INFORMATICA, 2015, Vol. 26, No. 3, 435–451

DOI: http://dx.doi.org/10.15388/Informatica.2015.57

Multi-Criteria Inventory Classification Using a New Method of Evaluation Based on Distance from Average Solution (EDAS)

Mehdi KESHAVARZ GHORABAEE[1],
Edmundas Kazimieras ZAVADSKAS[2]*, Laya OLFAT[1],
Zenonas TURSKIS[2]
[1]*Department of Industrial Management, Management and Accounting Faculty Allame Tabataba'i University, Tehran, Iran*
[2]*Research Institute of Smart Building Technologies, Civil Engineering Faculty Vilnius Gediminas Technical University, Vilnius, Lithuania*
e-mail: edmundas.zavadskas@vgtu.lt

Received: March 2015; accepted: June 2015

Abstract. An effective way for managing and controlling a large number of inventory items or stock keeping units (SKUs) is the inventory classification. Traditional ABC analysis which based on only a single criterion is commonly used for classification of SKUs. However, we should consider inventory classification as a multi-criteria problem in practice. In this study, a new method of *Evaluation based on Distance from Average Solution* (EDAS) is introduced for multi-criteria inventory classification (MCIC) problems. In the proposed method, we use positive and negative distances from the average solution for appraising alternatives (SKUs). To represent performance of the proposed method in MCIC problems, we use a common example with 47 SKUs. Comparing the results of the proposed method with some existing methods shows the good performance of it in ABC classification. The proposed method can also be used for multi-criteria decision-making (MCDM) problems. A comparative analysis is also made for showing the validity and stability of the proposed method in MCDM problems. We compare the proposed method with VIKOR, TOPSIS, SAW and COPRAS methods using an example. Seven sets of criteria weights and Spearman's correlation coefficient are used for this analysis. The results show that the proposed method is stable in different weights and well consistent with the other methods.
Key words: inventory management, ABC classification, multi-criteria inventory classification (MCIC), multi-criteria decision-making (MCDM), EDAS method.

1. Introduction

We usually observe companies of even moderate sizes to hold different items or SKUs in inventory. Inventory has been looked at as a major cost and source of uncertainty due to the volatility within the commodity market and demand for the value-added product. Manufacturing companies held inventory for reaching some advantages such as flexible

*Corresponding author.

production and economies of scale. Therefore, we can say that inventory management (control) plays a significant role in the company management. An important component of the inventory management process in many production companies is the classification of inventory. Because of a large number of inventory items in many companies, paying attention to classification of the inventory items is very consequential. Considering inventory classification usually needs to application of different managerial tools and techniques (Chase *et al.*, 2001). The classical ABC classification which introduced at General Electric during the 1950s is the most common techniques to classify the items in inventory. This technique is based on the Pareto principle, stating that 20% of the people controlled 80% of the wealth. In the classical ABC classification, items are only appraised based on their annual dollar usage values, which related to annual usage quantities and the average unit prices of the items. Class A includes small number of items that have more annual consumption value, and class C is constituted by the majority of items that control small portion of total annual consumption value. Items between the above classes constitute class B (Chen, 2011b). However, the procedure of classical ABC classification has a critical deficiency that may lead to the ineffectiveness of the procedure in some situations. If we consider only one criterion in the classification procedure, we may confront with significant financial loss. For example, if items with long lead times are classified in class C, financial losses may be incurred as a result of possible interruption of production. Therefore, multi-criteria inventory classification (MCIC) is used instead of classical ABC classification (Flores and Whybark, 1986, 1987).

Many researchers have studied MCIC problem so far. Partovi and Burton (1993) developed a method based on the analytic hierarchy process (AHP) for MCIC problems. Guvenir and Erel (1998) proposed a genetic algorithm for weighting criteria in a multi-criteria inventory classification problem. Partovi and Anandarajan (2002) presented an artificial neural network approach for ABC classification of inventory. Lei *et al.* (2005) introduced two methods for ABC classification of SKUs. The first method was based on principal components analysis (PCA) to classify inventory, and the second method combined PCA and artificial neural networks (ANNs) with the back-propagation algorithm. Ramanathan (2006) proposed a simple classification scheme for ABC classification using weighed linear optimization that is referred to as R-model. Ng (2007) developed a simple model for multi-criteria inventory classification that is called NG-model in this study. Zhou and Fan (2007) proposed an extended version of the R-model for multi-criteria inventory classification that is referred to as ZF-model. Bhattacharya *et al.* (2007) demonstrated a way of classifying inventory items using the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method. Cakir and Canbolat (2008) presented a web-based decision support system for multi-criteria inventory classification using fuzzy AHP methodology. Chu *et al.* (2008) proposed a new inventory control approach by combining ABC analysis and fuzzy classification. Tsai and Yeh (2008) presented a particle swarm optimization approach for inventory classification problems where inventory items were classified based on specific objective or multiple objectives. Hadi-Vencheh (2010) presented an extended version of the NG-model for multi-criteria inventory classification that is referred to as HV-model. Xiao *et al.* (2011) developed a new approach of inventory classification based on loss profit. Hadi-Vencheh and Mohamadghasemi (2011) proposed an integrated fuzzy analytic hierarchy process-data envelopment analysis (FAHP-DEA) for multi-criteria ABC inventory classification. Chen (2011a) developed an alternative approach to MCIC by using two virtual items and incorporating the TOPSIS method that is called Chen-model in this study. Torabi *et al.* (2012) proposed a modified version of an existent common weight DEA-like for ABC inventory classification in the presence of both quantitative and qualitative criteria. Kiriş (2013) presented a fuzzy analytic network process (ANP) approach to determine the weights of the criteria in the multi-criteria inventory classification. Kabir and Akhtar Hasin (2013) developed a multi-criteria inventory classification model by integrating the fuzzy AHP and ANNs. Lolli *et al.* (2014) introduced a new hybrid method for MCIC problems based on AHP and the K-means algorithm. Park *et al.* (2014) suggested a cross-evaluation-based weighted linear optimization model for multi-criteria inventory classification. Soylu and Akyol (2014) proposed a new approach for multi-criteria inventory classification by considering preferences of decision makers in terms of reference items. Hatefi and Torabi (2015) developed a novel methodology based on a common weight linear optimization model to solve the multi-criteria inventory classification problem that is referred to as HT-model hereafter.

