Management and Production Engineering Review
Volume 14 • Number 4 • December 2023 • pp. 92–99
DOI: 10.24425/mper.2023.147206

Inventory Classification with Limitations in the Number of Changeovers and Space for Inventory

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Received: 31 July 2023
Accepted: 23 October

Abstract
This research addresses an inventory classification problem in a company that manufactures plastic pallets. Classification of the inventory is difficult because it is subject to two restrictions: the number of changeovers and the size of inventory storage. A mathematical model is first proposed to maximize the fill rate by classifying all product items into four groups. Due to all items can be classified based on the monthly demand, in descending order. The present study then proposed a procedure to find the classification that is most efficient. According to the experimental results, the maximum fill rate in the current situation is 89.85%. The proposed methodology also tested different production batches and levels of demand. The proposed methodology was found to be appropriate for practical application.

Keywords
Inventory classification; ABC classification; Inventory management; Fill rate; Plastic pallet.

Introduction

Inventory classification is an effective way of managing and controlling a large number of inventory items (Keshavarz Ghorabaee et al., 2015), and has benefits for inventory managers (Sheikh-Zadeh et al., 2021). ABC analysis is one of the most efficient and widely employed techniques of inventory classification in organizations (Torabi et al., 2012). According to the definition of the American Production and Inventory Control Society (APICS), ABC analysis is the classification of a group of items in decreasing order of annual dollar volume or other criteria. This array is then split into three class, called A, B and C (Blackstone & Cox 2008). Class A should contain the most important items. Class B should contain the moderately important items. And Class C should include all the relatively unimportant items (Douissa & Jabeur, 2016).

The concept of ABC analysis can be extended to divide all items into more than three groups. A major challenge with inventory classification is determination of the cutoff value between classes, which this relies more on managerial judgement than quantitative analysis, and its effects on inventory performance generally remain invisible (Yang et al., 2017). The design of the production policy for each group should also be an important issue when manufacturing companies manage their inventory of finished goods. The size of the production batch is one of the important decisions in production policy. It affects the inventory level and production efficiency. Therefore, the selection of inventory classification and production policy should be optimized simultaneously.

The motivation for the presented study is a practical problem in a plastic pallet manufacturing company in Taiwan. Because of the long changeover time, the case company always tries to produce products in large batches to reduce the number of changeovers. This decision results in high inventory levels, although the inventory cost of plastic pallets is not an important issue for the case company. The problem for the company is that they have insufficient space for storing inventory. This kind of inventory problem becomes more serious as the number of product items increases. Therefore, the case company needs to classify all items into several groups and design a production policy for each group.

The limited number of changeovers and lack of inventory space are the main constraints on inventory management in the case company. The lengths and

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widths of plastic pallets are between 100 and 150 centimeters, and the heights are 10 to 15 centimeters. The main manufacturing process is injection molding. The weight of molds are between 10 and 20 tonnes, and the heaviest can be as much as 24 tonnes. A thirty-five tonne crane is used to exchange molds and the molds are moved slowly. After the molds are fixed on the machines, there are several adjustments that need the intervention of operators and all adjustments are executed slowly. Therefore, 6 to 8 hours are required for each mold exchange. The whole procedure of mold exchange is designed on the basis of safety issues and at least two operators are required. According to the standard operating procedure, while one operator is executing the operation of mold exchange, the other operator ensures that all situations are safe. Moreover, in order to ensure operators stay awake when executing the operations of mold exchange, mold exchange is not allowed on the night shift. There are only two qualified operators assigned to execute the mold exchange in the case company. Therefore, one mold exchange can be arranged per day. If one day of overtime per week is allowed, at most 25 mold exchanges per month can be arranged.

As regards inventory space, an automated storage and retrieval system (AS/RS) is designed to stock as many plastic pallets as possible. The capacity of the AS/RS is about 40,000 plastic pallets. All plastic pallets are stored in the AS/RS after injection molding. There are five sizes of storage space. A plastic pallet can be stored in a storage space only if its length and width is smaller than the width of the storage spaces. After injection molding, if there is no empty storage space or all empty storage space are too small to stock them, no space in the AS/RS can be used for storage.

