Sigma J Eng & Nat Sci 35 (3), 2017, 471-480

Sigma Journal of Engineering and Natural Sciences
Sigma Mühendislik ve Fen Bilimleri Dergisi

Research Article

DETERMINATION OF THE MATERIAL FOR THE CARBONATED SOFT DRINK PACKAGING WITH MULTI-CRITERIA DECISION MAKING METHODS

Ercan ŞENYİĞİT[1]*, Bilal DEMİREL[2]

[1]*Erciyes University, Department of Industrial Engineering, KAYSERI;* ORCID:0000-0002-9388-2633
[2]*Erciyes University, Department of Material Engineering, KAYSERI;* ORCID:0000-0002-5390-0630

Received: 26.01.2017 Revised: 13.07.2017 Accepted: 24.04.2017

ABSTRACT

Packages are of the indispensables of our life. They are used in all fields of the modern life. There are different kinds of packages for variety of purposes. These packages are also very different with each other in terms of both their areas of usage and designs and the products being stored in them. Some of them are used for solids, some of them for liquids and some of them for gases. On the other hand, the materials, by which these packages are made, also differ with respect to usage area and purposes. Some of these materials are based on inorganic, organic and some of them metallic. Aluminium, steel, cardboard, polymers such as PE, PET, HDPE, LDPE and glasses can be given as an example to packaging materials. In this study, 17 material alternatives are taken into account as selecting best material for packaging according to AHP, TOPSIS and SAW multi-criteria decision making methods. CO2 Permeability, Tensile Strength, Compressive Strength, Young Modules, Density, Price and Optical Properties are seven different criteria for the selection of the packaging material. Aluminium is determined as the advisable material for packaging.
Keywords: Multi-criteria decision making, material selection, packaging.

1. INTRODUCTION

Packages are important for our life. It is a very hard problem to select the best material with specific properties from a large number of alternatives by ourselves. So, there is a need to solve this problem by a scientific method, multi-criteria decision making (MCDM) method. Aluminium, steel, cardboard, glasses and polymers (PE, PET, HDPE, LDPE) can be given as examples to the packaging materials which are of the indispensables of our life, each of which also shows differences within themselves. Polymers, metals and glasses have too many types within themselves and the usage areas of each are different from each other. As for the production method, the methods of each of these materials differ from each other. Glasses are generally used for the products that are needed more sensitive storage and preferred especially in the packaging of carbonated soft drinks and of mineral waters due to their very low gas permeability properties. Beside the advantages mentioned above for the glass packaging, it can be regarded as disadvantages that their production requires higher energy compared to the substitutional

* Corresponding Author/Sorumlu Yazar: e-mail/e-ileti: senyigit@erciyes.edu.tr, tel: (505) 253 49 84

material, is expensive and susceptible to break. In addition, the fact that raw material is cheap can be considered as another advantage. Some metals such as Aluminium are preferred in packaging industry due to their high gas barrier properties and toughness. However, due to the fact that the cost of production has recently been rather high and there are some disadvantages in terms of health problems, they are not being used in the food packaging industry.

There are a lot of MCDM methods as AHP, ANP, SAW, TOPSIS, ELECTRE, PROMETHEE, VIKOR etc. Multi-criteria decision making (MCDM) is a well-known branch of decision making [1, 13]. It is a branch of a general class of operation research models which deal with decision problems under the presence of a number of decision criteria [2]. Multi-criteria decision making can be defined as the evaluation of the alternatives for the purpose of selection or ranking, using a number of qualitative and/or quantitative criteria that have different measurement units [3]. In MCDM methodologies, for the ranking among alternatives and the determination of their preference, it is necessary to determine the relative importance of criteria [4]. CO2 Permeability (CP), Tensile Strength (TS), Compressive Strength (CS), Young Modules (YM), Density (D), Price (P) and Optical Properties (OP) are seven different criteria for the selection of the best material.

