Traffic & Transportation

Optimising Traffic Safety – Locating Traffic Gendarmes Based on Multi-Criteria Decision Making

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ABSTRACT

Turkey's expanding population and growing economy have resulted in a significant increase in automobile ownership, leading to a rise in traffic volume and, subsequently, an increase in the number of accidents. The increase in the number of deaths and injuries caused by traffic accidents has motivated authorities and automobile manufacturers to work together to mitigate the impact of traffic accidents. Therefore, the demand for better roads, modern technologies and higher-quality driver training is becoming increasingly urgent for traffic safety. Due to the scale of harm to the country's economy and society caused by the material and moral losses, resulting from traffic accidents, traffic safety and management is one of the most important government initiatives. One of the responsible units of traffic safety and management in Turkey is the traffic gendarme. This study reviewed the categories of traffic accidents, the number of accidents, and the road network that occurred in a province's gendarme responsibility area in Turkey and linked them with the number of traffic gendarmes in that province. Thus, the study utilised mixed integer programming based on multi-criteria decision-making methods to identify the areas where these traffic gendarmes will be deployed according to established principles.

KEYWORDS

traffic; traffic safety; traffic gendarmes; multi-criteria decision making; CRITIC; mixed integer programming.

1. INTRODUCTION

The industrial revolution brought about fast transformations in the social structure, economy, technology and other key sectors. Rapid urbanisation and migration from rural areas to cities have increased both the population and the need for households. The effects of industrialisation on labour requirements, raw material demand and marketing operations have led to an increase in transportation activities. The dispersion of activity centres such as schools, homes and companies has highlighted the necessity for transportation between these locations. However, there have been some issues brought on by this increase in transportation activities, which vary depending on the country's level of development. Traffic jams, traffic accidents, environmental pollution, energy requirements and lost time are some of the challenges that need to be resolved. Turkey's transportation system struggles to support this density as a developing nation. Furthermore, a significant number of traffic accidents occur each year due to the rise in traffic offences by motorists and pedestrians.

Land transportation is the most intensively used mode of transportation in the world, and road transportation, where individual users are the most intense, draws the attention of the authorities with its intensity, the excess of accidents and the effects of their consequences. Accidents are defined as events that cannot be planned, they occur unexpectedly and at an unknown time, resulting in loss of life and property. This definition of accidents is based on their effects and severity, that is, the fact that they create a perception of risk. The number of accidents and their consequences should be reduced to an acceptable risk level.

According to data from the World Health Organisation, road traffic accidents result in approximately 1.3 million deaths worldwide each year and expose 20 to 50 million people to non-fatal injuries. Along with the moral damage caused by traffic accidents, individuals and their families are severely burdened financially by the expenditures associated with the injurer's medical care, their diminished output and other factors. Traffic accidents represent around 3% of any country's yearly gross domestic product, having a serious impact on national economies. Governments have established ambitious goals to reduce traffic accidents by 2030 and have identified measures to lower the risk of fatalities and injuries from traffic accidents [1]. Today, the problem of traffic safety and management caused by vehicles that emerged with the industrial revolution and meet the rapidly increasing need for transportation continues to worsen. As a developing country, Turkey is particularly affected by this issue. Traffic congestion leads to significant loss of time, and the material and moral consequences of traffic accidents have negative impacts on the well-being of the society. For these reasons, it is crucial to analyse data using analytical methods and propose effective solutions to improve traffic safety and management, which are essential for the development and prosperity of societies.

The traffic system includes not only people, vehicles and roads but also environmental factors such as education, inspection, road engineering, traffic management, first aid services, climate conditions and weather conditions, as well as management-related factors such as legislation and strategy. Traffic accidents can occur due to errors and flaws in these components alone or as a result of a combination of factors. Identifying and comparing the quantifiable and comparable traffic system components of different cities can aid in the planning of studies and the development of logical policies to prevent the material and moral losses caused by these incidents.