The case company aims to decide the production policies for all items. The policy is the production batch, which depends on the monthly demand. The higher the monthly demand, the larger the production batches. In order to simplify the management, all items are classified into groups. Then the items in the same group are assigned the same production ratio. The groups are divided into two types: the first is items with high demand, and the second is for the items with low demand.

For the items with high demand, the strategy is to maintain stock to reduce the number of mold changes. It is assumed that orders are always received before their due dates by a time that is longer than the production lead time. Therefore, the issue of safety stock is ignored in this case study. The size of production batches is an important decision. If the batches are too large, then the average inventory level would be too high, but if the batches are too small, more mold exchanges will be needed.

For the second group, according to historical data, the demand is low. The demand for some items may be much smaller than the throughput of one shift. Therefore, it may not be worth changing molds to produce such a low volume. Sometimes the case company produce the items in large batches, and then creates inventory that will be stored in the AS/RS for a long time. However, when a machine produces two items of the same size, mold exchange is not required. The case company accept orders for the items belonging to the second group if there are items of the same size in the first group. Otherwise the order is rejected. Therefore, for low-demand items, the production batches are the size of the order, and they are produced immediately after high demand items that are the same size. If this cannot be arranged, the orders for the items are rejected and the production batches are zero. As low-demand items are produced in batches that are equal to the customer demand, they are dispatched to customers immediately and are stored in the AS/RS.

The presented study aims to classify all items into groups in decreasing order of average monthly demand. The objective is to maximize the fill rate of customer demand and two decisions are considered for analysis. The first is the number of items classified into each group, and the second is the production batch for each group of high demand items. The remainder of this paper is organized as follows. Section Literature review reviews the relevant literature. Section Formulation for the proposed problem presents the model formulation for the proposed problem. Section Solution methodology for inventory classification presents the proposed methodology for inventory classification. Details of the empirical illustration and analysis of different scenarios are discussed in Section *Empirical illustrations.* Conclusions and future research opportunities are addressed in the last section.

Literature review

Various studies deal with the issue of inventory classification (van Kampen et al., 2012). Most of them focus on developing a method of inventory ranking (Sheikh-Zadeh et al. 2021), especially the multi-criteria decision-making method (Saracoglu, 2022). Their main objective is to optimize inventory performance or customer satisfaction. However, practical limitations are always ignored. The present study aims to classify all product items into groups and optimize the production batch size for items in each group. The objective is to maximize the fill rate of customer demand. Two practical limitations, inventory space and number of changeovers, are taken into consideration. Inventory classification with practical limitations is reported in the literature in only a few cases. Some related literature that considers the limitation of inventory space and number of changeovers is reviewed below.

Inventory classification with limited inventory space

Millstein et al. (2014) dealt with a multi groups inventory classification problem. Each product item was to be classified into a group with the same corresponding service level. If no product item was assigned to a group, the group and the corresponding service level is not required for the inventory classification problem. The more groups that are assigned no product, the fewer the groups are that are considered, and vice versa. According to the classification results, the total inventory level, and inventory budget, can be calculated based on the given mean and standard deviation of demand rate, and lead time of all product items. They inventory budget was assumed to be based on the value of inventory, and it was limited. The authors developed a mixed integer linear programming (MILP) to simultaneously make inventory classification and service level decisions to maximize profitability.

Ly & Raweewan (2017) dealt with an improved ABC inventory classification problem. All product items were grouped by annual use value based on the ABC approach. An MILP was developed to maximize the profit by choosing the optimal service level for each group under restrictions of inventory budget and the number of pallets that could be stored.

Yang et al. (2017) assumed that all product items can be assigned to different groups in different time periods. For each product item, the demand expected to in a time period is affected by its inventory level. A higher inventory level indicates more expected sales, but higher inventory cost. Moreover, inventory value in any given time period cannot exceed the available inventory capital. A MILP model was developed to dynamically integrate and optimize the inventory classification and inventory control decisions to maximize the net present value of profit over a planning horizon.

Ly & Raweewan (2021) refer to the mathematical model proposed by Millstein et al (2014) to deal with an inventory classification problem. However, Ly & Raweewan (2021) extend the mathematical model to consider the total number of pallets required as the constraint. Moreover, they modified the objective function to maximize the service levels under limited budget and limited warehouse space by optimizing the assignment of product items to groups.

