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Research Paper

Evaluation of the Five Busiest Airports in Turkey through Fuzzy FUCOM and MAIRCA

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ABSTRACT

Purpose: This study aims to evaluate and rank the performance of five major airports in Turkey through the proposed two-stage decision-making model.

Methodology: In the first stage of the approach developed, the weights of the criteria affecting the airport performance are determined by using the fuzzy Full Consistency Method (FUCOM) in line with the industry expert opinions. In the second stage, airports are ranked according to their performance through the Multi Attribute Ideal-Real Comparative Analysis (MAIRCA) method by using the data presented in the database of the Skytrax website.

Findings: As a result of the expert evaluation, it is determined that ground transportation and security screening services are the most important criteria in the assessment of airline performance. According to the findings obtained in the second phase of the application, the airport with the highest performance is Istanbul Airport.

Originality: The literature generally focuses on the evaluation of airline companies and there are not many studies comparing the performances of airports. In the current research, an integrated two-stage approach has been developed to compare the performance of five major airports in Turkey to fill this gap in the literature.

Keywords: Airport performance, success factors, fuzzy logic, FUCOM, MAICRA

1. Introduction

Today, the rapid increase in the demand for airport services has caused an unequal growth parity between the infrastructure and the number of passengers (Pandey, 2016). These conditions have increased the responsibilities of airport operators to provide and maintain a certain level of service quality (Prakash and Barua, 2016). In line with these outputs, one can put forward that in order to achieve long-term success and competitiveness, airports should develop strategies to improve their performance (Samad et al., 2021). Evaluation of airport performances and comparison with other airports, is thought to significantly contribute to the development of these strategies. However, although there

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are many studies focusing on this aforementioned question, the number of studies scrutinizing this context is not high (Pandey, 2016). It should also be emphasized that the ever-changing nature of airport management is an incentive for research in this context.

The Full Consistency Method (FUCOM) is a decision-making technique based on pairwise comparisons of criteria and validation of results along a deviation from maximum consistency (Pamučar et al., 2018) and proves advantageous in identifying deviations from maximum consistency as well as takes into account the concept of transitivity (Pamučar, Stević, & Sremac, 2018). Additionally fuzzy logic is an effective mathematical tool for solving the problems encompassing uncertain and incomplete information in real decision problems (Pamučar and Ecer, 2020). For this reason, the fuzzy FUCOM approach, in which fuzzy logic and FUCOM are integrated, can be proposed as an effective method in determining the weights of respective criterion. Furthermore, The Multi Attribute Ideal-Real Comparative Analysis (MAIRCA) method is a decision-making technique based on identifying the difference between theoretical and real results, bearing advantages such as the efficiency and ease of its use in problems with multiple evaluation criteria and alternatives, the ease of implementation and the producing of consistent solutions (Ecer, 2022).

In this assessment, the performances of five major airports in Turkey are compared through a two-stage process proposed. In the first stage, the weights of the respective criteria affecting the levels of performance are determined through the fuzzy FUCOM. An expert group consisting of three decision makers is formed to calculate the criterion weights and the decision makers evaluate these ten criteria vis-a-vis their importance levels. In the second part of the study, the service performance levels of five major airports in Turkey are compared using the MAIRCA technique. At this stage, the data presented in the Skytrax database is used (Skytrax, 2021).

There are studies in the literature that focus on solving problems encountered at airports by using Multi-Criteria Decision Making (MCDM) techniques. For example, Janic (2015) presents an approach in which alternatives are evaluated by applying MCDM methods to match the capacity of the airport system with demand. Ozdemır, Baslıgıl and Ak (2016) applied two different MCDM techniques to evaluate airport safety risk criteria. Shen, Peng and Tu (2019) presented an evaluation model for airport ground handling equipment vendor selection by integrating MCDM techniques with goal programming. Jia, Hu and Yu (2021), presenting a MCDM approach for optimal design of airport renewable energy system planning. However, in the literature review, no study was found in which the performances of airports were compared using an integrated MCDM approach.

In the second part of the study, studies evaluating airport performance and services using different techniques are presented in the literature. In the third section, the two-stage method adopted in the study is explained, and in the fourth section, the steps followed in the implementation process are stated. Finally, in the conclusions section, the findings obtained as a result of the analysis were evaluated and suggestions for future studies were made.

2. Literature Review

Today, the demand for both global and regional air travel is expanding, and this has increased the responsibilities of airport operators to improve their performance (Prakash and Barua, 2016). Detecting passenger expectations at airports and catering for these is a strategic goal for organizations (Pandey, 2016). In order to achieve long-term success and competitiveness, it is necessary to discern how airports can continuously improve their performance since studies show that improvement in quality leads to customer satisfaction (Tsafarakis, Kokotas, & Pantouvakis, 2017).

In recent years, many studies have been conducted to assess the performance of airports in order to increase their respective efficiency. Some of the studies in the literature examine the service quality of airports (Chien-Chang, 2012; Pandey, 2016; Prakash & Barua, 2016; Samad et al., 2021), compare the operational performances (Ahmad et al., 2019), determine the key success factors (Singh, Jayraj & Damodharan, 2018), prioritize the planned projects (Danaei, 2017) and analyze the environmental risks (Chen et al., 2011).

In this part, existing literature evaluating and comparing the performance and services of airports are elaborated upon. The studies in question were selected from among the researches using various quantitative or qualitative techniques in order to analyze the service quality, various success factors and performances of airports. In the literature review, no research was found that recommended an integrated MCDM approach to analyze airport performances.

Gillen and Lall (1997) developed a performance index for terminals and air operations using Data Envelopment Analysis (DEA). Francis, Humphreys and Fry (2002) tested the applicability of benchmarking as an improvement tool for airport managers. Janic and Reggiani (2002) evaluated seven airports in Europe according to nine performance criteria for the hub airport selection of an airline company. Pacheco, Fernandes and Santos (2006) used the DEA method to examine the effects of changes in management style on the efficiency of airports. Zografos and Madas (2006) developed a decision support system that uses a central database and human machine interface to analyze airport efficiency. Enoma and Allen (2007) aimed to develop and test a performance indicator for airport facility management based on security. Manataki and Zografos (2009) developed a decision support system based on the system dynamics approach to evaluate airport terminal performance.

Yu (2010) analyzed the production and service efficiency of airports using slacks-based measure network and DEA. Chen et al. (2011) present a multi-criteria approach using the ANP method through the perspective of an environmental risk assessment in order to prevent damage and losses under natural disasters in international airport projects. Chien-Chang (2012) compared the service quality of two international airports using data collected from passengers. Postorino and Praticò (2012) analyze the performance changes of a regional airport in North East Italy over a reference time period to describe the role and location of each airport within multiple airport systems.