2. MATERIAL AND METHOD

Firstly, in this study, AHP, TOPSIS and SAW which are MCDM methods are taken into account. The steps of all the methods are imported in order. Later, the application of these methodologies to the problem is presented. One of the most outstanding MCDM approaches is the AHP which has its roots in obtaining the relative weights among the factors and the total values of each alternative based on these weights. TOPSIS is a MCDM methodology which determines solution alternatives from a finite set on the basis of maximising the distance from the negative ideal point and minimising the distance from the positive ideal point [5]. SAW, which is also known as a weighted linear combination or scoring method, is a simple and commonly used MCDM method [6]. AHP, TOPSIS and SAW MCDM methods are explained in next sections. The material alternatives with their quantitative data are given in Table 1. Saaty developed AHP method. Please, see [4, 7, 8, 9, 11] references for steps of AHP method. A set of pair-wise comparison matrices for each of the lower levels with one matrix for each element are constructed in the level immediately above by using the relative scale measurement shown in [4, 7, 8, 9, 11] references. The pair-wise comparisons are done in terms of which element dominates the other. The consistency is determined by using the eigenvalue, λ_{max}, to calculate the consistency index (CI) as equation-1.

$$CI = (\lambda_{max} - n)/(n-1) \quad (1)$$

where n is the matrix size. Judgment consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value in [4, 7, 8, 9, 11] references. The CR is acceptable, if it does not exceed 0, 10. If it is more, the judgment matrix is inconsistent. TOPSIS method was developed by Huang and Yoon as an alternative to ELECTRE. The basic concept of this method is that the selected alternative should have the shortest distance from the negative ideal solution in a geometrical sense. The method assumes that each attribute has a monotonically increasing or decreasing utility. This makes it easy to locate the ideal and negative ideal solutions. Thus, the preference order of alternatives is yielded through comparing the Euclidean distances [2, 8]. TOPSIS method constructs the normalised decision matrix. This process tries to convert the various attribute dimensions into nondimensional attributes.

An element r_{ij} of the normalised decision matrix can be calculated as follows [2, 8]:

Table 1. Material alternatives

Materials	No	CP	TS	CS	YM	D	P	OP
Aluminum	(1)	0	341	195	72,4	2540	4,9	0
Borosilicate	(2)	0	35,1	351	69,7	2500	11,3	0
Borosilicate u16b	(3)	0	37,7	377	83,8	2500	22,7	2
Aluminosilicate	(4)	0	43,9	439	89,1	2540	3,02	2
Soda lime	(5)	0	32,2	322	72	2520	3,02	2
PVC	(6)	6,96	52,7	44,3	3,3	1490	2,82	2
PPS	(7)	8,39	86,2	116	3,39	1360	30,6	0
PES	(8)	0	114	109	12,3	1555	44,9	0
PEI	(9)	0	101	159	3,04	1280	35,3	2
PBT	(10)	23,2	60	100	3	1380	6,05	0
PAS	(11)	0	75,3	90,4	2,65	1370	19,4	1
PET	(12)	2,77	60	60	3	1390	4,5	2
PS	(13)	145	51,7	89,6	3,28	1050	4,28	2
HDPE	(14)	69,4	31	24,8	1,09	965	3,53	1
LDPE	(15)	193	26,4	17,4	0,283	932	3,61	1
PP	(16)	99,7	42,9	42,6	1,59	908	3,9	1
PEN	(17)	1	48,8	38,2	2,43	1390	8,36	2

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \tag{2}$$

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix} \tag{3}$$

A set of weights $(w_1, w_2, w_3, \dots, w_N)$,

$$\sum_{i=1}^{n} w_i = 1 \tag{4}$$

defined by the decision maker is accommodated to the decision matrix to generate the weighted normalised matrix Y_{ij} as follows:

$$Y_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \dots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \dots & w_n r_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ w_1 r_{m1} & w_2 r_{m2} & \dots & w_n r_{mn} \end{bmatrix} \tag{5}$$

The positive ideal solutions (A*) and negative ideal solutions (A−) are determined as follows:

$$A^* = \left\{ (\max_i v_{ij} \middle| j \in J), (\min_i v_{ij} \middle| j \in J' \right\} \tag{6}$$

$$A^- = \left\{ (\min_i v_{ij} \middle| j \in J), (\max_i v_{ij} \middle| j \in J' \right\} \tag{7}$$

The distance of each alternative from positive and negative ideal solution v_{ij}, v_{j*} and v_{j-} are the weighted normalised value, positive and negative ideal solutions are calculated, respectively. S_{i*} and S^-_i are the distance from positive and negative ideal solution.

