Bringing together a classification and a practical perspective in the design of an integrated approach for achieving effective spare parts management

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Abstract – Service logistics companies aim for their high value capital assets to be operationally available, to prevent lost revenues and customer dissatisfaction. To assure this maintenance is performed, and therefore spare parts are required. An important activity is to have spare parts available when they are demanded for conducting maintenance. However, the stock levels and operational costs should be minimised at the same time. This is difficult to achieve due to unpredictability of demand for spare parts, differentiated decisions about inventory and unpredictability of supply. In existing literature little attention is given to an integrated perspective and high practical applicability, which is required for companies to achieve overall effective spare parts management. In this article the following question is central: How can an integrated approach be designed that can be used to achieve a more desirable balance between spare parts availability, operational costs and working capital (stock levels) in service logistics companies with high value capital assets? Findings in a literature review and during field research at a rail transport operator are combined to design the integrated approach. It focuses on demand forecasting, inventory control and supply management and it is differentiated along the dimensions 'price', 'consumption rate' and 'supply risk'. This way a combination is made between an inventory classification and a supplier segmentation. The differentiation assists companies managing groups of spare parts with a suitable level of attention and with a suggested focus with respect to performance improvement. Based on the field research, also differentiated focus areas for organisational and process improvements are indicated. Finally, to make the approach simple and targeted in its use, the main activities are assigned to the three main departments that are concerned with spare parts management: maintenance, purchasing and logistics. The results show that the approach could help companies move forward, though the study can be extended in a number of directions. Hence, suggestions for future research are presented in this article.

Keywords: Spare parts management, demand forecasting, inventory control, supply management, classification, service logistics

1. Introduction
For companies that have high-value capital assets, these assets are often essential for providing their primary services. Therefore downtime of such assets, for instance due to maintenance, leads to lost revenues and customer dissatisfaction (Driessen et al., 2014). Often companies perform maintenance to these assets themselves to assure uptime. For these maintenance activities, spare parts are required. An important activity is to have spare parts available when they are demanded for conducting maintenance. However, the stock levels and operational costs should be minimised at the same time. Finding an optimal balance is a challenge due to the following factors:

- Unpredictability and unplanability of demand for spare parts. This is related to the planned and unplanned
character of maintenance activities for which spare parts are demanded.
- Differentiated decisions about inventory. What items to stock? What amount to stock? Where and when to stock it?
- Unpredictability of supply. This has to do with characteristics of the supply side. For instance delivery lead times can be long or have a high fluctuation.

The characteristics of spare parts together with the challenges of having high value capital assets make it difficult for companies to achieve overall effective spare parts management.

It is clearly presented in scientific literature that when executing spare parts management at a high level demand forecasting, inventory management and supply management are important decision functions. But at the moment there is a limited amount of research in scientific literature regarding an integrated perspective on spare parts management. An important aspect is also that maintenance strategies should be considered and that the approach is differentiated for various types of spare parts (based on multiple variables). This last point is important, as this way the peculiarities of spare parts are taken into account. The approach can take the form of a sophisticated classification of spare parts, taking into account all the different aspects, so that decisions can be made on which spare parts should be handled in which way. Finally, it is also relevant to design an approach that is easy to use and understand; so that it actually has practical value. Often models proposed in literature are perceived to be too complex by users at companies, while they have to work with it and make the actual difference to achieve overall effective spare parts management.

With an approach that involves integration, at the same time a classification, and which reduces the gap between theory and practice, this research provides a scientific contribution to the literature on maintenance spare parts planning. Hence, this the design of such an approach is the main objective of this article.

With the performance indicators in the triangle above in mind, this leads to the following main question for this article: How can an integrated approach be designed that can be used to achieve a more desirable balance between spare parts availability, operational costs and working capital (stock levels) in service logistics companies with high value capital assets?

The structure of this article is as follows. First the research method that forms the basis of this article is presented. In the following section the literature review is presented. In the fourth section the design and description of the approach is discussed. The design is based on the literature review, but also on a case study conducted within the maintenance organisation of a rail transport operator. In section five, finally, the conclusion and suggestions for future research are provided.

2. Research method
The nature of this research is practice-oriented. Therefore it is necessary to combine literature review with field research, which entails observing maintenance processes, interviewing stakeholders and executing data analysis with real-world data.

In order to get an increased insight in the current situation of maintenance spare parts planning and service logistics, a literature
review is conducted. The literature review has multiple focus areas, namely: current challenges in spare parts management and maintenance management, frameworks on spare parts management, the main components of an integrated approach and available models for (spare parts) classification. Several search engines (Google Scholar, Scopus and Web of Science) are used for the literature review. The following keywords (in varying combinations) are used during this search: Spare parts management, service logistics, maintenance, planning and control, demand forecasting, inventory control, supply chain management, spare parts classification, criticality, performance measurement and asset management. This search resulted in a number of useful articles for the literature review. In addition to these articles, a book on inventory management and production planning by Silver et al. (1998) and a book on purchasing and supply chain management by Van Weele (2014) are consulted.

For the field research, two types of data analysis are performed: quantitative and qualitative data analysis. Quantitative data is retrieved at the rail transport operator for desk research and data analysis. On the other hand, qualitative data is retrieved by conducting semi-structured interviews. Thereby, for the validation of the approach a group discussion with experts within the company is organised.

3. Literature review
In this section an analysis is presented of the main issues in the area of spare parts management that are relevant for the design of an integrated approach.

3.1 Spare parts management
In order to perform maintenance, spare parts are required. It is an important activity to match the supply and demand of the spare parts needed to conduct maintenance (Driessen et al., 2014). The tasks of maintenance are in the field of Service Logistics. Service Logistics is the after-sales service support for a product end user that exists of the provision of spare parts, maintenance and repair services during the entire life cycle of a product (Cohen et al., 1997). The management of spare parts is different from other parts, due to some specific characteristics. Spare parts inventories differ from other manufacturing inventories in multiple ways. First, they have another function, which is to assist a maintenance staff in keeping equipment in operation condition. Spare parts are not intermediate or final products to be sold to a customer. A second difference can be observed in the policies that govern spare parts inventories. Work-in-progress (WIP) and final product inventories for instance can be increased or decreased by for instance changing production rates and schedules, improving quality and reducing lead times. Spare parts inventory levels, however, are largely a function of how equipment is used and how it is maintained (Kennedy, 2002). Next to its function and policies that dictate the need, other conditions that make spare parts inventories different are listed below (Kennedy et al., 2002).

