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The Application of the Best-Worst Method to Gain the Premier Modified Asphalt Mixtures

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ABSTRACT: The main purpose of Hot Mix Asphalt (HMA) is to choose the most suitable and the most affordable mix of bitumen and aggregates, so that it can maintain the technical properties of the asphalt concrete in certain amounts. Different methods have been suggested for mixing the Hot Mix Asphalt (HMA) including the Marshall method, the modified Marshall method, Hveem method, and the Superpave mixing method. Concurrently, the project of mixing Hot Mix Asphalt (HMA) in Iran is done based on the Marshall method and the modified Marshall method. Regarding the weaknesses of the asphalt mixes in different situations, the engineers try to modify and improve the properties of the asphalt mix by use of different additives. On the other hand, the additional expenses of various additives to the asphalt mix for building one kilometer of the road is a negative parameter. However, by use of the additives, the technical properties of the asphalt mix improve. Therefore, to decide on a proper choice out of the alternatives would be a difficult task. This paper, tries to provide an appropriate method for evaluating and choosing the best alternative by taking into consideration all the technical criteria. In this article, we first evaluate the score and the weight of each alternative in each criterion. Then, the weight of each criterion is evaluated using the best-worst method, and eventually, taking all aspects into consideration, the rankings of different alternatives will be determined based on two situations: certain situation and uncertain situation.

Keywords: Best-Worst Method. HMA. Certain Situation. Uncertain Situation. Marshall Method.

1 INTRODUCTION

The main purpose of the project of Hot Mix Asphalt (HMA) and the asphalt concrete is to choose the most suitable and the most affordable aggregate mix and bitumen, so that it can maintain the following properties of the asphalt pavements:
A) It should have enough bitumen to make it stable and long-lasting.
B) It should be resistant enough to bear the load of the traffic without being deformed.
C) It should have enough empty space, so that the increase in the temperature and the extra density caused by the traffic cannot reduce its resistance and bitumen. This empty space should not allow the penetration of water and air into the asphalt.
D) It should be efficient enough to be distributed homogeneously and evenly.
E) The surface of the asphalt and its aggregates hardness should provide the suitable friction coefficient in improper weather conditions.
Different methods have been suggested for the project of mixing the asphalt mixes, including:
1) The Marshall method (ASTM D-1559) which is used in mixing and controlling the asphalt operation for aggregates with maximum length of 25 mm and dense grading.
2) The modified Marshall method (ASTM D-5581) which is used for aggregates with the maximum length of 50 mm and 15cm molds.
3) Hveem method (ASTM D-1560) which is used for aggregates with the maximum length of 25 mm to provide plans and control the operations just like the Marshall method.
4) The Superpave method which is a basic mixing method. This method has been developed based on Sharp researches and it has been accepted by AASHTO as a temporary standard.
Currently, the Marshall mixing method and the modified Marshall method are the most applied methods in Iran.
The decision-making issues have got vast influences on our lives, so that most of the issues we face, lead us to make a decision.
Different alternatives with various additives are tested to achieve a high quality asphalt mix in this popular test. Its results are expressed on the basis of six parameters. On the other hand, adding suitable addi-

tives to the mix, concerns about the rising cost of construction increases. Considering various results and the differences among several alternatives, it is difficult to decide on the premier alternatives. In the current study, several evaluation criteria have been introduced so as to evaluate the alternatives and to make decision on the best alternative(s). Then, using the Best-Worst Method, the evaluation of the proposed alternatives has been introduced. Finally, given the quantitative amounts of each criterion and determining the criteria weight, the best alternative is selected.

The use of additives to improve asphalt mixture has been considered by researchers [1], [2] and [3]. Multi-criteria decision making is a method used to solve engineering problems [4].

From a long time ago various methods have been suggested for truly analyzing the multi-criteria decision making. For example, in 1980, Saaty developed the AHP method [5]. The preference ranking organization method (PROMETHEE) was developed to deal with the multi-purpose decision-making issues [6].