The above literature takes the total volume of inventory as the restriction. Especially, Ly & Raweewan (2017) and Ly and Raweewan (2021) translate the volume of inventory into the number of pallets to be stored. However, they all assume that the size of all storage spaces are the same and all product items can be stored in any storage space.

Inventory classification with a limited number of changeovers

Research related to inventory classification that takes the number of changeovers as a constraint is not found in the literature. Kao et al. (2011) dealt with a two-stage supply chain inventory classification problem. They assumed that items in the same group are then jointly replenished and have the same order interval at the warehouse and the retailer. Based on the consideration of ordering cost, setup cost, carrying cost and variable cost, a formula was derived for the optimal order interval for each group. A selective regeneration particle swarm optimization (SRPSO) was applied to classify all items into groups.

Douissa and Jabeur (2016b) used a simplified ELECTRE III method as an aggregation procedure to compute the items scores. All items were classified into three groups based on the corresponding scores. According to the classification results, the total cost, which included order cost, set up cost and holding cost, can be calculated. Some parameter values are required by the simplified ELECTRE III method and different parameter values result in different item scores. A continuous variable neighborhood search was then proposed to find the optimal parameter values that can minimize the total cost.

Zhang et al. (2018) dealt with an inventory classification problem in which the replenishment policies for each group are taken into consideration. A GSAA-FCM (Genetic and simulated annealing algorithm-fuzzy clustering-means) algorithm was proposed to classify items into different groups with respect to the similarity of predefined criteria, such as annual dollar usage, lead time and criticality. Based on the classification, each group was then assigned an appropriate replenishment policy, optimizing both joint replenishment period and total costs. The total cost is the sum of setup costs and holding costs, and both depend on the replenishment period. The longer the replenishment period, the higher the holding costs and lower the setup cost, and vice versa.

Malindzakova et al. (2022), combined the ABC inventory and the MRP planning method to minimize the number of setting up production lines. In the ABC inventory method they wanted to optimize the ratio of total quantity of each group. With the MRP planning method, they wanted to optimize the production batches of items in each group. Four possible combinations of ABC inventory and MRP planning strategies were proposed for testing. According to the experimental results, when the ratio of Groups A, B, and C are 50%, 30% and 20% of total quantity, and the corresponding production batches are 1, 5, 10 days of demand, the number of set ups can be minimized.

In Kao et al. (2011), Douissa and Jabeur (2016a) and Zhang et al. (2018) the set up cost was part of the total cost that was to be minimized. In Malindzakova et al. (2022), the number of setting up production lines is the objective to be minimized. Therefore, no practical limitation is considered in the above research.

To the best of our knowledge, there are no existing studies which include warehouse space and number of changeovers in the inventory classification problem when determining production batches of items in each group and their associated optimal fill rate of customer demand.

Formulation for the proposed problem

This section formulates a mathematical model for classifying all items into four groups. The first two groups are for the items with high demand and the last two groups are for the items with low demand. All items are classified in decreasing order of monthly demand. Therefore the items in Group 1 have higher demand than those in Group 2. The production batches of items are proportional to monthly demand and the ratios are the same if the items are classified into the same group. The monthly demand for items in Group 1 are higher. Due to the limitation of inventory space, the ratio of Group 1 should be lower than Group 2. Moreover, the ratio can be more than 1, indicating that the production batch exceeds monthly demand.

As regards the items in last two groups, for an item to be classified into Group 3, at least one item in Groups 1 or 2 must have the same product size so that they and they can be scheduled to be produced one after the other. The production batches for Group 3 items are equal the order size. If an item is classified into Group 4, no item in Groups 1 or 2 is the same size, and orders will be rejected. Therefore, no more mold exchange is required for items in Groups 3 or 4. The objective is to maximize the fill rate of customer demand. The development of the mathematical model requires the following notation:

Notations

Indices:

- i index of product items ($i = 1, 2, 3, \dots, I$)
- g index of groups ($g = 1, 2, 3, 4$)
- s index of product size ($s = 1, 2, 3, \dots, S$)
- l index of storage space size ($l = 1, 2, 3, \dots, L$)

Parameters:

- d_i average monthly demand of production item i
- r_g ratio of production batch to monthly demand in group g

$$m_{is} = \begin{cases} 1, & \text{the size of product item } i \text{ is } s \\ 0, & \text{otherwise} \end{cases}$$

$$w_{il} = \begin{cases} 1, & \text{product item } i \text{ can be stocked} \\ & \text{in the storage space size } l \\ 0, & \text{otherwise} \end{cases}$$

- E the maximal number of mold exchange per month
- n_i the capacity of storage space size l

Decision Variables:

$$X_{ig} = \begin{cases} 1, & \text{product item } i \text{ is classified into group } g \\ 0, & \text{otherwise} \end{cases}$$

$$Y_{gs} = \begin{cases} 1, & \text{group } g \text{ includes products in size } s \\ 0, & \text{otherwise} \end{cases}$$

- F_{il} ratio of average monthly demand of item i stocked in storage size l
- $\underline{U}_g$ the minimal average monthly demand of item in group g
- $\overline{U}_g$ the maximal average monthly demand of item in group g

The mathematical model aims to minimize the fill rate as given in Equation (1). It is found that the items in Group 4 are not arranged to be produced. Equation (2) ensures that each items is classified into only one group. Equation (3) is used to judge the product sizes included in each group. Equation (4) ensures that if an item classified into Group 3, at least one item of the same size in classified into Group 1 or 2. The average number of mold exchanges for an item in Group 1 or 2 is equal to $1/r_1$ or $1/r_2$. Equation (5) is used to calculate the expected number of mold exchanges per month, and it cannot exceed the limit (25 per month). All items can only be stocked in a storage space that is larger than the product size. Equation (6) ensures that items are arranged to be stocked in reasonable storage spaces. Equation (7) ensures that the demand for all items are arranged to be stored. However, only items in Groups 1 and 2 will be stored in the AS/RS. Therefore, only items in Groups 1 and 2 will be restricted by the limitation of the capacity of all sizes of storage space which is represented in Equation (8). Because safety stock is ignored, the average inventory level of an item in Group 1 or 2 is equal to $r_1 d_i/2$ or $r_2 d_i/2$. Equation (8) ensures that the limitation of storage space can satisfy the average inventory level of all items in Groups 1 and 2. Equation (9) and (10) ensure the cutoff values between groups and the demand for items in Group 1 are higher than for items in Group 2 is represented by Equation (11). However, the upper bound of the items in Groups 3 and 4 are the same and represented by Equation (12).

$$\text{Maximize} \quad \sum_{i=1}^{I} d_i \left(X_{i1} + X_{i2} + X_{i1}\right) \Big/ \sum_{i=1}^{I} d_i \tag{1}$$

$$\sum_{g=1}^{4} X_{ig} = 1 \qquad \forall\, i \tag{2}$$

$$1 - \prod_{i=1}^{I} (1 - m_{is} X_{ig}) = Y_{gs} \quad \forall\, g, s \tag{3}$$

$$1 - (1 - Y_{1s})(1 - Y_{2s}) \geq (m_{is} X_{i3}) \quad \forall\, i, s \tag{4}$$

$$\frac{1}{r_1} \sum_{i=1}^{I} X_{i1} + \frac{1}{r_2} \sum_{i=1}^{I} X_{i2} \leq E \tag{5}$$

$$w_{il} \geq F_{il} \qquad \forall\, i, l \tag{6}$$

$$\sum_{g=1}^{L} F_{il} = 1 \qquad \forall\, i \tag{7}$$

$$\frac{r_1}{2} \sum_{i=1}^{I} d_1 X_{i1} F_{i1} + \frac{r_2}{2} \sum_{i=1}^{I} d_2 X_{i2} F_{i2} \geq n_l \quad \forall\, l \tag{8}$$

$$d_i \geq \underline{U}_g X_{ig} \qquad \forall\, i, g = 1 \land 2 \tag{9}$$

$$d_i X_{ig} \leq \overline{U}_g \qquad \forall\, i, g = 1, 2 \text{ and } 3 \tag{10}$$

$$\underline{U}_g \geq \underline{U}_{g+1} \qquad \forall\, g = 1 \land 2 \tag{11}$$

$$d_i X_{i4} \leq \overline{U}_3 \qquad \forall\, i \tag{12}$$

Solution methodology for inventory classification

All items are classified based on the decreasing order of monthly demand. In order to find the optimal classification efficiently, the presented study proposes a procedure to optimize the classification which is illustrated in Figure 1.