Pandey (2016) evaluated the service quality of the two airports and created a framework to improve them. An expert system is also used in the study, which provides managerial implications regarding the improvement areas. Prakash and Barua (2016) present an approach in which AHP and fuzzy TOPSIS methods are applied to compare airport service quality providers. The study concluded that the most important criteria in the evaluation of service providers are maintenance and accessibility. Danaei (2017) aims to analyze and select the projects located at Kish Island airport. In the study, thirteen proposed projects are prioritized using TOPSIS and SAW methods. Singh, Jayraj, and Damodharan (2018) use a fuzzy decision-making approach to examine the key success factors of low-cost regional airports. As a result, they conclude that the terminal structure and the promotion policy of the airport are the most important aspects. Schultz, Lorenz, Schmitz and Delgado (2018) presented an approach to quantify weather conditions at airports, using a dataset of flights and local weather data.

Ahmad et al. (2019) develop an approach to assess the operational performance of airports using the fuzzy SAW method. In the practical application of the aforementioned work, four decision makers evaluate three airlines by vis-a-vis fifteen criteria. The results of the study show that the most important criterion in airport evaluation is flight safety and control. Samad et al. (2021) used the AHP technique to evaluate the service quality performances of airlines. In this current study, Turkey's five busiest airports are compared using fuzzy FUCOM and MAIRCA, incorporating ten performance criteria.

3. Methodology

A two-stage process is adopted in the study. In the first stage, the weights of the criteria are determined through the fuzzy FUCOM, and subsequently, the alternatives are listed using the MAICRA.

3.1. Determination of Criterion Weights

Determining the importance of each respective criterion is one of the most crucial steps of decision-making problems. The FUCOM, which is developed to determine the criterion weights, is based on pairwise comparisons and validation of the results along a deviation from the maximum consistency (Pamučar et al., 2018). It can be stated that there is minimal need for a multitude of pairwise comparisons in the technique's application. The method also proves valuable in as identifying deviations from maximum consistency and taking into consideration the aspect of transitivity (Pamučar, Stević, & Sremac, 2018). Fuzzy logic is an effective mathematical tool for solving real decision problems that include uncertain, incomplete or inconsistent information. (Pamučar and Ecer, 2020). Thus, fuzzy FUCOM is used to calculate the criterion weights in the study.

Step 1. As a result of the evaluation of the decision makers, the criteria are ranked based on their importance.

Step 2. The criteria are compared against each other via the scale presented in Table 1. Then, the criterion comparison preference is calculated through Equation (1).

Table 1. Comparison Scale

Linguistic Variables	l_{ij}
Equally important (E)	(1; 1; 1)
Weakly important (W)	(0.667; 1; 1.5)
Moderately important (M)	(1.5; 2; 2.5)
Very important (V)	(2.5; 3; 3.5)
Absolutely important (A)	(3.5; 4; 4.5)

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$$\tilde{\varphi}_{k/(k+1)}=\frac{\tilde{w}c_{j(k+1)}}{\tilde{w}c_{j(k)}}=\frac{\tilde{w}c^{l}_{j(k+1)},\tilde{w}c^{m}_{j(k+1)}\tilde{w}c^{u}_{j(k+1)}}{\tilde{w}c^{l}_{j(k)},\tilde{w}c^{m}_{j(k)}\tilde{w}c^{u}_{j(k)}} \quad (1)$$

Step 3. The fuzzy weights of the criteria are calculated so that the conditions given in Equation (2) and Equation (3) are met. Equation (3) emphasizes transitivity and maximum consistency is met only when transitivity is adhered to.

$$\frac{w_k}{w_{k+1}}=\Phi_{k/(k+1)} \quad (2)$$

$$\frac{w_k}{w_{k+2}}=\Phi_{k/(k+1)}\,.\,\Phi_{(k+1)/(k+2)} \quad (3)$$

In order to determine the optimal fuzzy values of the criterion weights, the linear model given in Equation (4) is constructed. In this stage, the value of χ should be minimized to ensure maximum consistency. Also, conditions $\left|\frac{w_{j(k)}}{w_{j(k+1)}}-\Phi_{k/(k+1)}\right|\leq\chi$ and $\left|\frac{w_{j(k)}}{w_{j(k+2)}}-\Phi_{k/(k+1)}\,.\,\Phi_{(k+1)/(k+2)}\right|\leq\chi$ must be met.

$$\begin{aligned}&\text{Min } \chi\\&\text{Constraints:}\\&\left|\frac{\tilde{w}_{j(k)}}{\tilde{w}_{j(k+1)}}-\Phi_{k/(k+1)}\right|\leq\chi,\ \forall j\\&\left|\frac{\tilde{w}_{j(k)}}{\tilde{w}_{j(k+2)}}-\Phi_{k/(k+1)}\,.\,\Phi_{(k+1)/(k+2)}\right|\leq\chi,\ \forall j\\&\textstyle\sum_{j=1}^{n}\tilde{w}=1,\ \forall j\\&w_j^l\leq w_j^m\leq w_j^u\\&w_j^l\geq 0,\ \forall j\\&j=1,2,\ldots,n\end{aligned} \quad (4)$$

Since the objective is to provide the highest level of consistency the $\frac{w_{j(k)}}{w_{j(k+1)}}-\Phi_{k/(k+1)}=0$ and $\frac{w_{j(k)}}{w_{j(k+2)}}-\Phi_{k/(k+1)}\,.\,\Phi_{(k+1)/(k+2)}=0$ conditions must be met in the model. The model given in Equation (4) is transformed into the fuzzy linear model presented in Equation (5). After solving the model, optimal fuzzy values are obtained. In the established model, the expressions are presented in the form of $\tilde{w}_j=(w_j^l,w_j^m,w_j^u)$ and $\tilde{\Phi}_{k/(k+1)}=(\tilde{\Phi}^l_{k/(k+1)},\tilde{\Phi}^m_{k/(k+1)},\tilde{\Phi}^u_{k/(k+1)})$.

$$\begin{aligned}&\text{Min } \chi\\&\text{Constraints:}\\&\left|w_k-w_{k+1}\otimes\Phi_{k/(k+1)}\right|\leq\chi,\ \forall j\\&\left|w_k-w_{k+2}\otimes\Phi_{k/(k+1)}\otimes\Phi_{(k+1)/(k+2)}\right|\leq\chi,\ \forall j\\&\textstyle\sum_{j=1}^{n}\tilde{w}=1,\ \forall j\end{aligned} \quad (5)$$

$w_j^l \leq w_j^m \leq w_j^u$

$w_j^l \geq 0, \forall j$

$j = 1, 2, \ldots, n$

Step 4. Consequently, triangular fuzzy values of the criteria are also calculated and these variables are expressed as l_j, m_j, u_j. The geometric averages of the criteria weights are taken for all decision makers. The resulting fuzzy numbers are converted to net values through the $R(a_j) = (l_j + 4m_j + u_j)/6$ equation and then normalized by their sum. The sum of the normalized criterion weights ($w_1, w_2, w_3, \ldots, w_n$) is equal to one.