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \tag{8}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \tag{9}$$

For each alternative, determine a ratio C_i^* equal to the distance to the nadir divided by the sum of the distance to the nadir and the distance to the ideal.

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \tag{10}$$

Finally, the alternatives are ranked by using the C_i^* values. The alternative with the highest C_i^* value is the best alternative [1, 2, 8, 9, 10].

According to the SAW method, the decision matrix is normalised according to the Data. This procedure transforms various units in the decision matrix into dimensionless comparable units by using the following equations. The normalization formula used for maximizing criteria is as equation-11 and minimizing criteria is as equation-12, d_{ij} is i^{th} criterion's value for j^{th} alternative, max d_{ij} is the largest i^{th} criterion's value of all alternatives and min d_{ij} is the smallest i^{th} criterion's value of all alternatives.

$$r_{ij} = \frac{d_{ij}}{\max d_{ij}} \tag{11}$$

$$r_{ij} = \frac{\min d_{ij}}{d_{ij}} \tag{12}$$

The weights of criteria are determined by AHP method used in SAW method. The weighted normalised matrix is calculated by using the following equation:

$$A_i = \sum_{i=1}^{n} w_j x_{ij} = 1 \tag{13}$$

where x_{ij} is the score of the ith alternative with respect to the jth criteria, and w_j is the weight of the criteria. Ranking of the alternatives by calculating the sum of the rows of the weighted normalised vectors [6, 8, 9, 10, 11].

Table 2. The pairwise comparison matrix for criteria

	CP	TS	CS	YM	D	P	OP
CP	1,00	3,00	7,00	2,00	8,00	2,00	9,00
TS	0,33	1,00	3,00	0,50	8,00	0,33	9,00
CS	0,14	0,33	1,00	0,33	2,00	0,25	7,00
YM	0,50	2,00	3,00	1,00	7,00	1,00	7,00
D	0,13	0,13	0,50	0,14	1,00	0,13	2,00
P	0,50	3,00	4,00	1,00	8,00	1,00	9,00
OP	0,11	0,11	0,14	0,14	0,50	0,11	1,00

Table 3. The criteria weights

	CP	TS	CS	YM	D	P	OP
w_i	0,33	0,14	0,07	0,19	0,03	0,22	0,02

3. RESULTS

AHP, TOPSIS and SAW techniques were used to select best material. The decision hierarchy of material selection for AHP is shown in figure-1. The weights of seven criteria are obtained. After forming the decision hierarchy for the problem, the criteria was compared pairwise based on the experience of the authors using the scale and compiled in a pairwise comparison matrix as shown in Table 2. Consistency of the matrices was checked according to the consistency ratio and all of the consistency ratio values were lower than 0.1. As a result, the paired comparison matrices were convenient. The criteria weights (w_j) obtained using these pairwise comparisons are given in Table 3. The criteria weights can be calculated by different methods as Entropy method and compromised weighting method. We used AHP method in the study for page limitation [12]. The ranking of material alternatives for AHP is shown in the ‘overall’ column of table 4. Table 5 shows positive and negative ideal solutions and ratio values for TOPSIS method.