- Reliability information usually is not available to the extent needed for prediction of failure.
- Part failures are often dependant, which is a problem if the dependence relation is unknown.
- Missing a certain part leads to costs including quality and lost production, which are hard to quantify.
- Obsolescence might be a problem as certain components are no longer made.
- It is more likely to keep components of equipment in stock instead of complete units, if the major unit is expensive. Also repair might be preferred to replacement, if this is a possibility.
- Typical forecasting strategies used for other inventories do not always apply.
As mentioned at the start of this chapter, a lot of relevant areas of research regarding spare parts management are existing. Over the years multiple literature reviews have been performed on spare parts management (Guide & Srivastava, 1997; Kennedy et al., 2002; Basten & Van Houtum, 2012). These articles give a comprehensive overview of the state of the art in research at the time of writing. A decision-making framework for spare parts control is proposed by Cavalieri et al. (2008), to facilitate managers on how to pragmatically handle the management of maintenance spare parts in a company. The framework takes into account part coding, parts classification, part demand forecasting, stock management policy and a policy test and validation. A few years later, Driessen et al. (2014) constructed a framework with a broader perspective to facilitate decision-making regarding maintenance spare parts planning and control, taking all relevant areas into account. A simplified representation of the framework is shown in Figure 2. The red circle shows the focus of this research. The framework contains eight decision functions. For this research the main focus is on function demand forecasting, inventory control and supply management. This is based on the scope of this article; the three functions right of the circle are more on an operational level, decisions about assortment are made more on a strategic level. Thereby, findings in the literature point out that it is important to focus on the integration of these three decisions functions (Bacchetti & Saccani, 2012; Wahba et al., 2012). The focus on forecasting, inventory management and supply management is also supported by a roadmap for service logistics in the Netherlands that presented key improvement areas as seen by companies. Service logistics is a rather young discipline with a lot of movement and development. Therefore there is a need for knowledge development and circulation (sharing of experience and best practices). Some of the key improvement areas presented are (Innovation Zuid, 2012):

- Better cooperation in the chain and within the organisation
- Better forecasting and inventory management techniques
- Better use of information systems
- Extension of service portfolio
- Condition based logistics

In 3.2, 3.3 and 3.4 the three decision functions are further discussed.

Figure 2: Decision-making framework for maintenance spare parts planning; adapted from Driessen et al. (2014)
3.2 Demand forecasting

Demand forecasting entails the estimation of demand for parts in the future (Driessen et al., 2014). Future demand can be planned or unplanned, which relates to the maintenance type (2.2) in which the spare parts are used. It is possible to use advanced demand information for spare parts. Using this usually decreases the overall forecast error, but then again it is obvious that using this information increases the difficulty, the effort and therewith the operational costs to forecast demand (Hariharan & Zipkin, 1995; Benjaafar et al., 2011). When there is no information available or the decision is made not to use it, accordingly all demand is accumulated and one single demand stream is considered. In the other case, a planned and unplanned demand stream are taken into account (Driessen et al., 2014).

3.2.1 Demand patterns

For unplanned demand, another classification needs to be made in order to select a suitable forecasting method. This is determined by the demand pattern of a part. The four different patterns are listed below (Ghobbar & Friend, 2002), and in Figure 3 an example is shown of each demand pattern. Especially the intermittent and lumpy demand patterns complicate spare parts forecasting (Romeijnders et al., 2012).

- Smooth demand: demand occurs basically every time period and does not show a high variation in size. Hence, this pattern does not raise significant forecasting or inventory control difficulties; this pattern is usually for parts that are faster moving.
- Erratic demand: a highly variable pattern, relating to the demand size rather than demand per unit time period.
- Intermittent demand: demand appears randomly with many time periods having no demand, but not a high variation in size of the demand.
- Lumpy demand: this pattern seems random with many time periods having no demand and thereby, when demand occurs, it is highly variable.

![Demand patterns](image)

Figure 3: Demand patterns

The demand pattern is established by two values: the average demand interval (ADI) and the square coefficient of variation (CV²) (Syntetos, 2001).

3.2.2 Demand process and forecasting methods

When the decision is made on whether or not to separate demand streams, the process needs to be characterised. This has two reasons, relating to the two other decision functions within the scope Driessen et al., 2014):

1. To determine the number of spare parts to stock (inventory control)
2. To provide input for designing and updating contracts with suppliers (supply management)

Planned demand during the delivery lead time is deterministic, since all parts are requested well in advance. Expected planned demand after the delivery lead time is not known in advance exactly, hence this should be forecasted (Driessen et al., 2014).

For forecasting unplanned demand, three main methods exist: historical time series-
based forecasting (Croston, 1972; Silver et al., 1998; Syntetos & Boylan, 2001; Teunter et al., 2011), installed base forecasting (Dekker et al., 2010) and real-time forecasting (Driessen et al., 2014).

3.3 Inventory control
The process of inventory control is concerned with decision about what parts to stock, what amount to stock, where to stock it, in case of multiple locations, and when to stock it. The most important article on models for inventory control of spare parts is about METRIC-type models: multi-echelon technique for recoverable item control (Sherbrooke, 1968). Inventory control should be performed centrally for all locations of company, using the multi-echelon approach (Sherbrooke, 2004). For spare parts that are used for modifications or new projects usually a separate planning regarding inventory is made, therefore these are not further discussed here.

Inventory control is closely related to demand forecasting in most industries. An inventory control policy is used in order to provide a buffer of spare parts to match the uncertain demand. Such a policy requires accurate forecasts of the demand distribution. The main objective is to achieve a sufficient service level regarding spare parts, which is the chance that a part is available from stock at request, with minimum inventory investment and administrative costs (Huiskonen, 2001). Thus, this again points out the importance of the balance between costly excess stock, disruptive stock outs and operational costs.

In order to decide which parts are going to be in stock, the assortment of spare parts needs to be divided into different subsets. In scientific literature multiple classifications that can be used for this purpose are presented. These are discussed below.

