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Multi-criteria ABC inventory classification using AHP: a case study

AHP ile çok kriterli ABC stok sınıflandırma üzerine bir uygulama

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In ABC classification of inventory method, stocks are divided into three categories based on their importance. This classification guides managers while determining the inventory control policies of the products. The traditional ABC classification is based on a single criterion - annual usage value. However, when determining the importance of inventory items, the classification will be more accurate when more than one criterion such as annual usage values, lead time, availability, replacement possibilities, and the effects of out-of-stock situations are taken into account. By adapting multi-criteria decision models to the ABC inventory classification system, the importance levels of the inventory items can be determined using more than one criterion. In this study, it is aimed to present a practice for the use of the Analytical Hierarchy Process in multi-criteria ABC inventory classification and indicate the differences between single- and multi-criteria methods. In the application section, the products brought from abroad by a nutritional supplement company were studied and the products of the company were classified using the multi-criteria ABC inventory method. The classifications based on the traditional single-criterion ABC method and the multi-criteria ABC method were compared.

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ÖZET

ABC stok sınıflandırma sisteminde stok kalemleri önem seviyelerine göre üç gruba ayrılır. Ürünlerin stok kontrol politikaları belirlenirken bu sınıflandırmadan yararlanılır. Geleneksel ABC sınıflandırması, bir tek kritere - ürün kalemlerinin yıllık kullanım değerine göre yapılmaktadır. Oysa stok kalemlerinin önem dereceleri belirlenirken yıllık kullanım değerleri ile birlikte, tedarik süreleri, bulunabilirlikleri, ikame olanakları, stoksuzluğu durumundaki etkileri gibi birden fazla kriter dikkate alındığında, yapılan sınıflandırma daha doğru olacaktır. Çok kriterli karar modellerinin ABC stok sınıflandırma sistemine uyarlanması ile stok kalemlerinin önem dereceleri birden fazla kriter kullanılarak belirlenebilmektedir. Bu çalışmada, çok kriterli ABC stok sınıflandırmasında Analitik Hiyerarşi Prosesinin kullanımına yönelik bir uygulama ile tek kriterli ve çok kriterli sınıflama arasındaki farkları sunmak amaçlanmıştır. Uygulama kısmında bir besin destek ürünleri firmasının yurtdışından getirdiği ürünler ele alınmış ve işletmenin ürünleri çok kriterli ABC stok yöntemi kullanılarak sınıflandırılmıştır. Geleneksel tek kriterli ABC yöntemi ile çok kriterli ABC yöntemine göre oluşan sınıflandırmalar karşılaştırılmıştır.

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1. Introduction

Businesses keep inventory due to the reasons such as lead time, scale economy, uncertainty, seasonal demand changes. However, inventory policies are decisions that managers should make meticulously, as they have a large share in total costs, directly affect customer satisfaction and firm's flexibility to adapt. Although inventories are basically classified as raw materials, unfinished goods and finished goods, there are many inventory items under this classification. Applying the strictest tracking and control policies for each inventory item will result in high cost and unproductive workload increase. While businesses follow a tighter inventory control policy for important items by grouping all inventories according to their importance level, a lower level of control can be applied to less important items. The ABC inventory classification model, developed by the General Electric Company in 1951, divides inventory items into three groups according to their importance level. Group A stocks are defined as the most important, requiring strict control, group C stocks are the most insignificant requiring least attention, and group B as the inventories that fall between these two (Zimmermann, 1999). This classification helps managers to determine the inventory follow up and inventory control methods. The traditional ABC classification is based on a single criterion - the annual usage values of the items. However, the importance of an inventory item for the business is affected by many factors such as lead time, availability, replacement possibilities, out of stock situations, along with annual usage values (Flores & Whybark, 1986). Therefore, it would be more accurate to classify inventories by evaluating more than one qualitative and quantitative factor together. By adapting the multi-criteria decision models to the ABC inventory classification system, it is possible to determine the importance of stock items using more than one criterion. The purpose of this study is to present a practice for the use of the Analytical Hierarchy Process (AHP) in multi-criteria ABC inventory classification and indicate the differences between single- and multi-criteria methods. In the literature part of the study, first of all, ABC inventory classification models as single and multi-criteria have been examined. Then, the AHP is discussed as a multi-criteria decision-making technique. In the application part of the study, the inventories of a nutritional supplement company were classified using the multi-criteria ABC inventory method. The classifications based on the traditional single-criterion ABC method and the multi-criteria ABC method were compared.

2. ABC Inventory Classification System

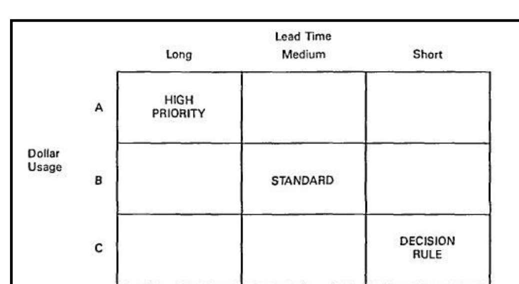
The basis of the ABC inventory classification system is Vilfredo Pareto's determination in 1906 that approximately 20% of the population owns 80% of the country's economy (Top & Yılmaz, 2018). This 80-20 rule, called Pareto analysis; has not only been adapted to economy in general, but also to many problems in enterprises such as inventory control, distribution planning, quality control, production planning, investment planning. ABC method in inventory management is the classification of inventory items according to their cumulative percentages in total (Öztürk, 2009). In the classical-single-criterion ABC classification method, the importance of inventory items is determined according to their annual usage or annual sales values. The annual usage (or sales) value of an inventory item is calculated by multiplying the annual usage (or sales) amount and the unit price. While Group A stocks constitute 15-20% of the total in terms of quantity, their annual sales values are 75-80%. Group C stocks constitute 40-50% of the total amount, while annual sales values are 5-10%. Group B refers to the inventory items other than group A or C. Based on those importance levels, managers decide on inventory control methods. By keeping less amount of A group inventory, inventory control will be tightened, thus reducing the cost of money tied to inventories. On the other hand, stock follow-up can be done more loosely by keeping a higher amount of C group stocks. (Thonemann, 2015).

