https://doi.org/10.24867/SYMOPIS-2024-51-044

Факултет техничких наука
Универзитета у Новом Саду
51. Симпозијум о операционим истраживањима
SYM-OP-IS 2024
Тара, 16-19. 9. 2024.

OPTIMIZING INVENTORY CLASSIFICATION: A MULTI-CRITERIA APPROACH BASED ON ORDINAL SUMS OF CONJUNCTIVE AND DISJUNCTIVE FUNCTIONS

OGNJEN ANĐELIĆ[1], PAVLE MILOŠEVIĆ[2], ZORAN RAKIĆEVIĆ[3], MIROSLAV HUDEC[4], NINA BARČÁKOVÁ[5]

[1] University of Belgrade - Faculty of Organizational Sciences, Belgrade, Republic of Serbia, ognjen.andjelic@fon.bg.ac.rs, ORCID: 0000-0001-6390-6545
[2] University of Belgrade - Faculty of Organizational Sciences, Belgrade, Republic of Serbia, pavle.milosevic@fon.bg.ac.rs, ORCID: 0000-0002-5943-6023
[3] University of Belgrade - Faculty of Organizational Sciences, Belgrade, Republic of Serbia, zoran.rakicevic@fon.bg.ac.rs, ORCID: 0000-0002-8114-7762
[4] University of Economics in Bratislava - Faculty of Economic Informatics, Bratislava, Slovak Republic, miroslav.hudec@euba.sk, ORCID: 0000-0002-2868-0322
[5] University of Economics in Bratislava - Faculty of Economic Informatics, Bratislava, Slovak Republic, nina.barcakova@euba.sk, ORCID: 0009-0002-7382-9701

Abstract: *Inventory management plays a significant role in manufacturing organizations as it balances supply and demand, i.e. ensures the continuity of production, the satisfaction of customer demand and the minimization of costs inventory level optimization. Efficient inventory management highly depends on the categorization of inventory items to simplify the management process and decide on an appropriate inventory management policy. In this paper, two different methods are used to classify 290 inventory items with the aim of examining the differences between them. The first method is the classical single-criteria ABC analysis based on consumption value, while the second is a multi-criteria ABC classification based on ordinal sums. Both classification methods categorize items into three classes, A, B and C, based on their importance. Although both classification methods have a relatively high agreement rate (73.84%), a third of all misclassification cases are cases that could lead inventory managers to neglect the items of the highest importance. Therefore, it is recommended to pay special attention to these items and make a timely decision on an appropriate inventory management policy for them. Finally, this article discusses topics for the future improvements of this first attempt to apply ordinal sums in this field.*

Keywords: *Inventory management and classification, ABC analysis, multi-criteria approach, ordinal sums of conjunctive and disjunctive functions*

1. INTRODUCTION

Inventory management plays a crucial role in the efficiency and profitability of companies in various industries. Effective inventory management ensures that the right amount of stock is maintained to meet customer demand while minimizing holding costs and reducing associated risks [19]. One of the key aspects of inventory management is the classification of inventory items, which helps organizations prioritize resources and decide on an appropriate inventory management policy. By categorizing inventory, companies can focus on the most important items that contribute the most to achieving established business goals [8]. There are various approaches to classifying inventory. Traditional methods, such as the commonly used ABC analysis, classify inventory items into categories A, B and C based on their consumption value, i.e. dollar usage value [10]. However, more sophisticated, multi-criteria techniques consider various financial and non-financial factors that go beyond a single criterion [17].

The goal of this paper is to compare the multi-criteria classification of inventory items based on ordinal sums of conjuctive and disjunctive (OSCD) operators [5,6] with the classical ABC analysis. This is done in order to bring a new perspective to the field of inventory management and to identify the borderline instances of item classification that require additional attention. The multi-criteria classification is performed taking into account three criteria and is based on OSCD operators, which is the first application in this field. This approach is beneficial because of its ability to through aggregation additionally minimize low values, while maximizing high values.