In Turkey, land transportation accounts for more than 90% of all transportation-related activities, and road accidents are one of the leading causes of mortality globally [2]. The increase in the number of automobiles on the road suggests that traffic accidents will continue to be a leading cause of various injuries and fatalities among humans in the coming years [3]. The driver, the vehicle and the surroundings together make up the system that causes the majority of traffic accidents. With a high failure rate of 95%, drivers contribute the most to these accidents. The primary elements affecting traffic management and safety in Turkey are as follows [4]:

- Unbalanced usage of the different forms of transportation (highways handle the majority of freight and passenger traffic),
- Road users are not sufficiently aware of the potential hazards in traffic,
- Misconduct of road users due to their physical characteristics (such as vision, hearing, reaction time, age, etc.) and psychological states,
- Vehicle-related causes (vehicles in traffic, operating in poor technical circumstances, being overloaded, inadequate vehicle maintenance, etc.),
- Deficiencies arising from highway infrastructure such as design, geometry and construction errors, incomplete-faulty marking, traffic control system deficiencies, insufficient lighting, etc.,
- Inadequacies in traffic control and management include the inability to conduct an effective and ongoing inspection, failure to act as a deterrent, issues with traffic management, etc.,
- Rapid and unplanned development, including poor sustainable planning and the absence of comprehensive transportation plans in quickly expanding cities,
- Variables relating to the environment, such as precipitation, icing, fog, landslides, floods, earthquakes, etc.,
- It may be categorised as the lack of societal concern for traffic and road safety as well as the insensitivity of road users to the prevention of accidents.

Traffic attendants try to minimise the effects of traffic accidents and their consequences with effective control. This issue is also handled as a government policy and attempts are made to reduce the effects of traffic accidents on the country's economy. *Table 1* shows the traffic accidents that have occurred in Turkey in the last five years.

The data utilised in this study were obtained from TUIK, encompassing information from both the General Directorate of Security and the Gendarmerie General Command. When looking at *Table 1*, which shows the number of accidents in Turkey, it can be observed that although the number of fatal-injury traffic accidents increased by 5.57% from 2018 to 2022, the number of deaths decreased by 65.8% and the number of injuries decreased by 5,18%. The lack of growth in 2020 and 2021 is mostly due to the Covid-19 related restrictions on transportation mobility and the effectiveness of the traffic authorities' tight audits during this period.

Table 1 – Traffic accidents in Turkey [5, 6]

Year	Total number of accidents	Number of fatal-injury accidents	Number of accidents with material damage	Number of deaths	Number of injured
2022	485,048	196,930	288,118	2,282	291,151
2021	1,186,353	187,963	998,390	5,362	274,615
2020	983,808	150,275	833,533	4,866	226,266
2019	1,168,144	174,896	993,248	5,473	283,234
2018	1,229,364	186,532	1,042,832	6,675	307,071

It is predicted that by 2023, the number of automobiles in Turkey will approach 35 million due to consumer purchasing behaviour. This increase in vehicle volume will have a significant impact on road transportation. To meet this demand, the physical, geometric and operational standards of the road network must be improved. New infrastructure projects should also be developed to accommodate future road transportation needs. In this context, the following becomes mandatory [7]:

– Improving traffic safety, together with the transport sector,
– Ensuring uninterrupted traffic flow by increasing travel comfort, and
– Making necessary Research and Development (R&D) studies and legal regulations for the needs.

Due to several factors such as personal usage and the fact that not every nation has a seacoast, using highways becomes necessary. This commitment necessitates taking action to control and improve traffic safety. Insufficient infrastructure, education, supervision and other factors prevent measures from being performed at the necessary level, and traffic accidents are caused by these deficiencies. Therefore, precautions are more than necessary for Turkey because traffic accidents are one of the unfavourable aspects of transportation systems [8].

Studies are conducted in various areas, including driver and pedestrian education, improvement of road and environmental conditions, and upgrading safety features in vehicles to prevent traffic accidents. *Table 2* displays the issues identified as a result of the effective audits conducted in this regard.

Table 2 – The number of transactions made by traffic personnel in 2022 [5]

Procedure	2021	2022	Variation (%)
Number of drunk drivers	174,740	213,662	22%
Number of drivers completing 100 penalty points	6,673	7,848	18%
Number of drivers exceeding the speed limit 5 times	763	692	0.09%
Number of vehicles banned from traffic	1,327,794	1,314,598	0.01%

These statistics suggest that, despite training and awareness initiatives for road users, personal attitudes and behaviours have not changed enough. This incident highlights the need for more effective traffic management and control.

Traffic accidents are the primary issue brought on by transportation-related activities, resulting in a significant amount of financial and moral losses. This loss places a considerable financial burden on the national economy. Road accidents are a serious risk to the general population in both developed and developing countries. The widespread use of motor vehicles and highways for transportation has increased the risk of accidents. To reduce the frequency of road accidents in Turkey, it is essential to implement efficient measures. In-depth analyses of the variables causing traffic accidents, such as high traffic volumes, road conditions and driver behaviour, are necessary for these interventions to be effective. However, studies aimed at addressing this issue have revealed challenges in developing efficient research techniques due to the multidisciplinary and inter-institutional nature of the problem. It is necessary to fully comprehend the necessity of conducting scientific studies and applying scientific methods to solve problems. Inspection, control and intervention come to the fore in the prevention of traffic accidents and the regulation of traffic.