Although the single-criterion ABC inventory classification method is an easy method to calculate and implement, classification based on annual sales value alone can be misleading or incomplete. In addition to the usage value, various qualitative and quantitative factors affect the importance of an inventory item. When inventory is classified by considering more than one criterion, it will be possible to present more accurate data for inventory control decisions. The most commonly used criteria in determining the importance of inventories are unit price, demand, abrasion (depreciation) rate, lead time, substitutability, usage for more than one product and criticality.

In the classical ABC method, the annual usage value is a criterion that can be measured numerically, so the ordering of the inventory items can be done using objective numerical values without any need for expert interpretation. However, since other criteria affecting the importance of inventory cannot be expressed with numerical measurements, the opinions and experiences of experts are used in determining the degree of importance. Since the quantification of these verbal evaluations based on personal judgments and accordingly the ordering and classification of the importance of the inventory items is a very complex problem, there is no valid solution method in all conditions, but various models have been proposed in the literature (Pérez Vergara, Arias Sánchez, Poveda-Bautista, & Diego-Mas, 2020).

Studies on the solution of the multi-criteria inventory classification problem can be grouped under the titles of binary matrix method, Analytical Hierarchy Process (AHP), clustering analysis, linear optimization-data envelopment analysis (DEA) and heuristic methods (Ravinder & Misra, 2014). The first study in the literature on multi-criteria inventory classification (MCIC) was the study of Flores and Whybark (1986). According to this study which became a reference to many publications in the following years, besides the annual usage value, the criteria of depreciation rate, lead time, substitutability, use for more than one product and cost of stock-out also affect the importance level. Flores and Whybark proposed a two-criteria inventory classification model in which each of these criteria is added to the annual usage value criteria separately, and compared the application results in a business with the single-criterion method. In Figure 1, a classification matrix according to annual sales value and lead time criteria is given as an example from the study. In their second study in 1987, Flores and Whybark applied multi-criteria ABC analysis recommendations to service and manufacturing businesses and compared the results (Flores & Whybark, 1987).

Figure 1. Flores and Whybark's two criteria inventory classification matrix



Source: Flores and Whybark, 1986

In future studies on multi-criteria inventory classification, ABC classes were determined by weighting according to importance-effects, instead of accepting criteria weights as equal. One of the commonly used methods for determining the relative weights of criteria is the Analytical Hierarchy Process - AHP. Flores, Olson and Dorai (1992) applied AHP method developed by Saaty (1977) for multi-criteria decision problems to the determination of criterion weights in multi-criteria ABC analysis. For the multi-criteria ABC analysis, the weights of the average unit cost, annual sales value, criticality and lead time criteria were compared with the single-criterion and multi-criteria inventory classification results by applying the model they determined with AHP in a business. Partavi Burton (1993) proposed a model in which all of the criteria of price, demand, depreciation rate, lead time, substitutability, being repairable, use for multiple products and out-of-stock cost were used in ABC analysis by determining their relative weights with AHP and showed the results of application in a pharmaceutical company. Özdemir and Özveri (2004), Ertuğrul and Tanrıverdi (2013), in their practical studies, classified the inventory items by determining the weights of the criteria in multi-criteria inventory classification with AHP and compared the results with the results of classical ABC analysis. Kumar, Karthik, and Kumar (2017) compared classical ABC analysis with AHP, SAW and TOPSIS methods in multi-criteria ABC analysis. The criteria and weights used in multi-criteria inventory classification may vary according to the sectors. Böker and Çetin (2020), over the results of a case study; they compared the cost, consumption and criticality criteria and ABC-VED method, which are widely used in the classification of inventory in the health sector, with the AHP and TOPSIS methods by adding supplier risk to these three criteria. Cebi, Kahraman and Bolat (2010), Kabir and Hasin (2011), Kılıç etc. (2014), Dursun and Gürgen (2020) used the Fuzzy Analytical Hierarchy Process (FAHP) in multi-criteria ABC classification in their studies.

Cohen and Ernst (1988) proposed a cluster analysis model to classify inventory according to criteria important to both strategic and operational purposes of the business. Aydın Keskin and Özkan (2013) proposed a fuzzy clustering model for multi-criteria ABC inventory classification and evaluated the results in a case study.

Liu and Huang (2006) developed a model based on Data Envelopment Analysis (DEA) for the determination of inventory classes in multi-criteria ABC analysis and compared the results according to their proposed DEA method and AHP method over a sample data set. Ramanathan (2006) presented a model for determining criterion weights by simple weighted linear optimization in multi-criteria ABC analysis and compared the results by solving the model with data they applied AHP analysis in Flores, Olson and Dorai's study (1992). Zhou and Fan (2007) stated in their study that Ramanathan's weighted linear optimization model, known as the R-model, in some cases caused the error of including an insignificant inventory item in class A, and proposed an extended R-model to correct this. Ng (2007) developed a weighted linear optimization model for calculating criterion weights in multi-criteria ABC analysis and compared the results using this model with the case study data from Ramanathan's (2006) study. Hatefi, Torabi, and Bagheri (2014) used a linear optimization model similar to data envelopment analysis to determine the weights of qualitative and quantitative factors in the classification of inventory. Soylu (2017) proposed a data envelopment analysis-based model in multi-criteria ABC classification for the stocking area assignment problem and compared the results of the classical method and the proposed method in a case study.

