443	1,819	1,064	3,772	2,098	678	5,484	2,006	2,110	107	25,978
	6.0%	3.2%	17.1%	7.0%	4.1%	14.5%	8.1%	2.6%	21.1%	7.7%	8.1%	0.4%	100%
	2,397		6,262		15,102						2,217		25,978
Sales value [€] during last 2 years	45,317	188,022	152,370	213,392	2,638,885	24,481,152	264,915	325,032	624,021	1,754,089	108,488	2,482	30,798,165
	0.1%	0.6%	0.5%	0.7%	8.6%	79.5%	0.9%	1.1%	2.0%	5.7%	0.4%	0.0%	100%
	233,339		365,762		30,088,094						110,970		30,798,165
Sales volume [unit] during last 2 years	11,667	5,258	88,371	7,428	531,457	3,452,914	54,177	8,740	196,455	51,309	10,241	210	4,418,227
	0.3%	0.1%	2.0%	0.2%	12.0%	78.2%	1.2%	0.2%	4.4%	1.2%	0.2%	0.0%	100%
	16,925		95,799		4,295,052						10,451		4,418,227

Table 8. Descriptive statistics for the various classes of SKUs

4.5. The selection of appropriate policies for in use parts with at least 3 demand orders

In order to select the most appropriate inventory approaches for classes 5, 6, 7, 8, 9, and 10, a simulation study was carried out the objective of which was to compare the performance of the alternative policies suggested in the previous section. The simulation was conducted using Microsoft Office Excel and the code was written in Visual Basic (embedded in the Excel version). We focus on a sample of the SKUs available to us and performance of the various policies is examined over the out-of-sample period of 1 year (July 2008 - June 2009). The selected number of SKUs per class was not derived based on statistical sampling techniques but rather it was the outcome of discussions with the company's management.

We evaluate in a dynamic fashion what would have happened if any of these policies had been applied in practice in real terms. According to the criticality classification of each item and the target service levels, the simulation identifies the policy (per class) that meets the target CSL at the minimum inventory costs: inventory holding costs (average inventory costs per period = average positive inventory on hand *x* cost per unit *x* inventory holding charge) and ordering costs (total number of orders multiplied by the cost per order). An inventory holding charge of 6% was viewed as a realistic representation of the current situation in the case study organisation; the same charge was assumed for all inventory classes. The cost per order was assumed to be fixed at 4 €/order, again regardless of the SKUs being dealt with. Backordering costs have not

been considered since the company was not in a position to estimate their economic impact. Inclusion of such costs was viewed as potentially distorting the 'final picture' rather than adding any value in our analysis.

Consequently, the outcome of the simulation is summarised through: i) the *service hit ratio* – the average service level achieved across all SKUs in a particular class (without implying than the target is necessarily met for each single SKU; ii) the total inventory costs per class.

Table 9 summarizes the simulation results for classes 5 and 6; Table 10 summarizes the relevant results for the remaining classes considered in this part of our research.

CLASS	# SAMPLE PARTS	TOTAL # PARTS	Part criticality	Target Fill rate %	*(T, S) policy fixed re-ordering time T=1 month*				*(T,S) Policy, S=monthly forecasted quantity with SES method*				*Fixed re-ordering point EOQ, weekly discontinuous control, (EOQ upper bound=average demand during 18 months)*			
					Achieved hit ratio %	*Inventory holding costs [€/year]*	*Orders generation costs [€/year]*	*Overall costs [€/year]*	*Achieved hit ratio %*	*Inventory holding costs [€/year]*	*Orders generation costs [€/year]*	*Overall costs [€/year]*	*Achieved hit ratio %*	*Inventory holding costs [€/year]*	*Orders generation costs [€/year]*	*Overall costs [€/year]*
5	451	1,064	*Aest*	90%	94%	3,800	14,665	18,465	90%	2,000	16,933	18,933	97%	3,051	2,807	5,858
6	370	3,772	*Funct*	95%	93%	11,569	13,556	25,125	90%	6,473	14,948	21,421	96%	6,689	3,841	10,531

Table 9. Simulation results – selection of the most suitable management policy for classes 5 & 6

The simulation results suggest that for classes 5 and 6 (*In-use parts with high demand frequency*) the most cost-efficient management policy consists of a fixed periodic (weekly) re-ordering point Economic Order Quantity, with safety stocks dimensioned according to target service levels and based on a long time (6 months) aggregate forecasting Moving Average process. The choice of the averaging method relates to the lower forecast errors reported in our preliminary analysis/simulation in comparison with the SES estimator.