According to Hwang and Yoon 1981 [7] classification, the Multi-Criteria Decision-Making (MCDM) is divided into multiple attribute decision-making (MADM) and multiple objective decision-making (MODM). MADM is used to evaluate discrete variables. In addition, this is an a priori process. Experts take part in the initial stage of the process, giving the weightings of the criteria or assessing any attribute of the problem. Finally, the best solution or a solution ranking is obtained [8]. MODM allows for the obtainment of a continuous set of solutions regarding two or more criteria, called Pareto front. These solutions are characterized by each being considered equally good. The experts also take part in the final stage of the process, choosing one among the many solutions [8].

In the past years many methods have been suggested. In 2015, Rezaei developed the Best-Worst method. This method which is based on a mathematical method, has got acceptable results. It has been accepted vastly by many researches in recent years [9]. Rezaei (2016) developed the initial method in a linear form and used it in some real issues [10]. Mou et al. (2016) developed a best-worst method for the problems of collective multi-criteria decision-making issues [11]. Ahmad et al. (2017) used this method to determine the influences of external forces on gas supply chain [12]. Askarifar et al. (2018) used the best-worst method and Topsis method to develop an investment strategy in Iranian coast lines [13]. Gupta (2017) presented a comparison between the best-worst method and Vlse Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [14] method. Multi-criteria decision making is broadly used in different fields as a useful tool in dealing with different issues with different criteria [15].

2 METHODOLOGY

To make the study self-contained, the best-worst method which is developed by Rezaei (2016) is re-expressed in this section [10].

The main part of each MCDM problem is a decision-making matrix made of some alternatives (A_1, A_2, A_3…, A_m), several criteria (C_1, C_2, C_3…, C_n), and the score of each alternative with respect to each criterion (P_{11}, P_{12}, P_{13}…, P_{mn}). Hence, an MCDM problem can be shown as the following matrix.

In a decision-making problem, the best alternative should be found. Therefore, the overall score of each alternative is needed to choose the best one. Using the additive weighted value of each criterion is the simplest way. We can use the following equation to obtain the overall score of each alternative [16].

In this equation, the score of each alternative is needed with respect to each criterion (P_{ij}) and the weight of each criterion (W_j) to determine the overall score of each alternative. The score of each alternative with respect to each criterion (P_{ij}) is made by the decision-maker and the weight of each criterion (W_j) is the output of best-worst method.

The final weight of each criterion is the result of the following stages.

Step 1. Defining a set of criteria

In this section, a set of criteria is defined by the decision-maker (C_1, C_2, C_3…, C_n).

Step 2. Determining the best and the worst criteria

In this step, the best (the most important) and the worst (the least important) criteria are determined by the decision-maker.

Step 3. Specifying the preferences of the best criterion over other criteria

At this point, the Best-to-Other vector are determined by the decision-maker with respect to the preference of the best criterion B over the criterion j (a_{Bj}) as the following:

The value of a_{Bj} is an integer number in the range of [1, 9].

Step 4. Defining the preferences of each criterion over the worst criterion

In this step the Other-to-Worst vector with respect to the preference of each criterion j over the worst criterion W (a_{jw}) is made by the decision-maker as the following:
The value of a_{jw} is an integer number in the range of [1, 9].
Step 5. Determining the weight of each criterion
The following linear programming is used to determine the weight of each criterion:
This problem has a unique solution and provides the optimal weight of each criterion and the indicator of consistency (ξ_L). The lower value of this indicator shows the higher consistency. (For more details see [10]).