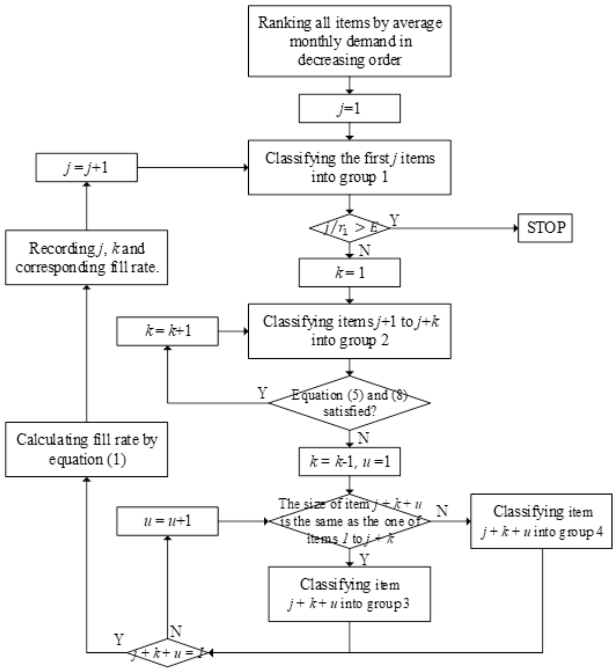

Fig. 1. The proposed procedure for inventory classification

All items are classified in decreasing order by average monthly demand. The first j items are classified into first group, and items $j+1$ to $j+k$ are classified into Group 2, and remaining items are classified into Group 3 or 4 depending on their product sizes.

$1/r_1$ mold exchanges per month are required for each item in Group 1, and the maximum number of mold exchanges per month is E(25). Therefore, the number of items classified into Group 1 may not be more than the E. Thus $j/r_1 \leq E$. Based on the first j items classified into Group 1, the procedure tries to classify items into Group 2 one by one. If the maximum number of mold exchanges per month and the sizes of all inventory spaces required can be satisfied after classifying item $j+k$ into Group 2, the classification is accepted. However, if the maximum number of mold exchanges per month or the sizes of inventory spaces required cannot be satisfied after classifying item $j+k+1$ into Group 2, the procedure classifies items $j+k+1$ to I into one of Group 3 and 4. For the items $j+k+1$ to I, if the size of the item is the same as one that has been classified into Group 1 or 2 (items 1 to $j+k$), then the item will be classified into Group 3. Otherwise it will be classified into Group 4.

For each j ($j = 1$ to j/r_1), one inventory classification is generated. The procedure calculates the fill rate of customer demand for each classification and the one with the highest fill rate will be adopted.

Empirical illustrations

Case study

The present study collected the data of orders from January 2021 to September 2022. There are 196 items and the corresponding monthly demands are shown in Figure 2. Demand mainly depends on a few product items and the demand for other products items is much lower. Thus, inventory classification is helpful for inventory management.

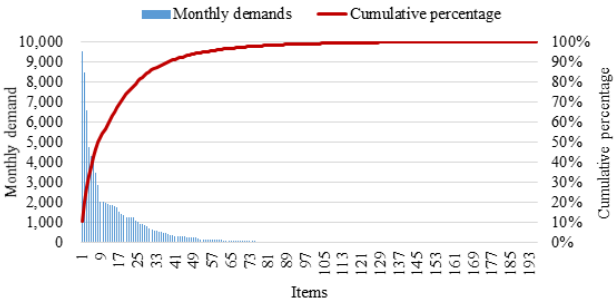

Fig. 2. The average monthly demand for product items

Five combinations of ratio of production batch to monthly demand are tested and the ratio of items classified into Group 1 is half that of items classified into Group 2. The combinations of ratio are (0.5, 1.0), (0.6, 1.2), (0.7, 1.4), (0.8, 1.6) and (0.9, 1.8). The results of the inventory classification by the proposed procedure are illustrated in Figure 3. For each combination of ratios, Figure 3 illustrates the fill rates for all items classified into Group 1. In general, as the number of items that are classified into Group 1 increases, the fill rates increase in the beginning, and then decrease after reaching a maximum. The highest fill rate, 89.85%, can be reached when the first 3