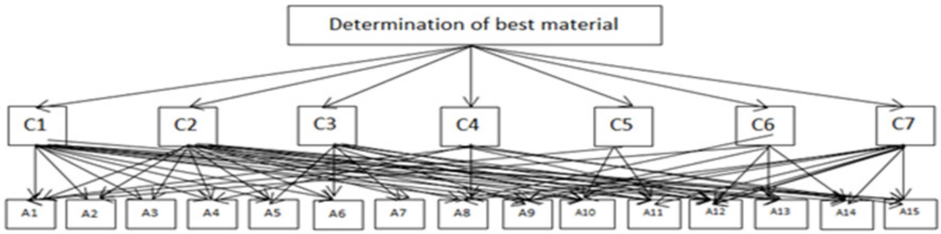

Figure 1. The decision hierarchy of material selection

Table 6 shows normalised comparison and weighted normalised matrix for SAW method. According to these results, the advisable material for the packaging of carbonated soft drinks is Aluminium. Spearman's rank correlation test was done by using MINITAB. Spearman's rank correlation coefficients between the rankings obtained using AHP, TOPSIS and SAW methods (see Table 7) are shown in table 8. The coefficient between TOPSIS and AHP (0,66) is higher than those of other pairs (see table-8).

Table 4. Priority matrix for AHP method

Materials	CP	TS	CS	YM	D	P	OP	Overall
Aluminum	**0,08**	**0,27**	**0,08**	**0,15**	**0,10**	**0,02**	**0,03**	**0,107**
Borosilicate	0,08	0,03	0,13	0,15	0,10	0,06	0,03	0,084
Borosilicate u16b	0,08	0,03	0,14	0,15	0,10	0,11	0,08	0,097
Aluminosilicate	0,08	0,04	0,15	0,15	0,10	0,02	0,08	0,079
Soda lime	0,08	0,03	0,13	0,15	0,10	0,02	0,08	0,077
PVC	0,05	0,04	0,02	0,02	0,04	0,02	0,08	0,033
PPS	0,04	0,06	0,05	0,02	0,04	0,15	0,02	0,064
PES	0,10	0,08	0,05	0,06	0,05	0,18	0,02	0,101
PEI	0,10	0,08	0,06	0,02	0,04	0,17	0,08	0,094
PBT	0,02	0,05	0,04	0,02	0,04	0,03	0,02	0,028
PAS	0,10	0,06	0,04	0,02	0,04	0,09	0,04	0,072
PET	0,05	0,05	0,02	0,02	0,04	0,02	0,15	0,039
PS	0,02	0,05	0,04	0,02	0,04	0,02	0,15	0,028
HDPE	0,01	0,03	0,01	0,01	0,04	0,02	0,04	0,016
LDPE	0,01	0,02	0,01	0,01	0,04	0,02	0,04	0,014
PP	0,01	0,04	0,02	0,01	0,04	0,02	0,04	0,018
PEN	0,08	0,04	0,02	0,02	0,04	0,04	0,07	0,048

Table 5. Positive and negative ideal solution and ratio values for TOPSIS method.

Materials	S^*_i	S^-_i	C^*_i
Aluminum	**0,00**	**0,08**	**0,99**
Borosilicate	0,01	0,06	0,82
Borosilicate u16b	0,02	0,06	0,79
Aluminosilicate	0,01	0,07	0,86
Soda lime	0,01	0,07	0,84
PVC	0,02	0,06	0,74
PPS	0,02	0,04	0,64
PES	0,03	0,05	0,61
PEI	0,03	0,05	0,64
PBT	0,02	0,05	0,70
PAS	0,02	0,05	0,71
PET	0,02	0,06	0,75
PS	0,05	0,02	0,27
HDPE	0,03	0,03	0,54
LDPE	0,07	0,01	0,18
PP	0,03	0,03	0,43
PEN	0,02	0,06	0,73

Table 6. Normalised comparison and Weighted Normalised matrix for SAW method.