3.2. Ranking of Alternatives

The MAIRCA method is a decision-making approach that aims to define the difference between theoretical and real results. The technique is based on identifying the discrepancy between theoretical and real rating. This difference is called the gap, and, the total gap is obtained for each alternative by summing of the gaps (Pamučar et al., 2017). The general consensus in the existing literature posits that the alternative with the lowest total gap value is the one with the closest value to the ideal ratings (Pamučar et al., 2018). Subsequently, the alternative with the lowest total gap level that is the closest to the ideal ratings is accepted as the most suitable alternative. The method proves advantageous in its usefulness to tackle problems with multiple evaluation criteria and alternatives, ability to solve problems with both qualitative and quantitative evaluation criteria, ease in understanding and applying of, as well as producing consistent solutions (Ecer, 2022). In the current study, the MAIRCA method is adopted to rank the alternatives.

Step 1. The decision matrix is formed with the criterion values (C_j) obtained from all alternatives (A_i) (Equation 6).

$$X = \begin{matrix} A_1 \\ A_2 \\ \cdots \\ A_4 \end{matrix} \overset{\begin{matrix} C_1 & C_2 & \cdots & C_4 \end{matrix}}{\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{12} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}} \quad (6)$$

Step 2. The priority values of the alternatives (P_{A_i}) are calculated using Equation (7) to define the alternative selection preferences. The m value here indicates the total number of alternatives. As stated in Equation (8), all preferences for choosing individual alternatives are equal.

$$P_{A_i} = \frac{1}{m}; \sum_{i=1}^{m} P_{A_i} = 1, i=1,2,\ldots,m \quad (7)$$

$$P_{A_1} = P_{A_2} = \ldots = P_{A_m} \quad (8)$$

Theoretical estimates matrix (T_p) is obtained by multiplying the priorities of the alternatives (P_{A_1}) with the criteria weights (w_j) (Equation 9). The elements of the theoretical estimates matrix are expressed in the form of t_{pij}.

$$T_p = \begin{bmatrix} t_{p11} & t_{p12} & \cdots & t_{p1n} \\ t_{p21} & t_{p22} & \cdots & t_{p2n} \\ \vdots & \vdots & \cdots & \vdots \\ t_{pm1} & t_{pm2} & \cdots & t_{pmn} \end{bmatrix} = \begin{bmatrix} P_{A_1}.w_1 & P_{A_1}.w_2 & \cdots & P_{A_1}.w_n \\ P_{A_2}.w_1 & P_{A_2}.w_2 & \cdots & P_{A_2}.w_n \\ \vdots & \vdots & \cdots & \vdots \\ P_{A_m}.w_1 & P_{A_m}.w_2 & \cdots & P_{A_m}.w_n \end{bmatrix} \quad (9)$$

Step 3. Using the theoretical estimates matrix and the initial decision matrix, the real assessment matrix (T_r) is created (Equation 10). Equation (11) and Equation (12) are used for maximization-based and minimization-based criteria, respectivelyThe expression x_{ij}^+ in the equations indicates the highest value of the criterion from the alternatives, whereas the notation x_{ij}^- signifies the lowest value.

$$T_r = \begin{bmatrix} t_{r11} & t_{r12} & \cdots & t_{r1n} \\ t_{r21} & t_{r22} & \cdots & t_{r2n} \\ \vdots & \vdots & \cdots & \vdots \\ t_{rm1} & t_{rm2} & \cdots & t_{rmn} \end{bmatrix} \quad (10)$$

$$t_{rij} = t_{pij} \left(\frac{x_{ij}-x_{ij}^-}{x_{ij}^+-x_{ij}^-}\right) \quad (11)$$

$$t_{rij} = t_{pij} \left(\frac{x_{ij}-x_{ij}^+}{x_{ij}^--x_{ij}^+}\right) \quad (11)$$

Step 4. The difference between the theoretical estimates matrix and the real assessment matrix is taken, as shown in Equation (12). Then the total gap matrix (G) is obtained (Equation 13).

$$g_{ij} = t_{pij} - t_{rij} \qquad g_{ij} \in [0, \infty) \quad (12)$$

$$G = T_p - T_r = \begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1n} \\ g_{21} & g_{22} & \cdots & g_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ g_{m1} & g_{m2} & \cdots & g_{mn} \end{bmatrix} \quad (13)$$

Step 5. For each alternative, the final criterion function value (Q_i) of the alternatives is calculated using Equation (14). The initial rankings ($S_{initial}$) of the alternatives are determined by their criterion function values.

$$Q_i = \sum_{j=1}^{n} g_{ij},\ i=1,2,\ldots,m \quad (14)$$

Step 6. Using equation (15), the dominance index ($A_{D,A_{*/j}}$) of the best alternative over the others is determined. The Q_* value in Equation (15) represents the criterion function value of the best alternative, the Q_n value denotes the criterion function value of the last alternative, and the Q_j value demonstrates the criterion function value of the alternative compared with the best alternative.

$$A_{D,A_{*-j}} = \left|\frac{|Q_j|-|Q_*|}{|Q_n|}\right| \quad (15)$$

The dominance threshold value (I_d) is calculated via Equation (16) where the m value in Equation (16) indicates the number of alternatives.

$$I_D = \frac{m-1}{m^2} \quad (16)$$

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If the dominance index values of the best alternative over the other alternatives are greater than or equal to the dominance threshold value, the final ranking results (S_{final}) is thought to not change and therefore obtained ranking will be preserved.

4. Application

In this study, a two-stage process is adopted where in the first stage, the weights of the criteria are determined using the fuzzy FUCOM, and, subsequently the airports are compared. Initially, an expert group consisting of three decision makers is formed to determine the criterion weights. The group consists of an airport operations staff (DM_1), an academic who has worked on aviation management (DM_2), and a staff member (DM_3) who works as a passenger services officer in an airline company. Decision makers evaluated the ten specified criteria according to their relative importance levels. In the second part, Ankara Esenboğa (A_1), Antalya (A_2), Istanbul (A_3), Istanbul Sabiha Gökçen (A_4), Izmir Adnan Menderes (A_5) airports are ranked using the MAIRCA technique. At this step, the airport data provided in the Skytrax database is used (Skytrax, 2021). The criteria used in the study are listed as ground transportation (C_1), security screening (C_2), gate service (C_3), wayfinding & signage (C_4), arrival (C_5), departure (C_6), terminal comfort (C_7), terminal facilities (C_8), shopping facilities (C_9) and food & beverage (C_{10}).

4.1. Determination of Criterion Weights

In the first step, the weights of the criteria are calculated in line with the evaluations made by the decision makers. At this phase, fuzzy FUCOM is adopted and the steps applied are given below.

Step 1. The three decision makers consulted rank the criteria in order of their importance (Table 2).

Table 2. Ranking of Criteria on the Basis of the Opinions of Decision Makers

Decision Makers	Criteria
DM_1	$C_1>C_6>C_2>C_5>C_8>C_7>C_4>C_9>C_{10}>C_3$
DM_2	$C_2>C_4>C_1>C_3>C_5>C_6>C_8>C_7>C_{10}>C_9$
DM_3	$C_1>C_2>C_6>C_5>C_3>C_7>C_4>C_8>C_9>C_{10}$

Step 2. Using the comparison scale (Table 1), each criterion is compared against the other where the results are presented in Table 3. Through an application of equation (1), the comparative preferences of the criteria are calculated. The preference vectors obtained for all decision makers are shown in Table 4.