The reminder of the paper is organized as follows: Section 2 provides a brief literature review on inventory management and classification, along with some common approaches. Section 3 provides a more detailed explanation of ordinal sums of conjunctive and disjunctive functions. Section 4 explains the approach to conducting the research and achieving the afforementioned goals. Section 5 presents the results of the research. Finally, section 6 discusses the results, suggests appropriate actions, recommendations and draws conclusions.

2. LITERATURE REVIEW

For manufacturing-oriented organizations, inventory, as essential resources, and therefore inventory management is crucial to ensure continuity of production and to meet customer demand [11]. Inventory management involves maintaining optimal levels of raw materials, work in process, and finished goods to ensure adequate supply and minimize costs [13], as well as monitoring and controlling inventory levels to meet customer demand [15]. Inventory management is crucial as it affects purchasing, sales and logistics [12] by providing adequate control over ordering, storage and utilization of machinery [10].

Inventory management is specific in the sense that inventory is necessary to ensure that required goods are always available and no sales are missed [1] but too much inventory ties up organizational capital and has a negative impact on an organization's liquidity [15]. It is precisely for this reason that effective inventory management increases the performance and competitiveness of manufacturing companies [3], prompting companies to constantly and continuously improve their inventory management policies [2]. In [17], it is stated that to address fundamental inventory management issues and decide on an appropriate inventory policy, managers must determine the importance of the item in order to make an appropriate decision on whether the inventory status should be reviewed continuously or periodically, the form of the inventory policy and the specific cost or service targets that should be set. Even in a medium-sized companies, there are thousands or even tens of thousands of inventory items to manage, so it makes sense to pay more attention to the most important items.

One of the most widely used methods to classify different inventory items based on their importance is ABC analysis [10], which divides the inventory into three categories, A, B and C [17]. ABC analysis classifies inventory based on its cost into groups A for items with the highest consumption value, often referred to as cost or just value, B for items with medium value, and C with the least value to the organization [12]. Based on this, different inventory management policies are determined for each group, with category A requiring the most attention and strictest control, with the degree of control decreasing for categories B and C. Theoretically, a small number of items hold the greatest monetary value, so managers can focus their attention on a small number of the most important items [2]. This is consistent with the Pareto principle, also known as the 20/80 rule, which in this application can be interpreted as the rule that 20% of inventory items account for about 80% of inventory value.

While there are several criticisms of this traditional implementation of ABC analysis [9], the most prominent one is that the use of a single criterion for classifying inventory does not reflect the different interests of the various departments within a company and does not take into account non-financial criteria such as usage rates, demand fluctuations, lead times, substitutability and criticality of an inventory item [9, 16, 20]. For this reason, it is recommended that at least two criteria should be used in ABC categorization [9]. In the last 30 years, research has focused on a multi-criteria approach to ABC analysis that better reflects the complexity of modern supply chains [16].

Over the years, three general approaches and their combinations have emerged for multi-criteria ABC analysis [16]. The first approach is subjective weighting and rating, where each type of inventory item is scored for each criterion and these scores are then combined using a subjective weighting scheme, usually using the Analytic Hierarchy Process (AHP), often in combination with a fuzzy approach [14]. The second approach is linear optimization, which avoids the tedious and potentially inconsistent subjective inputs of the first method. Instead, it relies on the data itself to suggest weights that minimize a reasonable criterion. Data envelopment analysis is a method commonly used in this context [21]. The third approach involves clustering, genetic algorithms and neural networks that use training sets of already categorized data from experienced managers to learn how to classify items into A, B or C categories [18], where in the case of fuzzy clustering, each item can belong to each group to varying degrees [4].

3. ORDINAL SUMS OF CONJUNCTIVE AND DISJUNCTIVE FUNCTIONS

Ordinal sums of aggregation operators, and subsequently of conjunction and disjunction functions, are first introduced in [5]. In this study, aggregation operators are discussed in the most general sense and considered as families of operators. In fact, OSCD operators combine features of conjunctive and disjunctive aggregation, allowing for flexible aggregation of attributes [6]. The main idea behind this approach is to use one of three defined aggregation functions based on attributes values. In fact, OSCD of two attributes x and y, with respect of boundary a, may be defined as:

$$A(x,y) = A_1(a \wedge x, a \wedge y) + A_2(a \vee x, a \vee y) - a \tag{1}$$

Depending on the value of the input attributes, we may obtain following expression:

$$A(x,y) = \begin{cases} A_1(x\,,y) = t(x\,,y), iff\ x,y \in [0,a]^2 \\ A_2(x\,,y) = s(x\,,y), iff\ x,y \in [a,1]^2 \\ A_v(x\,,y) = x + y - a, otherwise \end{cases} \tag{2}$$