Multi-criteria decision-making approach is very useful in many problems such as project selection, supplier selection, risk assessment, contractor evaluation, etc. Many studies have been made on MCDM methods and applications. Krylovas *et al.* (2014) proposed new KEMIRA method for determining criteria priority and weights in solving MCDM problem. Turskis *et al.* (2013) proposed ARAS-G method for multiple criteria prioritizing of heritage value. Zavadskas *et al.* (2014) proposed extension of weighted aggregated sum product assessment with interval-valued intuitionistic fuzzy numbers (WASPAS-IVIF). Šiožinytė and Antuchevičienė (2013), Šiožinytė *et al.* (2014) applied TOPSIS, COPRAS and WASPAS, also TOPSIS grey and AHP (Analytic Hierarch Process) methods for the presented case study of upgrading the old vernacular buildings. Ruzgys *et al.* (2014) proposed SWARA-TODIM MCDM method for evaluation of external wall insulation. Hashemkhani Zolfani and Bahrami (2014) proposed SWARA-COPRAS for investment prioritizing in industries. Kildienė *et al.* (2014) used permutation MCDM method for assessment model for advances technology deployment. Kou *et al.* (2014) applied TOPSIS method for evaluating bank loan default models. Zeng *et al.* (2013) presented a new method to derive the weights of experts and rank the preference order of alternatives based on projection models, and utilized it for a supplier selection problem. Ulucan and Atici (2013) presented a multi-criteria sorting methodology with multiple classification criteria and used it for risk evaluation. Stanujkic *et al.* (2013) proposed a new multi-criteria ranking procedure based on distance from decision maker preferences which the decision maker was asked to define the preferred performance for each criterion. Kahraman *et al.* (2013) proposed a fuzzy MCDM method based on AHP and TOPSIS methods and used it for evaluation of government investments in higher education. Keshavarz Ghorabaee *et al.* (2014) developed a multi-criteria decision-making method for supplier selection based on COPRAS method with interval type-2 fuzzy sets. Stanujkic *et al.* (2014) developed an efficient and simple multi-criteria model for a grinding circuit selection based on MOORA method. Kahraman *et al.* (2014) developed a fuzzy multi-criteria decision-making method based on AHP for evaluating of health research investments. Chakraborty and Zavadskas (2014) explored the applicability of weighted aggregated sum product assessment (WASPAS) method for solving eight manufacturing decision-making problems (selection of cutting fluid, electroplating system, forging condition, arc welding process, industrial robot, milling condition, machinability of materials, and electro-discharge micro-machining process parameters). Rostamzadeh *et al.* (2015) utilized the VIKOR (Vlsekriterijumska Optimizacija I Kompromisno Resenje) method for evaluation of green supply chain management practices.

In this study, a new multi-criteria decision-making method is proposed for ABC classification of inventory items. The proposed method that is called EDAS (Evaluation based on Distance from Average Solution) uses average solution for appraising the alternatives (inventory items). Two measures which called *PDA* (positive distance from average) and *NDA* (negative distance from average) are considered for the appraisal in this study. These measures are calculated according to the type of criteria (beneficial or non-beneficial). Using a common example of ABC inventory classification, we compare the proposed method with some existing methods (R-model, NG-model, ZF-model, HV-model, Chen-model and HT-model) and represent good performance of it in classification problems. Although we use the proposed method for ABC classification of inventory items, this method can also be used for MCDM problems. To show the performance of EDAS method as an MCDM method, a comparative analysis is made by an example. In this analysis, we compare EDAS method with VIKOR, TOPSIS, SAW (Simple Additive Weighting) and COPRAS methods using seven sets of criteria weights and Spearman's correlation coefficient. The results of this comparative analysis show that EDAS method is stable in different weights and well consistent with the other methods.

The rest of this paper is organized as follows. In Section 2, a new method of Evaluation based on Distance from Average Solution (EDAS) is presented in detail. In Section 3, we use the proposed method for multi-criteria inventory classification problem and a comparison is made by a common example of MCIC problem. In Section 4, the proposed method is compared with four MCDM methods for showing its performance as a multi-criteria decision-making method. The conclusions are discussed in the last section.

2. New Method of Evaluation Based on Distance from Average Solution (EDAS)

In this section, we propose a new multi-criteria decision-making method that is called Evaluation based on Distance from Average Solution (EDAS). This method is very useful when we have some conflicting criteria. In the compromise MCDM methods such as VIKOR and TOPSIS (Opricovic and Tzeng, 2004), the best alternative is obtained by calculating the distance from ideal and nadir solutions. The desirable alternative has lower distance from ideal solution and higher distance from nadir solution in these MCDM methods. However, the best alternative in the proposed method is related to the distance from average solution (AV). We don't need to calculate the ideal and the nadir solution in the proposed method. In this method, we have two measures dealing with the desirability of the alternatives. The first measure is the positive distance from average (*PDA*), and the second is the negative distance from average (*NDA*). These measures can show the difference between each solution (alternative) and the average solution. The evaluation of the alternatives is made according to higher values of *PDA* and lower values of *NDA*. Higher values of *PDA* and/or lower values of *NDA* represent that the solution (alternative) is better than average solution. Suppose that we have n alternatives and m criteria. The steps for using the proposed method are presented as follows:

Step 1: Select the most important criteria that describe alternatives.

Step 2: Construct the decision-making matrix (X), shown as follows:

$$X = [X_{ij}]_{n\times m} = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1m} \\ X_{21} & X_{22} & \cdots & X_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ X_{n1} & X_{n2} & \cdots & X_{nm} \end{bmatrix}, \tag{1}$$

where X_{ij} denotes the performance value of ith alternative on jth criterion.