3.3.1 Classification of spare part inventories
Inventory classifications are used to divide parts into different classes based on their importance. Important refers to a certain score on criteria that a company sees as determinative; what these variables are can differ per company (Syntetos et al., 2009). Thereby, a classification is done in order to facilitate decision-making with regards to demand forecasting, inventory control and supply management, and to enable involved people (planners, purchasers, engineers) to give a higher level of attention to these parts that need it most (Syntetos et al., 2009). Traditional ABC classification ranks the items according to the annual turnover (Silver et al., 1998). This classification is based on the Pareto principle. Class A parts are relatively few in number but constitute a relatively large amount of annual turnover, while Class C parts are relatively large in number but constitute a relatively small amount of annual turnover. Accordingly, parts that are in between are called Class B items. Another main technique is XYZ analysis, which is based on usage regularity (fluctuations in consumption) (Schol-Reiter et al., 2012). Silver et al. (1998) also mention that a classification based on moving rates, which basically are consumption rates that can be either fast, medium or slow. These traditional classifications are based on only a single criterion, but it is generally recognized in scientific literature that multiple criteria should be considered in practice. A number of multi-criteria inventory classification (MCIC) methods are proposed in literature, and most of them have slightly different characteristics.

Ramanathan (2006) proposes a weighted linear optimization model for classifying inventory items in the presence of multiple criteria. The criteria average unit cost, annual dollar usage, critical factor and lead time are used to determine an optimal inventory score. The model is very simple and therefore can be easily understood by inventory managers. It is similar to linear programming models employed in data envelopment analysis (DEA). Another model for MCIC uses fuzzy set theory and fuzzy Analytical Hierarchy Process (AHP) (Rezaei, 2007). It is applicable to any
multi criteria classification problem with any number of classes. Rezaei & Dowlatshahi (2010) present a simple, effective and practical rule-based method for inventory classification, which is designed and implemented in a real world case using MATLAB software. This method has the main characteristic that it is taking into account the inherent ambiguities that exist in the reasoning process of the system of classification. Another approach is presented by Chen (2011). In this research a peer-estimation approach is proposed for MCIC, where the performance of each inventory item is estimated by criteria weights not only most favourable and least favourable to itself, but also to its peers. Torabi et al. (2012) acknowledge that recently several methods have been developed for ABC classification, and then especially DEA-like models that account for multiple criteria lead to more logical results in practice. They state though that these models assume that all criteria are of quantitative type and hence cannot handle the qualitative criteria which are not stated numerically but as linguistics terms. Therefore Torabi et al. (2012) propose a modified version of an existent DEA-like model by using concepts from the imprecise DEA (IDEA) models, and then they use this in the context of ABC inventory classification. This way both quantitative and qualitative criteria can be assessed simultaneously.

Two scientific articles state that most MCIC methods treat ABC inventory classification as a ranking problem. Babai et al. (2015) mention that most of the ranking methods are without interest in the original goal of ABC classification, namely the combined service-cost inventory performance. Also they compare different MCIC methods in an empirical study. This shows that the MCIC methods that impose a descending ranking of the criteria, with a dominance of the annual dollar usage and the unit cost criteria, have the lowest combined cost-service performance efficiency. The practical recommendation presented is the strict use of MCIC methods where a non-ranking order is imposed between the criteria, especially, the unit cost or the annual dollar usage criteria. Douissa & Jabeur (2016) present a method to tackle ABC inventory classification models as an assignment problem instead of a ranking problem. This means that an inventory item is classified to the category with which it has the most similar characteristics. For this purpose they use the PROAFTN method. Experimental results have shown that this method outperformed all other existing classification models according to inventory costs and that it generates a competitive fill rate.

Kartal et al. (2016) propose a hybrid methodology that integrates machine learning algorithms with multi-criteria decision-making (MCDM) techniques to effectively conduct MCIC. It is the first research that combines these techniques and it is practically applicable in various inventory settings. Van Wingerden et al. (2016) describe a new method for dealing with a multi-item, single-location inventory control problem. They present a generalized ABC classification scheme to minimize the inventory investment costs while satisfying an aggregate fill rate constraint by considering four different aspects of a classification. These four aspects are: the classification criteria, the number of classes, the class sizes and the target fill rate per class. Near-optimal results are found by applying the approach. The most important insight presented is that the best class sizes, which need to be carefully decided, depend on the target aggregate fill rate, whereas common used rules of thumb to determine class sizes may lead to large inventory investment costs. Another classification approach is presented based on the outranking model for multiple criteria ABC analysis by Liu et al. (2016). In this research the non-compensation in the multiple criteria ABC analysis is considered, compared to most methods being fully compensatory. This means that a part scoring badly on one or
more key criteria could be placed in good classes because these bad performances are compensated by other criteria. To cope with non-compensation among criteria, the outranking model is used.

Rezaei & Salimi (2015) state that ABC inventory classification has been generally considered as a multi-criteria problem. They present a different perspective, proposing a novel optimisation model for ABC inventory classification in the form of an interval programming problem. The proposed model has two important new features: it provides optimal results instead of an expert-based classification and it does not require precise values of item parameters, which are often not available before classification has to be executed.

Other classifications include for instance demand patterns and criticality as criteria, where criticality usually is described as the impact of a shortage of a part on operations (production), safety and environment (Syntetos et al., 2009; Molenaers et al., 2012). Botter & Fortuin (2000) present a multi-criteria approach to identify important parts based on several criteria that determine criticality, like response time, stage in life cycle, demand, purchase lead time and price. It was concluded that a simplified VED (vital, essential, desirable) approach was more suitable than the traditional AHP, because of its higher functionality and more practical value. Roda et al. (2014) made a comparison of multiple classification models and researched the gap between literature and practice. This research depicts that barriers are existing that leave gaps between theory and practice of an effective multi-criteria spare parts classification. New approaches should aim to reduce this distance between research and industry. This is supported by Bacchetti & Saccani (2012), who describe that non-adoption of methods and the discrepancy between theory and practice is a problem. They mention that approaches proposed in literature are often perceived as too complex by potential users. In other words, an approach with a clear practical applicability is desired to move towards actual improvements with regards to effectiveness of spare parts management.

3.4 Supply management
The third decision function from the framework that is in the scope is supply management. Supply management also has a close relation with demand forecasting. For instance, information sharing with suppliers could lead to better forecast, or more intense supplier cooperation (better agreements and communication) could lead to a lower need for forecasts, because of a higher flexibility and shorter delivery lead times.