In this study, the impact of the traffic gendarme's selection of facility locations is addressed from a variety of academic perspectives. One province in Turkey was chosen to create a model as a pilot region and to achieve simplicity in its implementation. If this model is accepted, it will be possible to apply it in places with higher traffic density and even throughout Turkey. In the literature, regarding traffic in Turkey; smart traffic control and management [9], calculating the traffic risk indexes of provinces in Turkey [4], traffic accident analysis with Bayesian networks [10], traffic accident modelling with artificial neural networks [11] and traffic accident analysis with Geographical Information Systems [12] have been carried out. These studies show that a variety of factors influence traffic safety, therefore decision-making is a challenge for academics trying to find solutions. To assist researchers to achieve scientific decisions, this study employed multi-criteria decision making (MCDM) techniques. By taking into account a variety of factors, MCDM methodologies enable decision-makers to assess practically every area of life – gendarme station facility location selection [13], the weighting of different biodiesel fuel properties [14], electric vehicle battery selection [15], house planning [16], personnel selection [17], selection of the power plant facility location [18], evaluation of smart city logistics solutions [19]. Criteria Importance Through Inter Criteria Correlation (CRITIC), which is one of the methods used to determine the objective weights of the criteria in MCDM problems; site selection for hospital construction [20, 21], visibility ranking of university e-learning websites [22] and studies along with other methods. In addition, it is seen that mathematical models are frequently used in efficiency and productivity calculations in the analytical modelling and solving of many life problems. Analysis of search and rescue missions of coast guard vehicles [23], selection of coast guard elements' facility locations [24], multi-flight routing optimisation [25], security operations planning in an environment of uncertainty [26], routing and charging of electric vehicles [27], medicine distribution between pharmacy warehouse and pharmacies [28], determination of police checkpoints that intervene in traffic accidents on highways [29]. To the best of our knowledge, no previous studies have utilised the CRITIC method in conjunction with mathematical modelling to optimise the selection of traffic gendarme facility locations, determine their duties and improve overall efficiency.

In this study, the primary aim is to determine the important factors contributing to traffic safety and to provide decision support to the managers for the determination of the facility locations where the traffic gendarmes will work, by using MCDM methods. The study was conducted in several stages. The stages of the study are shown in *Figure 1*.

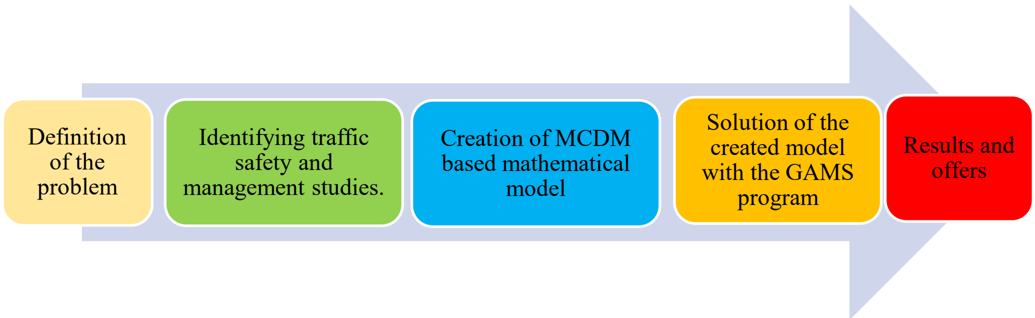

Figure 1 – Stages of study

2. METHODOLOGY

In this study, a literature review was conducted to gather information from various sources such as studies, websites, reports, magazines and books on MCDM methods, which are widely used in almost all areas of life. The obtained data were analysed using quantitative methods, and Criteria Importance Through Inter Criteria Correlation (CRITIC) method, which was developed by Diakoulaki et al. in 1995 [30], was chosen for this purpose.

2.1 CRITIC method

In decision-making problems, criteria are used to provide information and evaluate alternatives. The importance weights of the criteria reflect the amount of information they contribute to the decision-making process. This weight is referred to as "objective weight." The CRITIC method is a widely used MCDM technique that helps determine the objective weights of the criteria. In the CRITIC method, the available data are taken into account to weigh the evaluation criteria and the method is often used in conjunction with other MCDM techniques [31]. The most important feature that distinguishes the CRITIC method from other methods is that it provides an objective weighting based on the standard deviations of the criteria and the correlation between the criteria, rather than relying on subjective opinions from experts. The CRITIC method solution process involves five basic steps [30, 32–34].