Step 3: Determine the average solution according to all criteria, shown as follows:

$$AV = [AV_j]_{1\times m}, \tag{2}$$

where,

$$AV_j = \frac{\sum_{i=1}^{n} X_{ij}}{n}. \tag{3}$$

Step 4: Calculate the positive distance from average (*PDA*) and the negative distance from average (*NDA*) matrixes according to the type of criteria (benefit and cost), shown as follows:

$$PDA = [PDA_{ij}]_{n\times m}, \tag{4}$$

$$NDA = [NDA_{ij}]_{n\times m} \tag{5}$$

if jth criterion is beneficial,

$$PDA_{ij} = \frac{\max(0, (X_{ij} - AV_j))}{AV_j}, \tag{6}$$

$$NDA_{ij} = \frac{\max(0, (AV_j - X_{ij}))}{AV_j} \tag{7}$$

and if jth criterion is non-beneficial,

$$PDA_{ij} = \frac{\max(0, (AV_j - X_{ij}))}{AV_j}, \tag{8}$$

$$NDA_{ij} = \frac{\max(0, (X_{ij} - AV_j)))}{AV_j}, \tag{9}$$

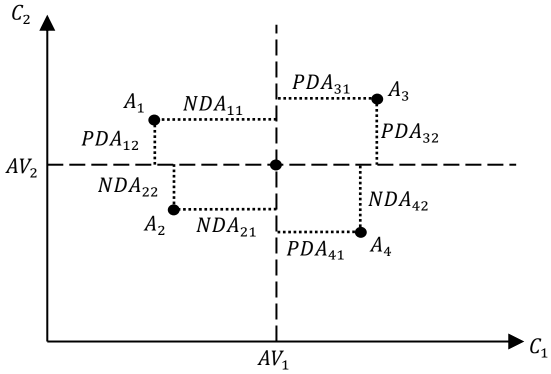

Fig. 1. PDA and NDA values in a simple situation.

where PDA_{ij} and NDA_{ij} denote the positive and negative distance of ith alternative from average solution in terms of jth criterion, respectively.

Step 5: Determine the weighted sum of *PDA* and *NDA* for all alternatives, shown as follows:

$$SP_i = \sum_{j=1}^{m} w_j PDA_{ij}; \tag{10}$$

$$SN_i = \sum_{j=1}^{m} w_j NDA_{ij}, \tag{11}$$

where w_j is the weight of jth criterion.

Step 6: Normalize the values of *SP* and *SN* for all alternatives, shown as follows:

$$NSP_i = \frac{SP_i}{\max_i(SP_i)}; \tag{12}$$

$$NSN_i = 1 - \frac{SN_i}{\max_i(SN_i)}. \tag{13}$$

Step 7: Calculate the appraisal score (*AS*) for all alternatives, shown as follows:

$$AS_i = \frac{1}{2}(NSP_i + NSN_i), \tag{14}$$

where $0 \leqslant AS_i \leqslant 1$.

Step 8: Rank the alternatives according to the decreasing values of appraisal score (*AS*). The alternative with the highest *AS* is the best choice among the candidate alternatives. We can classify the alternatives with respect to this ranking.

In Fig. 1, we show a simple situation with four alternatives and two beneficial criteria. *PDA* and *NDA* values of each alternative in terms of each criterion are shown in this figure.

If *PDA* value of an alternative is greater than zero, corresponding *NDA* value equals to zero. Also, we have $PDA = 0$ when *NDA* is greater than zero. In this figure, we don't represent $PDA = 0$ and $NDA = 0$. As can be seen, A_3 that has *PDA* values regarding both criteria is the best, and A_2 that has *NDA* values regarding both criteria is the worst alternative. For ranking A_1 and A_4, we have to obtain the appraisal score according to the proposed method.

3. Inventory ABC Classification Using EDAS

In this section, we use the proposed method for inventory classification. The example that we utilize for illustrating the proposed method has been considered by many researchers in the past (Ramanathan, 2006; Ng, 2007; Zhou and Fan, 2007; Hadi-Vencheh, 2010; Chen, 2011a, 2011b; Hatefi and Torabi, 2015). 47 inventory items (SKUs) are evaluated in terms of three criteria in this example. Average unit cost, annual dollar usage and lead time are considered as criteria of ABC classification. These criteria are positively related to the importance level of inventory items. Therefore, we can use them as beneficial criteria in the proposed method. In this study, weights of criteria are equally distributed for classifying inventory items. Criteria data on the inventory items (decision matrix) and the corresponding average solution (AV) which represent steps 1 to 3 of the proposed method are shown in Table 1. The results of steps 4 to 7 of the proposed method are shown in Table 2. In this table, the values of *PDA*, *NDA*, *SP*, *SN*, *NSP*, *NSN* and *AS* can be seen in terms of each alternative (item).

We can classify the inventory items with respect to values of appraisal scores (AS) in Table 2. The classifying distribution with 10 Class A, 14 Class B and 23 Class C, which considered in the previous research works is utilized for describing and comparing the proposed method. We compare the classification of the proposed method with the result of R-model, NG-model, ZF-model, HV-model, Chen-model and HT-model. The results of ABC classification with different methods are shown in Table 3.

As can be seen in Table 3, all items' classification in the proposed method is consistent with at least one method except for five items (items 16, 33, 34, 40 and 45). Therefore, the proposed method is relatively credible for classifying the inventory items. For comparing the classification results in detail, we introduce a new similarity ratio (S_r) to make a comparison between two methods. This ratio is defined as follows:

$$S_r = \frac{\sum_{i=1}^{n} w_i(x_i, y_i)}{n} \quad \text{and } x_i, y_i \in \{A, B, C\}. \tag{15}$$

where,

$$w(x, y) = \begin{cases} 1 & \text{if } x = y, \\ 0 & \text{if } x \neq y, \end{cases} \tag{16}$$

n is the number of items, x_i is the class of ith item in the first method of comparison and y_i is the class of ith item in the second method of comparison. The results of comparison between all considered methods are shown in Table 4.

Table 1
Data of the inventory classification problem and average solutions.