Table 3. Pairwise Comparisons of Criteria

Decision Makers	Pairwise Comparisons								
DM_1	C_1-C_6	C_6-C_2	C_2-C_5	C_5-C_8	C_8-C_7	C_7-C_4	C_4-C_9	C_9-C_{10}	C_{10}-C_3
	V	E	W	W	E	W	A	E	W
DM_2	C_2-C_4	C_4-C_1	C_1-C_3	C_3-C_5	C_5-C_6	C_6-C_8	C_8-C_7	C_7-C_{10}	C_{10}-C_9
	W	W	E	W	E	E	W	V	E
DM_3	C_1-C_2	C_2-C_6	C_6-C_5	C_5-C_3	C_3-C_7	C_7-C_4	C_4-C_8	C_8-C_9	C_9-C_{10}
	E	V	W	E	E	W	E	M	W

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The comparative preference calculation for DM_1 is given below.

$\widetilde{\varphi}_{1/6}$ = $\widetilde{w}_{C_1}/\widetilde{w}_{C_6}$ = (2.5; 3; 3.5) / (1; 1; 1) = ($\frac{2.5}{1}$; $\frac{3}{1}$; $\frac{3.5}{1}$) = (2.5; 3; 3.5)

$\widetilde{\varphi}_{6/2}$ = $\widetilde{w}_{C_6}/\widetilde{w}_{C_2}$ = (1; 1; 1) / (2.5; 3; 3.5) = ($\frac{1}{3.5}$; $\frac{1}{3}$; $\frac{1}{2.5}$) = (0.286; 0.333; 0.4)

$\widetilde{\varphi}_{2/5}$ = $\widetilde{w}_{C_2}/\widetilde{w}_{C_5}$ = (0.667; 1; 1.5) / (1; 1; 1) = ($\frac{0.667}{1}$; $\frac{1}{1}$; $\frac{1.5}{1}$) = (0.667; 1; 1.5)

$\widetilde{\varphi}_{5/8}$ = $\widetilde{w}_{C_5}/\widetilde{w}_{C_8}$ = (0.667; 1; 1.5) / (0.667; 1; 1.5) = ($\frac{0.667}{1.5}$; $\frac{1}{1}$; $\frac{1.5}{0.667}$) = (0.445; 1; 2.249)

$\widetilde{\varphi}_{8/7}$ = $\widetilde{w}_{C_8}/\widetilde{w}_{C_7}$ = (1; 1; 1) / (0.667; 1; 1.5) = ($\frac{1}{1.5}$; $\frac{1}{1}$; $\frac{1}{0.667}$) = (0.667; 1; 1.5)

$\widetilde{\varphi}_{7/4}$ = $\widetilde{w}_{C_7}/\widetilde{w}_{C_4}$ = (0.667; 1; 1.5) / (1; 1; 1) = ($\frac{0.667}{1}$; $\frac{1}{1}$; $\frac{1.5}{1}$) = (0.667; 1; 1.5)

$\widetilde{\varphi}_{4/9}$ = $\widetilde{w}_{C_4}/\widetilde{w}_{C_9}$ = (3.5; 4; 4.5) / (0.667; 1; 1.5) = ($\frac{3.5}{1.5}$; $\frac{4}{1}$; $\frac{4.5}{0.667}$) = (2.333; 4; 6.747)

$\widetilde{\varphi}_{9/10}$ = $\widetilde{w}_{C_9}/\widetilde{w}_{C_{10}}$ = (1; 1; 1) / (3.5; 4; 4.5) = ($\frac{1}{4.5}$; $\frac{1}{4}$; $\frac{1}{3.5}$) = (0.222; 0.25; 0.286)

$\widetilde{\varphi}_{10/3}$ = $\widetilde{w}_{C_{10}}/\widetilde{w}_{C_3}$ = (0.667; 1; 1.5) / (1; 1; 1) = ($\frac{0.667}{1}$; $\frac{1}{1}$; $\frac{1.5}{1}$) = (0.667; 1; 1.5)

Table 4. Comparative Preference Vectors

Decision Makers	Comparative preference vector
DM_1	$\widetilde{\Phi}_{DM_1}$ = ((2.5; 3; 3.5). (0.286; 0.333; 0.4). (0.667; 1; 1.5). (0.445; 1; 2.249). (0.667; 1; 1.5). (0.667; 1; 1.5). (2.333; 4; 6.747). (0.222; 0.25; 0.286). (0.667; 1; 1.5))
DM_2	$\widetilde{\Phi}_{DM_2}$ = ((0.667; 1; 1.5). (0.445; 1; 2.249). (0.667; 1; 1.5). (0.667; 1; 1.5). (0.667; 1; 1.5). (1; 1; 1). (0.667; 1; 1.5). (1.667; 3; 5.247). (0.286; 0.333; 0.4))
DM_3	$\widetilde{\Phi}_{DM_3}$ = ((1; 1; 1). (2.5; 3; 3.5). (0.191; 0.333; 0.6). (0.667; 1; 1.5). (1; 1; 1). (0.667; 1; 1.5). (0.667; 1; 1.5). (1.5; 2; 2.5). (0.267; 0.5; 1))

Step 3. Through Equation (3), transitivity criteria are acquired. The transitivity values calculated for DM_1 are presented below.

$\widetilde{w}_{C_1}/\widetilde{w}_{C_2}$ = $\widetilde{w}_{C_1}/\widetilde{w}_{C_6}$. $\widetilde{w}_{C_6}/\widetilde{w}_{C_2}$ = (2.5; 3; 3.5). (0.286; 0.333; 0.4) = (1.668; 1; 1.4)

$\widetilde{w}_{C_6}/\widetilde{w}_{C_5}$ = $\widetilde{w}_{C_6}/\widetilde{w}_{C_2}$. $\widetilde{w}_{C_2}/\widetilde{w}_{C_5}$ = (0.286; 0.333; 0.4). (0.667; 1; 1.5) = (0.191; 0.333; 0.6)

$\widetilde{w}_{C_2}/\widetilde{w}_{C_8}$ = $\widetilde{w}_{C_2}/\widetilde{w}_{C_5}$. $\widetilde{w}_{C_5}/\widetilde{w}_{C_8}$ = (0.667; 1; 1.5). (0.445; 1; 2.249) = (0.297; 1; 3.374)

$\widetilde{w}_{C_5}/\widetilde{w}_{C_7}$ = $\widetilde{w}_{C_5}/\widetilde{w}_{C_8}$. $\widetilde{w}_{C_8}/\widetilde{w}_{C_7}$ = (0.445; 1; 2.249). (0.667; 1; 1.5) = (0.297; 1; 3.374)

$\widetilde{w}_{C_8}/\widetilde{w}_{C_4}$ = $\widetilde{w}_{C_8}/\widetilde{w}_{C_7}$. $\widetilde{w}_{C_7}/\widetilde{w}_{C_4}$ = (0.667; 1; 1.5). (0.667; 1; 1.5) = (0.445; 1; 2.25)