For In-use low and high demand frequency parts, on the contrary, the best policy appears to be the periodic (*s*, *S*) one with a monthly review period. It has to be noted that for the high value parts the (*T*, *S*) policy appears to offer comparatively higher achieved service levels (at the expense though of considerably higher inventory related costs). However, in both cases the target service level is either met or exceeded and, as such, the (*s*, *S*) policy is preferred since it leads to lower costs.

MACRO-CLASS	# SAMPLE PARTS	TOTAL # PARTS	Part criticality	Part value	Target Fill rate %	(T,S) Policy, S=monthly forecasted quantity with Croston's method				(T,S) Policy, S=Poisson quantity				(s, S) Policy, differentiated for part value			
						Achieved hit ratio %	Inventory holding costs [€/year]	Orders generation costs [€/year]	Overall costs [€/year]	Achieved hit ratio %	Inventory holding costs [€/year]	Orders generation costs [€/year]	Overall costs [€/year]	Achieved hit ratio %	Inventory holding costs [€/year]	Orders generation costs [€/year]	Overall costs [€/year]
7	158	2,098	Aest	L	90%	87%	91	1,883	1,974	95%	126	2,130	2,256	96%	204	480	684
8	213	678	Funct	H	90%	87%	487	2,046	2,533	98%	1,017	2,354	3,371	96%	857	1,214	2,071
9	169	5,484	Aest	L	95%	85%	45	2,042	2,086	94%	77	2,328	2,404	96%	112	660	772
10	199	2,006	Funct	H	95%	88%	1,108	2,108	3,216	96%	1,757	2,737	4,494	95%	1,835	1,263	3,097

Table 10. Simulation results – selection of the most suitable management policy for classes 7, 8, 9 & 10

Considering the simulation results presented above and the analysis conducted in sub-sections 4.2 and 4.3, Table 11 outlines the policy proposed for each class of items.

CLASS	SALES CYCLE PHASE	RESPONSE LEAD TIME TO CUSTOMERS	# DEMAND ORDERS	DEMAND FREQUENCY	PART CRITICALITY	PART VALUE	PROPOSED POLICY
1	INTRODUCTION	< replenishment LT	Not evaluated	Not evaluated	Not evaluated	Low	Demand satisfied from stock. Causal demand forecasting, using demand rate of the same functionality components. No safety stock. Inventory policy (s, S) with S = yearly average demand, s = 2*average D during LT. Bi-weekly review period.
2						High	Demand satisfied from stock. Causal demand forecasting, using demand rate of the same functionality components. No safety stock. Inventory policy (s, S) with S = 6 months average demand, s = 2*average demand during LT. Bi-weekly review period.
3	IN-USE	< replenishment LT	Not enough (<3)	Not evaluated	Not evaluated	Low	Demand satisfied from stock. Policy S without safety stock, with S = max required quantity during the last 2 years demand history. Monthly review period.
4						High	Demand satisfied from stock. Policy S without safety stock, with S = average required quantity during the last 2 years demand history. Monthly review period.
5			Enough	High	Aesthetic part		Demand satisfied from stock. MA yearly aggregate forecasting. Fixed re-ordering point inventory management, EOQ. Weekly review period. Fill rate target = 90%.

6					Low	Functional part		Demand satisfied from stock. MA yearly aggregate forecasting. Fixed re-ordering point inventory management, EOQ. Weekly review period. Fill rate target = 95%.
7						Aesthetic part	Low	Demand satisfied from stock. Policy (s, S) monthly review period. S = yearly average demand s = average demand during LT, Safety Stock (SS) dimensioned using target fill rate = 90%
8							High	Demand satisfied from stock. Policy (s, S) monthly review period. S = 4months average demand s = average demand during LT, SS dimensioned using target fill rate = 90%
9						Functional part	Low	Demand satisfied from stock. Policy (s, S) monthly review period. S = yearly average demand s = average demand during LT, SS dimensioned using target fill rate = 95%
10							High	Demand satisfied from stock. Policy (s, S) monthly review period. S = 4months average demand s = average demand during LT, SS dimensioned using target fill rate = 95%
11	DISMISSED	∨ replenishment LT	Not evaluated	Not evaluated				Demand satisfied from stock. Policy S monthly review period, S=Poisson quantity, Stock availability = SUM stock availability on central + subsidiaries warehouses. No safety stock.
12		∧| replenishment LT						Parts not kept in stock. Demand satisfied from order.