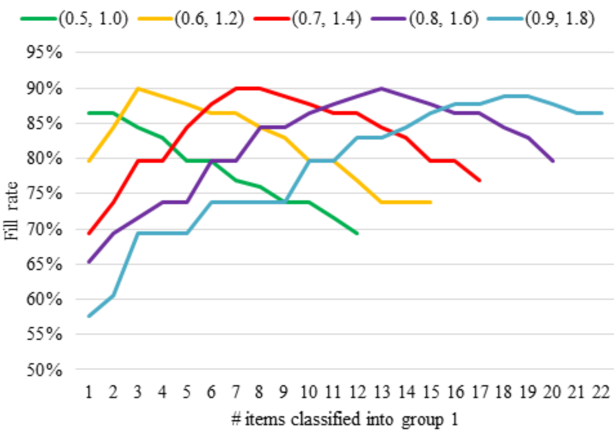

Fig. 3. Results of different production policies

items classified into Group 1 in the combination of ratios (0.6, 1.2), the first 7 or 8 items classified into Group 1 in the combination of ratio (0.7, 1.4), and the first 13 items classified into Group 1 in the combination of ratio (0.8, 1.6).

Figure 4 shows more detailed classification results for the combination of ratios (0.8, 1.6). When only the first few items (fewer than 13) are classified into Group 1, as more items are classified into Group 1, more items can be classified into Group 2, and higher fill rates can result. When the first 13 items are classified into Group 1, 14 items are classified into Group 2, and the corresponding fill rate is 89.85%, the highest. After that, the more that are items classified into Group 1, the fewer can be classified into Group 2 due to the limitation on the number of mold exchanges, and lower fill rates result.

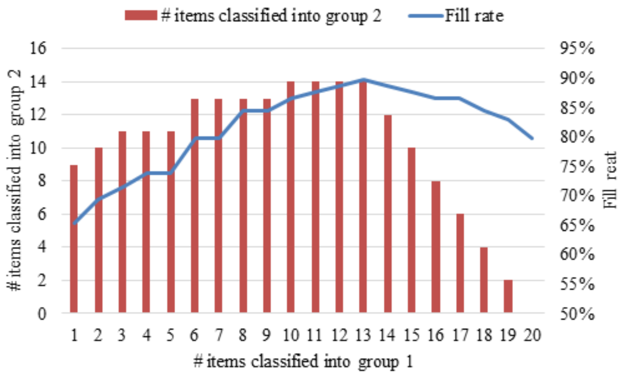

Fig. 4. Results of production batch with ratio (0.8,1.6)

According to the results in both Figure 3 and 4, in the beginning of the proposed procedure, the limitation of storage space affects the result of inventory classification. The more items classified into Group 1, the higher fill rates. Fill rate increases to the highest when the limitation of number of mold exchanges affects the inventory classification. Then, fewer and fewer items can be classified into Group 2, and the fill rate decreases.

Sensitivity analysis

Increasing the number of mold exchanges is an opportunity to increase the fill rate of customer demand. The case company planned to achieve this objective in two ways, first by reducing the time required for every mold exchange, and second by training two more operators to execute the mold exchanges. The case company think that two mold exchanges per day can be achieved. The present study assumes that the number of mold exchanges can be increased to 40 per month without one day overtime per week. The results of different production policies (combination of ratios) after the improvement of the mold exchange are shown in Figure 5.

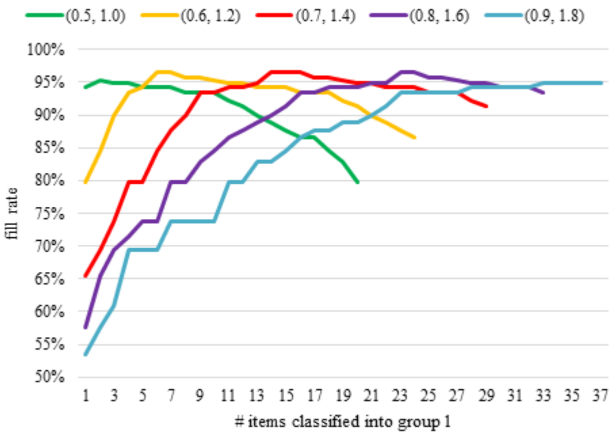

Fig. 5. Results of different production policies after improving the mold exchange

In Figure 5, it is shown that the maximum fill rate for all production policies are higher than the results shown in Figure 3. The highest fill rate of combination of ratios (0.6, 1.2), (0.7, 1.4) and (0.8, 1.6) are all 96.45%. However, the improvements are not huge (from 89.85% to 96.45%), because when the production batches are reduced, more items can be classified into Groups 1, 2 and 3. However, only the demand of items classified into Group 3, which had previously been classified into Group 4, would affect the increase of fill rate. The demand for these "new" items in Group 3 is low.

