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Determination of optimal order-up to level quantities for dependent spare parts using data mining

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ABSTRACT

Consumable spare parts play an important role during regular and periodic maintenance activities depending on equipment criticality of a manufacturing firm. Usually, these spare parts are consumed together on a regular basis to different equipment with a high percentage of commonality. Complete or partial shutdown of maintenance activity may happen if there is shortages in any of these common parts and at the same time, maintaining a high inventory of these parts lead to more cost. If there is a shortage of a spare part, then there is a chance that other dependent spares may remain as idle inventory and incur the opportunity cost. In this paper, a noble approach is adopted to incorporate dependency of items in periodic review (T, S) policy to determine the optimal stock of dependent spare parts considering common cycle time and fill rate for each spares. Our results show that there is considerable reduction of stock level and total cost of inventory when associated spares are considered together for management of inventory instead of considering them individually. Finally, the developed model is applied to a case company.

1. Introduction

In today's competitive business environment, one of the important issues in a manufacturing firm is the management of spare parts. Consumable spare parts play an important role during regular and periodic maintenance activities depending upon equipment criticality. Many firms store thousands of spare parts in inventory that shares the major percentage of inventory cost. A large inventory of spare part results in high holding and obsolescence cost. On the other hand, low level of inventory in store causes severe production loss due to shortages.

During maintenance operations of equipment, many spare parts are consumed together depending upon their correlations among themselves. Quite often use of one spare part leads to the use of another spare part whereas sometimes it does not happen. For example, during the maintenance of a two wheeler when bearing races are replaced, there is a high chance that shock absorber spring also gets replaced. In this paper, we have termed these spares as associated spare parts. Among these spares, if one spare is out of stock, then there is maximum likelihood that the consumption of the other spare part also gets affected like fall in the demand rate or pile up of inventory in stock. In case of single item inventory control when there is a shortage or occurrence of stock out, only the effect of independent items is considered but in case of associated items, stock out of one item causes the excess of inventory holding of other related items. Usually, maintenance database of a company keeps a large number of past consumption records with respect to maintenance activities for various equipment. However, it is very difficult to use statistical analysis to estimate frequent consumption of spares in group and also the dependency. Even though over the years, many mathematical models have been developed in the literature for the management of independent spare parts, yet only a few of them have seen the light of actual application in the field due to its complex mathematical structure.

In recent times, data mining application has received considerable attention from various sectors like medical service, intrusion detection, and customer relationship management. Various methods of data mining such as association rule, classification, clustering, sequence mining, and regression are applied for the above areas (Han & Kamber, 2006). Association rule mining aims at understanding the relationships among items in transactions or market baskets (Agrawal, Imilienski, & Swami, 1993). But till date, no such application is seen in the areas of spare parts inventory management. This has motivated us to take up this new approach for the management of consumable dependent spare

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parts. In the current IT era, most of the firms have implemented ERP package and as a result all transaction data related to consumable spare parts are available with them. In this paper, data mining methodologies are used to estimate the dependency factor among the consumable spare parts and finally developed inventory control policy. Prior to association rule mining, frequent item sets are determined from database transactions. Frequent item set is the number of items consumed together in a particular period of time satisfying minimum threshold support value. Based on this frequent item set and association rule mining methodologies, a few authors have carried out studies related to item-item relationship or dependency and in the next section; a review of literature is provided.

2. Literature review

Currently, there are very few contributions of data mining are available in the domain of inventory management and more specifically on spare parts management. A brief review of literature related to our work on data mining applications in inventory management is discussed here. Brijs, Swinnen, Vanhoof, and Wets (1999) used association rules for item selection problem with the consideration of relationships among retail items to discover frequent itemsets and have determined the profitability per set of items by identifying the cross-sales effect of product items and used this information for better product selection. This model was extended by Brijs, Goethals, Swinnen, Vanhoof, and Wets (2000) to enable retailers to add category restrictions. Wong, Fu, and Wang (2005) followed the earlier work of Brijs et al. (1999) and proposed a method for actionable recommendations from itemset analysis and investigated an application of the concepts of association rules-maximal-profit item selection with cross-selling effect. Bala, Sural, and Banerjee (2010) proposed a model for finding purchase dependence association rules for retail products to take inventory replenishment decisions. As per their observation, in a multi-item retail inventory with a very large number of items, purchase dependence among the items is often observed and when there is stock-out of one item, it may result a non-purchase of another item. Yin, Kaku, Tang, and Zhu (2011) described the association rule mining in an inventory database. They have given brief explanations for frequent item/item sets, apriori algorithm, discovering association rules from frequent item sets, multi-dimensional association rules and association rules with time-window.