In such manner, OSCD includes three functions: conjunctive function A_1 (t-norm), disjunctive function A_2 (s-norm), and the averaging function A_v. The main property of the OSCD aggregation approach is that it minimizes the aggregation score if both input attributes have small values, due to the properties of t-norms. On the other hand, if both input attributes have large values, the final aggregation score is maximized, due to the properties of s-norms. This makes OSCD very useful in numerous problem settings. However, OSCD is a binary operator that is not associative in nature, which may be considered a major challenge when dealing with many input attributes.

4. METHODOLOGY

The proposed methodology for inventory item classification consists of 6 steps: Consuption value calculation; implementation of the classical ABC analysis; data preparation for multi-criteria inventory item classification; data aggregation using OSCD; multi-criteria ABC classification; comparison of different classification methods.

The data consists of information on 290 inventory items, their quantities expressed in units of weight, unit prices expressed as the monetary value of a single unit of weight, frequency of demand, which shows how often a particular inventory item was required, and average lead times, which show how much time elapses between ordering an inventory item and its arrival.

In the consumption value calculation step, the information about quantities and unit prices is used to calculate the consumption value. Based on the consumption value as a sole criterion, a classic ABC analysis is performed. The items are classified such that 20% of the items with the highest consumption value are assigned to class A, 30% of the following items are assigned to class B and the last 50% of the items are assigned to class C [20]. These results become a point of comparison for further evaluation of the multi-criteria item classification.

The multi-criteria classification of inventory items is based on three input attributes, consumption value, previously used as a single criterion, as well as the frequency of demand and average lead times. For each input attribute, the higher the value, the more important the item and the more attention it should be given when deciding on an appropriate inventory policy. To perform the classification, each of the attributes must first be normalized. For frequency of demand and average lead time, this was done with a simple min-max normalization. For consumption value, since the distribution is heavily skewed towards lower values, a suitable upper bound was chosen as the cut-off point based on expert opinion and a standard min-max normalization was used with the upper bound as the maximum value. In the data aggregation step, normalized values were aggregated using the functions showcased by Eq. 3 [6].

$$A(x,y) = \begin{cases} 2xy, \; x,y \in [0, 0.5]^2 \\ -1 + 2x + 2y - 2xy, \; x,y \in [\,0.5, 1]^2 \\ x + y - \frac{1}{2}, otherwise \end{cases} \tag{3}$$

This variation of conjunctive, disjunctive and averaging functions in OSCD was chosen since it exhibits the desired behavior of upward or downward strict reinforcement when both values are high or low, respectively, and is averaging in all other cases [6]. As OSCD are not associative, the aggregation was performed in two steps. First, the non-financial input attributes average lead time and frequency of demand were aggregated into a single non-financial input attribute, which was then aggregated with the financial input attribute consumption value to obtain the final aggregated measure.

On the basis of this final aggregated measure, an ABC categorization is performed in the same way as in the classic ABC analysis, in which 20% of the items with the highest measure values are assigned to class A, 30% of the items to class B and 50% of the items to class C.

Finally, the various classifications are compared to discuss the degree of agreement between them and possible differences in classification.

5. RESULTS

Table 1 represents a contingency table based on the classification of 290 inventory items according to the traditional ABC classification method and the multi-criteria ABC classification based on OSCD. From the perspective of data science and machine learning, Table 1 can be seen as a classification confusion matrix. Still, we do not consider the items off the main diagonal as misclassified – they just need special attention during the decision-making process.