Supply management mainly concerns the process of ensuring that one or multiple sources are available to supply spare parts at any given moment in time with predetermined supplier characteristics, like delivery lead time and procurement contracts (price, order quantity). It is important to manage supplier availability, to control supply lead times and supply parameters and to select supply sources and contacts (Driessen et al., 2014).

As business is becoming more and more competitive, supply management is increasingly recognised by top managers as a key business driver. Since most companies today spend more than half of their sales turnover on purchased parts and services, efficient and constructive relationships with suppliers are key to the company’s short term financial results and long term competitive position (Van Weele, 2014).

3.4.1 Supplier segmentation
A major aspect of supply management, is supplier segmentation, where products are segmented in different groups based on a selection of criteria. Accordingly, a segmentation assists in determining the differentiated strategies for the concerned products. Kraljic (1983) was the first to introduce a matrix that classifies a company's purchased products into four categories based
on their profit impact and supply risk; it was also called a purchasing portfolio approach. It is shown in Figure 9. About 20 years ago, Kraljic advised managers to protect their companies against heavy supply interruptions and to cope with changing economic and technological dynamics. His message was that ‘purchasing must become supply management’ (Gelderman & Van Weele, 2005). For the two dimensions, a product can score either high or low; the result is 2x2 matrix with four categories: noncritical, bottleneck, leverage and strategic items.

![Figure 9: Supplier segmentation by Kraljic (1983)](image)

Other authors described models that are very similar to the original Kraljic matrix (Elliott-Shircore & Steele, 1985; Hadeler & Evans, 1994; Lilliecreutz & Ydreskog, 1999; Van Weele, 2002). Kraljic’s approach faced various criticism through the years though, mainly related to the following aspects (Gelderman & Van Weele, 2005):

- How to operationalize supply risk and profit impact?
- How to know if the most relevant variables are chosen?
- How to measure the variables?
- Where is the difference between ‘high’ and ‘low’?
- How to make strategies based on only two dimensions?
- Limitation in handling dependency between products

The references mentioned above all focus more on plotting products, while it is also possible to focus on plotting the suppliers themselves. To manage supplier relationships, it is necessary to include the characteristics of the suppliers and the relationships. Svensson (2004) presents a supplier segmentation for the automotive industry. In this research various models are combined. One model consists of two dimensions: the supplier’s commitment to a vehicle manufacturer and the commodity’s importance to a vehicle manufacturer. In extension, another model of dynamic relationship strategies is introduced, which consists of four relationship strategies towards suppliers: family, business partner, friendly, and transactional. Though it is specifically designed for the automotive industry, it may be generalised to industries with similar business environments and relationship criteria.

In another article a taxonomy of segmentation bases is presented which builds a multi-disciplinary approach to supplier segmentation (Day et al., 2010). They state that organisations have to allocate their limited human, financial and technical resources on a selective basis to those relationships in its supply base from which it expects to generate the highest return. Their taxonomy gives a holistic view of supplier segmentation covering supply market conditions, product/service characteristics, supplier characteristics, buyer characteristics, and buyer-supplier relational factors.

Rezai & Ortt (2012) propose a new approach for supplier segmentation that focuses on the relationship management aspects. The need for a new approach is substantiated by stating the shortcomings of standard supplier segmentation methods: they often use a limited number of criteria and they are not able to capture the complicated interaction between various supplier aspects. The new approach is called the supplier potential matrix (SPM) and it includes the following two overarching dimensions to capture all available segmentation criteria: suppliers’ capabilities and supplier willingness. Based on
the new approach, three requirements for making an overarching approach to supplier segmentation are described. Supplier segmentation should be based on long-term potential, other functional areas beyond purchasing have to be considered and it should be viewed as a step in a longitudinal process that includes selection, segmentation, managing the relation and development (Rezaei & Ortt, 2012). With the capabilities and willingness as basic dimensions, a multi-criteria decision framework is developed for supplier segmentation in collaborative supply chains (Hudnurkar et al., 2016). This segmentation takes into account the changes that are caused by increased collaboration between buyers and suppliers to respond to dynamic market conditions.

Thereby, two multi-criteria decision making (MCDM) methods are proposed to assess the position of suppliers with regards to the dimensions suppliers’ capabilities and supplier willingness, namely a fuzzy rule-based system and a DEA-like linear programming model (Rezaei & Ortt, 2011). A general sensitivity analysis procedure for fuzzy rule-based systems is proposed and implemented in a real-world situation to identify the most important criteria for the two overarching dimensions and to formulate better supplier development strategies. Thereby it is concluded that the fuzzy logic approach to supplier segmentation is simple to apply in practice (Rezaei & Ortt, 2013b). Also a method for MCDM is proposed that includes a fuzzy AHP, which uses fuzzy preference relations to incorporate the ambiguities and uncertainties that usually exist in human judgment. For the different segments that can be identified, strategies for handling them are discussed (Rezaei & Ortt, 2013a). Azar et al. (2015) performed an empirical study with the fuzzy AHP method in supplier segmentation.

As discussed above, it is important that a segmentation is viewed in a broader perspective that includes supplier selection, segmentation, managing the relation and development. Supplier development is another strategic supplier-related activity designed to upgrade the performance level of suppliers in order to create and maintain a network of competent suppliers. This has a major influence of the competitive advantage of a buying company. In order to allocate limited resources more efficiently, for different supplier segment different development strategies should be used. This link between supplier segmentation and supplier development is presented by Rezaei et al. (2015). As a MCDM method in this article the Best Worst Method (BWM) is used.

Akman (2015) introduces another important criterion that is increasingly important in the current society, namely environmental or green performance of suppliers. A first segmentation is done via fuzzy c-means, to determine whether a supplier is good, medium or poor in terms of environmental performance. Then, suppliers within the poor group are linked to green supplier development programs by using the VIKOR method.