$\widetilde{w}_{C_7}/\widetilde{w}_{C_9}$ = $\widetilde{w}_{C_7}/\widetilde{w}_{C_4}$. $\widetilde{w}_{C_4}/\widetilde{w}_{C_9}$ = (0.667; 1; 1.5). (2.333; 4; 6.747) = (1.556; 4; 10.121)

$\widetilde{w}_{C_4}/\widetilde{w}_{C_{10}}$ = $\widetilde{w}_{C_4}/\widetilde{w}_{C_9}$. $\widetilde{w}_{C_9}/\widetilde{w}_{C_{10}}$ = (2.333; 4; 6.747). (0.222; 0.25; 0.286) = (0.518; 1; 1.93)

$\widetilde{w}_{C_9}/\widetilde{w}_{C_3}$ = $\widetilde{w}_{C_9}/\widetilde{w}_{C_{10}}$. $\widetilde{w}_{C_{10}}/\widetilde{w}_{C_3}$ = (0.222; 0.25; 0.286). (0.667; 1; 1.5) = (0.148; 0.25; 0.429)

The mathematical model is then constructed using Equation (2) and Equation (3). In order to derive the fuzzy optimal values of the respective criterion weights, a mathematical model is created for three decision makers (Equation (5)). The mathematical model constructed for DM_1 is presented in Appendix 1.

Step 4. In the last step, triangular fuzzy values are obtained for the criteria. The geometric averages of the fuzzy values calculated for the three decision makers are taken and defuzzified using the "R(a_j) = (l_j+ 4m_j+u_j)/6" equation. These values are then normalized and the final criterion weights are derived. The final criteria weights are listed as w_1 = 0.136, w_2 = 0.133, w_3 = 0.083, w_4 = 0.116, w_5 = 0.132, w_6 = 0.126, w_7 = 0.098, w_8 = 0.094, w_9 = 0.037 and w_{10} = 0.046.

It is therefore deduced from these calculations that the most important criteria for decision makers are ground transport facilities, level of security screening and arrival services. In addition, values of, χ_{DM_1}= 0.043, χ_{DM_2}= 0.035 and χ_{DM_3}= 0.036 are found for three decision makers.

4.2. Ranking of Alternatives

In the second stage, airports are compared using the MAIRCA technique. The data used in this part are collected from the Skytrax database (Skytrax, 2021). The steps followed in this application are explained below.

Step 1. In this study, five airports are evaluated based on the scores they received for each of the ten established criteria. The decision matrix formed as a result of the criterion values of the alternatives is given in Table 5.

Table 5. Decision Matrix

-	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
A_1	3.750	3.833	3.9	4.05	4.083	4.083	3.727	3.333	3.7	4.111
A_2	3.5	2.917	3.5	3.2	3.583	2.75	2.864	2.722	3.1	3.500
A_3	4.625	4.333	4.3	4.45	4.5	4.75	4.545	4.333	4.5	4.278
A_4	2.875	2.75	3.3	3	3.25	2.417	2.903	2.556	3.2	3.278
A_5	3.75	3.833	3.8	3.6	3.833	3.917	3.545	3.222	3.9	4

Step 2. As stated in Equation (7), the priority values of the alternatives are calculated. Since there are five alternatives prevalent, the priority value of each alternative is equal to 0.2. Then, the criteria weights determined in the first stage of the application are multiplied with the priority values of the alternatives to formulate the theoretical estimates matrix given in Table 6.

Table 6. Theoretical Estimates Matrix

-	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
A_1	0.027	0.027	0.017	0.023	0.026	0.025	0.02	0.019	0.007	0.009
A_2	0.027	0.027	0.017	0.023	0.026	0.025	0.02	0.019	0.007	0.009
A_3	0.027	0.027	0.017	0.023	0.026	0.025	0.02	0.019	0.007	0.009
A_4	0.027	0.027	0.017	0.023	0.026	0.025	0.02	0.019	0.007	0.009
A_5	0.027	0.027	0.017	0.023	0.026	0.025	0.02	0.019	0.007	0.009

Step 3. Since all criteria in the application are based on maximization, the actual evaluation matrix is created using Equation (11) (Table 7).

Table 7. Real Assessment Matrix

-	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
A_1	0.014	0.018	0.01	0.017	0.018	0.018	0.01	0.008	0.003	0.008
A_2	0.01	0.003	0.003	0.003	0.007	0.004	0	0.002	0	0.002
A_3	0.027	0.027	0.017	0.023	0.026	0.025	0.02	0.019	0.007	0.009
A_4	0	0	0	0	0	0	0.001	0	0.001	0
A_5	0.014	0.018	0.008	0.010	0.012	0.016	0.008	0.007	0.004	0.007

Step 4. Equation (12) is applied to form the total gap matrix which is presented in Table 8.

Table 8. Total Gap Matrix

-	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
A_1	0.014	0.008	0.007	0.006	0.009	0.007	0.01	0.011	0.004	0.002
A_2	0.017	0.024	0.013	0.02	0.019	0.022	0.02	0.017	0.007	0.007
A_3	0	0	0	0	0	0	0	0	0	0
A_4	0.027	0.027	0.017	0.023	0.026	0.025	0.019	0.019	0.007	0.009
A_5	0.014	0.008	0.008	0.014	0.014	0.009	0.012	0.012	0.003	0.003

Step 5. For each alternative, the value of the final criterion functions (Q_i) of the alternatives is calculated using Equation (14).

The final criterion functions values of all alternatives are calculated via Equation (14). These values are listed as 0.077, 0.167, 0.199 and 0.096.

Step 6. The initial ranking results ($S_{initial}$) of the alternatives are determined based on the values of the criterion functions. According to the first order, the best alternative is A_3. However, it is necessary to determine whether A_3 is sufficiently dominant over the other alternatives. Therefore, the dominance index ($A_{D,A_{*/j}}$) of the best alternative over the other alternatives should be determined using Equation (15). If the ($A_{D,A_{*/j}}$) value exceeds the dominance threshold value (I_D), the final ranking results (S_{final}) of the alternatives is not expected to not change.

Since there are five alternatives prevalent in this application, the dominance threshold value is calculated to be 0.16 (Equation 16). The dominance index values of the best alternative (A_3) over all the alternatives calculated are shown below.

$$A_1 \rightarrow A_{D.A_{3/1}} = \frac{Q_1 - Q_3}{Q_4} = 0.386$$

$$A_2 \rightarrow A_{D.A_{3/2}} = \frac{Q_2 - Q_3}{Q_4} = 0.839$$

$$A_4 \rightarrow A_{D.A_{3/4}} = \frac{Q_4 - Q_3}{Q_4} = 1$$

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$$A_5 \rightarrow A_{D.A_{3/5}} = \frac{Q_5 - Q_3}{Q_4} = 0.482$$

Condition $A_{D,A_{*-j}} \geq I_D$ is satisfied for all alternatives. Therefore, it is concluded that $S_{initial}$=S_{final}. In addition, the alternatives are listed as A_3>A_1>A_5>A_2>A_4 and the alternative ranking is presented in Table 9.