Güvenir and Erel (1998) proposed a genetic algorithm (GA) method to determine the weights of the criteria and the classes of inventory items in multi-criteria ABC analysis. In the case study section, they compared the results of two methods by classifying the data they received from the purchasing department of a university with GA and AHP. Partovi and Anandarajan (2002) proposed a model with artificial neural networks in ABC classification of inventory items and interpreted the results of a case study in a pharmaceutical company. Yu (2011) applied multi-criteria ABC analysis by using artificial intelligence-based classification methods.

3. Analytical Hierarchy Process (AHP)

According to George A. Miller (1956), the human brain can process at most seven factors simultaneously. When it is desired to make a decision according to more than one criterion, determining their relative values with pairwise comparisons instead of evaluating all the criteria at the same time, facilitates the solution of the problem. The Analytical Hierarchy Process, in multi-criteria decision problems, is a method for obtaining the values of criteria weights and alternatives according to each criterion as a result of pairwise comparisons and ranking the alternatives as per their weighted values (Tayalı & Timor, 2017). Quantitative ranking and comparison, of qualitative assessments by scoring with pairwise comparison was first introduced by Myers and Alpert in 1968 (Myers & Alpert, 1968). Previous studies on consumers' buying decisions were only aimed at determining what factors affect buying decisions. In their study, Myers and Alpert transformed the qualitative comparison of the factors affecting the purchasing decision of customers into quantitative data and formed the order of importance of the effects of these factors on purchasing behavior. Inspired by this study, Thomas Saaty made the method of converting qualitative comparisons based on personal judgments into quantitative values a viable model in solving multi-criteria decision making problems (Saaty, 1977). The AHP method provides the opportunity to solve a problem by arranging the purpose, criteria and alternatives in a hierarchical structure in a complex decision problem. The process consists of first subdividing the problem and creating the hierarchical structure, then defining the pairwise comparison of decision criteria and alternatives based on subjective evaluations, assigning quantitative values to these qualitative comparisons, and finally calculating the importance levels of the alternatives (Mutlu & Sarı, 2017). In multi-criteria decision problems, AHP method is used in business literature in a wide variety of fields such as inventory management, investment decisions (Gülenç & Aydın Bilgin, 2010), supplier selection (Yılmaz, 2012), performance evaluations (Kaya Samut, 2014), logistics management (Küçük Çırpın & Kabadayı, 2015), production management (Başkaya & Akar, 2005), innovation management (İnel & Türker, 2016), technology selection (Erbay & Yıldırım, 2019).

The solution of multi-criteria decision problems with AHP consists of the following steps:

Step 1 - Defining the hierarchy of the decision problem. In this initial step, the decision problem is divided into its components in a hierarchical structure for easier understanding and evaluation. At the top of the hierarchy, the goal is defined, at the middle level the decision criteria, and at the lowest level, alternatives are defined. Figure 2 shows the hierarchical tree diagram of the AHP decision process.

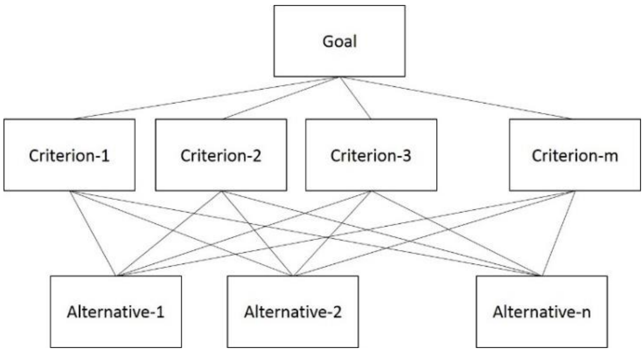


Figure 2. AHP decision hierarchy

Source: Encyclopedia of Operations Research and Management Science, 2001

Step 2 - Creating pairwise comparison matrixes. In this step, firstly, the importance levels of criteria and alternatives are defined with pairwise comparisons based on the subjective judgments of the decision maker. By converting these qualitative comparisons to quantitative values, pairwise comparison matrixes are obtained. In pairwise comparison matrix A, a_{ij} value expresses the importance (preference) level of element *i* over element *j* (Aydın, Öznehir & Akçalı, 2009).

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix}$$

The relative importance scale defined by Thomas L. Saaty is widely used in the literature to convert pairwise qualitative comparisons into quantitative values (Table 1).

Table 1. Saaty's scale of relative importance

Intensity of Importance	Definition
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2,4,6,8	Intermediate values between the two adjacent judgments
Reciprocal values	When option j is compared to option i, option i gets the reciprocal of the assigned value in comparison to option j.

Source: Saaty, 2008

While relative advantages are defined with Saaty's scale in Table 1 in pairwise comparison matrixes, reciprocal values are determined by the inverse symmetric square matrix relationship.

$$\boldsymbol{a_{ji}} = \frac{1}{a_{ij}}$$

Step 3 - Decision criteria and determination of the weights of the alternatives. After the pairwise comparison matrixes are created, the priority (relative importance) of each element being compared is calculated. This process, called the synthesis stage, includes the calculation and normalization of the largest eigenvalue and the corresponding eigenvector (relative importance vector) (Kuruüzüm & Atsan, 2001). The most common normalization method is calculated by dividing the elements of each column by the sum of that column. Denoting by B the normalized pairwise comparison matrix, the value bij is calculated by the following equation:

$$B = \begin{bmatrix} b_{11} & b_{12} & \dots & b_{1n} \\ b_{21} & b_{22} & \dots & b_{2n} \\ \dots & \dots & \dots & \dots \\ b_{n1} & b_{n2} & \dots & b_{nn} \end{bmatrix} \qquad \boldsymbol{b_{ij}} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$

After this process, the priorities (weights) of the alternatives and criteria are obtained by taking the arithmetic average of the values in each row in the normalized pairwise comparison matrixes (Supçiller & Cross, 2011). W the column vector, to show the criteria, and weighted values of alternatives (score) as per each criterion, *wj* the weighted value is calculated with the following equation by using B matrix values.