Segura & Maroto (2016) propose an integrated system, which allows qualifying providers and also supplier segmentation by monitoring the performance based on a multiple criteria tool for systematic decision making. Both compensatory and non-compensatory methods are used and compared. It is shown that a value function approach is the appropriate method to qualify providers, as this only depends on own features of a supplier. However, outranking methods such as PROMETHEE have shown greater potential and robustness to develop portfolios with suppliers and to identify types of relationships. It is the first supplier segmentation proposal applied to industry in which decision making takes into account historical data and expert knowledge, next to the standard opinions and judgements (Segura & Maroto, 2016). Based on the PROMETHEE principles, concepts are proposed in order to analyse the characteristics of each cluster on the different
criteria: the preference profile of a cluster, the similarity profile of a cluster and the inconsistency profile of a cluster (Boujelben, 2016). These concepts allow to interpret and better understand the obtained segmentation based on the PROMETHEE principles.

Notwithstanding the importance of the buyer-supplier relationships, in this research the focus is more on supply characteristics of commodities than supplier relationship characteristics. Also it has been set as an objective to design an approach that is easy to work with by the actual users. This is taken into account when selecting the dimensions during the design of the integrated approach in the next chapter.

4. Design of an integrated approach

As the literature review showed, the design of the approach should integrate demand forecasting, inventory control and supply management and it should be practically relevant (easy to understand and use). The practical relevance is important, because in the end at the user level the changes are applied and the operational results are directly affected. They have to understand why and how they should change their daily work activities. This is also acknowledged by Bacchetti & Saccani (2012), who mention that method complexity is often overlooked and that practical applicability of an approach should be an important goal. Therefore it has to be aligned with users’ skills, and with data availability. It is thinkable that a complex approach is proposed but that the knowledge to handle this at a company is missing.

The traditional ABC classification is easy to understand and implement, but it only has the potential to work successfully when the assortment differs in terms of one single criterion. When considering spare parts of service logistics companies with high value capital assets, the assortment is much more heterogeneous and ABC-classification based on one parameter is therefore not considered as the most suitable method (Partovi & Anarajan, 2002; Ramanathan, 2006). Teunter et al. (2010) even showed that the ABC ranking criterion of annual turnover can lead to cost inefficient solutions for inventory management. Therefore, at least more than one dimension should be incorporated.

The selection of dimensions for the integrated approach is made in a qualitative way. The objectives of the research are considered and accordingly three dimensions are chosen. This choice should be further grounded with an expert survey or multi-criteria decision-making method (also to add weighing factors). But for now the following dimensions are included:

- Price of a part
- Consumption rate of a part
- Supply risk of a part

With the choice of these dimensions, a combination is made between an inventory classification and a supplier segmentation. This is required to achieve the desired integrated focus, whereby the three main decision functions for spare parts management as described in this article are combined.

The dimension supply risk can be explained in various ways, because multiple variables affect this risk. The dimension is in the first instance based on the x-axis of the Kraljic matrix. Kraljic (1983) discusses risk in terms of supply market complexity. Kraljic’s perspective of risk incorporates supply scarcity, the pace of technology and materials substitution, entry barriers, logistics complexity, and monopoly or oligopoly conditions. As described in the literature review, Kraljic’s matrix faced quite an amount of criticism. However, for this research it is a suitable approach due to its focus on the component level instead of supplier level. Fenson (2008) describes that Kraljic’s dimensions profit impact and supply risk can be used for plotting the commodities, but not for the suppliers. Also, relating to the practical
value; the Kraljic matrix has become the standard in the field of purchasing portfolio models (Gelderman, 2003). Besides this, a lot of other models focussing on commodities show no significant changes (Ferreira et al., 2015). Therefore, Kraljic’s take on supply risk is taken into account. Gelderman & Van Weele (2003) acknowledge that companies handle measurement of the Kraljic dimensions differently. One reason could be to match the prevailing conditions in the industry. For this approach the supply risk variables are matched with what is important for the rail transport operator and its industry. Based on a discussion at the company and on the presentation of different variables in multiple scientific articles (Kraljic, 1983; Zsidisin, 2003; Fenson, 2008; Ferreira et al., 2015), the variables listed below are taken into account. This choice should be further grounded with an expert survey or multi-criteria decision-making method.

- Number of available suppliers (Substitution possibilities)
- Product availability
- Delivery time
- Priority for buyer and supplier (dependency)
- Market complexity

Criticality is considered to a limited extent in this article. Mainly to keep the approach simpler; criticality is namely determined by a lot of qualitative variables that are hard to measure (Botter & Fortuin, 2000; Molenaers et al., 2012). This also applies to supply risk, but within this research it is more important to take this into account related to the integration of supply management. Thereby, for determining what makes a part critical, an extensive assessment should be done to determine the suitable criteria and weighing factors. This is based on the perception of decision-makers at the company. Also at the rail transport operator it is a more strategic decision, and therefore outside the scope of this research, which is the tactical level.

This is a limitation of the approach though, as it is clear that this is an important criterion to consider when it comes to assigning different level of attention to different parts (Rezaei & Salimi, 2015). It is mentioned in the approach though, that for some categories it is very important to consider the criticality in a risk analysis or decision about stock (level). Still, this should be further elaborated.

Then short about the two other dimensions, the price and consumption rate. In ABC classification and in the Kraljic matrix, annual turnover and profit impact are considered as one dimension. In this classification, there is a split between price and consumption rate. This has to do with the desired practical value of the approach, and thereby with the focus on an improved balance in the triangle of availability, operational costs and working capital. It is explained in these two short examples, provided by the rail transport operator:

- **Example 1:** a company does not want to manage an inexpensive filter the same way as an expensive wheel tire. Especially regarding inventory control, because a lot of stock for the filters with a low price does not matter, while for the wheel tires it does.
- **Example 2:** a company cannot manage a board power supply converter that is used not even once a year the same as a wheel tire that is used over twenty times a year. Especially regarding demand forecasting, as one needs a certain amount of data points for this. Also a company’s supply management approach is influenced by how the level of priority is for both buyer and supplier.
4.2 Overview of the model
In Figure 8 the classification model is shown, with the dimensions product price, consumption rate and supply risk. The main considerations for making six different groups, so for bundling a number of classes, are the facts that the targeted focus in the triangle of availability, operational cost and working capital and the desired approach in terms of forecasting, inventory control, supply management and process elements are similar. This is determined in a discussion at the rail transport operator with the logistics manager, head of material planners, tactical planner and coordinator of the component maintenance process. Looking at the two-dimensional matrix of product price and consumption rate, the bundling as applied in this model is now already used at the company. No reason is found to change this; this would only make it less practical. With regards to supply risk being high or low, for group 1 and 6 this does not significantly change the way a company should manage parts, while for the other groups it does. This is further explained in 4.3.