Table 9. Alternative Ranking Results

Alternative	Q	$S_{initial}$	S_{final}
A_1	0.077	2	2
A_2	0.167	4	4
A_3	0	1	1
A_4	0.199	5	5
A_5	0.096	3	3

In the first stage of the application, it has been seen that the criteria of round transportation, security screening and arrival services are the most effective criteria on airport performance. These findings will guide the airport managers who want to increase the service level and passenger satisfaction of the airports they are authorized. In the second phase of the application, it was observed that Istanbul Airport showed the highest performance among the major airports in Turkey (Table 9). Other airports, especially Antalya and Istanbul Sabiha Gökçen airports, should develop strategies to increase service quality, taking into account the findings obtained in practice.

5. Conclusions

In today's competitive air travel market, airports need to offer their passengers a high level of quality (Prakash and Barua, 2016). Consequently, airports need to determine the strategies they will implement in order to satisfy their current and potential customers and seek ways to improve their performance. Comparison of airports' performance provides useful findings about current situation and possible improvement areas. Even though existing literature has generally focused on the evaluation of the airline companies, there are not many studies comparing the performances of airports using MCDM techniques. In the current research, an approach has been developed to compare the performance of five major airports in Turkey in order to fill this gap in the literature.

In the initial stage of the proposed model, critical success factors for airport development are aimed to be defined by determining the criterion weights through the fuzzy FUCOM. At this step, criteria thought to be effective on airport performance are evaluated based on the opinions of industry experts. In the second phase of the study, airports are ranked according to their success levels, using the data presented on the Skytrax website (Skytrax, 2021) where The MAIRCA technique is used.

The outputs of the study show that ground transportation, security screening and arrival services are the most important aspects influencing the performance of airports. Criteria affecting airport performance, according to their importance are ranked as follows: ground transportation (0.136), security scanning (0.133), arrival services (0.132), departure services (0.126), wayfinding and signage (0.116), terminal comfort (0.098), terminal facilities (0.094), gate services (0.083), food and beverage (0.046) and shopping facilities (0.037). It is believed that these findings will contribute to the development of strategies that will increase airport service quality. In addition, the study concludes that the airport with the highest performance is Istanbul Airport, and the lowest one is Istanbul Sabiha Gökçen Airport.

The research results presented in the article contribute to the literature both theoretically and practically. In the theoretical perspective, the proposed integrated MCDM technique will inspire studies in the similar field. In the future, applications where different MCDM methods are used or different approaches are integrated with MCDM methods can be used especially in studies where airport performances are analyzed. In the practical perspective, findings that will contribute to the decision makers who want to develop strategies that will increase the service quality of airports have been obtained. However, there are several limitations to the research conducted. For example, the criteria used when analyzing the performances of airports are taken from the data presented in the Skytrax database (Skytrax, 2021). A decision maker group consisting of experts in the field of airport management should be formed and these criteria should be reviewed. As a result of this process, it is possible to remove some of the criteria or to include new criteria. Future studies will contribute to the relevant literature if researchers carry out studies in this direction.

It is safe to state that there still remains ample ground for future study. The developed approach can be tested in an application that compares airports internationally. A study comparing the performances of the largest airports in the world is a research topic that will contribute to the literature. Additionally, researching different performance criteria and incorporating them in the evaluation model can improve the application, and hence may result in more thorough outcomes that can prove useful in policy-making. Moreover, testing different decision-making techniques and comparing ranking results can also be the focus of future research.

References

CNCDA. (2020). *Estratégia Nacional e Plano de Ação de Combate ao Desperdício Alimentar*. Comissão Nacional de Combate ao Desperdício Alimentar https://www.cncda.gov.pt/images/Resultados/9RelProgressoDez2020.pdf

Ahmad, A., Akram, S., Tabassum, M. F., Kausar, A., & Ilyas, N. (2019). Multi-criteria decision-making for airport operation performance using triangular fuzzy numbers. *Scientific Inquiry and Review*, *3*(3), 1-15. https://doi.org/10.32350/sir.31.01

Chen, Z., Li, H., Ren, H., Xu, Q., & Hong, J. (2011). A total environmental risk assessment model for international hub airports. *International Journal of Project Management*, *29*(7), 856-866. doi:10.1016/j.ijproman.2011.03.004

Chien-Chang, C. (2012). Evaluating the quality of airport service using the fuzzy multi-criteria decision-making method: A case study of Taiwanese airports. *Expert Systems*, *29*(3), 246-260. https://doi.org/10.1111/j.1468-0394.2010.00574.x

Danaei, J. (2017). Prioritization of kish airport projects using multi-criteria decision-making (weighting: shannon entropy). *Amazonia Investiga*, *6*(11), 122-131. https://amazoniainvestiga.info/index.php/amazonia/article/view/604

Ecer, F. (2022). An extended MAIRCA method using intuitionistic fuzzy sets for coronavirus vaccine selection in the age of COVID-19. *Neural Computing and Applications*, 34, 5603–5623. https://doi.org/10.1007/s00521-021-06728-7

Enoma, A., & Allen, S. (2007). Developing key performance indicators for airport safety and security. *Facilities*. 25(7), 296-315. doi:10.1108/02632770710753334

Francis, G., Humphreys, I., & Fry, J. (2002). The benchmarking of airport performance. *Journal of air transport management*, *8*(4), 239-247. doi:10.1108/02632770710753334

Gillen, D., & Lall, A. (1997). Developing measures of airport productivity and performance: an application of data envelopment analysis. *Transportation Research Part E: Logistics and Transportation Review*, *33*(4), 261-273. doi:10.1016/s1366-5545(97)00028-8

Janic, M. (2015). A multi-criteria evaluation of solutions and alternatives for matching capacity to demand in an airport system: The case of London. Transportation Planning and Technology, 38(7), 709-737. http://dx.doi.org/10.1080/03081060.2015.1059120

Janic, M., & Reggiani, A. (2002). An application of the multiple criteria decision making (MCDM) analysis to the selection of a new hub airport. *European Journal of Transport and Infrastructure Research*, *2*(2/3), 113-141. https://doi.org/10.18757/ejtir.2002.2.2.3692

Jia, Q., Hu, H. Q., & Yu, J. L. (2021). The model construction in airport renewable energy system scale planning based in Multi-Criteria Decision Making. Energy Reports, 7, 92-98. https://doi.org/10.1016/j.egyr.2021.08.068

Manataki, I. E., & Zografos, K. G. (2009). A generic system dynamics based tool for airport terminal performance analysis. *Transportation Research Part C: Emerging Technologies*, *17*(4), 428-443. doi:10.1016/j.trc.2009.02.001

Ozdemır, Y., Baslıgıl, H., & Ak, M. F. (2016). Airport safety risk evaluation based on fuzzy ANP and fuzzy AHP. In Uncertainty Modelling in Knowledge Engineering and Decision Making: Proceedings of the 12th International FLINS Conference, 1056-1062. https://doi.org/10.1142/9789813146976_0163