Table 11. The proposed policy management for the 12 parts classes

5. Performance assessment

5.1. Assessment of overall costs and benefits

The last step of this project consisted of the performance comparison between the proposed solution and the practices currently employed by the case study organization. Our aim was to quantify the possible benefits derived from our approach and communicate the findings to the management of the company. The comparison was made with regards to the achieved service levels and inventory costs along the lines discussed in the previous section. We have simulated in a dynamic fashion what would have happened if the proposed solution was to be used instead of what the company actually achieved in a specified time period. The simulation was carried out on the last year of the data available to us (July 2008 – June 2009). Strictly speaking, this provides a potential advantage to our proposed solution since the management policies specified for classes 5-10 (inclusive) were selected over the same time period (see sub-section 4.5). Although longer histories of data could have been made available to us (see also sub-section 4.2), the relevant recency

of the data ensures that the fast changing environment of the industry under concern is reflected in our analysis. In that respect we have opted for sacrificing a true out-of-sample evaluation of the performance of the new approach for the purpose of ensuring the 'relevance' of our results

At this point it is important to note the following: for the *Introduction* spare parts the proposed solution advices to estimate future demand using the demand rate and the finished products sale values. Unfortunately at the time of the comparison not all the necessary data about products sales could be made available to us and as such no comparisons were undertaken that involved the proposed classes 1 and 2. Moreover it is important to underline that no part movements have been considered from one class to another. That is, in a real setting (real running conditions) a part may move upon periodic evaluations from one class to another. Although this could have been reflected in our simulation, such a realistic representation of a running system wouldn't have contributed any additional value in our analysis due to the shortness of the evaluation period. As a result though, a further exclusion of some classes became necessary. The actual initial stock for the SKUs belonging to classes 3 and 4 is very large due to the fact that such items would in fact, until recently, be classified as *Introduction* codes. In these cases, the company keeps an inflated stock favoring service level rather than inventory costs and consequently, and due to the nature of our simulation, the results would have definitely showed an improvement of the proposed approach when compared with the current system. As such, classes 3 and 4 have also been excluded from our simulation. Similarly, we have also not quantified the savings associated with the decision of adopting a new approach for SKUs belonging to class 12. In this case, the proposed solution consists of not keeping stock at all whereas clearly it is possible that some stock should have been available if the items were to be-classified upon consecutive reviews.

As such, costs and benefits are finally evaluated only on classes 5, 6, 7, 8, 9, 10, 11; those constitute collectively more than 97% of the overall spare parts demand value and consequently the corresponding results may explain to a great extent performance across the entire stock-base. Table 12 reports the comparison results between the proposed approach and the solution currently employed by the case study organization.

| MACRO-CLASS | CLASS | # SAMPLE PARTS | TOTAL # PARTS | Target Fill rate % | Achieved hit ratio % | PROPOSED SOLUTION PERFORMANCE | | | CURRENT SOLUTION PERFORMANCE | | | % SAVINGS |
						Inventory holding costs [€/year]	Orders generation costs [€/year]	Overall costs [€/year]	Inventory holding costs [€/year]	Orders generation costs [€/year]	Overall costs [€/year]	
IN USE WITH HIGH DEMAND FREQUENCY	CL5	451	1,064	90%	97%	3,050	2,807	5,857	4,777	2,252	7,029	16.67%
	CL6	370	3,772	95%	96%	6,689	3,841	10,530	23,935	2,292	26,227	59.85%

IN USE WITH LOW DEMAND FREQUENCY	CL7	158	2,098	90%	96%	204	480	684	683	176	859	20.39%
	CL8	213	678	90%	96%	857	1,214	2,071	2,514	334	2,849	27.28%
	CL9	169	5,484	95%	96%	112	660	772	540	172	711	-8.48%
	CL10	199	2,006	95%	95%	1,835	1,263	3,097	6,366	458	6,824	54.61%
DISMISSED	CL11	221	2,110	90%	93%	585	321	907	1,068	35	1,103	17.58%

Table 12. Performance comparison between the proposed approach and the current situation (sample items)