Table 1: Contingency table for different classification methods

Classic ABC classification	OSCD ABC Classification			Total
	A	B	C	
A	46	12	0	58
B	7	52	27	86
C	5	22	119	146
Total	58	86	146	290

Examining the diagonal elements, we see that 46 out of 58 items are assigned to class A, 52 out of 86 items to class B and 119 out of 146 items to class C, regardless of the classification method used. We can therefore say that there is agreement between the different classification methods for 217 out of 290 inventory items, which corresponds to an agreement rate of 74.83%.

The elements outside the diagonal represent the number of inventory items for which the two classification methods do not agree. A total of 13 items that were assigned to class A according to the multi-criteria OSCD classification were assigned to either class B or C according to the traditional ABC classification method. 7 of these were assigned to class B and 5 to class C. A total of 34 articles that were assigned to class B in the OSCD classification were assigned to either class A or C in the traditional ABC classification, 12 of which were assigned to class A and 22 to class C. A total of 27 items that were assigned to class C in the OSCD classification were assigned to a different class in the traditional ABC classification, class B.

6. DISCUSSION AND CONCLUSIONS

Inventory management is crucial to the success and competitiveness of manufacturing-oriented companies. It ensures that resources are used efficiently, production processes remain uninterrupted and customer needs are met on time, improving the company's performance and market position. Effective inventory management relies on the classification of inventory items. By categorizing inventory items, managers can prioritize and implement appropriate inventory management strategies to optimize stock levels, reduce costs and minimize the overstocking and understocking risks.

ABC analysis is one of the basic methods for classifying invnetory items. It usually classifies the different inventory items in terms of their consumption value. Although it is a valuable and commonly used method, it is based on a single criterion that does not do justice to the complexity of modern businesses. For this reason, a multi-criteria approach to inventory classification is recommended in the literature to overcome the limitations of single-criteria methods such as ABC analysis.

In this paper, 290 inventory items were classified into three groups using a multi-criteria classification method based on OSCD and the results of this classification were compared with a traditional single-criteria ABC classification method. The use of OSCD is beneficial because of its ability to through aggregation further minimize low values and further maximize high values, bringing fresh perspective on inventory management through identification of borderline cases. Out of 290 inventory items, 217 were assigned to the same class in both cases, with an agreement of 74.83%. For 73 items that differed in classification, the methods did not agree on whether an item should be assigned to class B or class C in approximately 67% of cases. This can be considered more of a nuisance than a problem, as both class B and C are items of medium to low priority in inventory management. The reduction of this problem, is a topic for future research, where we can use parametric class of *t*-norms to adjust the border between categories more adequately. In about 27% of cases, the methods did not agree on whether an inventory item should be assigned to class A or B. This is more of an issue as class A items are the most important items and should receive the highest degree of attention from inventory managers. In this case, the perspective is in the parametrization of *s*-norm function. Finally, in about 6% of cases, items that were assigned to class C in the traditional ABC analysis were assigned to class A in the multi-criteria OSCD ABC classification. This problem is for a deeper analysis. Presumably, the solution might be in the parametrization of averaging function [7]. This inconsistency in classification could prove to be very detrimental and lead to warehouse managers more or less neglecting an important item for organizational performance. A recommendation to warehouse managers would be to pay special attention to those inventory items where there are discrepancies in item classification and make a timely decision on an appropriate inventory management policy for these items.

Acknowledgements: This study was supported by the University of Belgrade – Faculty of Organizational Sciences, as well as the Ministry of Science, Technological Development and Innovation of Serbia, and the Slovak Research and Development Agency under Grant No. 337-00-3/2024-05/18 on the Serbian side and APVV No. SK-SRB-23-0007 on the Slovak side.

REFERENCES

[1] Asana, I. M. D. P., Radhitya, M. L., Widiartha, K. K., Santika, P. P., & Wiguna, I. K. A. G. (2020). Inventory control using ABC and min-max analysis on retail management information system. *Journal of Physics: Conference Series*, 1469(1), (pp. 012097). IOP Publishing.

[2] Atnafu, D., & Balda, A. (2018). The impact of inventory management practice on firms' competitiveness and organizational performance: Empirical evidence from micro and small enterprises in Ethiopia. *Cogent Business & Management*, *5*(1), 1503219.