$$\vec{\boldsymbol{w}} = \begin{bmatrix} \boldsymbol{w_1} \\ \boldsymbol{w_2} \\ \dots \\ \boldsymbol{w_n} \end{bmatrix} \qquad \boldsymbol{w_i} = \frac{\sum_{j=1}^{n} b_{ij}}{n}$$

Step 4 - Making the Consistency Analysis. These comparison results must be consistent so that the values obtained from the pairwise comparison matrixes can be used in decision making. Being able to control of the inconsistency is one of the strongest features of the AHP method, which increases its reliability. The consistency ratios of the matrixes are less than 0.1, indicating that the pairwise comparison is consistent. If the consistency ratio is higher than 0.1, pairwise comparisons are required to be revised (Ulucan, 2004). The consistency ratio (CR) is the ratio of the consistency index to the random index. Ci representing the consistency criterion, CI representing the consistency index and RI representing the random index, are calculated with the following equations:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \quad , \quad \mathrm{CI} = \frac{\sum_i \frac{C_i}{n} - n}{n-1} \quad , \quad C_i = \frac{\sum_j a_{ij} \cdot w_j}{w_i}$$

The randomness index data are given in Table 2:

Table 2. Random index values

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49

Source: Saaty, 2001

Step 5 - Calculation of the multi-criteria score of each alternative and choosing the best alternative. Multi-criteria weighted scores of alternatives are calculated by multiplying the weights of the criteria and the superiority (weight) values of the alternatives according to this criterion. Finally, the decision alternatives are ranked according to their multi-criteria weighted scores and the alternative with the highest score is determined as the most suitable alternative.

4. Case Study

The case study has been conducted in a nutrition supplement company. The company has been selling products in Turkey which are imported from different countries. In this study, ABC inventory classification has been made for 73 product items in the company's portfolio. The classification of products based on importance, will guide the firm in inventory control decisions. The data needed for the analysis were collected through the use of internal sources and face-to-face interviews as secondary and primary data. Classical and multi-criteria ABC methods were used in the classification of inventory and the results were compared. In the multi-criteria ABC analysis, AHP was used to calculate the weights of the criteria and the criterion scores of the inventory items.

4.1. Solution with the Classical ABC Method

For the classical ABC method, firstly, annual sales values were calculated by multiplying the unit prices of 73 inventory items with the annual sales amounts, and then the cumulative percentages were determined by sorting the inventory items from largest to the smallest according to their annual sales values. 16 inventory items, which are in the first 75% of the cumulative annual sales value ratio, are defined as group A. The annual sales values of these 16 inventory items are €707,785,74 in total. In the cumulative ranking, 40 inventory items that fall in the last 10% are defined as C group. Total annual sales values of Group C stocks are €91,454,80. Apart from these, 17 inventory items with a total annual sales value of € 154,354.71 are defined as Group B (Table 3).

Table 3. Sorting of inventory items according to annual sales values

Rank	Product Code	Unit Price (Euro)	Annual Demand	Annual Sales Value	Cumulated Annual Sales Value	Cumulated Annual Sales Percent
Group A						
1	Prod.34	19,65	3482	68.421	68.421	7,18%
2	Prod.60	20,82	3147	65.521	133.942	14,05%
3	Prod.33	16,00	4063	65.008	198.950	20,86%
4	Prod.42	14,96	3997	59.795	258.745	27,13%
5	Prod.61	17,32	3271	56.654	315.399	33,07%
6	Prod.11	22,70	2463	55.910	371.309	38,94%
7	Prod.17	8,95	5572	49.869	421.178	44,17%
8	Prod.73	9,62	4985	47.956	469.134	49,20%
9	Prod.10	18,00	2488	44.784	513.918	53,89%
10	Prod.21	9,98	3866	38.583	552.501	57,94%
11	Prod.65	10,62	3298	35.025	587.525	61,61%
12	Prod.53	15,60	2140	33.384	620.909	65,11%
13	Prod.35	14,30	1989	28.443	649.352	68,10%
14	Prod.5	8,30	2786	23.124	672.476	70,52%
15	Prod.62	6,82	2608	17.787	690.262	72,39%
16	Prod.20	7,74	2264	17.523	707.786	74,22%
Group B						
17	Prod.32	11,92	1287	15.341	723.127	75,83%
18	Prod.18	8,85	1652	14.620	737.747	77,36%
19	Prod.27	15,10	866	13.077	750.824	78,74%
20	Prod.9	10,26	1110	11.389	762.212	79,93%
21	Prod.48	2,42	3946	9.549	771.762	80,93%
22	Prod.47	3,22	2897	9.328	781.090	81,91%
23	Prod.6	3,98	2314	9.210	790.300	82,88%
24	Prod.29	7,80	1163	9.071	799.371	83,83%
25	Prod.54	20,20	422	8.524	807.895	84,72%
26	Prod.72	5,22	1585	8.274	816.169	85,59%
27	Prod.19	7,55	984	7.429	823.598	86,37%
28	Prod.64	4,12	1722	7.095	830.693	87,11%
29	Prod.8	5,42	1277	6.921	837.614	87,84%
30	Prod.58	4,55	1416	6.443	844.057	88,51%
31	Prod.68	1,45	4254	6.168	850.225	89,16%
32	Prod.43	7,05	859	6.056	856.281	89,80%
33	Prod.52	4,62	1268	5.858	862.139	90,41%
Group C						
34	Prod.44	1,76	2449	4.310	866.450	90,86%
35	Prod.55	8,40	513	4.309	870.759	91,31%
36	Prod.69	1,32	3252	4.293	875.052	91,76%
37	Prod.24	5,64	731	4.123	879.174	92,20%
38	Prod.28	2,80	1463	4.096	883.271	92,63%
39	Prod.23	3,81	1012	3.856	887.126	93,03%
40	Prod.70	2,40	1578	3.787	890.914	93,43%
41	Prod.30	2,15	1689	3.631	894.545	93,81%
42	Prod.63	7,86	451	3.545	898.090	94,18%
43	Prod.59	8,82	399	3.519	901.609	94,55%
44	Prod.4	3,26	1019	3.322	904.931	94,90%
45	Prod.41	2,65	1172	3.106	908.037	95,22%
46	Prod.40	1,36	2134	2.902	910.939	95,53%
47	Prod.15	1,12	2502	2.802	913.741	95,82%
48	Prod.39	1,23	2203	2.710	916.451	96,10%
49	Prod.49	0,50	5064	2.532	918.983	96,37%
50	Prod.51	1,85	1322	2.446	921.429	96,63%
51	Prod.3	0,63	3706	2.335	923.763	96,87%
52	Prod.12	1,68	1320	2.218	925.981	97,10%
53	Prod.38	1,45	1458	2.114	928.095	97,33%
54	Prod.16	1,85	1136	2.102	930.197	97,55%
55	Prod.37	1,05	1961	2.059	932.256	97,76%
56	Prod.36	1,56	1301	2.030	934.285	97,98%
57	Prod.50	0,62	3230	2.003	936.288	98,19%
58	Prod.25	0,42	4711	1.979	938.267	98,39%
59	Prod.13	1,10	1718	1.890	940.156	98,59%
60	Prod.7	0,46	3579	1.646	941.803	98,76%
61	Prod.22	0,50	2952	1.476	943.279	98,92%
62	Prod.14	1,65	875	1.444	944.722	99,07%
63	Prod.31	0,46	2764	1.271	945.994	99,20%
64	Prod.45	1,13	1083	1.224	947.218	99,33%
65	Prod.66	0,82	1461	1.198	948.416	99,46%
66	Prod.46	0,22	4542	999	949.415	99,56%
67	Prod.2	0,50	1669	835	950.249	99,65%
68	Prod.56	0,84	987	829	951.079	99,74%
69	Prod.71	0,56	1321	740	951.818	99,81%
70	Prod.57	0,63	1095	690	952.508	99,89%
71	Prod.67	0,26	1502	391	952.899	99,93%
72	Prod.1	0,37	1016	376	953.275	99,97%
73	Prod.26	0,61	524	320	953.594	100,00%