Step 1: Creation of the initial (decision) matrix. In the first stage, the X decision matrix formed from x_{ij} values is shown in *Equation 1*.

$$X = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix} \quad (1)$$

Step 2: Normalisation of the decision matrix. The normalisation process is carried out using *Equation 2* for maximisation-oriented criteria and *Equation 3* for minimisation-oriented criteria.

$$r_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}} \quad j = 1,2,\ldots..,n \quad (2)$$

$$r_{ij} = \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}} \quad j = 1,2,\ldots..,n \quad (3)$$

Step 3: Creating the correlation coefficient matrix. To measure the degree of relations between the evaluation criteria, a correlation coefficient matrix consisting of linear correlation coefficients (ρ_{jk}) is created. The correlation coefficients are calculated using *Equation 4,* which takes into account the covariance between criteria j and k and the standard deviations of the two criteria.

$$\rho_{jk} = \frac{\sum_{i=1}^{m}\left(r_{ij} - \overline{r_j}\right).\left(r_{ik} - \overline{r_k}\right)}{\sqrt{\sum_{i=1}^{m}\left(r_{ij} - \overline{r_j}\right)^2 \sum_{i=1}^{m}\left(r_{ik} - \overline{r_k}\right)^2}} \quad j,k = 1,2,\ldots,n \quad (4)$$

Step 4: Calculation of C_j values. The CRITIC method aims to obtain information on MCDM problems from the contrast intensity and conflicts in the evaluation criteria. In this context, *Equations 5 and 6* are used to calculate C_j values combining both features and expressing the total information found in the j criteria.

$$C_j = \sigma_j \sum_{k=1}^{n}\left(1 - \rho_{jk}\right) \quad j = 1,2,\ldots,n \quad (5)$$

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m}\left(r_{ij} - \overline{r_j}\right)^2}{m-1}} \quad (6)$$

Step 5: Calculation of criterion weights. In the last step, with *Equation 7* the C_j value of a criterion is proportioned to the sum of the C_j values of all criteria, and the final weight values (W_j) of the criteria are obtained.

$$W_j = \frac{C_j}{\sum_{k=1}^{n} C_j} \quad (7)$$

2.2 Mixed Integer Programming (MIP)

In this study, various factors that influence location selection will be represented as linear inequalities, and their maximisation or minimisation will be determined using integer programming. The main objective of these models is to provide decision support to managers for addressing the identified issues. The models aim to improve efficiency while minimising overall cost or maximising profit. Sets and indices, parameters, decision variables, restrictions and active functions may all be found in an integer-programming paradigm [17]. The created model was solved with the GAMS program. The GAMS program was utilised to identify intervention areas that can enhance the scale of traffic safety and management.

3. RESULTS AND DISCUSSION

In this study, the CRITIC method, an MCDM approach, was used to determine the weights of the components that contribute to traffic safety and represent the risk coefficients. The objective is to assist managers in selecting the most efficient and thorough locations for traffic gendarmes to operate by using the mathematical model developed with these weights.

3.1 Risk Coefficients for Traffic Gendarme Establishment with CRITIC

The factors based on effective traffic safety and management studies are presented in *Table 3* on a district basis. The units for criteria 4, 5 and 6 in *Table 3* are expressed in kilometres (km), while the remaining criteria are specified in terms of quantity. The used data was taken from the actual records of the jurisdiction of the traffic gendarme. These factors were evaluated using the CRITIC method, and their importance levels, referred to as risk coefficients, were calculated.

Table 3 – Decision matrix consisting of evaluation criteria used within the scope of the study

Location/ criteria	Number of accidents			Road condition			Number of villages in the district (k_7)	Population (k_8)
	Material damage (k_1)	Injured (k_2)	Fatal (k_3)	State road [km] (k_4)	Provincial road [km] (k_5)	Village road [km] (k_6)		
Criterion direction	min	min	min	max	max	max	max	max
L_1	30	69	2	13	0	169	9	7323
L_2	20	18	2	8	0	107	5	1275
L_3	21	42	2	0	33	347	28	3974
L_4	23	56	4	26	7	171	13	1666
L_5	17	42	2	0	9	439	40	6252
L_6	32	49	1	25	0	25	2	287
L_7	33	65	4	2	78	515	55	6816
L_8	18	45	2	0	17	328	26	4398
L_9	23	31	1	0	0	132	7	2706

In *Table 3*, since the direction of the first three criteria is maximisation, *Equation 2* has been used to normalise them, while *Equation 3* has been used to normalise the other criteria as they are in the direction of minimisation. The normalised decision matrix can be seen in *Table 4*.