[3] Chan, S. W., Tasmin, R., Aziati, A. N., Rasi, R. Z., Ismail, F. B., & Yaw, L. P. (2017). Factors influencing the effectiveness of inventory management in manufacturing SMEs. In *IOP Conference Series: Materials Science and Engineering, 226*(1), (pp. 012024). IOP Publishing.

[4] Chawla, V., Itika, I., Singh, P., & Singh, S. (2024). A fuzzy Pythagorean TODIM method for sustainable ABC analysis in inventory management. *Journal of Future Sustainability*, *4*(2), 85-100.

[5] De Baets, B., & Mesiar, R. (2002). Ordinal sums of aggregation operators. *Technologies for Constructing Intelligent Systems 2: Tools*, 137-147.

[6] Hudec, M., Mináriková, E., Mesiar, R., Saranti, A., Holzinger, A. (2021). Classification by ordinal sums of conjunctive and disjunctive functions for explainable AI and interpretable machine learning solutions. *Knowledge–Based Systems*, *220*, 106916.

[7] Hudec, M., Mináriková, E., & Mesiar, R. (2022). Aggregation functions in flexible classification by ordinal sums. In *International Conference on Information Processing and Management of Uncertainty in Knowledge-Based Systems* (pp. 372-383). Cham: Springer International Publishing.

[8] Mohammaditabar, D., Ghodsypour, S. H., & O'Brien, C. (2012). Inventory control system design by integrating inventory classification and policy selection. *International Journal of Production Economics*, *140*(2), 655-659.

[9] Muller, M. (2011). *Essentials of inventory management (2nd ed.)*, AMACOM.

[10] Nallusamy, S., Balaji, R., & Sundar, S. (2017). Proposed model for inventory review policy through ABC analysis in an automotive manufacturing industry. *International Journal of Engineering Research in Africa*, *29*, 165-174.

[11] Nowotyńska, I. (2013). An application of xyz analysis in company stock management. *Modern Management Review*, *18*(20(1)), 77-86.

[12] Oluwaseyi, J. A., Onifade, M. K., & Odeyinka, O. F. (2017). Evaluation of the role of inventory management in logistics chain of an organisation. *LOGI–Scientific Journal on Transport and Logistics*, *8*(2), 1-11.

[13] Pandya, B., & Thakkar, H. (2016). A review on inventory management control techniques: ABC-XYZ analysis. *REST Journal on Emerging trends in Modelling and Manufacturing*, *2*(3), 2016.

[14] Paredes Rodríguez, A. M., Bravo Bastidas, J. J., Osorio Gómez, J. C., Peña Orozco, D. L., & González Feliu, J. (2023). Fuzzy AHP TOPSIS Methodology for Multicriteria ABC Inventory Classification. *Journal of Engineering*, *2023*(1), 7661628.

[15] Priniotakis, G., & Argyropoulos, P. (2018). Inventory management concepts and techniques. In *IOP conference series: Materials Science and Engineering*, *459*(1), (pp. 012060). IOP Publishing.

[16] Ravinder, H., & Misra, R. B. (2014). ABC analysis for inventory management: Bridging the gap between research and classroom. *American Journal of Business Education*.

[17] Silver, E. A., Pyke, D. F., & Peterson, R. (1998). *Inventory management and production planning and scheduling*, *3*, (pp. 30). New York: Wiley.

[18] Šarić, T., Šimunović, K., Pezer, D., & Šimunović, G. (2014). Inventory classification using multi–criteria ABC analysis, neural networks and cluster analysis. *Tehnički vjesnik*, *21*(5), 1109-1115.

[19] Torabi, S. A., Hatefi, S. M., & Pay, B. S. (2012). ABC inventory classification in the presence of both quantitative and qualitative criteria. *Computers & Industrial Engineering*, *63*(2), 530-537.

[20] Vollman, B., & Whybark, J. (2011). *Manufacturing planning and control for supply chain management*. McGraw Hill.

[21] Xu, N., & Xu, W. (2020). A Classification Method of Inventory Spare Parts Based on Improved Super Efficient DEA-ABC Model. In *International Symposium on Emerging Technologies for Education* (pp. 214-224). Cham: Springer International Publishing.