Item no.	Average unit cost (S) ($j = 1$)	Annual dollar usage (S) ($j = 2$)	Lead time ($j = 3$)
S1	49.92	5840.64	2
S2	210	5670	5
S3	23.76	5037.12	4
S4	27.73	4769.56	1
S5	57.98	3478.8	3
S6	31.24	2936.67	3
S7	28.2	2820	3
S8	55	2640	4
S9	73.44	2423.52	6
S10	160.5	2407.5	4
S11	5.12	1075.2	2
S12	20.87	1043.5	5
S13	86.5	1038	7
S14	110.4	883.2	5
S15	71.2	854.4	3
S16	45	810	3
S17	14.66	703.68	4
S18	49.5	594	6
S19	47.5	570	5
S20	58.45	467.6	4
S21	24.4	463.6	4
S22	65	455	4
S23	86.5	432.5	4
S24	33.2	398.4	3
S25	37.05	370.5	1
S26	33.84	338.4	3
S27	84.03	336.12	1
S28	78.4	313.6	6
S29	134.34	268.68	7
S30	56	224	1
S31	72	216	5
S32	53.02	212.08	2
S33	49.48	197.92	5
S34	7.07	190.89	7
S35	60.6	181.8	3
S36	40.82	163.28	3
S37	30	150	5
S38	67.4	134.8	3
S39	59.6	119.2	5
S40	51.68	103.36	6
S41	19.8	79.2	2
S42	37.7	75.4	2
S43	29.89	59.78	5
S44	48.3	48.3	3
S45	34.4	34.4	7
S46	28.8	28.8	3
S47	8.46	25.38	5
AV	54.44	1099.68	3.91

Table 2
The results of the proposed method.

i	PDA_{i1}	PDA_{i2}	PDA_{i3}	NDA_{i1}	NDA_{i2}	NDA_{i3}	SP_i	NSP_i	SN_i	NSN_i	AS_i
1	0.00	4.31	0.00	0.08	0.00	0.49	4.31	0.59	0.57	0.72	0.66
2	2.86	4.16	0.28	0.00	0.00	0.00	7.29	1.00	0.00	1.00	1.00
3	0.00	3.58	0.02	0.56	0.00	0.00	3.60	0.49	0.56	0.73	0.61
4	0.00	3.34	0.00	0.49	0.00	0.75	3.34	0.46	1.24	0.40	0.43
5	0.07	2.16	0.00	0.00	0.00	0.23	2.23	0.31	0.23	0.89	0.60
6	0.00	1.67	0.00	0.43	0.00	0.23	1.67	0.23	0.66	0.68	0.45
7	0.00	1.56	0.00	0.48	0.00	0.23	1.56	0.22	0.72	0.65	0.43
8	0.01	1.40	0.02	0.00	0.00	0.00	1.43	0.20	0.00	1.00	0.60
9	0.35	1.20	0.53	0.00	0.00	0.00	2.09	0.29	0.00	1.00	0.64
10	1.95	1.19	0.02	0.00	0.00	0.00	3.16	0.43	0.00	1.00	0.72
11	0.00	0.00	0.00	0.91	0.02	0.49	0.00	0.00	1.42	0.31	0.16
12	0.00	0.00	0.28	0.62	0.05	0.00	0.28	0.04	0.67	0.68	0.36
13	0.59	0.00	0.79	0.00	0.06	0.00	1.38	0.19	0.06	0.97	0.58
14	1.03	0.00	0.28	0.00	0.20	0.00	1.31	0.18	0.20	0.90	0.54
15	0.31	0.00	0.00	0.00	0.22	0.23	0.31	0.04	0.46	0.78	0.41
16	0.00	0.00	0.00	0.17	0.26	0.23	0.00	0.00	0.67	0.67	0.34
17	0.00	0.00	0.02	0.73	0.36	0.00	0.02	0.00	1.09	0.47	0.24
18	0.00	0.00	0.53	0.09	0.46	0.00	0.53	0.07	0.55	0.73	0.40
19	0.00	0.00	0.28	0.13	0.48	0.00	0.28	0.04	0.61	0.70	0.37
20	0.07	0.00	0.02	0.00	0.58	0.00	0.10	0.01	0.58	0.72	0.37
21	0.00	0.00	0.02	0.55	0.58	0.00	0.02	0.00	1.13	0.45	0.23
22	0.19	0.00	0.02	0.00	0.59	0.00	0.22	0.03	0.59	0.72	0.37
23	0.59	0.00	0.02	0.00	0.61	0.00	0.61	0.08	0.61	0.71	0.39
24	0.00	0.00	0.00	0.39	0.64	0.23	0.00	0.00	1.26	0.39	0.19
25	0.00	0.00	0.00	0.32	0.66	0.75	0.00	0.00	1.73	0.16	0.08
26	0.00	0.00	0.00	0.38	0.69	0.23	0.00	0.00	1.30	0.37	0.18
27	0.54	0.00	0.00	0.00	0.69	0.75	0.54	0.08	1.44	0.30	0.19
28	0.44	0.00	0.53	0.00	0.72	0.00	0.97	0.13	0.72	0.65	0.39
29	1.47	0.00	0.79	0.00	0.76	0.00	2.26	0.31	0.76	0.63	0.47
30	0.03	0.00	0.00	0.00	0.80	0.75	0.03	0.00	1.54	0.25	0.13
31	0.32	0.00	0.28	0.00	0.80	0.00	0.60	0.08	0.80	0.61	0.35
32	0.00	0.00	0.00	0.03	0.81	0.49	0.00	0.00	1.32	0.36	0.18
33	0.00	0.00	0.28	0.09	0.82	0.00	0.28	0.04	0.91	0.56	0.30
34	0.00	0.00	0.79	0.87	0.83	0.00	0.79	0.11	1.70	0.17	0.14
35	0.11	0.00	0.00	0.00	0.84	0.23	0.11	0.02	1.07	0.48	0.25
36	0.00	0.00	0.00	0.25	0.85	0.23	0.00	0.00	1.34	0.35	0.18
37	0.00	0.00	0.28	0.45	0.86	0.00	0.28	0.04	1.31	0.36	0.20
38	0.24	0.00	0.00	0.00	0.88	0.23	0.24	0.03	1.11	0.46	0.25
39	0.10	0.00	0.28	0.00	0.89	0.00	0.37	0.05	0.89	0.57	0.31
40	0.00	0.00	0.53	0.05	0.91	0.00	0.53	0.07	0.96	0.53	0.30
41	0.00	0.00	0.00	0.64	0.93	0.49	0.00	0.00	2.05	0.00	0.00
42	0.00	0.00	0.00	0.31	0.93	0.49	0.00	0.00	1.73	0.16	0.08
43	0.00	0.00	0.28	0.45	0.95	0.00	0.28	0.04	1.40	0.32	0.18
44	0.00	0.00	0.00	0.11	0.96	0.23	0.00	0.00	1.30	0.37	0.18
45	0.00	0.00	0.79	0.37	0.97	0.00	0.79	0.11	1.34	0.35	0.23
46	0.00	0.00	0.00	0.47	0.97	0.23	0.00	0.00	1.68	0.18	0.09
47	0.00	0.00	0.28	0.85	0.98	0.00	0.28	0.04	1.82	0.11	0.08

Table 3
The result of ABC classification with different methods.