Table 4 – Normalised decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
L_1	0.566667	0,260870	0.500000	0.500000	0.000000	0.328155	0.163636	1.000000
L_2	0.850000	1.000000	0.500000	0.307692	0.000000	0.207767	0.090909	0.174109
L_3	0.809524	0.428571	0.500000	0.000000	0.423077	0.673786	0.509091	0.542674
L_4	0.739130	0.321429	0.250000	1.000000	0.089744	0.332039	0.236364	0.227502
L_5	1.000000	0.428571	0.500000	0.000000	0.115385	0.852427	0.727273	0.853748
L_6	0.531250	0.367347	1.000000	0.961538	0.000000	0.048544	0.036364	0.039192
L_7	0.515152	0.276923	0.250000	0.076923	1.000000	1.000000	1.000000	0.930766
L_8	0.944444	0.400000	0.500000	0.000000	0.217949	0.636893	0.472727	0.600574
L_9	0.739130	0.580645	1.000000	0.000000	0.000000	0.256311	0.127273	0.369521

In the next step, the correlation coefficient matrix consisting of linear relationship coefficients (ρ_{jk}) was created using *Equation 4*. *Table 5* was created for the correlation matrix between the criteria.

Table 5 – Correlation matrix between criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
C_1	1	0.411311	-0.130186	-0.482091	-0.274806	0.246561	0.122246	-0.016704
C_2	0.411311	1	0.198783	-0.200913	-0.350901	-0.352230	-0.379499	-0.482782
C_3	-0.130186	0.198783	1	0.058947	-0.520490	-0.599896	-0.576905	-0.456348
C_4	-0.482091	-0.200913	0.058947	1	-0.381581	-0.644936	-0.556029	-0.524792
C_5	-0.274806	-0.350901	-0.520490	-0.381581	1	0.781783	0.847056	0.475799
C_6	0.246561	-0.352230	-0.599896	-0.644936	0.781783	1	0.981655	0.735337
C_7	0.122246	-0.379499	-0.576905	-0.556029	0.847056	0.981655	1	0.678536
C_8	-0.016704	-0.482782	-0.456348	-0.524792	0.475799	0.735337	0.678536	1

In the last stage, C_j values were calculated for each criterion using *Equations 5 and 6*. C_j values are shown in *Table 6*.

Table 6 – Criteria values

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	Total
C_j	1.26024	1.85106	2.46617	4.03454	2.11716	1.88087	1.93208	2.30232	17.84443

As a result, the final importance degrees of all criteria are obtained by using *Equation 7*. The results obtained with the CRITIC method are shown in *Table 7*.

Table 7 – Criteria weights

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
W_j	0.07062	0.10373	0.13820	0.22610	0.11865	0.10540	0.10827	0.12902

The most significant criterion was identified as C_4 (inspections on the state road) based on the criteria weights derived using the CRITIC approach in *Table 7*. Following C_4 are criteria C_3 (reducing fatal road accidents) and C_8 (population mobility)

3.2 MCDM-based MIP for facility location selection for traffic gendarmes

The map in *Figure 2* shows the nine districts that fall under the province's responsibility for traffic safety and management. However, not all areas require the same number of traffic gendarmes to ensure effectiveness and productivity. The central district will have a minimum of three and a maximum of four traffic gendarmes, while the other districts will have a minimum of two and a maximum of three. It is not desirable to have a traffic gendarme stationed permanently in each district due to the nature of their work and the need for flexibility.

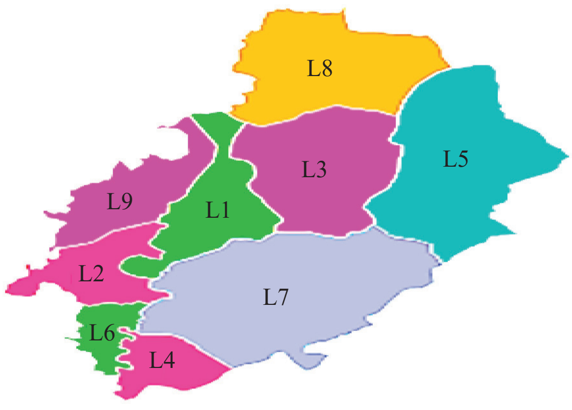

Figure 2 – Settlements

The distance between these settlements is shown in *Table 8* and the distance of the settlements to each other is measured in minutes.