The development of diversified groups is among others based on the desired focus within the triangle. In the description of the groups in 4.5 the triangle is shown with a blue circle that points out where the focus is located; so how the priorities for the performance indicators are diversified between the groups. Below a short definition is given of what the performance indicators mean in this article:

- **Availability.** A comparison between the number of spare parts that are delivered completely and in time to the customer and the total number of spare parts delivered.
- **Operational costs.** The expenses that are made for managing a part. In this research ordering costs and salary expenses related to the time/attention spend on a part are considered.
- **Working capital.** Officially the difference between a company's current assets and its current liabilities. Within this article, only the stock level is considered.

In literature it is found that performance management should be integrated together with demand forecasting, inventory control and supply management in an approach for achieving optimal spare parts management (Bacchetti & Saccani, 2012). Here a first step towards this integration is made.

4.3 Description of characteristics per group
For each group the characteristics of parts, the main focus in the triangle of performance indicators and a description for each decision function and the process is presented. The description are based on a combination of findings in the literature review and the field research.

**Group 1.** Parts with a low value, high/medium consumption rate and low/high supplier risk
Typically, parts in this group are characterised by their low product value. They have a fast moving rate and are mostly nonspecific parts. As the parts are rather standard, multiple suppliers are available, the market is not very complex and delivery lead times tend to be short. For this group supply risk could be high as well, but this does not change the desired method of managing these parts and the focus in the triangle is the same.

Regarding the trade-off between availability, operational costs and stock, the focus for parts in this segment is on operational costs. With regards to working capital, high quantities on stock do not have a high impact.

### Demand forecasting
- Statistical forecasting is possible
- Forecasting is not important

### Inventory control
- Focus on availability and have parts on stock
- Focus on low ordering costs; large ordering intervals, optimal order quantities

### Supply management
- Single sourcing
- Minimisation of supply base
- Focus on availability (supplier delivers from stock)
- Focus on price
- Focus on order efficiency with supplier
- Focus on additional services from supplier

### Process
- Efficient order processing (minimal handling and minimal administration)

### Group 2. Parts with a high/medium value, high/medium consumption rate and low supply risk

Parts in this category are expensive products. They are frequently requested and are not very specific (commodity products). The supply risk in this group is low, due to the high priority for the supplier, the high priority for the company itself and the availability of alternative suppliers.

The focus for these parts is on providing proper availability with minimal stock levels. It is the objective to minimise the stock in the total chain. It is also important to exploit options for minimising operational costs, by setting up an efficient process. Thereby the availability should not be forgotten, but it can relatively easy be covered due to the low supply risk.

### Demand forecasting
- Statistical forecasting is possible
- Forecasting is important

### Inventory control
- Focus on low stock levels
- Focus on availability and have parts on stock

### Supply management
- Single sourcing
- Back up source ready
- Focus on availability (supplier delivers from stock)
- Focus on price
- Focus on minimal stock levels / stock upstream
Focus on order efficiency with supplier

**Process**

- Efficient order processing (minimal handling and minimal administration)
- Quick response to changes (focus on availability)
- Well-structured and effective decision-making

**Group 3. Parts with a high/medium value, high/medium consumption rate and high supply risk**

Parts in this category have a high price and are frequently requested. Supply risk for these parts is high, as typically only one supplier is available and thus there is dependence on a supplier. Also lead times can be long.

The focus for parts in this category is on finding an optimal balance between availability, stock levels and operational costs. Stock levels should not be high due to the high price, but it should be high enough to cover the future demand in line with the expected risk in supply. As the parts have a high consumption rate, the operational costs should be monitored as well.

| Demand forecasting | Statistical forecasting is possible
|                    | Forecasting is important
| Inventory control  | Focus on low stock levels
|                    | Focus on availability and have parts on stock
| Supply management  | Single sourcing
|                    | Try to have a backup source ready

**Group 4. Parts with a low value, low consumption rate and low supply risk**

Parts in this category typically have a low price and they are standard. However, they are not often required. The supply risk is low as several alternative suppliers are available, the market is not complex and delivery lead times are short. Basically these parts are similar to the ones in category 1, with the difference that they are not often consumed.

The focus for this group is mainly on minimising operational costs. Rather high stock levels would not matter due to the low prices, but they do not have to be high, as parts can be easily and quickly purchased. A trade off can be made between high quantities on stock or no stock and a quick response in case of a request.

| Demand forecasting | Forecasting is difficult
|                    | Forecasting is not important
|                    | Make initial estimate of product ever needed during life cycle
### Inventory control
- Focus on availability, have parts on stock or have no stock and a quick response in case of a request

### Supply management
- **Inventory control**: Focus on availability and have parts on stock
- **Supply management**: Single sourcing
  - Minimise supply base
  - Focus on availability (supplier delivers from stock)
  - Focus on order efficiency with supplier
  - Focus on additional services from supplier

### Process
- Efficient order processing (minimal handling and minimal administration)

### Group 5. Parts with a low value, low consumption rate and high supply risk

Parts in this category typically have a low value and a low consumption rate. Parts are rather specific, which contributes to the high supply risk. Also the fact that mostly few suppliers are available and that the priority for both the company and the supplier are low cause the supply risk to be high.

![Availability triangle](image)

**Availability**

- **Working capital**
- **Operational costs**

The focus for this category is mainly on achieving the desired availability. Compared to parts in group 4, for these parts sooner the decision is made to hold a stock (of a higher quantity). If possible, operational costs should also be minimised, but this is of minor importance.

### Demand forecasting
- Forecasting is difficult
- Forecasting is not important

### Group 6. Parts with a high/medium value, low consumption rate and low/high supply risk

In the last category, parts are characterised by a high value and low consumption rate. Often asset critical parts have these features. The supply risk is in general high in this category, because few or even only one supplier(s) are available and as the company has a low priority for suppliers. Also delivery lead times tend to be long. Supply risk could potentially be low as well, but this does not significantly change the method of managing these parts and the focus in the triangle.