Item no.	*AS*	Proposed method	R-model	NG-model	ZF-model	HV-model	Chen-model	HT-model
S2	1.00	A	A	A	A	A	A	A
S10	0.72	A	B	A	A	A	A	A
S1	0.66	A	A	A	A	A	A	B
S9	0.64	A	A	A	A	A	A	A
S3	0.61	A	A	A	A	A	A	A
S8	0.60	A	B	B	B	B	A	B
S5	0.60	A	B	A	B	A	B	B
S13	0.58	A	A	A	A	A	A	A
S14	0.54	A	B	B	A	A	A	A
S29	0.47	A	A	A	A	A	A	A
S6	0.45	B	C	A	C	B	B	C
S7	0.43	B	C	B	C	B	B	C
S4	0.43	B	B	A	C	A	B	C
S15	0.41	B	C	C	C	C	B	B
S18	0.40	B	A	B	A	B	B	A
S23	0.39	B	C	B	B	B	B	B
S28	0.39	B	A	B	A	B	A	A
S22	0.37	B	C	C	B	C	B	B
S19	0.37	B	B	B	B	B	B	B
S20	0.37	B	C	C	B	C	C	B
S12	0.36	B	B	B	B	B	C	B
S31	0.35	B	B	B	B	B	B	B
S16	0.34	B	C	C	C	C	C	C
S39	0.31	B	B	B	B	B	B	B
S40	0.30	C	B	B	B	B	B	B
S33	0.30	C	B	B	B	B	B	B
S35	0.25	C	C	C	C	C	C	C
S38	0.25	C	C	C	C	C	C	C
S17	0.24	C	C	C	C	C	C	C
S45	0.23	C	A	B	B	B	B	A
S21	0.23	C	C	C	C	C	C	C
S37	0.20	C	B	C	B	C	C	C
S24	0.19	C	C	C	C	C	C	C
S27	0.19	C	C	C	C	C	C	C
S44	0.18	C	C	C	C	C	C	C
S26	0.18	C	C	C	C	C	C	C
S43	0.18	C	B	C	C	C	C	C
S32	0.18	C	C	C	C	C	C	C
S36	0.18	C	C	C	C	C	C	C
S11	0.16	C	C	C	C	C	C	C
S34	0.14	C	A	B	B	B	C	B
S30	0.13	C	C	C	C	C	C	C
S46	0.09	C	C	C	C	C	C	C
S25	0.08	C	C	C	C	C	C	C
S42	0.08	C	C	C	C	C	C	C
S47	0.08	C	B	C	C	C	C	C
S41	0.00	C	C	C	C	C	C	C

Table 4
The values of S_r for comparison between ABC classification methods.

	Proposed method	R-model	NG-model	ZF-model	HV-model	Chen-model	HT-model
Proposed method	1	0.574	0.745	0.702	0.787	0.830	0.723
R-model	–	1	0.723	0.787	0.702	0.681	0.745
NG-model	–	–	1	0.787	0.957	0.787	0.723
ZF-model	–	–	–	1	0.809	0.787	0.915
HV-model	–	–	–	–	1	0.830	0.766
Chen-model	–	–	–	–	–	1	0.787
HT-model	–	–	–	–	–	–	1

Table 5
Data of the MCDM problem for comparative analysis.

Alternatives	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	23	264	2.37	0.05	167	8900	8.71
A_2	20	220	2.2	0.04	171	9100	8.23
A_3	17	231	1.98	0.15	192	10800	9.91
A_4	12	210	1.73	0.2	195	12300	10.21
A_5	15	243	2	0.14	187	12600	9.34
A_6	14	222	1.89	0.13	180	13200	9.22
A_7	21	262	2.43	0.06	160	10300	8.93
A_8	20	256	2.6	0.07	163	11400	8.44
A_9	19	266	2.1	0.06	157	11200	9.04
A_{10}	8	218	1.94	0.11	190	13400	10.11

As can be seen in Table 4, there is good similarity between the proposed method and the other methods. Moreover, all methods that have chosen for comparison use DEA-like mathematical modeling for classifying the items. Using this mathematical modeling technique usually leads to a high computational process. However, we can say that the simplicity and lower computational process are the major advantages of the proposed method.

4. A Comparative Analysis

As mentioned earlier, we can use EDAS method as an MCDM method for ranking the alternatives with respect to the values of appraisal score (AS). In this section, an example is utilized for analyzing and comparing the results of EDAS method as an MCDM method. As can be seen in Table 5, ten alternatives and seven criteria are considered in this example. We assume that C_1, C_2 and C_3 are beneficial, and C_4, C_5, C_6 and C_7 are non-beneficial criteria. We compare EDAS method with VIKOR, TOPSIS, SAW and COPRAS methods to show the validity of outranking results. It should be noted that we consider the common version of TOPSIS, which used Euclidean distance (Opricovic and Tzeng, 2004). Seven sets of criteria weights are used for showing the stability of EDAS method in different weights of criteria.

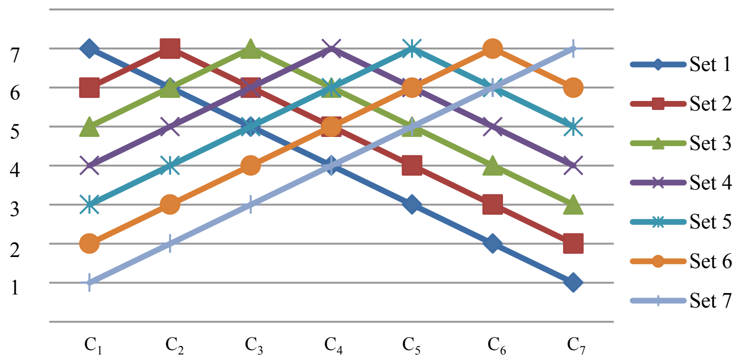

Fig. 2. Importance level of criteria in different sets.