Table 8 – Distances of settlements to each other

	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9
L_1	0	8	22	57	55	33	27	52	6
L_2	8	0	30	49	63	25	19	60	11
L_3	22	30	0	79	33	55	49	30	28
L_4	57	49	79	0	112	23	25	109	63
L_5	55	63	33	112	0	88	83	107	61
L_6	33	25	55	23	88	0	38	55	39
L_7	27	19	49	25	83	38	0	79	31
L_8	52	60	30	109	107	55	79	0	58
L_9	6	11	28	63	61	39	31	58	0

Then, the importance levels of the criteria to be used in the model were determined using the CRITIC method. The criteria weights obtained are shown in *Table 7*. A minimum of two gendarmes are assigned to each traffic team. In light of the above-mentioned data, a mathematical model was created that will allow us to perform the traffic tasks in the most effective, fastest and most affordable manner.

This is a Minisum facility location problem [35]. In this model, we set up by changing the objective function to maximise the criterion weights we found with MCDM;

$$\text{Max } z=\sum_{k=1}^{8}\sum_{i=1}^{9}\sum_{j=1}^{9} w_{jk} y_{ij} \tag{8}$$

where indices $k \in K$ are the factor that affects traffic safety and management, $i \in I$ is the district of the city that is to be a response centre, $j \in J$ is the district of the city that requires traffic control, w_{jk} is a parameter of the weight of factor k in district j and y_{ij} is a binary decision variable which takes the value 1 if demand district j is served by district i, and otherwise 0.

$$\sum_{i=1}^{9} x_i = C \tag{9}$$

where x_i is a binary decision variable which takes the value 1 if the district is located at $i \in I$ as a response centre, otherwise 0, and C is the parameter of the number of response centres to be located.

$$y_{ij} \le x_i \quad \forall i \in I,\ j \in I \tag{10}$$

$$y_{ij} d_{ij} \le S \quad \forall i \in I,\ j \in I \tag{11}$$

where d_{ij} is the parameter of the duration from potential response centre location i to demand location j and S is the parameter of the response time of the traffic gendarme to the incident.

$$\sum_{i=1}^{9} y_{ij} = 1 \quad \forall j \in I \tag{12}$$

$$x_i, y_{ij} \in \{0,1\} \quad \forall i \in I,\ j \in I \tag{13}$$

The objective function *Equation 8* aims to maximise the effectiveness of traffic safety and management by taking into account the criteria that affect traffic safety provision. *Equation 9* specifies the number of districts to be selected as intervention centres. *Equation 10* indicates that if district i is chosen as the traffic intervention centre, it can intervene in district j, which is requested from district i. *Equation 11* requires that the intervention takes place within S minutes, and *Equation 12* states that only one county can intervene in the requesting county j. *Equation 13* represents the integer constraint.

The created integer programming model was solved in 0.15 seconds on a computer with 32 GB RAM capacity with Intel 7 processor by using the GAMS 24.8.5 version program and the result was reached. The results obtained determine the districts to be intervened for maximising the effectiveness of traffic safety and management studies, and do not take into account the total response time or where to intervene in the districts to be intervened. Therefore, the second scenario was created for the problem.

In the first scenario, the demand regions were determined by running the model aiming to maximise the efficiency of traffic safety and management studies, while in the second scenario, a model aiming to minimise the total response time was developed. With this model, it will be concluded which candidate districts will be intervened as demanded by the regions. For this purpose, only the objective function was changed and the J set was updated as J' to include the demand regions obtained from the first model.

$$\text{Min } z = \sum_{i=1}^{9}\sum_{j=1}^{9} d_{ij} y_{ij} \quad (14)$$

The objective of the second scenario was to minimise the total response time by determining the candidate districts for intervention regions. The objective function *Equation 14* aimed to minimise the sum of intervention time from the selected intervention centres to the demand regions. *Equations 9–13* from the first scenario were used again in the second scenario. The obtained results are presented in *Tables 9–14*. It was found that even one intervention centre could provide maximum efficiency within a maximum intervention period of 40 minutes. However, as the maximum response time decreased, the efficiency also decreased, which could be improved by increasing the number of intervention centres. Two different results were obtained from the tables: the necessity of choosing the central district as the intervention centre due to legal requirements and the absence of this requirement. It was observed that in some cases, not establishing an intervention centre in the central district could yield better results.

Table 9 – Locating one response centre

Response time (≤S) [min]	Response centres					
	Including centre district (L_1)			District		
	District	Efficiency	Total response time [min]	District	Efficiency	Total response time [min]
40	L_1	1.00	175	L_1	1.00	175
30	L_1	0.647	65	L_7	0.697	95
20	L_1	0.538	43	L_2	0.647	64
15	L_1	0.331	25	L_2	0.432	27

Table 10 shows that it is more advantageous to set up a Response centre in two districts away from the central district in terms of both efficiency and overall response time.