3 DATA ANALYSIS

This paper selects 6 parameters of Marshall Test including Stability, Density, VTM, Flow, VMA, and VFA, as well as the cost of the construction of one kilometer of asphalt as the evaluation criteria in the Best-Worst Method. Therefore, 7 factors were involved in the calculations as factor (j)

3.1. Research inputs (raw data)

Table 1 shows the raw data P_{ij} (Marshall Results) used in the Best-Worst Method. Various alternatives included different percentages for adding additives to the asphalt mix, and thus, 25 alternatives (i) were involved and compared in the calculations. The percentage of polyester fibers, black Nano-carbon added to the asphalt mix, and the number of the related alternative are shown in table 2.

Table1. Result of Marshall P_{ij} [17], [18] and [19]

Alternative objective	1	2	3	4
Stability(kg)	835	1010	815	775
unite weight	2.36	2.32	2.29	2.25
VTM	4.5	6.04	7.38	8.37
flow	2.7	3.46	3.84	3.97
VMA	16.11	17.44	18.64	19.93
VFA	72.07	65.37	60.1	55.5
Price ($)	0	1511288.9	3022577.8	4533866.7

5	6	7	8	9
550	734	848	1427	1304
2.16	2.3	2.41	2.41	2.4
12.5	7.04	2.38	2.38	2.79
4.22	3.15	1.72	1.3	1.3
23.1	18.33	14.23	14.23	14.59
3				
45.9	61.59	83.3	83.3	80.88
5				
9067	23988	47977	71966	95954
733.4	7125	4250	1375	8500

10	11	12	13	14
999	1120	1265	1200	1140
2.33	2.26	2.29	2.31	2.33
5.79	8.4	7.38	6.44	5.79
4.45	5.97	6.91	7.17	5
17.3	19.5	18.6	17.8	17.3
66.4	57	60.4	63.8	66.4
241398	242909	244420	248954	481285
413.9	702.8	991.7	858.4	538.9

15	16	17	18	19
1140	1140	1100	1305	1100
2.35	2.27	2.25	2.37	2.31
4.65	8.13	8.37	4.08	6.44
4.65	3.58	3.07	4.1	4.61
16.2	19.3	19.9	15.7	17.8
71.3	57.9	55.5	74.1	63.8
482796	484308	488841	721172	722683
827.8	116.7	983.4	663.9	952.8

20	21	22	23	24	25
1430	1200	980	1265	815	800
2.31	2.3	1.3	2.3	2.29	2.28
6.44	6.68	6.68	6.68	7.38	7.65
6.66	7.17	6.91	5.89	5	4.35
17.8	18	18	18	18.6	18.9
63.8	62.9	62.9	62.9	60.4	59.3
7241	28,72	9610	9625	9640	9686
95241.7	9,108.40	59788.9	71077.8	82366.7	16233.4

Table2. Percent of additives in mixtures [17], [18] and [19]

Alternative number	percent of Nano carbon black in the mixtures	percent of polyester fiber in the mixtures
1	0	0
2	0	0.5
3	0	1
4	0	1.5
5	0	3
6	5	0
7	10	0
8	15	0
9	20	0
10	5	0.5
11	5	1
12	5	1.5
13	5	3
14	10	0.5
15	10	1
16	10	1.5
17	10	3
18	15	0.5
19	15	1
20	15	1.5
21	15	3
22	20	0.5
23	20	1
24	20	1.5
25	20	3

3.2. Data normalization

Various criteria were normalized so that for the criteria with better maximum or minimum, the following section is used:
If J is a positive criterion (if higher amounts are better):

$$z_{ij} = \frac{z_{ij}}{\max\, z_{kj}} \qquad (1)$$

If J is a negative criterion (if lower amounts are better):

$$z_{ij} = 1 - \frac{z_{ij}}{\max\, z_{kj}} \qquad (2)$$

Z_{ij} = the amount of J evaluation for alternative i.
Max Z_{kj}= the highest amount for different alternatives in a special criterion.
But procedural interval was considered for some criteria, so that the middle of the interval was considered as the maximum and equal to 1. The more we go away from the middle of the range, the more this number reduces. This approach is summarized as follows:
Let us assume that, the procedural interval is defined as (a, b), and for a specific alternative, the obtained numbers are as max and min values. The middle interval is defined as follows:

$$C = \frac{a+b}{2} \qquad (3)$$

And also,

$$X = \max P_{ij}$$

$$Y = \min P_{ij}$$

$$P_{ij} = raw\ data$$

The VTM, FLOW and VFA Criteria, were normalized as follows:

$$r_{ij} = 1 + \frac{P_{ij} - C}{C - X} \quad for \quad P_{ij} \geq C$$

$$r_{ij} = \frac{P_{ij} - C + X}{X} \quad for \quad P_{ij} \leq C \qquad (4)$$

4 ANALYZING THE DATA

In this section, we use certain and uncertain situations to select the premier alternatives.

4.1. Certain Situations

In this article, we try to rank different alternatives. To do so, we need the score of each alternative in each criterion. The weight of each criterion is needed, too. We evaluate the weight of each criterion based on the best-worst method. To do so, we use the algorithm presented in section 2. The following table has been presented by the experts as BO and OW entries.

Table 3. BO and OW entries by experts

BO	c_1	c_2	c_3	c_4	c_5	c_6	c_7
Best criterion: c_1	1	1.571	1.571	2	2.2	2.444	1.1

OW	Worst criterion: c_6
c_1	2.444
c_2	1.555
c_3	1.555
c_4	1.222
c_5	1.111
c_6	1
c_7	2.222

In the main study, we should use the integer numbers in the range of 1 to 9. In this study, most of the criteria are of the same importance. In order to increase the preciseness of the project and keep the weights of the criteria from being equal, we use this scoring method. Since all the numbers in the above table are in the same scale, and the presented method is based on mathematical modeling, there is no problem with using this kind of scoring.

4.2. Uncertain Situation

In real world we cannot completely trust in the experts' opinions. Their opinions may be faulty to some extent. In order to make the results more valid, we take into account some error in the course of the project. Suppose that in this study, the expert's opinion has got some amount of error which cannot be neglected. As a result, BO and OW are defined as the following (table. 4).

Table 4 BO and OW entries by experts

BO	c_1	c_2	c_3	c_4	c_5	c_6	c_7	
Best criterion: c_1	1	1.571±0.15	1.571±0.15	2±0.2	2.2±0.24	2.444±0.1	1.1±0.1	
OW								Worst criterion: c_6
c_1								2.444±0.1
c_2								1.555±0.15
c_3								1.555±0.15
c_4								1.222±0.2
c_5								1.111±0.22
c_6								1
c_7								2.222±0.12

5 WEIGHTING SYSTEM

5.1. Certain Situation

Using the algorithm presented in section 2, the following weights are gained for each criterion in the certain situation (table 5).

Table 5. The weight gained in the certain situation

Inconsistency	Price ($)	VFA	VMA	Flow	VTM	Unite Weight	Stability (kg)
0.000014	0.199	0.090	0.099	0.109	0.140	0.140	0.219

The low amount of the incompatibility indicates the preciseness of the method, collected data, and the expert's opinions. In this study, the amount of incompatibility can be neglected and the system can be considered as completely compatible.

5.2 Uncertain Situation

Using the Bental method of Sadjadi and Karimi (2018) with the error amount of 10^{-6} [20]:

Table 6 The weight gained in the uncertain situation

Inconsistency	Price ($)	VFA	VMA	Flow	VTM	Unite Weight	Stability (kg)
0.023	0.201	0.0921	0.0989	0.1097	0.1402	0.1402	0.2176

As it can be seen (table 6), the incompatibility increased but its amount (0.02) is so low that it does not question the validity of the results.