The results indicate that the proposed solution (albeit not evaluated in its entire range) leads to considerable cost reductions (about 20% on average) whilst exceeding the target service levels. The highest savings rate corresponds to the *In use* items with *high demand frequency*. This is one of largest categories in terms of the number of SKUs included and as such the relevant performance improvement is regarded as a very important result. The savings are comparatively lower (but still considerable) for the *In use* items with *low demand frequency*; this can be explained in terms of the flexibility of the current manual approach that may adapt to specific peculiarities of the ordering process. More specifically, the current approach allows the planners to manage some critical parts according to qualitative information that may not be available to a quantitative model. Sometimes, for example, planners may exercise judgment in the presence of some customer obtained information and decide not to keep stock for some periods since they are confident that no orders are to be received. This action will consequently lead to the reduction of both ordering and holding costs. In such a case it is very difficult for our proposed structured model to outperform the existing manual one. For class 9 in particular, the results indicate that the current approach outperforms our proposed solution. Syntetos et al. (2009) examined the effects of judgmental adjustments to statistical forecasts of intermittent demand items and found that such adjustments were beneficial with regards to both forecast accuracy and stock control consequences. The incorporation of human judgment into the process of managing spare parts inventories is an area that hasn't received considerable attention in the academic community; this issue is further discussed in the next section of our paper.

6. Discussion and implications for the OM theory and practice

The case study presented in this paper shows how the adoption of a structured spare parts (inventory) management methodology may provide significant benefits to industrial organisations that deal with a considerable number of SKUs and invest tremendous amounts on the relevant inventories. Although the results presented here may not necessarily be generalised, the findings of our work should offer valuable insights to managers and stock controllers in a wide range of industries. Moreover, we believe that this study contributes significantly towards advancing knowledge in the field of Operations Management (OM) and it constitutes an important addition to the current body of the literature in this area. In the remainder of this section we first discuss the implications of our work for the OM practice followed by a discussion of our contribution to the OM theory.

With regards to the specific case study organization we have investigated, there are a number of important benefits and lessons learned to be reported. These should contribute towards advancing practices in other companies as well.

- Our analysis led to the identification of a number of important criteria to be used for classification purposes. Although not all such criteria were relevant towards the specification of all the classes of items, they may in fact collectively constitute a useful starting point when other organizations embark on inventory classification exercises.

- The major outcome of this study has been the proposal of a hierarchical classification scheme that is easy enough to operate and explain to a company's management. Although other classification parameters may in general be included, or indeed some of the proposed ones be omitted according to a specific situation, the very construction of the scheme and its development should offer valuable lessons to other organizations as well.

- A major benefit associated with our intervention is the very involvement of the company's management in the development of the scheme and their exposure to SKU characteristics that were not necessarily perceived as important prior to our project. Our discussions with the company's managers created a higher awareness of spare parts characteristics and allowed the formalisation of internal (tacit) knowledge with regards to relevant issues. As previously discussed in our paper, it is important to note that several criteria (along with their threshold values) were decided upon consultation with the company's management.

- The linkage between SKU classification, forecasting and stock control may not be particularly obvious in an industrial context. (In fact, we believe that this is also true in the academic literature concerning inventory management but we return to this issue later in this section.) The development of the classification scheme enabled the company to appreciate how this linkage actually works and led to the development of formalised, though very simple, policies, processes and procedures for spare parts management.

- Also, the company appreciated that the transition from a manual (judgement relying) system to a formal one should not necessarily be a difficult exercise. Involving the managers in the very development of the formalised system enables the key characteristics to be captured whilst management may not feel threatened in the presence of a new solution. This is typically the re-action in the introduction of new specialised software packages and enterprise-wise solutions bought without appropriate consultation with the users of such a solution.

- The demonstration of the benefits of the new approach through a simulation study was very well received. Dynamic simulations and quantitative summarisations of the prospective benefits of a new approach are simple yet very powerful ways of convincing management of the value of such an approach (see also Syntetos et al., 2010).

With regards to the implications of this work for the OM theory, there are a number of important points to be made.

- From a methodological point of view, multi-criteria classification models are "richer" than a simple ABC approach (although admittedly substantial progress has been made recently in the latter area, see, for example Zhang et al., 2001; Teunter et al., 2010). Such models allow for the consideration of the specificity of a company's environment and therefore lead to more "tailored" solutions. On the other hand of course, their adoption is not as straightforward as that associated with an ABC-type approach, increasing the managerial complexity and raising issues related to their generalization and application in different contexts. Given the importance of SKU classification solutions for inventory management further research into the trade-offs between various possible approaches would appear to be merited.

- The linkage between SKU classification rules, forecast accuracy and stock control performance is a rather complex one. In this work, a qualitative approach was employed for the very specification of the SKU classes but also for the determination of the most appropriate policies per category. The very sequence of performing such tasks as well as the interactions of the relevant steps is an area that may benefit from further empirical investigations as well as analytical work.