4.2. Solution with Multi-Criteria ABC Method Using AHP

The high annual sales value of an inventory item increases the importance of that item. However, it was stated in the previous section that it can be misleading to evaluate inventory only according to price and demand criteria when determining the degree of importance. Criteria such as the long lead time, the frequent disruptions in supply, insufficient substitution conditions, being a necessary material for the production of more than one product, high ratio of depreciation and the high stock-out costs increase the importance of an inventory item. The multi-criteria ABC problem was defined by selecting four of these criteria in line with the expert opinions in the business considered in practice. The steps of AHP used in solving the problem are as follows:

4.2.1. Defining the hierarchy of the decision problem

As a result of the meeting with the sector-experienced manager of the company where the case study was conducted, it was decided to use the criteria of lead time and disruption in supply, in addition to price and demand, in the classification of importance of inventories. Due to the fact that the inventory of the business comes from different countries, the lead times that differ significantly and the frequency of disruptions in the supply process such as customs procedures, order acceptance, shipment affect the importance of stocks. The analytical hierarchy process diagram for the multi-criteria ABC analysis of the business is shown in Figure3.

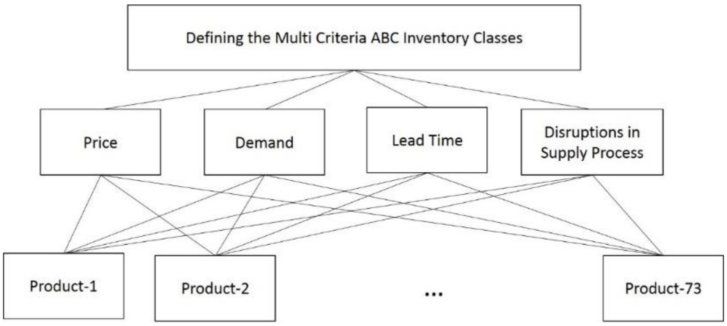


Figure 3. Decision hierarchy of the multi-criteria ABC problem for the case study

4.2.2. Creating pairwise comparison matrixes of criteria and determining their weights

In order to determine the importance of the criteria, the company manager and the purchasing supervisor were interviewed and asked to compare the criteria in pairs according to Saaty's 1-9 scale. The pairwise comparison matrix of the criteria based on expert opinion is shown in Table 4.

Table 4. Pairwise comparison matrix of criteria according to expert opinions

	Price	Demand	Lead Time	Disruption in Supply
Price	1	3	7	7
Demand	1/3	1	5	5
Lead Time	1/7	1/5	1	3
Disruption in Supply	1/7	1/5	1/3	1

In order to calculate the criteria weights, column totals were calculated in the pairwise comparison matrixes of the criteria based on the opinions of the experts, shown in Table 4, and matrix values were normalized by dividing the relevant cell value of each criterion by the column total. The weights of the criteria were calculated from the normalized pairwise comparison matrix (Table 5 and Table 6).