Therefore, the present study tested the proposed procedure by increasing the demand for all items. Assuming that the production capacity of the company is ignored, and demand for all items are increased by increments of 10%. Based on the combination of ratio (0.6, 1.2), the results are illustrated in Figure 6.

In Figure 6, as the demand of all items increase from 0% to 70%, the fill rates decrease from 89.85% to 73.78% if the maximum number of mold exchanges is 25, and decrease from 96.45% to 86.51% if the maximum number of mold exchanges is 40. The trend shows that when the mold exchange is improved, the more demand increases, the greater the improvement of the fill rate. Moreover, if the case company can increase the maximum number of mold exchanges to 40, they can accept a larger volume of customer demand from 85,078 to 129,731 as the demand increased by 70%, that is an improvement of 52.48%.

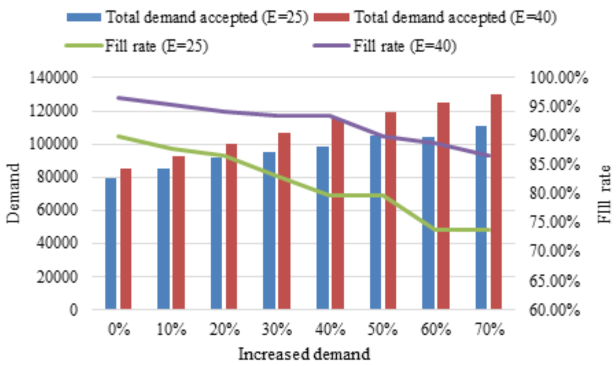

Fig. 6. Results for different increases of demand

Conclusions

Inventory classification is important for managing inventory. Most research deals with inventory classification by considering the characteristics of items and ignoring the practical limitations. The present study aims to solve the inventory classification problem in a plastic pallet manufacturing company. Two limitations, inventory space and number of mold exchanges, are taken into consideration. All items are classified into four groups. The first two groups are for the items with higher demand, and they are stocked in an AS/RS. The demand for items in Group 1 are higher than items in Group 2. The third group is for the items with lower demand, and the product sizes are the same as at least one item that is classified into Group 1 or 2. They are produced right after the items in Group 1 or 2 and the production batches are equal to the volume of the order. For items in Group 4, the corresponding orders are not accepted. Therefore, no inventory space and mold exchanges are required for the items in Groups 3 and 4.

This research proposed a mathematical model for the proposed inventory classification problem. Because all items are classified by decreasing order of average monthly demand, a procedure is proposed to optimize classification. Moreover, five production policies are proposed. Each policy indicates the production batches (ratio of production batch to monthly demand) of items in Groups 1 and 2. The production batches will affect the average inventory level in the AS/RS, and the number of expected mold exchanges per month. The results show that when the production batches are the combination of ratios (0.6, 1.2), (0.7, 1.4) and (0.8, 1.6), the fill rate can be maximized.

The present study also tested the proposed procedure in scenarios where the number of mold exchanges can increase from 25 to 40. The results show that the fill rate can be improved from 89.85% to 96.45%. Therefore, the proposed procedure can provide a satisfactory inventory classification under the current limitations.

The proposed procedure can optimize the inventory classification by classifying all items into four groups with the given combination of ratios. Classifying items into more groups or choosing more combinations of ratios may results higher fill rates. This would be the work of future studies, developing the argument of this study.

This study also assumes that items in Group 3 will be produced immediately after the items in Group 1 or 2, and orders are assumed always to be received with sufficient time for production before their due dates. Some customers may place their orders that are more urgent and need to be produced first. Therefore, proposing a mechanism of scheduling to satisfy the demands of customers could also be a research issue in the future.

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