Pacheco, R. R., Fernandes, E., & Santos, M. P. S. (2006). Management style and airport performance in Brazil. *Journal of Air Transport Management*, *12*(6), 324-330. doi:10.1016/j.jairtraman.2006.07.010

Pamucar, D., & Ecer, F. (2020). Prioritizing the weights of the evaluation criteria under fuzziness: The fuzzy full consistency method–FUCOM-F. *Facta Universitatis, Series: Mechanical Engineering*, *18*(3), 419-437. https://doi.org/10.22190/FUME200602034P

Pamučar, D., Mihajlović, M., Obradović, R., & Atanasković, P. (2017). Novel approach to group multi-criteria decision making based on interval rough numbers: Hybrid DEMATEL-ANP-MAIRCA model. *Expert Systems with Applications*, *88*, 58-80. https://doi.org/10.1016/j.eswa.2017.06.037

Pamučar, D., Lukovac, V., Božanić, D., & Komazec, N. (2018). Multi-criteria FUCOM-MAIRCA model for the evaluation of level crossings: Case study in the Republic of Serbia. *Operational Research in Engineering Sciences: Theory and Applications*, *1*(1), 108-129. https://doi.org/10.31181/oresta190120101108p

Pamučar, D., Stević, Ž., & Sremac, S. (2018). A new model for determining weight coefficients of criteria in MCDM models: Full consistency method (FUCOM). *Symmetry*, *10*(9), 393-415. https://doi.org/10.3390/sym10090393

Pandey, M. M. (2016). Evaluating the service quality of airports in Thailand using fuzzy multi-criteria decision making method. *Journal of Air Transport Management*, *57*, 241-249. https://doi.org/10.1016/j.jairtraman.2016.08.014

Postorino, M. N., & Praticò, F. G. (2012). An application of the multi-criteria decision-making analysis to a regional multi-airport system. *Research in Transportation Business & Management*, *4*, 44-52. https://doi.org/10.1016/j.rtbm.2012.06.015

Prakash, C., & Barua, M. K. (2016). A robust multi-criteria decision-making framework for evaluation of the airport service quality enablers for ranking the airports. *Journal of Quality Assurance in Hospitality & Tourism*, *17*(3), 351-370. https://doi.org/10.1080/1528008X.2015.1096753

Samad, S., Nilashi, M., Supriyanto, E., Tofigh, S. M., Ghabban, F., Asadi, S., ... & Ibrahim, O. (2021). Factors impacting airport service quality using multi-criteria decision making approach. *Journal of Soft Computing and Decision Support Systems*, *8*(2), 1-13. https://www.jscdss.com/index.php/files/article/view/247

Schultz, M., Lorenz, S., Schmitz, R., & Delgado, L. (2018). Weather impact on airport performance. *Aerospace*, 5(4), 109-128. doi:10.3390/aerospace5040109

Shen, C. W., Peng, Y. T., & Tu, C. S. (2019). Multi-criteria decision-making techniques for solving the airport ground handling service equipment vendor selection problem. Sustainability, 11(12), 3466. doi:10.3390/su11123466

Singh, D., Jayraj, R., & Damodharan, K. (2018). Evaluating the success factors for development and sustenance of low-cost regional airports in India using fuzzy multi-criteria decision making method. *Journal of Applied Economic Sciences*. 1(55), 89-101. https://www.ceeol.com/search/article-detail?id=727115

Skytrax (2021). Airports, https://skytraxratings.com/airports. Access Date: 14.03.2021.

Tsafarakis, S., Kokotas, T., & Pantouvakis, A. (2018). A multiple criteria approach for airline passenger satisfaction measurement and service quality improvement. *Journal of Air Transport Management*, *68*, 61-75. https://doi.org/10.1016/j.jairtraman.2017.09.010

Yu, M. M. (2010). Assessment of airport performance using the SBM-NDEA model. *Omega*, *38*(6), 440-452. doi:10.1016/j.omega.2009.11.003

Zografos, K. G., & Madas, M. A. (2006). Development and demonstration of an integrated decision support system for airport performance analysis. *Transportation Research Part C: Emerging Technologies*, *14*(1), 1-17. doi:10.1016/j.trc.2006.04.001

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Appendix 1

Mathematical model created for DM_1

Min χ .

Constraints: .