- The results of our analysis indicate that in many cases human judgment may be irreplaceable as qualitative information that would be lost otherwise, when applying a quantitative methodology, is taken into account. The value of judgment in an intermittent demand context was recently explored in a forecasting study conducted by Syntetos et al. (2009). Although the time series analyzed in that paper did not relate to spare parts, they did in fact represent patterns commonly encountered in such a context of application. The findings of this study suggested that managers may add considerable value into the forecasting process. Further studies that evaluate the effects of human judgment into stock replenishment decisions would help to advance considerably the current sate of knowledge in the area of inventory management.

- The presence or absence of relevant data plays a major role in the process of developing a classification scheme and specifying its parameters; however, it is often neglected in academic pieces of work. More specifically, the very intermittent nature of demand renders potentially the exploration of the underlying patterns an infeasible task. Furthermore, the average inter-demand interval - which has been shown in the literature (Boylan et al., 2007) to be a very robust criterion for classification purposes - may not even be defined, should the number of orders recorded in the item's history be less than three. In our case for example, demand frequency could only be measured for 58.1% of all the SKUs (classes 5-10 inclusive). Although the relevant items accounted for nearly all the demand value received by the company (97.7%) service level targets necessitate a further analysis of the remaining SKUs. The development or specification of other criteria to be used in the absence of demand data (too many zero demand periods) is a very important issue both from an academic and practitioner perspective.

- The life-cycle phase of a spare part constitutes an important classification criterion in industrial contexts characterized by a growing number of *new* items and items rapidly evolving into *dismissed* ones

(following the terminology used in this case study). Although this aspect may allow dealing more effectively with the complexity related to a wide range of spare parts, it has in fact been overlooked in the literature. In more detail, only 2 out of the 25 contributions reviewed in sub-section 2.1 suggested this criterion.

• The important role of *part criticality* and *part value* discussed by several studies (outlined in sub-section 2.1) is confirmed in this case. Although these are not necessarily the most relevant criteria for deciding the inventory and forecasting policies to be adopted, they are fundamental towards the specification of target service levels. Therefore, these factors play a key role in shaping a company's efforts and investment in inventories.

• Although no claims can be made in our study about the generalization of its results, we do feel that it should provide very useful insights to a wide range of other organizations and in particular to most durable goods companies. This is especially true if such companies are characterized by a large variety of products, a long usage life at the end-customers and a fast renewal rate of product ranges, resulting in a very high number of SKUs evolving into different lifecycle phases. In such a dynamic environment, SKU classification becomes a very difficult task and we hope that our study has raised many important pertinent issues and it will consequently motivate a great number of further academic investigations.

7. Conclusions, limitations and extensions

The after sales/ spare parts industry has become a very important one in the current business environment. Yet, the number of academic contributions in this area neither reflects its importance as a crucial business function nor does it make justice to the tremendous investments companies are currently undertaking to ensure availability and high customer satisfaction. Cost effective spare parts management relies upon appropriate classification methodologies. This is due to the highly varying nature of spare parts and the tremendous numbers by which they are represented in the relevant business contexts that necessitate a comprehensive approach to distinguish between them for forecasting and stock control purposes. The number of factors potentially affecting/influencing the 'nature' of a spare part leads to the consideration of multi-criteria classification methodologies. Although such solutions may not be easy to develop, they have been reported to offer tangible benefits to companies dealing with relevant inventories. The development of such a solution along with the evaluation of its benefits has been described in this paper through an extensive case study performed in the white goods industry. In particular, we looked at the very many factors influencing decision making in that context of application and built, in consultation with the company's management, a hierarchical classification scheme that enables a better control of their stock-base. A detailed review of the literature has been offered, which constitutes the theoretical background of our research, followed by the introduction of the case study organisation and a discussion of the rationale behind various choices and the construction of the actual classification scheme. The implications of our work for the Operations Management theory and practice have also been explicitly addressed.

Through this case study we have demonstrated that a rather simple, yet well-informed solution, has led to substantial organisational benefits. Similar results have been reported in other recent case study papers (e.g. Syntetos et al., 2009, 2010) and this outcome is not particularly surprising since real-world practices follow considerably behind the relevant theoretical propositions in the area of inventory management. In fact, one of the main perceived contributions of our work is actually bridging the gap between theory and practice in this area.

