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Multi-criteria inventory classification with reference items ☆

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ABSTRACT

The ABC method is a well-known approach to classify inventory items into ordered categories, such as A, B and C. As emphasized in the literature, it is reasonable to evaluate the inventory classification problem in the multi-criteria context. From this point of view, it corresponds to a sorting problem where categories are ordered. Here, one important issue is that the weights of the criteria and categorization preferences can change from industry to industry. This requires the analysis of the problem in a specific framework where the decision maker (expert)'s preferences are considered. In this study, the preferences of the decision maker are incorporated into the decision making process in terms of reference items into each class. We apply two utility functions based sorting methods to the problem. We perform an experiment and compare results with other algorithms from the literature.

1. Introduction

The ABC method has been used by business firms to manage a huge number of distinct items, referred to as stock keeping units (SKUs). As the size of the inventory increases, controlling the items needs time and additional expenditure. A reasonable strategy in this case is to classify the SKUs in terms of inspection priority. Therefore, the SKUs with high priority may be inspected more frequently to prevent stock-out cases and the resulting losses, while the SKUs with low priority may be inspected less frequently in order to reduce inspection costs. This tradeoff reveals that each SKU should have an inspection priority to minimize total inventory costs. Inventory classification is not only related to inventory management but also related to production planning. Selection of the appropriate production planning technique should also be considered together with the inventory classification.

Traditionally, the ABC analysis classifies items into three categories, namely, A (very important), B (moderately important) and C (least important) according to the annual usage value. Here, the priority criterion is the annual usage value which determines the class of the SKU. Since closely monitoring all items is too costly, a suitable inventory management policy is to concentrate more on class A items than on classes B and C items. Here, class C items also receive a more relaxed control policy than class B items (Silver, Pyke, & Preterson, 1998). However, authors agree that other characteristics of the inventory like criticality, lead time, ordering cost, commonality, repairability, and durability may affect and change the class of items (Flores & Whybark, 1987; Güvenir & Erel, 1998; Partovi & Anandarajan, 2002; Ramanathan, 2006). To take into account these characteristics we require multiple criteria decision analysis. Evaluating the problem in the multi-criteria context may also improve inventory investments (see Bhattacharya, Sarkar, & Mukherjee, 2007, for a comparison study of traditional and multi-criteria inventory classification via simulation). This problem has already been addressed in the literature. Recently, Ramanathan (2006) proposed a weighted linear optimization model where an LP model maximizing the weighted sum of criteria for the considered inventory item is solved and the resulting weights are assigned as favorable weights of this item. After that, Zhou and Fan (2007) presented an extended version of Ramanathan's model. Another weighted linear optimization model was given by Ng (2007) and Hadi-Vencheh (2010).

One different study about this problem is the case-based distance model by Chen, Kevi, Marc Kilgour, and Hipel (2008). This was originally a sorting procedure, which classifies actions into ordered classes. The decision maker (DM) assigns in advance some reference items into each class, and a mathematical model determines the thresholds and weights. (Fuzzy) AHP based approaches have also been presented for this problem in the literature (Partovi & Hopton, 1993; Çakır & Canbolat, 2008). Genetic algorithms (Güvenir & Erel, 1998), particle swarm optimization (Tsai & Yeh, 2008), fuzzy classification (Chu, Liang, & Liao 2008; Keskin & Özkan, 2013), TOPSIS (Bhattacharya et al., 2007) and neural networks (Partovi & Anandarajan, 2002) have also been applied to this problem.

All the studies mentioned above present different perspectives for the multi-criteria inventory classification. Despite the advantages of these methods, it should be noted that the importance of criteria and the categorization may change from industry to industry

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and even from company to company. Several authors also emphasize this issue (Taylor, Sewart, & Bolander, 1981; Kampen, Akkerman, & Donk, 2012). For instance, the lead time criterion is more important in the drug industry than in the furniture industry. The adaptation of a methodology to these differences might be possible by adjusting the problem parameters in accordance with the decision maker (DM)'s judgment. The DM's judgment can be obtained directly by assigning values to the problem parameters like weights, thresholds, etc. Alternatively, this information can be indirectly inferred from some classification examples (see for instance, Mousseau & Slowinski, 1998; Soylu, 2011). The latter has some advantages since it is more understandable by the DM and more agreeable in the case of multiple DMs.

In this study, we apply UTADIS (Doumpos & Zopounidis, 2004) based sorting methods to the multi-criteria ABC inventory classification problem. We assume that the DM assigns in advance some reference items for each class. It is assumed that these assignments actually reflect the characteristics of the industry involved. That means the weights given to criteria in this industry can be inferred from these category examples. A mathematical model constructs a utility function and determines thresholds between classes with respect to reference items. The aim of the model is to minimize the total classification error over reference items. That means the corresponding utility value of an item should place it in its correct class otherwise the classification error occurs. Based on this information, unclassified items are placed manually. We evaluate two function types, which are linear and piece-wise linear utility functions.

The paper is organized as follows. We explain the utility function based approaches in Sections 2 and 3. We present computational results in Section 4. We conclude with a discussion and further research directions in Section 5.

2. A linear utility function based approach

In the first approach, we utilize a classification scheme based on a linear utility function. It is a specific version of the UTADIS method since we deal with the linear utility function rather than a piece-wise utility function. Each SKU gets a single score from this linear utility function and is classified by using the thresholds of categories. The parameters of the linear utility function and thresholds are determined over reference items. For this purpose, a mathematical model is constructed and solved. The details of the method are given below.