Table 5. Normalization of pairwise comparison matrix of criteria

	Price	Demand	Lead Time	Disruption in Supply
Price	1,00	3,00	7,00	7,00
Demand	0,33	1,00	5,00	5,00
Lead Time	0,14	0,20	1,00	3,00
Disruption in Supply	0,14	0,20	0,33	1,00
Column Total	1,62	4,40	13,33	16,00

Table 6. Normalized pairwise comparison matrix of criteria and their weights

	Price	Demand	Lead Time	Disruption in Supply	Criteria Weights
Price	0,62	0,68	0,53	0,44	0,57
Demand	0,21	0,23	0,38	0,31	0,28
Lead Time	0,09	0,05	0,08	0,19	0,10
Disruption in Supply	0,09	0,05	0,03	0,06	0,06
Column Total	1,00	1,00	1,00	1,00	

Accordingly, the importance weights of the criteria were calculated as 0.57 for the price; 0.28 for demand; 0.10 for lead time and 0.06 for disruption in supply.

4.2.3. Creating pairwise comparison matrices of inventory items and calculating criterion scores

For the pairwise comparisons of the products according to the criteria, firstly, groups were defined according to expert evaluations. (Tables 7-8-9 and 10).

Table 7. Groups for unit prices of products

Definition based on expert opinions	
If the unit price of the product is less than 1 Euro, the price is very low.	very low
If the unit price of the product is between 1-2.99 Euros, the price is low.	low
If the unit price of the product is between 3-6.99 Euros, the price is medium.	medium
If the unit price of the product is between 7-10.99 Euros, the price is high.	high
If the unit price of the product is 11 Euros or more, the price is too high.	too high

Table 8. Groups for annual demand amounts of products

Definition based on expert opinions	
If the annual demand of the product is less than 1500 units, the demand is very low.	very low
If the annual demand of the product is between 1500-2499 units, the demand is low.	low
If the annual demand of the product is between 2500-3499 units, the demand is medium.	medium
If the annual demand of the product is between 3500-4499 units, the demand is high.	high
If the annual demand of the product is 4500 or more, the demand is very high.	too high

Table 9. Groups for product lead times

Definition based on expert opinions	
If the lead time of the product is less than 15 days, the lead time is very short.	very low
If the lead time of the product is between 15-25 days, the lead time is short.	low
If the lead time of the product is between 26-40 days, the lead time is medium.	medium
If the lead time of the product is between 41-55 days, the lead time is long.	high
If the lead time of the product is more than 55 days, the lead time is too long.	too high

Table 10. Groups for disruptions in the supply of products

Definition based on expert opinions	
There is almost no problem in the supply of the product.	very low
Disruptions in the supply of the product are very rare.	low
Disruptions in the supply of the product are rare.	medium
Problems in the supply of the product are frequent.	high
Disruptions in the supply of the product are very common.	too high

The data on the price, demand and lead times of the products were obtained numerically from the business database, and the data based on the experience and opinions of the purchasing manager were defined for the criterion for disruption in supply. Partovi and Burton's (1993) study was used to group numerical data distributed over a wide range and by determining the pairwise comparison matrix. In order to determine the pairwise comparison values of the inventory items according to the criteria, firstly, the pairwise comparison matrix was created (Table 11). The scores of the scale values were calculated by normalizing this pairwise comparison matrix (Table 12 and Table 13).

Table 11. Pairwise comparison matrix

	very low	low	medium	high	too high
very low	1	1/3	1/5	1/7	1/9
low	3	1	1/3	1/5	1/7
medium	5	3	1	1/3	1/5
high	7	5	3	1	1/3
too high	9	7	5	3	1

Table 12. Normalization of pairwise comparison matrix

	very low	low	medium	high	too high
very low	1,00	0,33	0,20	0,14	0,11
low	3,00	1,00	0,33	0,20	0,14
medium	5,00	3,00	1,00	0,33	0,20
high	7,00	5,00	3,00	1,00	0,33
too high	9,00	7,00	5,00	3,00	1,00
Column Total	25,00	16,33	9,53	4,68	1,79

Table 13. Normalized pairwise comparison matrix and scores

	very low	low	medium	high	too high	Score of Scale Values
very low	0,04	0,02	0,02	0,03	0,06	**0,035**
low	0,12	0,06	0,03	0,04	0,08	**0,068**
medium	0,20	0,18	0,10	0,07	0,11	**0,134**
high	0,28	0,31	0,31	0,21	0,19	**0,260**
too high	0,36	0,43	0,52	0,64	0,56	**0,503**
Column Total	1,00	1,00	1,00	1,00	1,00	

Accordingly, for example, a product with a unit price of € 0.46 and a price criterion group “very low” will have a pairwise comparison score of 0.035; a product with a unit price of €15.10 and a price criterion group “too high” will have a pairwise comparison score of 0.503.

4.2.4. Performing the consistency analysis

In order for the values obtained from the pairwise comparison matrixes to be used in decision making, these comparison results must be consistent.

C_i Consistency measures in the pairwise comparison matrix of the criteria is calculated as below:

$$C_i = \begin{bmatrix} 4,397 \\ 4,427 \\ 4,056 \\ 4,071 \end{bmatrix}$$

According to this, for being consistency index (CI)=0.079 and, for n=4, random index (RI)=0.09, consistency ratio was calculated (CR)= 0.08. The fact that the consistency ratio is less than 0.1 indicates that this matrix is consistent and that the criterion weights can be used in the AHP scoreboard.

In the pairwise comparison matrix of the scale values of the inventory items according to the criteria, the consistency criteria were calculated as follows:

$$C_i = \begin{bmatrix} 5,09 \\ 5,03 \\ 5,20 \\ 5,43 \\ 5,46 \end{bmatrix}$$

Accordingly, it was calculated that the consistency index (CI)=0.06 and the random index (RI)=1.12 for n=5, the consistency ratio (CR)=0.054. The fact that the consistency ratio is less than 0.1 indicates that this matrix is consistent and that the scale values of the inventory items can be used in the AHP score table according to the criteria.