6 RESULTS AND DISCUSSIONS

6.1 Certain Situation

Using this data and the calculated weights, the final score of each alternative is gained based on the following formula [16]:

$$V_i = \sum_{j=1}^{n} w_j p_{ij} \quad (5)$$

W_j is the weight of each criterion and P_{ij} is the score of each alternative in each criterion.
The results are presented in Table 7:

Table7. Each alternative's score in the certain situation.

alternative	**overall score**
1	0.800882
2	0.800878
3	0.726415
4	0.687535
5	0.548353
6	0.691351
7	0.625938
8	0.659033
9	0.606822
10	0.731436
11	0.645183
12	0.669893
13	0.676266
14	0.689909
15	0.702545
16	0.664761
17	0.660061
18	0.689159
19	0.626779
20	0.626215
21	0.715365
22	0.437394

23	0.564405
24	0.499611
25	0.505029

Based on these results, when we completely trust the expert's opinions, the best alternative is alternative one. Based on the cost of the alternative 1 which was zero, this result was predictable.
The following table shows the top 5 alternatives:

Table 8. Final results in the certain situation

	Alterna-tive	percent of polyester fiber in the mixtures	Score
1	1	The mixture without additives	**0.80089**
2	2	Mixture with 0.5% replacement polyester fiber	**0.80080**
3	10	Mixture with 0.5% replacement polyester fiber and 5% of the bitumen weight of Nano carbon black	**0.73143**
4	3	Mixture with 1% replacement polyester fiber	**0.72641**
5	21	Mixture with 3% replacement polyester fiber and 15% of the bitumen weight of Nano carbon black	**0.71536**

6.2. Uncertain Situation
In this situation, the final score of each alternative is as the following (table 9):

Table 9. Each alternative's score in the certain situation

alternative	overall score
1	**0.801982**
2	**0.802314**
3	**0.728077**
4	**0.689183**
5	**0.550168**
6	**0.692858**
7	**0.624871**
8	**0.656745**
9	**0.604807**
10	**0.732700**
11	**0.646130**
12	**0.670736**
13	**0.677305**
14	**0.690695**
15	**0.702800**
16	**0.665257**
17	**0.660543**
18	**0.688440**
19	**0.627259**
20	**0.626282**
21	**0.716641**
22	**0.437828**
23	**0.564394**
24	**0.500227**
25	**0.505600**

As it can be seen from the results, in this situation alternative 2 is the best one. The results are presented in Table 10:

Table 10. Final results in the uncertain situation

Alterna-tive	percent of polyester fiber in the mixtures	Score
2	Mixture with 0.5% replacement polyester fiber	**0.8023**
1	The mixture without additives	**0.8019**
10	Mixture with 0.5% replacement polyester fiber and 5% of the bitumen weight of Nano carbon black	**0.7327**
3	Mixture with 1% replacement polyester fiber	**0.7280**
21	Mixture with 3% replacement polyester fiber and 15% of the bitumen weight of Nano carbon black	**0.7166**

7 CONCLOSION

The purpose of this study was to determine the best asphalt mix in two certain and uncertain situations. To do this, 25 samples of asphalt mix containing additive were selected:

- To validate the results and compare them, two certain situation and uncertain situation methods were used.
- In the certain situation, the mixture without additives, Mixture with 0.5% replacement polyester fiber and Mixture with 0.5% replacement polyester fiber and 5% of the bitumen weight of Nano carbon black obtained the rank 1 to 3.
- In the uncertain situation, the mixture with 0.5% replacement polyester fiber, the mixture without additives and Mixture with 0.5% replacement polyester fiber and 5% of the bitumen weight of Nano carbon black obtained the rank 1 to 3.

Based on the aforementioned points, we can conclude that in a situation in which the expert's opinion is regarded to have low error, the final alternative will be replaced and the asphalt mix with 0.5 fiber will be the best alternative. We can hope to gain better results with a low cost. Since the cost is one of the criteria in this study, and due to the fact that alternative 1 is of no cost, choosing alternative 2 in the uncertain situation indicates an improvement in the properties of this alternative.

Conflict of Interest: The authors declare that they have no conflict of interest.

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