$$\left(w_1^l - 2{,}5w_6^u\right) \le \chi \quad \left(w_4^l - 2{,}333w_9^u\right) \le \chi \quad \left(w_5^l - 0{,}297w_7^u\right) \le \chi$$
$$\left(w_1^l - 2{,}5w_6^u\right) \ge -\chi \quad \left(w_4^l - 2{,}333w_9^u\right) \ge -\chi \quad \left(w_5^l - 0{,}297w_7^u\right) \ge -\chi$$
$$(w_1^m - 3w_6^m) \le \chi \quad (w_4^m - 4w_9^m) \le \chi \quad (w_5^m - w_7^m) \le \chi$$
$$(w_1^m - 3w_6^m) \ge -\chi \quad (w_4^m - 4w_9^m) \ge -\chi \quad (w_5^m - w_7^m) \ge -\chi$$
$$\left(w_1^u - 3{,}5w_6^l\right) \le \chi \quad \left(w_4^u - 6{,}747w_9^l\right) \le \chi \quad \left(w_5^u - 3{,}374w_7^l\right) \le \chi$$
$$\left(w_1^u - 3{,}5w_6^l\right) \ge -\chi \quad \left(w_4^u - 6{,}747w_9^l\right) \ge -\chi \quad \left(w_5^u - 3{,}374w_7^l\right) \ge -\chi$$
$$\left(w_6^l - 0{,}286w_2^u\right) \le \chi \quad \left(w_9^l - 0{,}222w_{10}^u\right) \le \chi \quad \left(w_8^l - 0{,}445w_4^u\right) \le \chi$$
$$\left(w_6^l - 0{,}286w_2^u\right) \ge -\chi \quad \left(w_9^l - 0{,}222w_{10}^u\right) \ge -\chi \quad \left(w_8^l - 0{,}445w_4^u\right) \ge -\chi$$
$$(w_6^m - 0{,}333w_2^m) \le \chi \quad (w_9^m - 0{,}25w_{10}^m) \le \chi \quad (w_8^m - w_4^m) \le \chi$$
$$(w_6^m - 0{,}333w_2^m) \ge -\chi \quad (w_9^m - 0{,}25w_{10}^m) \ge -\chi \quad (w_8^m - w_4^m) \ge -\chi$$
$$\left(w_6^u - 0{,}4w_2^l\right) \ge \chi \quad \left(w_9^u - 0{,}286w_{10}^l\right) \ge \chi \quad \left(w_8^u - 2{,}25w_4^l\right) \ge \chi$$
$$\left(w_6^u - 0{,}4w_2^l\right) \ge -\chi \quad \left(w_9^u - 0{,}286w_{10}^l\right) \ge -\chi \quad \left(w_8^u - 2{,}25w_4^l\right) \ge -\chi$$
$$\left(w_2^l - 0{,}667w_5^u\right) \ge \chi \quad \left(w_{10}^l - 0{,}667w_3^u\right) \ge \chi \quad \left(w_7^l - 1{,}556w_9^u\right) \ge \chi$$
$$\left(w_2^l - 0{,}667w_5^u\right) \ge -\chi \quad \left(w_{10}^l - 0{,}667w_3^u\right) \ge -\chi \quad \left(w_7^l - 1{,}556w_9^u\right) \ge -\chi$$
$$(w_2^m - w_5^m) \ge \chi \quad (w_{10}^m - w_3^m) \ge \chi \quad (w_7^m - 4w_9^m) \ge \chi$$
$$(w_2^m - w_5^m) \le -\chi \quad (w_{10}^m - w_3^m) \le -\chi \quad (w_7^m - 4w_9^m) \le -\chi$$
$$\left(w_2^u - 1{,}5w_5^l\right) \ge \chi \quad \left(w_{10}^u - 1{,}5w_3^l\right) \ge \chi \quad \left(w_7^u - 10{,}121w_9^l\right) \ge \chi$$
$$\left(w_2^u - 1{,}5w_5^l\right) \le -\chi \quad \left(w_{10}^u - 1{,}5w_3^l\right) \le -\chi \quad \left(w_7^u - 10{,}121w_9^l\right) \le -\chi$$
$$\left(w_5^l - 0{,}445w_8^u\right) \ge \chi \quad \left(w_1^l - 1{,}668w_2^u\right) \ge \chi \quad \left(w_4^l - 0{,}518w_{10}^u\right) \ge \chi$$
$$\left(w_5^l - 0{,}445w_8^u\right) \le -\chi \quad \left(w_1^l - 1{,}668w_2^u\right) \le -\chi \quad \left(w_4^l - 0{,}518w_{10}^u\right) \le -\chi$$
$$(w_5^m - w_8^m) \ge \chi \quad (w_1^m - w_2^m) \ge \chi \quad (w_4^m - w_{10}^m) \ge \chi$$
$$(w_5^m - w_8^m) \ge -\chi \quad (w_1^m - w_2^m) \ge -\chi \quad (w_4^m - w_{10}^m) \ge -\chi$$
$$\left(w_5^u - 2{,}249w_8^l\right) \ge \chi \quad \left(w_1^u - 1{,}4w_2^l\right) \ge \chi \quad \left(w_4^u - 1{,}193w_{10}^l\right) \ge \chi$$
$$\left(w_5^u - 2{,}249w_8^l\right) \ge -\chi \quad \left(w_1^u - 1{,}4w_2^l\right) \ge -\chi \quad \left(w_4^u - 1{,}193w_{10}^l\right) \ge -\chi$$
$$\left(w_8^l - 0{,}667w_7^u\right) \ge \chi \quad \left(w_6^l - 0{,}191w_5^u\right) \ge \chi \quad \left(w_9^l - 0{,}148w_3^u\right) \ge \chi$$

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$$\left(w_8^l - 0{,}667w_7^u\right) \geq -\chi \quad \left(w_6^l - 0{,}191w_5^u\right) \geq -\chi \quad \left(w_9^l - 0{,}148w_3^u\right) \geq -\chi$$

$$(w_8^m - w_7^m) \leq \chi \quad (w_6^m - 0{,}333w_5^m) \leq \chi \quad (w_9^m - 0{,}25w_3^m) \leq \chi$$

$$(w_8^m - w_7^m) \geq -\chi \quad (w_6^m - 0{,}333w_5^m) \geq -\chi \quad (w_9^m - 0{,}25w_3^m) \geq -\chi$$

$$\left(w_8^u - 1{,}5w_7^l\right) \leq \chi \quad \left(w_6^u - 0{,}6w_5^l\right) \leq \chi \quad \left(w_9^u - 0{,}429w_3^l\right) \leq \chi$$

$$\left(w_8^u - 1{,}5w_7^l\right) \geq -\chi \quad \left(w_6^u - 0{,}6w_5^l\right) \geq -\chi \quad \left(w_9^u - 0{,}429w_3^l\right) \geq -\chi$$

$$\left(w_7^l - 0{,}667w_4^u\right) \leq \chi \quad \left(w_2^l - 0{,}297w_8^u\right) \leq \chi \quad \left(w_3^l\right) \leq \chi$$

$$\left(w_7^l - 0{,}667w_4^u\right) \geq -\chi \quad \left(w_2^l - 0{,}297w_8^u\right) \geq -\chi \quad \left(w_3^l\right) \geq -\chi$$

$$(w_7^m - w_4^m) \geq \chi \quad (w_2^m - w_8^m) \geq \chi \quad (w_3^m) \geq \chi$$

$$(w_7^m - w_4^m) \geq -\chi \quad (w_2^m - w_8^m) \geq -\chi \quad (w_3^m) \geq -\chi$$

$$\left(w_7^u - 1{,}5w_4^l\right) \geq \chi \quad \left(w_2^u - 3{,}374w_8^l\right) \geq \chi \quad (w_3^u) \geq \chi$$

$$\left(w_7^u - 1{,}5w_4^l\right) \geq -\chi \quad \left(w_2^u - 3{,}374w_8^l\right) \geq -\chi \quad (w_3^u) \geq -\chi$$

$$(w_1^l + 4w_1^m + w_1^u)/6 + (w_2^l + 4w_2^m + w_2^u)/6 + (w_3^l + 4w_3^m + w_3^u)/6 + (w_4^l + 4w_4^m + w_4^u)/6\ (w_5^l + 4w_5^m + w_5^u)/6 + (w_6^l + 4w_6^m + w_6^u)/6 + (w_7^l + 4w_7^m + w_7^u)/6 + (w_8^l + 4w_8^m + w_8^u)/6 + (w_9^l + 4w_9^m + w_9^u)/6 + (w_{10}^l + 4w_{10}^m + w_{10}^u)/6 = 1$$

$$w_1^l \leq w_1^m \leq w_1^u;\ w_2^l \leq w_2^m \leq w_2^u;\ w_3^l \leq w_3^m \leq w_3^u;\ w_4^l \leq w_4^m \leq w_4^u;\ w_5^l \leq w_5^m \leq w_5^u;\ w_6^l \leq w_6^m \leq w_6^u;\ w_7^l \leq w_7^m \leq w_7^u;\ w_8^l \leq w_8^m \leq w_8^u;\ w_9^l \leq w_9^m \leq w_9^u;\ w_{10}^l \leq w_{10}^m \leq w_{10}^u$$

$$w_1^l, w_1^m, w_1^u, w_2^l, w_2^m, w_2^u, w_3^l, w_3^m, w_3^u, w_4^l, w_4^m, w_4^u, w_5^l, w_5^m, w_5^u, w_6^l, w_6^m, w_6^u, w_7^l, w_7^m, w_7^u, w_8^l, w_8^m, w_8^u, w_9^l, w_9^m, w_9^u, w_{10}^l, w_{10}^m, w_{10}^u \geq 0$$