Table 6
Normalized weights of criteria in different sets.

Sets	Criteria						
	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Set 1	0.250	0.214	0.179	0.143	0.107	0.071	0.036
Set 2	0.182	0.212	0.182	0.152	0.121	0.091	0.061
Set 3	0.139	0.167	0.194	0.167	0.139	0.111	0.083
Set 4	0.108	0.135	0.162	0.189	0.162	0.135	0.108
Set 5	0.083	0.111	0.139	0.167	0.194	0.167	0.139
Set 6	0.061	0.091	0.121	0.152	0.182	0.212	0.182
Set 7	0.036	0.071	0.107	0.143	0.179	0.214	0.250

Figure 2 represents the importance level of each criterion in each set, and Table 6 shows the normalized weights of criteria in these sets. In each set, one of the criteria has the highest weight. The ranking results that obtained by different methods and weights are shown in Table 7. We use also the Spearman's correlation coefficient (r_s) for analyzing the correlation between the results of the proposed method and the other methods in different criteria weights. The results of this analysis are shown in Table 8.

According to Table 8, all correlation coefficients are greater than 0.8; therefore, we can say that the results of the proposed method are well consistent with the other methods. Also, the results of using different weights for criteria show that EDAS method has good stability in ranking alternatives.

5. Conclusion

Because of the surplus stock in most companies, great attention is given to the inventory classification, and various management tools are applied to those different classes. The ABC classification which based on the Pareto principle is a frequently used analytical method for classifying inventory into the three A, B and C classes. The traditional ABC classification method uses only one criterion (annual dollar usage) for classifying

Table 7
The results of ranking with EDAS method and four MCDM methods.

Set	Method	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}
Set 1	EDAS	1	4	6	10	7	8	2	3	5	9
	VIKOR	2	5	7	9	6	8	1	3	4	10
	TOPSIS	1	4	6	10	7	8	2	3	5	9
	SAW	1	3	6	9	7	8	2	4	5	10
	COPRAS	1	3	6	10	7	8	2	4	5	9
Set 2	EDAS	1	4	6	10	7	8	2	3	5	9
	VIKOR	2	5	7	10	6	8	1	3	4	9
	TOPSIS	1	4	6	10	7	8	2	3	5	9
	SAW	1	2	6	10	7	8	3	4	5	9
	COPRAS	1	3	6	10	7	8	2	4	5	9
Set 3	EDAS	1	3	7	10	6	8	2	4	5	9
	VIKOR	2	5	7	10	6	8	1	3	4	9
	TOPSIS	1	3	9	10	8	7	2	4	5	6
	SAW	1	2	6	10	7	8	3	4	5	9
	COPRAS	1	2	6	10	7	8	3	4	5	9
Set 4	EDAS	1	2	7	10	6	8	3	4	5	9
	VIKOR	1	5	8	10	6	7	2	3	4	9
	TOPSIS	1	2	9	10	8	7	3	5	4	6
	SAW	1	2	6	10	7	8	3	4	5	9
	COPRAS	1	2	7	10	6	8	3	4	5	9
Set 5	EDAS	1	2	6	10	7	8	3	4	5	9
	VIKOR	1	5	8	10	6	7	2	3	4	9
	TOPSIS	1	2	9	10	8	7	3	5	4	6
	SAW	1	2	6	10	7	8	3	4	5	9
	COPRAS	1	2	7	10	6	8	3	4	5	9
Set 6	EDAS	1	2	6	10	7	8	3	4	5	9
	VIKOR	1	3	6	9	7	8	2	4	5	10
	TOPSIS	1	2	9	10	8	7	3	5	4	6
	SAW	2	1	6	10	7	8	3	4	5	9
	COPRAS	1	2	6	10	7	8	3	4	5	9
Set 7	EDAS	1	2	6	10	7	8	3	4	5	9
	VIKOR	1	2	8	10	6	7	3	4	5	9
	TOPSIS	1	2	9	10	8	7	3	5	4	6
	SAW	2	1	6	10	7	8	3	4	5	9
	COPRAS	2	1	7	10	6	8	3	4	5	9

Table 8
Values of Spearman's correlation coefficient (r_s) in different sets.

Method	r_s						
	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7
VIKOR	0.952	0.964	0.952	0.915	0.891	0.976	0.964
TOPSIS	1	1	0.891	0.879	0.867	0.867	0.867
SAW	0.976	0.964	0.976	0.988	1	0.988	0.988
COPRAS	0.988	0.988	0.976	1	0.988	1	0.976

inventory items. However, inventory classification should be considered as a multi-criteria problem in practice. In this study, we have proposed a new multi-criteria decision-making method for inventory classification. A comparison has been made between the proposed method and some existing methods by a common example of inventory classification. This comparison shows the good performance of the proposed method in the inventory classification problems. The proposed method is also an appropriate method for dealing with other MCDM problems. We have used an example with seven sets of criteria weights to represent the performance of the proposed method in comparison with VIKOR, TOPSIS, SAW and COPRAS methods. The comparison results have been analyzed using Spearman's correlation coefficient. The analysis shows that the proposed MCDM method is stable in different criteria weights and well consistent with the other methods.

References

Bhattacharya, A., Sarkar, B., Mukherjee, S.K. (2007). Distance-based consensus method for ABC analysis. *International Journal of Production Research*, 45(15), 3405–3420.

Cakir, O., Canbolat, M.S. (2008). A web-based decision support system for multi-criteria inventory classification using fuzzy AHP methodology. *Expert Systems with Applications*, 35(3), 1367–1378.

Chakraborty, S., Zavadskas, E.K. (2014). Applications of WASPAS method in manufacturing decision making. *Informatica*, 25(1), 1–20.

Chase, R.B., Aquilano, N.J., Jacobs, F.R. (2001). *Operations Management for Competitive Advantage*. McGraw-Hill/Irwin, New York.