4.2.5. Calculating the weighted multi-criteria score of each alternative and choosing the best alternative

At final step, the weighted total scores of 73 inventory items were calculated according to the criteria of price, demand, lead time and disruption in supply, by sorting from largest to smallest; first 15 items of inventory (20% of total amount) were defined as group A, last 37 items of inventory (50% of total inventory) were defined as group C, 20 items of inventory in between (30% of total inventory), were defined as group B (Table 14). When inventory items are classified by multi-criteria ABC analysis, the annual sales values of 15 inventory items defined as A group are €651,269.30, 21 inventory items in B group are €203,274.27, and 37 inventory items in group C are €99,050.68.

Table 15. Comparison of single-criterion and multi-criteria ABC classification results

Classification with the Classical ABC Method

Stock Group	Product Item	% of Annual Sales Amount	% of Annual Sales Value	Total of Annual Sales Value
A	16	%33	%74.2	707.785,74 €
B	17	%19	%16,2	154.353,71 €
C	40	%48	%9,6	91.454,80 €

Classification with Multi-Criteria ABC Method with AHP

Stock Group	Product Item	% of Annual Sales Amount	% of Annual Sales Value	Total of Annual Sales Value
A	15	%28	%68,3	651.269,30 €
B	21	%31	%21,3	203.274,27 €
C	37	%41	%10,4	99.050,68 €

As seen in Table 15, while the annual total sales value of the products defined as group A in the single-criterion method was €707,785, when the inventory classes were determined by the multi-criteria ABC method, the products defined as group A changed and thus the annual sales value of class A products decreased to €651.269. In addition, while the annual sales amount of 16 product items defined as Class A with the single-criterion method was 33%, the annual sales percentage of 15 Class-A product items determined by the multi-criteria method was 28%. In this way, the workload will decrease as the number of products that require strict control of the enterprise is reduced.

Table 14. Ranking of inventory items according to weighted multi-criteria AHP scores

Rank.	Product Code	Price (0,57)	Demand (0,28)	LT (0,10)	DS (0,06)	Weighted Total Score	Rank.	Product Code	Price (0,57)	Demand (0,28)	LT (0,10)	DS (0,06)	Weighted Total Score
			Group A							**Group C**			
1	Prod.61	0,504	0,134	0,503	0,503	0,4053	37	Prod.48	0,068	0,260	0,134	0,068	0,1290
2	Prod.60	0,504	0,134	0,503	0,260	0,3907	38	Prod.7	0,035	0,260	0,260	0,134	0,1268
3	Prod.33	0,504	0,260	0,068	0,068	0,3710	39	Prod.3	0,035	0,260	0,260	0,035	0,1209
4	Prod.73	0,261	0,503	0,503	0,503	0,3701	40	Prod.8	0,135	0,035	0,260	0,134	0,1208
5	Prod.42	0,504	0,260	0,035	0,068	0,3677	41	Prod.23	0,135	0,035	0,260	0,134	0,1208
6	Prod.11	0,504	0,068	0,260	0,503	0,3625	42	Prod.24	0,135	0,035	0,260	0,134	0,1208
7	Prod.10	0,504	0,068	0,260	0,134	0,3404	43	Prod.4	0,135	0,035	0,260	0,035	0,1149
8	Prod.34	0,504	0,134	0,068	0,068	0,3357	44	Prod.70	0,068	0,068	0,503	0,068	0,1122
9	Prod.53	0,504	0,068	0,134	0,260	0,3353	45	Prod.58	0,135	0,035	0,134	0,134	0,1082
10	Prod.54	0,504	0,035	0,134	0,260	0,3261	46	Prod.15	0,068	0,134	0,260	0,068	0,1064
11	Prod.17	0,261	0,503	0,260	0,068	0,3197	47	Prod.52	0,135	0,035	0,134	0,068	0,1042
12	Prod.35	0,504	0,068	0,068	0,068	0,3172	48	Prod.67	0,035	0,068	0,503	0,068	0,0934
13	Prod.27	0,504	0,035	0,068	0,068	0,3080	49	Prod.13	0,068	0,068	0,260	0,068	0,0879
14	Prod.32	0,504	0,035	0,068	0,068	0,3080	50	Prod.22	0,035	0,134	0,260	0,035	0,0856
15	Prod.21	0,261	0,260	0,260	0,134	0,2556	51	Prod.66	0,035	0,035	0,503	0,068	0,0841
			Group B				52	Prod.71	0,035	0,035	0,503	0,068	0,0841
16	Prod.65	0,261	0,134	0,503	0,134	0,2446	53	Prod.37	0,068	0,068	0,068	0,260	0,0802
17	Prod.5	0,261	0,134	0,260	0,134	0,2203	54	Prod.39	0,068	0,068	0,068	0,260	0,0802
18	Prod.63	0,261	0,035	0,503	0,134	0,2169	55	Prod.40	0,068	0,068	0,068	0,260	0,0802
19	Prod.18	0,261	0,068	0,260	0,035	0,1959	56	Prod.12	0,068	0,035	0,260	0,068	0,0786
20	Prod.20	0,261	0,068	0,260	0,035	0,1959	57	Prod.14	0,068	0,035	0,260	0,068	0,0786
21	Prod.9	0,261	0,035	0,260	0,134	0,1926	58	Prod.16	0,068	0,035	0,260	0,068	0,0786
22	Prod.19	0,261	0,035	0,260	0,035	0,1867	59	Prod.50	0,035	0,134	0,134	0,068	0,0750
23	Prod.59	0,261	0,035	0,134	0,134	0,1800	60	Prod.36	0,068	0,035	0,068	0,260	0,0710
24	Prod.49	0,035	0,503	0,134	0,068	0,1783	61	Prod.38	0,068	0,035	0,068	0,260	0,0710
25	Prod.55	0,261	0,035	0,134	0,068	0,1761	62	Prod.44	0,068	0,068	0,035	0,134	0,0693
26	Prod.62	0,135	0,134	0,503	0,134	0,1728	63	Prod.30	0,068	0,068	0,068	0,068	0,0687
27	Prod.43	0,261	0,035	0,035	0,134	0,1701	64	Prod.31	0,035	0,134	0,068	0,068	0,0684
28	Prod.25	0,035	0,503	0,068	0,035	0,1697	65	Prod.41	0,068	0,035	0,035	0,260	0,0677
29	Prod.29	0,261	0,035	0,068	0,068	0,1695	66	Prod.2	0,035	0,068	0,260	0,035	0,0671
30	Prod.46	0,035	0,503	0,035	0,035	0,1664	67	Prod.51	0,068	0,035	0,134	0,068	0,0660
31	Prod.68	0,068	0,260	0,503	0,068	0,1659	68	Prod.45	0,068	0,035	0,035	0,134	0,0601
32	Prod.64	0,135	0,068	0,503	0,068	0,1504	69	Prod.28	0,068	0,035	0,068	0,068	0,0594
33	Prod.72	0,135	0,068	0,503	0,068	0,1504	70	Prod.1	0,035	0,035	0,260	0,035	0,0579
34	Prod.47	0,135	0,134	0,134	0,068	0,1320	71	Prod.56	0,035	0,035	0,134	0,068	0,0472
35	Prod.69	0,068	0,134	0,503	0,068	0,1307	72	Prod.57	0,035	0,035	0,134	0,068	0,0472
36	Prod.6	0,135	0,068	0,260	0,134	0,1300	73	Prod.26	0,035	0,035	0,068	0,035	0,0387