	Normalised comparison matrix							Weighted Normalised matrix							
Materials	CP	TS	CS	YM	D	P	OP	CP	TS	CS	YM	D	P	OP	Overall
Aluminum	1,00	1,00	0,44	0,81	0,36	0,58	0,00	0,33	0,14	0,03	0,15	0,01	0,13	0,00	0,79
Borosilicate	1,00	0,10	0,80	0,78	0,36	0,25	0,00	0,33	0,01	0,05	0,15	0,01	0,06	0,00	0,61
Borosilicate u16b	1,00	0,11	0,86	0,94	0,36	0,12	1,00	0,33	0,02	0,06	0,18	0,01	0,03	0,02	0,64
Aluminosilicate	**1,00**	**0,13**	**1,00**	**1,00**	**0,36**	**0,93**	**1,00**	**0,33**	**0,02**	**0,07**	**0,19**	**0,01**	**0,21**	**0,02**	**0,84**
Soda lime	1,00	0,09	0,73	0,81	0,36	0,93	1,00	0,33	0,01	0,05	0,15	0,01	0,21	0,02	0,78
PVC	0,00	0,15	0,10	0,04	0,61	1,00	1,00	0,00	0,02	0,01	0,01	0,02	0,22	0,02	0,30
PPS	0,00	0,25	0,26	0,04	0,67	0,09	0,00	0,00	0,04	0,02	0,01	0,02	0,02	0,00	0,10
PES	1,00	0,33	0,25	0,14	0,58	0,06	0,00	0,33	0,05	0,02	0,03	0,02	0,01	0,00	0,45
PEI	1,00	0,30	0,36	0,03	0,71	0,08	1,00	0,33	0,04	0,02	0,01	0,02	0,02	0,02	0,46
PBT	0,00	0,18	0,23	0,03	0,66	0,47	0,00	0,00	0,02	0,02	0,01	0,02	0,10	0,00	0,17
PAS	1,00	0,22	0,21	0,03	0,66	0,15	0,50	0,33	0,03	0,01	0,01	0,02	0,03	0,01	0,44
PET	0,00	0,18	0,14	0,03	0,65	0,63	1,00	0,00	0,02	0,01	0,01	0,02	0,14	0,02	0,22
PS	0,00	0,15	0,20	0,04	0,86	0,66	1,00	0,00	0,02	0,01	0,01	0,03	0,15	0,02	0,24
HDPE	0,00	0,09	0,06	0,01	0,94	0,80	0,50	0,00	0,01	0,00	0,00	0,03	0,18	0,01	0,24
LDPE	0,00	0,08	0,04	0,00	0,97	0,78	0,50	0,00	0,01	0,00	0,00	0,03	0,17	0,01	0,23
PP	0,00	0,13	0,10	0,02	1,00	0,72	0,50	0,00	0,02	0,01	0,00	0,03	0,16	0,01	0,23
PEN	0,00	0,14	0,09	0,03	0,65	0,34	1,00	0,00	0,02	0,01	0,01	0,02	0,07	0,02	0,15

Table 7. Rankings of materials

Material	AHP	TOPSIS	SAW
1	1	1	4
2	8	4	1
3	3	5	5
4	9	2	3
5	2	3	2
6	4	12	9
7	5	6	8
8	11	17	11
9	7	11	6
10	17	10	13
11	12	7	14
12	6	9	15
13	10	8	16
14	13	14	12
15	16	16	10
16	14	13	17
17	15	15	7

Table 8. Spearman's rank correlation coefficient values

Method	AHP	TOPSIS	SAW
AHP	-	0,66	0,53
TOPSIS		-	0,54
SAW			-

4. CONCLUSIONS

The material selection problem for carbonated soft drink packaging is examined as a multi-criteria decision making problem. AHP, TOPSIS and SAW methods are used to solve this problem. See references [12,13] for comparison the results in the literature. The best materials were found as Aluminium (for AHP and TOPSIS) and Aluminosilicate (for SAW). The worst materials were found as LDPE (for AHP and TOPSIS) and PPS (for SAW). Multi-criteria decision making methods as AHP, TOPSIS and SAW methods outperform in material selection problem. Spearman's rank correlation test was used to assess correlation between AHP, TOPSIS and SAW methods. The systematic in the study could be used to select best material for new designs. We will use new criteria weighting methods and mathematical model to determine optimum material for the material selection problem for carbonated soft drink packaging in our future study.

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