Table 10 – Locating two response centres

Response time (≤S) [min]	Response centres					
	Including centre district (L_1)			Districts		
	Districts	Efficiency	Total response time [min]	Districts	Efficiency	Total response time [min]
40	L_1,L_3	1.00	130	L_2,L_3	1.00	125
30	L_1,L_3	0.843	92	L_3,L_4	1.00	95
20	L_1,L_4	0.803	58	L_3,L_4	0.895	64
15	L_1,L_7	0.538	25	L_2,L_4	0.588	27

Table 11 shows that the solution set that includes the central district can achieve the best result in response times of 40 and 30 minutes in the scenario of building three response centres.

Table 11 – Locating three response centres

Response time (≤*S*) [min]	Response centres					
	Including centre district (L_1)			Districts		
	Districts	Efficiency	Total response time [min]	Districts	Efficiency	Total response time [min]
40	L_1,L_3,L_4	1.00	85	L_1,L_3,L_4	1.00	85
30	L_1,L_3,L_4	1.00	85	L_1,L_3,L_4	1.00	85
20	L_1,L_4,L_5	0.908	58	L_3,L_4,L_5	1.00	107
15	L_1,L_4,L_7	0.694	25	L_2,L_4,L_6	0.697	27

As seen in *Tables 12–14*, all ideal outcomes for the establishment of Response centres 4, 5 and 6 include the core district. Similarly, it is seen that when the number of response centres rises, the overall intervention time lowers.

Table 12 – Locating four response centres

Response time (≤*S*) [min]	Response centres					
	Including centre district (L_1)			Districts		
	Districts	Efficiency	Total response time [min]	Districts	Efficiency	Total response time [min]
40	L_1,L_4,L_5,L_8	1.00	58	L_1,L_4,L_5,L_8	1.00	58
30	L_1,L_4,L_5,L_8	1.00	58	L_1,L_4,L_5,L_8	1.00	58
20	L_1,L_4,L_5,L_8	1.00	58	L_1,L_4,L_5,L_8	1.00	58
15	L_1,L_4,L_6,L_7	0.803	25	L_1,L_4,L_6,L_7	0.803	25

Table 13 – Locating five response centres

Response time (≤*S*) [min]	Response centres					
	Including centre district (L_1)			Districts		
	Districts	Efficiency	Total response time [min]	Districts	Efficiency	Total response time [min]
40	L_1,L_5,L_6,L_7,L_8	1.00	41	L_1,L_5,L_6,L_7,L_8	1.00	41
30	L_1,L_5,L_6,L_7,L_8	1.00	41	L_1,L_5,L_6,L_7,L_8	1.00	41
20	L_1,L_5,L_6,L_7,L_8	1.00	41	L_1,L_5,L_6,L_7,L_8	1.00	41
15	L_1,L_4,L_5,L_6,L_7	0.803	25	L_1,L_4,L_5,L_6,L_7	0.803	25

Table 14 – Locating six response centres

Response time (≤*S*) [min]	Response centres					
	Including centre district (L_1)			Districts		
	Districts	Efficiency	Total response time [min]	Districts	Efficiency	Total response time [min]
40	L_1,L_4,L_5,L_6,L_7,L_8	1.00	25	L_1,L_4,L_5,L_6,L_7,L_8	1.00	25
30	L_1,L_4,L_5,L_6,L_7,L_8	1.00	25	L_1,L_4,L_5,L_6,L_7,L_8	1.00	25
20	L_1,L_4,L_5,L_6,L_7,L_8	1.00	25	L_1,L_4,L_5,L_6,L_7,L_8	1.00	25
15	L_1,L_4,L_5,L_6,L_7,L_8	1.00	25	L_1,L_4,L_5,L_6,L_7,L_8	1.00	25

Figure 3 briefly shows how the effectiveness of traffic safety and management studies changes according to the maximum response time and the number of districts to be selected as intervention centres. When the graph is examined;

- In case the maximum response time is reduced to less than 15 minutes, full effectiveness can be achieved with the establishment of 6 or more intervention centres,
- In cases where the maximum reaction time is less than 20 minutes, it is evident that fewer (3) intervention centres are necessary to ensure full effectiveness, and in cases where the maximum response time is less than 30 minutes, two intervention centres would be sufficient.