Chen, J.-X. (2011a). Multiple criteria ABC inventory classification using two virtual items. *International Journal of Production Research*, 50(6), 1702–1713.

Chen, J.-X. (2011b). Peer-estimation for multiple criteria ABC inventory classification. *Computers & Operations Research*, 38(12), 1784–1791.

Chu, C.-W., Liang, G.-S., Liao, C.-T. (2008). Controlling inventory by combining ABC analysis and fuzzy classification. *Computers & Industrial Engineering*, 55(4), 841–851.

Flores, B.E., Whybark, D.C. (1986). Multiple criteria ABC analysis. *International Journal of Operations & Production Management*, 6(3), 38–46.

Flores, B.E., Whybark, D.C. (1987). Implementing multiple criteria ABC analysis. *Journal of Operations Management*, 7(1–2), 79–85.

Guvenir, A.H., Erel, E. (1998). Multicriteria inventory classification using a genetic algorithm. *European Journal of Operational Research*, 105(1), 29–37.

Hadi-Vencheh, A. (2010). An improvement to multiple criteria ABC inventory classification. *European Journal of Operational Research*, 201(3), 962–965.

Hadi-Vencheh, A., Mohamadghasemi, A. (2011). A fuzzy AHP-DEA approach for multiple criteria ABC inventory classification. *Expert Systems with Applications*, 38(4), 3346–3352.

Hashemkhani Zolfani, S., Bahrami M. 2014. Investment prioritizing in high tech industries based on SWARA-COPRAS approach. *Technological and Economic Development of Economy*, 20(3), 534–553.

Hatefi, S.M., Torabi, S.A. (2015). A common weight linear optimization approach for multicriteria ABC inventory classification. *Advances in Decision Sciences*. http://dx.doi.org/10.1155/2015/645746.

Kabir, G., Akhtar Hasin, M.A. (2013). Multi-criteria inventory classification through integration of fuzzy analytic hierarchy process and artificial neural network. *International Journal of Industrial and Systems Engineering*, 14(1), 74–103.

Kahraman, C., Suder, A., Cebi, S. (2013). Fuzzy multi-criteria and multi-experts evaluation of government investments in higher education: the case of Turkey. *Technological and Economic Development of Economy*, 19(4), 549–569.

Kahraman, C., Süder, A., Kaya, İ. (2014). Fuzzy multicriteria evaluation of health research investments. *Technological and Economic Development of Economy*, 20(2), 210–226.

Keshavarz Ghorabaee, M., Amiri, M., Salehi Sadaghiani, J., Hassani Goodarzi, G. (2014). Multiple criteria group decision-making for supplier selection based on COPRAS method with interval type-2 fuzzy sets. *The International Journal of Advanced Manufacturing Technology*, 75(5–8), 1115–1130.

Kildienė, S., Zavadskas, E.K., Tamošaitienė, J. (2014). Complex technology assessment model for technology development and implementation. *Journal of Civil Engineering and Management*, 20(2), 280–290.

Kiriş, Ş. (2013). Multi-criteria inventory classification by using a fuzzy analytic network process (ANP) approach. *Informatica*, 24(2), 199–217.

Krylovas, A., Zavadskas, E.K., Kosareva, N., Dadelo, S. (2014). New KEMIRA method for determining criteria priority and weights in solving MCDM problem. *International Journal of Information Technology & Decision Making*, 13(6), 1119–1133.

Kou, G., Peng, Y., Lu, C. (2014). MCDM approach to evaluating bank loan default models. *Technological and Economic Development of Economy*, 20(2), 292–311.

Lei, Q., Chen, J., Zhou, Q. (2005). Multiple criteria inventory classification based on principal components analysis and neural network. In: Wang, J., Liao, X.-F., Yi, Z. (Eds.), *Advances in Neural Networks – ISNN 2005*. Springer, Berlin, Heidelberg, pp. 1058–1063.

Lolli, F., Ishizaka, A., Gamberini, R. (2014). New AHP-based approaches for multi-criteria inventory classification. *International Journal of Production Economics*, 156, 62–74.

Ng, W.L. (2007). A simple classifier for multiple criteria ABC analysis. *European Journal of Operational Research*, 177(1), 344–353.

Opricovic, S., Tzeng, G.-H. (2004). Compromise solution by MCDM methods: a comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research*, 156(2), 445–455.

Park, J., Bae, H., Bae, J. (2014). Cross-evaluation-based weighted linear optimization for multi-criteria ABC inventory classification. *Computers & Industrial Engineering*, 76, 40–48.

Partovi, F.Y., Anandarajan, M. (2002). Classifying inventory using an artificial neural network approach. *Computers & Industrial Engineering*, 41(4), 389–404.

Partovi, F.Y., Burton, J. (1993). Using the analytic hierarchy process for ABC analysis. *International Journal of Operations & Production Management*, 13(9), 29–44.

Ramanathan, R. (2006). ABC inventory classification with multiple-criteria using weighted linear optimization. *Computers & Operations Research*, 33(3), 695–700.

Rostamzadeh, R., Govindan, K., Esmaeili, A., Sabaghi, M. (2015). Application of fuzzy VIKOR for evaluation of green supply chain management practices. *Ecological Indicators*, 49, 188–203.

Ruzgys, A., Volvačiovas, R., Ignatavičius, Č., Turskis, Z. (2014). Integrated evaluation of external wall insulation in residential buildings using SWARA-TODIM MCDM method. *Journal of Civil Engineering and Management*, 20(1), 103–110.

Soylu, B., Akyol, B. (2014). Multi-criteria inventory classification with reference items. *Computers & Industrial Engineering*, 69, 12–20.

Stanujkic, D., Magdalinovic, N., Jovanovic, R. (2013). A multi-attribute decision making model based on distance from decision maker's preferences. *Informatica*, 24(1), 103–118.

Stanujkic, D., Magdalinovic, N., Milanovic, D., Magdalinovic, S., Popovic, G. (2014). An efficient and simple multiple criteria model for a grinding circuit selection based on MOORA method. *Informatica*, 25(1), 73–93.

Šiožinytė, E., Antuchevičienė, J. 2013. Solving the problems of daylighting and tradition continuity in a reconstructed vernacular building. *Journal of Civil Engineering and Management*, 19(6), 873–882.