![Availability triangle](image)

**Availability**

- **Working capital**
- **Operational costs**

For parts in this group the focus is on stock level and availability. Regarding cost reduction, most improvement can be achieved by controlling the stock levels, as a small stock already leads to high stocking costs. As mentioned, often these parts are asset critical, hence the desired availability of a part is an important consideration in relation to the stock level. Operational costs are not a prime focus, as for these parts it is valuable to spend...
enough time on managing them in an optimal way.

| Demand forecasting          | Forecasting is difficult  
|                             | Make initial estimate of  
|                             | product every needed  
|                             | during life cycle  
|                             | Make initial estimate of  
|                             | risk to have spare part not  
|                             | on stock  |

| Inventory control           | Focus on low stock levels  
|                             | Focus on availability and  
|                             | have parts on stock  
|                             | Focus on availability and  
|                             | have other solution if  
|                             | replacement product not  
|                             | on stock  
|                             | Focus on low ordering  
|                             | costs; large ordering  
|                             | intervals, optimal order  
|                             | quantities)  |

| Supply management           | Single sourcing  
|                             | Focus on availability  
|                             | (supplier delivers from  
|                             | stock)  
|                             | Focus on a good  
|                             | relationship with suppliers  |

| Process                     | Quick response to changes  
|                             | (focus on availability)  
|                             | Well-structured and  
|                             | effective decision-making  |

The approach has to have practical applicability and it should be easy to understand and apply by users. This way the problem of non-adoption due to complexity can be overcome, and then the approach can actually be used to improve the performance at the company.

4.4 Guidelines for users of the approach

The users of the integrated approach can be divided in three main groups; the Maintenance department, the Purchasing department and the Logistics department. The main activities that these departments should focus on as part of the integrated approach are presented below. Compared to last chapter, here the focus is more on actual activities that are on a user level. Also for each department a flowchart has been designed that can be used for applying the approach; these are placed in Appendix I. The guidelines and the flowcharts per department are validated with people from the concerning departments in a focus group.

Group 1. Parts with a low value, high/medium consumption rate and low/high supplier risk

<table>
<thead>
<tr>
<th>Department</th>
<th>Main activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>Product fully specified and documented at moment of creation</td>
</tr>
<tr>
<td>Purchasing</td>
<td>Define supplier and set up info records at creation</td>
</tr>
<tr>
<td></td>
<td>Info records periodically reviewed and updated</td>
</tr>
<tr>
<td></td>
<td>Standard contract; focus on good price, availability, order efficiency</td>
</tr>
<tr>
<td></td>
<td>Focus on suppliers capable to deliver additional services</td>
</tr>
<tr>
<td></td>
<td>Reduce supply base</td>
</tr>
<tr>
<td>Logistics</td>
<td>Focus on order efficiency (minimal handling and minimal administration)</td>
</tr>
</tbody>
</table>

Group 2. Parts with a high/medium value, high/medium consumption rate and low supply risk

<table>
<thead>
<tr>
<th>Department</th>
<th>Main activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>Product fully specified and documented at moment of creation</td>
</tr>
<tr>
<td></td>
<td>Product specification and documentation periodically reviewed</td>
</tr>
<tr>
<td></td>
<td>Indicate if products can be ordered with various suppliers</td>
</tr>
<tr>
<td></td>
<td>Indicate criticality factor</td>
</tr>
<tr>
<td></td>
<td>Indicate risk of product failure</td>
</tr>
<tr>
<td></td>
<td>Provide future (initial) demand forecast</td>
</tr>
<tr>
<td>Purchasing</td>
<td>Define supplier and set up info records at creation</td>
</tr>
<tr>
<td></td>
<td>Info records periodically reviewed and updated</td>
</tr>
</tbody>
</table>
**Logistics**

- Focus on order efficiency (minimal handling and minimal administration)
- Focus on quick response
- Focus on well-structured process and effective decision making
- Focus on low stock levels
- Set up forecasting and analyse trends
- Review meetings with suppliers (focus on logistics elements)

**Group 3. Parts with a high/medium value, high/medium consumption rate and high supply risk**

<table>
<thead>
<tr>
<th>Department</th>
<th>Main activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>Product fully specified and documented at moment of creation&lt;br&gt;Product specification and documentation periodically reviewed&lt;br&gt;Indicate if products can be ordered with various suppliers&lt;br&gt;Indicate criticality factor&lt;br&gt;Indicate risk of product failure&lt;br&gt;Provide future (initial) demand forecast</td>
</tr>
<tr>
<td>Purchasing</td>
<td>Define supplier and set up info records at creation&lt;br&gt;Info records periodically reviewed and updated&lt;br&gt;Define back up supplier&lt;br&gt;Customised contract; focus on availability&lt;br&gt;Review meetings with suppliers&lt;br&gt;Supplier collaboration</td>
</tr>
<tr>
<td>Logistics</td>
<td>Focus on quick response&lt;br&gt;Focus on well-structured process and effective decision making&lt;br&gt;Focus on low stock levels</td>
</tr>
</tbody>
</table>

**Group 4. Parts with a low value, low consumption rate and low supply risk**

<table>
<thead>
<tr>
<th>Department</th>
<th>Main activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>Product fully specified and documented at moment of creation</td>
</tr>
<tr>
<td>Purchasing</td>
<td>Define supplier and set up info records at creation&lt;br&gt;Standard contract; focus on good price, availability, order efficiency&lt;br&gt;Focus on suppliers capable to deliver additional services&lt;br&gt;Reduce supply base</td>
</tr>
<tr>
<td>Logistics</td>
<td>Focus on order efficiency (minimal handling and minimal administration)</td>
</tr>
</tbody>
</table>

**Group 5. Parts with a low value, low consumption rate and high supply risk**

<table>
<thead>
<tr>
<th>Department</th>
<th>Main activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>Product fully specified and documented at moment of creation&lt;br&gt;Indicate if products can be ordered with various suppliers&lt;br&gt;Indicate criticality factor&lt;br&gt;Indicate risk of product failure</td>
</tr>
<tr>
<td>Purchasing</td>
<td>Define supplier and set up info records at creation&lt;br&gt;Define a backup supplier</td>
</tr>
<tr>
<td>Logistics</td>
<td>Focus on quick response&lt;br&gt;Make risk analysis to define product on stock</td>
</tr>
</tbody>
</table>