Without loss of generality, we assume that all criteria are of the maximization type so the SKU with better utility is located in the better class. SKUs are categorized into three ordered classes as C_A, C_B, and C_C. Here C_A refers to the class of SKUs with highest inspection priority and C_C refers to the class of SKUs with lowest inspection priority. Let S be the set of SKUs that should be classified, R be the set of reference SKUs and $C_n^{Ref} \subset C_n$ be the set of reference SKUs in class C_n, $n = A, B, C$. Let z_i^j be the value of the ith criterion $i = 1,2,\ldots,m$ for SKU $j \in S$.

Note that, in many multiple criteria problems, the ranges of different criteria could be different. A scaling procedure might be useful in this case. In this study, we use the following technique to scale the ranges of criteria conveniently at the beginning of the algorithm.

$$Z_i^j = \frac{\hat{z}_i^j - z_i^{min}}{z_i^{max} - z_i^{min}} \tag{1}$$

where $z_i^j \in [0, 1]$ is the scaled value of $\hat{z}_i^j$, z_i^{min} and z_i^{max} are the minimum and maximum values of criterion i by considering SKUs in $S \cup R$.

In the proposed approach, a linear utility function $U(z^j) = \sum_{i=1}^m w_i z_i^j$ is defined. Here w_i is the weight of the ith criterion. Let u_k be the utility threshold that distinguishes classes k and $k + 1$ for $k = A, B$.

We expect the following three cases. Otherwise, the classification error occurs.

$$\begin{aligned}
&\text{If } j \in C_A^{Ref} \text{ then } U(z^j) \geqslant u_A\\
&\text{If } j \in C_B^{Ref} \text{ then } u_A > U(z^j) \geqslant u_B\\
&\text{If } j \in C_C^{Ref} \text{ then } u_B > U(z^j)
\end{aligned}$$

The following LP determines the utility function parameters, $\boldsymbol{w}$, and thresholds, u_A and u_B.

$$\text{LP 1}: \quad Min\ f = \frac{\sum_{\forall j \in C_A^{ref}} e_j^+}{|C_A^{ref}|} + \frac{\sum_{\forall j \in C_B^{ref}} e_j^+ + e_j^-}{|C_B^{ref}|} + \frac{\sum_{\forall j \in C_C^{ref}} e_j^-}{|C_C^{ref}|} \tag{2}$$

$$\sum_{i=1}^m w_i z_i^j - u_A + e_j^+ \geqslant 0 \quad \forall j \in C_A^{ref} \tag{3}$$

$$\sum_{i=1}^m w_i z_i^j - u_B + e_j^+ \geqslant 0 \quad \forall j \in C_B^{ref} \tag{4}$$

$$\sum_{i=1}^m w_i z_i^j - u_A - e_j^- \leqslant -\delta \quad \forall j \in C_B^{ref} \tag{5}$$

$$\sum_{i=1}^m w_i z_i^j - u_B - e_j^- \leqslant -\delta \quad \forall j \in C_C^{ref} \tag{6}$$

$$\sum_{i=1}^m w_i = 1 \tag{7}$$

$$u_A - u_B \geqslant s \tag{8}$$

$$\begin{aligned}
&w_i \geqslant 0 \quad \forall i = 1,2,\ldots,m\\
&e_j^+, e_j^- \geqslant 0 \quad \forall j = 1,2,\ldots,n\\
&u_A, u_B \geqslant 0\\
&\delta = 0.0001,\ s = 0.0002 \quad \textit{user defined small positive constants}
\end{aligned}$$

The objective function of LP1 is to minimize the average classification errors over the reference SKUs. Constraint set (3) ensures that the utility value of an SKU $j \in C_A^{ref}$ should be greater than the threshold u_A, otherwise a positive classification error, e_j^+, occurs. Constraint sets (4) and (5) require that the utility value of an SKU $j \in C_B^{ref}$ should be in between thresholds u_A and u_B. Constraint set (6) ensures that the utility value of an SKU $j \in C_C^{ref}$ should be strictly less than the threshold u_B. Constraint (7) implies that the sum of all weights should be 1 and constraint (8) requires that the threshold u_A should be strictly greater than the threshold u_B. δ_1 and s are positive constants to satisfy inequalities strictly. The classification errors are explained using an example as follows. Assume that $C_A^{Ref} = \{a_1, a_2, a_3\}$, $C_B^{Ref} = \{b_1, b_2, b_3\}$ and $C_C^{Ref} = \{c_1, c_2\}$. If we classify them as in Fig. 1, corresponding errors occur. For instance, since a_3 is classified wrongly in C_C, the classification error $e_{a_3}^+ = u_A - u(Z^{a_3})$ exists.

In a specific case of the LP1, it may be possible to have a solution with no classification error, i.e. objective value $f = 0$. This may happen if the DM chooses well-classified references. In this case, thresholds may take alternative optimal values in the following ranges.

$$\min_{\forall j \in C_A^{Ref}} \{u(z^j)\} \geqslant u_A \geqslant \max_{\forall t \in C_B^{Ref}} \{u(z^t)\} + \delta$$

$$\min_{\forall j \in C_B^{Ref}} \{u(z^j)\} \geqslant u_B \geqslant \max_{\forall t \in C_C^{Ref}} \{u(z^t)\} + \delta$$

In other words, if the utility of an SKU is in the first range, this SKU can be placed either in C_A or C_B. We will call this set as C_A/C_B. Similarly, if the utility of an SKU is in the second range, this SKU