Šiožinytė, E., Antuchevičienė, J., Kutut, V. 2014. Upgrading the old vernacular building to contemporary norms: multiple criteria approach. *Journal of Civil Engineering and Management* 20(2), 291–298.

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

Tsai, C.-Y., Yeh, S.-W. (2008). A multiple objective particle swarm optimization approach for inventory classification. *International Journal of Production Economics*, 114(2), 656–666.

Turskis, Z., Zavadskas, E.K., Kutut, V. 2013. A model based on ARAS-G and AHP methods for multiple criteria prioritizing of heritage value. *International Journal of Information Technology & Decision Making* 12(1), 45–73.

Ulucan, A., Atici, K.B. (2013). A multiple criteria sorting methodology with multiple classification criteria and an application to country risk evaluation. *Technological and Economic Development of Economy*, 19(1), 93–124.

Xiao, Y.-y., Zhang, R.-q., Kaku, I. (2011). A new approach of inventory classification based on loss profit. *Expert Systems with Applications*, 38(8), 9382–9391.

Zavadskas, E.K., Antucheviciene, J., Razavi Hajiagha, S.H., Hashemi, S.S. 2014. Extension of weighted aggregated sum product assessment with interval-valued intuitionistic fuzzy numbers (WASPAS-IVIF). *Applied Soft Computing* 24, 1013–1021.

Zeng, S., Baležentis, T., Chen, J., Luo, G. (2013). A projection method for multiple attribute group decision making with intuitionistic fuzzy information. *Informatica*, 24(3), 485–503.

Zhou, P., Fan, L. (2007). A note on multi-criteria ABC inventory classification using weighted linear optimization. *European Journal of Operational Research*, 182(3), 1488–1491.

M. Keshavarz Ghorabaee received the BS degree in electrical engineering from the University of Guilan, Rasht, Iran in 2010 and the MS degree in production management from the Allame Tabataba'i University, Tehran, Iran in 2013. He is currently working toward the PhD degree in management (Operations Research) at Allame Tabataba'i University. He has published some papers in leading international journals. His research interests include multi-criteria decision making (MCDM), multi-objective evolutionary algorithms, genetic algorithm, fuzzy MCDM, inventory control, supply chain management, scheduling and reliability engineering.

E.K. Zavadskas PhD, DSc, h.c.multi. Prof., the Head of the Department of Construction Technology and Management of Vilnius Gediminas Technical University, Lithuania. Senior Research Fellow at the Research Institute of Smart Building Technologies. PhD in Building Structures (1973). Dr Sc. (1987) in Building Technology and Management. A member of Lithuanian and several foreign Academies of Sciences. Doctore Honoris Causa from Poznan, Saint Petersburg and Kiev universities. The Honorary International Chair Professor in the National Taipei University of Technology. A member of international organizations; a member of steering and programme committees at many international conferences; a member of the editorial boards of several research journals; the author and co-author of more than 400 papers and a number of monographs in Lithuanian, English, German and Russian. Editor-in-chief of journals Technological and Economic Development of Economy and Journal of Civil Engineering and Management. Research interests: building technology and management, decision-making theory, automation in design and decision support systems.

L. Olfat is an Associate Professor with the Department of Industrial Management, Allame Tabataba'i University, Tehran, Iran. She received the M.S. degree in industrial engineering from the University of Birmingham, UK and the PhD degree in management (Operations Research) from the University of Tehran, Iran. She is currently Dean of the Management and Accounting Faculty of Allame Tabataba'i University. Her research interests include supply chain management (SCM), production planning, inventory control, scheduling, green SCM, optimization, multi-criteria decision making, project management and manufacturing systems.

Z. Turskis Prof. Dr of Technical Sciences, Senior Research Fellow at the Laboratory of Construction Technology and Management, Vilnius Gediminas Technical University. Research interests: building technology and management, decision-making theory, computer-aided automation in design, expert systems.

Daugiakriteris inventoriaus klasifikavimas pagal naują vertinimo metodą pagrįstą atstumu nuo vidutinio sprendinio (EDAS)

Mehdi KESHAVARZ GHORABAEE, Edmundas Kazimieras ZAVADSKAS, Laya OLFAT, Zenonas TURSKIS

Veiksmingas būdas valdyti ir kontroliuoti didelį kiekį saugomo inventoriaus ar vertybinių popierių (SKU) yra inventoriaus klasifikavimas. Tradicinė “ABC analizė”, kuri pagrindžiama tik vienu kriterijumi yra įprastai taikoma SKU klasifikuoti. Tačiau praktikoje mes turėtume taikyti daugiakriterius uždavinių sprendimo metodus inventoriui klasifikuoti. Šiame tyrime naujas vertinimo metodas pagrįstas atstumu nuo vidutinio sprendinio (EDAS) yra pristatytas spręsti daugialypius inventoriaus klasifikavimo (MCIC) uždavinius. Siūlomame metode, naudojami teigiami ir neigiami atstumai nuo vidutinio sprendinio nagrinėjamoms alternatyvoms (SKU) vertinti. Siūlomo metodo efektyvumui parodyti sprendžiant MCIC uždavinius, sprendžiamas bendras pavyzdys su 47 SKU. Siūlomo metodo rezultatai palyginti su kai kurių esamų metodų rezultatais rodo gerą metodo efektyvuma ABC klasifikacijos uždaviniams spręsti. Siūlomas metodas taip pat gali būti naudojamas daugiakriteriams sprendimų pagrindimo (MCDM) uždaviniams spręsti. Lyginamoji analizė taip pat atlikta. Ji rodo siūlomo metodo pagrįstumą ir stabilumą sprendžiant MCDM uždavinius. Lyginami gauti uždavinio sprendimo rezultatai taikant EDAS metodą su rezultatais sprendžiant uždavinį VIKOR, TOPSIS, SAW ir COPRAS metodais. Septyni kriterijų svorių vektoriai ir Spearman koreliacijos koeficientas yra naudojami šiai analizei. Gauti rezultatai rodo, kad siūlomas metodas yra stabilus prie skirtingų kriterijų svorių ir rezultatai gerai dera su rezultatais gautais kitais metodais.