**Group 6. Parts with a high/medium value, low consumption rate and low/high supply risk**

<table>
<thead>
<tr>
<th>Department</th>
<th>Main activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>Product fully specified and documented at moment of creation&lt;br&gt;Indicate if products can be ordered with various suppliers&lt;br&gt;Indicate criticality factor&lt;br&gt;Indicate risk of product failure</td>
</tr>
<tr>
<td>Purchasing</td>
<td>Define supplier and set up info records at creation&lt;br&gt;Define a backup supplier</td>
</tr>
<tr>
<td>Logistics</td>
<td>Focus on quick response&lt;br&gt;Make risk analysis to define product on stock</td>
</tr>
</tbody>
</table>
4.5 Validation of the approach

The validation is performed by organising a discussion with a delegation of experts from the maintenance department, purchasing department and logistics department. This validation method is chosen for a few reasons. First of all, it has to be checked whether the approach is perceived as practical and effective by potential users, as this is one of the goals of the design. Thereby, as the approach is made slightly more from a logistics perspective, it is interesting to look at similarities and differences between the views of the different departments. With a discussion between experts, these can be identified and there can be looked at ways of dealing with the possible differences in perspective. Limitations of the expert review as a validation are the subjectivity of the experts and the specificity for a certain context, as experts of only one company are approached. A (simulation) model based on quantitative variables can be used for a more objective and trustworthy validation, but in order to do this the integrated approach has to be extended with quantitative variables. Though, for the current objectives an expert review is viewed as sufficient based on the reasons discussed above.

Prior to the discussion meeting, an e-mail with the subject, goal and expectations of the meeting is send to the participants.

- Maintenance engineer
- Purchasing manager
- Logistics manager
- Tactical planner
- Head of material planners
- Material planner

The approach is introduced and explained by the researcher, who afterwards takes the role of a moderator during the discussion. After the clarification by the researcher, the participants discussed about their agreement or disagreement with the integrated approach. They also provided their view on the value of the model, and on the practical usability. During the discussion, the researcher made sure that all participants provided feedback and that each subject was extensively treated. Also, the researcher made notes of important comments during the discussion. The main findings are summarised by the researcher. This summary, existing of the main general comments, is presented below.

- The importance of including demand forecasting, inventory control, supply
management and process elements is logical.
- The importance of differentiating the approach for various groups of spare parts is clear.
- The classification into six groups with the corresponding characteristics is logical.
- The dimensions are clear, though also a few other criteria could be considered.
- Focus within the triangle is well positioned for each group.
- The approach is workable, but in order for it to be applied in actual operations of the rail transport operator still some improvements are desirable.
  - Make supply risk the most important variable, due to its impact in the sector.
  - Inclusion of obsolescence as a variable of supply risk.
  - Increased inclusion of risk from a maintenance perspective (criticality, stock out cost).
  - Quantification of the dimensions.

5. Conclusion and future research
In this study an approach is designed with the objective to achieve more overall effective spare parts management and hence a better balance between the performance indicators availability, operational cost and working capital. The approach allows the users to take an integrated perspective by focusing on demand forecasting, inventory control and supply management. Thereby, it gives users a directive to differentiate their activities for parts with various characteristics. The important characteristics are covered by the three dimensions ‘price’, ‘consumption rate’ and ‘supply risk’. After bundling a number of categories, this leads to six different groups. Next to different activities, another focus regarding performance improvement is specified as well. Based on the field research, it is also found that the approach will not be optimally effective, if not at the same time the organisation and process are upgraded. Therefore it is essential that awareness is created in a company that a successful change depends on the process execution by the staff. An environment at the company should be created where everyone feels a sense of urgency and at the same time comfortable to work with the designed approach.

To make the approach simple and targeted in its use, the main activities are assigned to the three main departments that are concerned with spare parts management: maintenance, purchasing and logistics.

As input for the design qualitative and quantitative analysis at a company operating in the rail transport sector is used. Experts from this company have validated the approach.

This article offers a significant contribution, as it has an integrated perspective, while at the same time it is differentiated for various types of spare parts. Thereby it reduces the gap between theory and practice, by including organisation and process elements based on field research at a rail transport operator and by focusing on a high level of practical applicability with its simplicity. Notwithstanding its relevance, the study can be extended in a number of directions.

First of all, since this approach was abstracted from a practical study rather than from a rich and profound methodological research, the scientific argumentation behind (the creation of) this approach is limited. A pure methodological and theory-based research might evaluate the constructed approach in a further way. Second, the company studied during this research is active in the rail transport sector, hence the results present some specificities depending on this context. The effect of contextual factors on a spare parts management approach like this could be further researched. Also the applicability of the approach in other sectors can be further examined.

One of the main contributions of this research, is the combination that is made between an
inventory classification and a supplier segmentation. Though, to assure practical usability, it is chosen to work with relatively simple differentiations methods. Namely price and consumption rate, as used in traditional ABC classification, and supply risk as used in the Kraljic matrix. In chapter 3.3.1 more advanced inventory classifications, which consider multiple criteria, are presented. While in chapter 3.4.1 more advanced supplier segmentations are presented, that also consider multiple criteria and that focus more on buyer-supplier relationships (instead of products). Besides this, also different methods for executing the segmentations are named (MCDM methods). Interesting future research could focus on how to use other segmentations than Kraljic, for instance with the dimensions suppliers’ capabilities and supplier willingness, in combination with an inventory classification. And furthermore, how to use other methods to execute the segmentation in the design of an integrated approach for spare parts management.

The approach is robust and validated with experts for the designated departments. Though, multiple choices during the research are based on qualitative information. For the following aspects, quantitative data could make the choices more robust: selecting the variables of supply risk, selecting the dimensions of the classification and the bundling of groups. Besides this, certain assumptions are made due to the scope of this research. For the following aspects this means that they should be further explored in the future: the differences between repairable parts and consumables in the approach, the inclusion of criticality (stock out cost) in an approach together with price, consumption rate and supply risk and dependencies between parts that are placed in different groups.

Finally, for this approach it has been assessed for each group of spare parts where the company’s focus is regarding availability, operational cost and working capital on the tactical level. Such a differentiated focus can also be researched for strategic and operational performance indicators. That way performance measurement can be increasingly integrated in the approach.

Bibliography


W.W.F. van der Vorst / Design of an integrated and practical approach for spare parts management