Case studies do not necessarily offer generalisable solutions; they illuminate the actual problems operations managers deal with and the complexity involved in the solution development process, as opposed to deductive studies that essentially define how managers should make decisions. Through case studies, academics can explore the implementation of managerial norms and the practical validity/utility and relevance (or the lack of it) of theoretical propositions. With this study we feel that valuable lessons have been reported to influence similar exercises in other contexts of application. Having mentioned that, we do of course recognise several limitations of our study that may in fact be also perceived as natural extensions of the work described in this paper. In particular:

- A more realistic representation of an inventory system would comprise variable inventory holding and ordering charges in contrast with our simulation specification that assumed fixed charges across the entire stock-base. In addition, no backordering costs have been considered for the purposes of our analysis. Although the relevant effect has been captured through achieved service levels, backordering costs constitute a major determinant of the total inventory costs.

- Similarly, the potential cost of obsolescence has also not been explicitly addressed as part of our simulations. The intermittent nature of the underlying demand patterns dictates that such costs are very important and future analyses should take them into account.

- A recent work conducted by Syntetos et al. (2010) highlighted the importance of the distributional assumptions employed in parametric approaches to managing spare parts inventories. The assumption made, where applicable, in this paper was that demand is normally distributed and such a hypothesis deviates significantly from the distributions actually encountered in practice. The linkage between other more appropriate distributions (such as the Negative Binomial or the Stuttering Poisson) and the development of classification schemes should be evaluated in more detail.

- Our proposed scheme consisted only of periodic review policies, albeit in some cases with very short (weekly) review intervals to resemble as much as possible the function of continuous systems. This was due to the company's reluctance to embark into re-order level control systems but obviously such a possibility worth further investigation.

- Also, on the technical side, longer demand data series may facilitate true out-of-sample evaluations of a proposed solution. This is to be contrasted to the need for relatively recent demand information in the context of a fast changing business environment.

- Finally, it would definitely be very interesting to assess the relevance of the classification parameters proposed in our work in other industrial contexts.

Before we close our paper it should be noted that the proposed classification method needs obviously to be revisited, during its actual application, in order to allow for the re-classification of SKUs. The frequency of such an exercise is to be set according to the company's requirements (in our case every 3 or 6 months). It is indeed reasonable to expect that over time the spare parts' features such as the underlying demand pattern and other qualifying characteristics may change resulting to a specific part moving from one class to another. During our project we haven't focused on the issue of re-classifying SKUs. However, we have elaborated, from a qualitative point of view, on how one spare part may move from one category to another and communicated this to the company's management. Figure 6 indicates some possible re-classification scenarios.
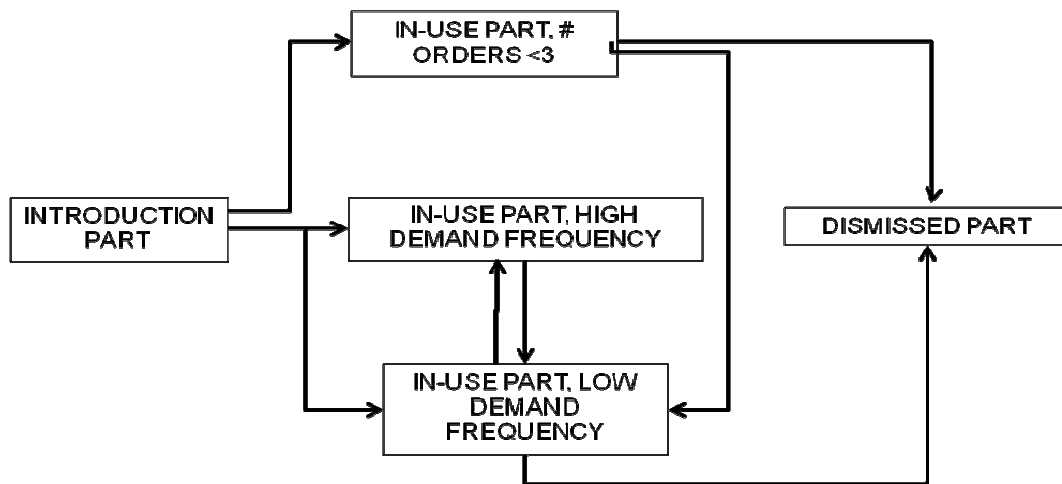

Figure 6. Possible re-classification scenarios in running conditions

The company is currently introducing our proposed approach on an ongoing basis. This task has yet to be completed since it requires the implementation of a new information system in order to support the automation of the different managerial steps over such a large number of SKUs. This requires a substantial investment on the part of the company but one that has been agreed for execution.

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