The basic method of data mining for finding association rules from frequent items as given in Yin et al. (2011) is explained here for the easy understanding of the reader. Suppose, we have a rule called $X \Rightarrow Y$ where X and Y are two item sets, then the rule confidence is given as follows:

$$\text{Confidence of rule } X \Rightarrow Y = Conf(X \Rightarrow Y) = \frac{|X \cup Y|}{|X|} = \frac{Sup(X \cup Y)}{Sup(X)}$$

where support of X is $Sup(X) = |X|/|D|$ and $|D|$ represents the whole data base records. A rule satisfying both threshold support and confidence values (which are identified by experts) is called strong or valid. The items inside these rules are called associated items. Liiv (2007) proposed an inventory classification method using visualization and data mining technique considering interdependency among the products. Association rule method of data mining is used for classification of inventories by Zhenyu, Yan, and Zhenying (2009). The authors used weighted association rule concept to build a new evaluation criterion based on weighted dollar consumption.

Adopting a classical approach, many researchers have proposed coordinated or joint replenishment policy for multi item inventory control. It is always beneficial to order items in group for better management of inventory control decisions rather than concentrating on individual item. Ramani and Krishnan (1985) suggested that it is necessary to group various spare parts into different categories, which are associated to a particular equipment or maintenance activity to apply different ordering policies (i.e. multi-item inventory control) according to the importance of each category. This leads to a lesser amount of effort for managing the stock of the spares that are falling in the same group and at the same time, number of spares becomes less that requires more management attention. Razi and Tarn (2003) developed another methodology of item grouping approach for estimating demands. These groups are based on annual demand units and lead time and a common group demand distribution was determined. They applied (T, S) periodic review policy to estimate the base stock level (S) with service level constraints.

Again, many researchers have studied coordinated or joint replenishment models for multi item inventory control systems. Among those, Balintfy (1964) proposed a (S, c, s) policy, which is also called can-order replenishment policy and is widely discussed in the literature. In this policy, each item can have a can-order level c in spite of their own must order level s. When the inventory position of item i reaches its must order level s_i, a replenishment order is placed. At the same time, any item j with inventory position at or below its can order level c_j is included in the order to make the order up-to level of S_i and S_j for item i and j respectively. Silver (1974) used this (S, c, s) policy for estimating order up-to level, can-order point and must order point using poisson demand and non-zero lead time. They proved that around 18.8% savings are resulted because of the coordinated model compared to independent model. Other researchers have also developed inventory control models for multiple items considering correlated demands. Liu and Yuan (2000) proposed coordinated replenishment model considering correlated demands for multi item inventory control. The authors utilized Markovian model for two item inventory system with correlated demands and estimated total cost per unit time. Finally, they concluded that cost saving increases when there is a decrease in demand covariance, and the total cost involved in coordinated policy with correlated demands is less than independent control.

Khouja and Goyal (2008) have provided an excellent review of literature on joint replenishment problems from 1989 to 2005. Fung, Ma, and Lau (2001) suggested (T, S) coordinated replenishment model for multi-item inventory systems considering compound Poisson demand, non-zero lead time and service level constraints. They made a comparison of their model with (S, c, s) model and concluded that (T, S) model gives better results than (S, c, s) model considering non-zero lead-times. An association clustering method was proposed by Tsai, Tsai, and Huang (2009) for can-order policies for joint replenishment problem, and the suggested model gives better result compared to several traditional replenishment models. A different approach of periodic review of multi-item inventory control was proposed by Nenes, Panagiotidou, and Tagaras (2010) by taking stochastic demand for fast and slow moving spares. They used Gamma and Poisson distribution for fast-moving and slow moving spares respectively to estimate the accurate base stock level with desired fill rate constraints.

Again, Pentico and Drake (2009) proposed a new methodology to determine EOQ with partial backordering considering fill rate and backordering percentages. Later Pentico, Drake, and Toews (2009) demonstrated similar work for EPQ model with partial backordering. Using the similar concept, Zhang, Kaku, and Xiao (2011) presented deterministic EOQ model for dependent products considering cross-selling effects between the items. They