Note: LT: Lead Time, DS: Disruption in Supply

Table 16. Products whose importance classes vary according to single-criterion and multi-criteria ABC classification

Product Code	Classical ABC Classification	Multi-Criteria ABC Classification with AHP
27, 32, 54	B	A
5, 20, 62, 65	A	B
8, 48, 52, 58	B	C
25, 46, 49, 55, 59, 63	C	B

Table 16 shows the products whose classes vary according to the single-criterion and multi-criteria inventory classification methods. This table shows the change in the importance classes of the products, considering the annual sales value, the duration of the supply and the criteria for disruption in the supply.

5. Results and Recommendations

In this study, it is aimed to present a practice for the use of the Analytical Hierarchy Process in multi-criteria ABC inventory classification and indicate the differences between single- and multi-criteria methods. The suggested road-steps were implemented in a nutritional supplement company and ABC inventory classification was made for 73 product items in the company's portfolio. The classification of products based on importance, will guide the firm in inventory control decisions.

In the first part of the application section, classification was made with the classical ABC method. To this end, firstly, annual sales values were calculated by multiplying the unit prices of 73 inventory items with the annual sales amounts, and then the cumulative percentages were determined by sorting the inventory items from largest to the smallest according to their annual sales values. 16 inventory items, which are in the first 75% of the cumulative annual sales value ratio, are defined as Group A. The annual sales values of these 16 inventory items are €707,785,74 in total. In the cumulative ranking, 40 inventory items that fall in the last 10% are defined as Group C. Total annual sales values of Group C stocks are €91,454,80. Apart from these, 17 inventory items with a total annual sales value of € 154,354.71 are defined as Group B.

In the second part of the application, classification was made with the multi-criteria ABC using AHP. As a result of the meeting with the sector-experienced manager of the company where the case study was conducted, it was decided to use the criteria of lead time and disruption in supply, in addition to price and demand, in the classification of importance of inventories. Due to the fact that the inventory of the business comes from different countries, the lead times that differ significantly and the frequency of disruptions in the supply process such as customs procedures, order acceptance, shipment affect the importance of stocks. In order to determine the importance of the criteria, foremost, the company manager and the purchasing supervisor were interviewed and asked to compare the criteria in pairs according to Saaty's 1-9 scale. The importance weights of the criteria were calculated from the normalized pairwise comparison matrix as 0.57 for the price; 0.28 for demand; 0.10 for lead time and 0.06 for disruption in supply. Then, pairwise comparisons of the products were made according to these four criteria, and the scores of the products for each criterion were calculated by normalizing the pairwise comparison matrices. Before proceeding to the decision phase, consistency analysis was performed for all pairwise comparison matrices and it was seen that the matrix values were consistent. At final step, the weighted total scores of 73 inventory items were calculated according to the criteria of price, demand, lead time and disruption in supply, by sorting from largest to smallest; first 15 items of inventory (20% of total amount) were defined as group A, last 37 items of inventory (50% of total inventory) were defined as group C, 20 items of inventory in between (30% of total inventory), were defined as group B (Table 14). When inventory items are classified by multi-criteria ABC analysis, the annual sales values of 15 inventory items defined as group A are €651,269.30, 21 inventory items in group B are €203,274.27, and 37 inventory items in group C are €99,050.68.

As the classification results according to the classical and multi-criteria ABC methods were compared, it was seen that, while the annual total sales value of the products defined as group A to the single-criterion method was €707,785, when the inventory classes were determined by the multi-criteria ABC method, the products defined as group A changed and thus the annual sales value of class A products decreased to €651.269. In addition, while the annual sales amount of 16 product items defined as Class A with the single-criterion method was 33%, the annual sales percentage of 15 Class-A product items determined by the multi-criteria method was 28%. In this way, the workload will decrease as the number of products that require strict control of the enterprise is reduced.

In this study, price, demand, lead time and supply disruption criteria were used for multi-criteria classification. In future studies, differences can be compared by testing other criteria. In addition, AHP was used as multi-criteria decision making method. The study can be extended with other multi-criteria decision making methods.

Yazar Katkı Oranı Beyanı

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Çatışma Beyanı

Çalışmada yazarlar arasında çıkar çatışması yoktur.

Destek Beyanı

Bu çalışma için herhangi bir kurumdan destek alınmamıştır.

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