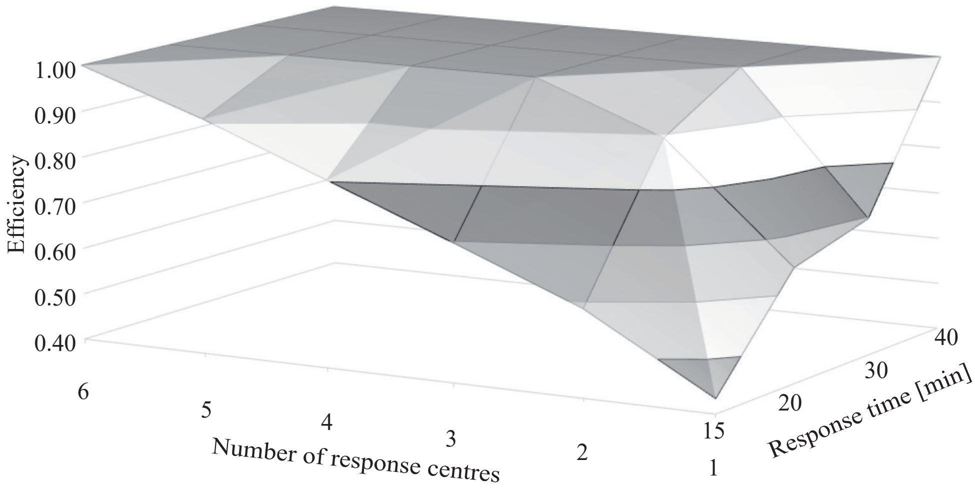

Figure 3 – Traffic efficiency by response time and number of response centres

Therefore, setting the maximum reaction time at 20 minutes and choosing three districts as the response centre are thought to be the most feasible combinations.

4. CONCLUSION AND RECOMMENDATIONS

In Turkey, traffic management and control are overseen by two entities: the traffic police and the traffic gendarme, both operating under the Ministry of the Interior. Typically, the traffic police handle city centres, while the traffic gendarme takes charge of rural areas. For this study, a small-scale province was selected, focusing solely on the data within the jurisdiction of the traffic gendarme. The purpose of this study is to draw attention to the negative effects of traffic accidents, which are a major problem in Turkey. The study aims to eliminate traffic irregularities, ensure traffic safety and discipline, and demonstrate that it is possible to provide informational safety measures to people who are driving and walking on the road. Thus, using scientific methods, nine districts were evaluated according to eight different criteria, and the MCDM-based mixed-integer programming model was run using the GAMS computer program to determine the establishment locations of traffic gendarmes within the scope of Turkey's traffic safety and management policies. This study will contribute to increasing the efficiency of the traffic gendarmes in the following ways:

- The area where the traffic gendarmes will be located within the determined criteria is better than other areas.
- Due to a flaw in the mathematical model's objective function, which ensures that events are interfered in as quickly and effectively as possible, there are now three response centres.
- *Figure 3* shows the response centres L_1, L_4, and L_5 that will offer the most effective, quickest and most efficient intervention within 20 minutes.

As a result of studies conducted throughout Turkey, there is a growing need to establish a decision-making system for selecting the locations of traffic gendarme facilities. This can be achieved by creating a model that increases the possibility and capability of making quick and accurate decisions using computer programs. In this way, public order can be improved and transactions can be carried out at minimum cost. Additionally, the study's findings suggest that the efficiency and effectiveness of traffic gendarmes can be increased by identifying optimal locations for military units, UAVs, traffic checkpoints, training centres, search and rescue units, fire stations, 112 emergency response teams and other related facilities.

This study focuses on a small-scale province as a starting point, proposing a model that can be adapted to more complex medium and large-scale provinces. The objective is to explore its feasibility in all provinces across Turkey. To ensure comprehensive analysis, the data will be evaluated over a period of at least one year for the ongoing research.

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Trafik Güvenliğinin Optimizasyonu: Çok Kriterli Karar Verme Yöntemiyle Trafik Jandarmalarının Yerleştirilmesi

Özet

Türkiye'nin genişleyen nüfusu ve büyüyen ekonomisi, otomobil sahipliliğinde önemli bir artışa yol açmış, bu da trafik hacminin artmasına ve sonuç olarak kaza sayılarının artmasına neden olmuştur. Trafik kazalarının yol açtığı ölüm ve yaralanma sayısındaki artış, yetkilileri ve otomobil üreticilerini trafik kazalarının etkilerini azaltmak için işbirliği yapmaya teşvik etmiştir. Bu nedenle trafik güvenliği için daha iyi yollar, modern teknolojiler ve daha yüksek kaliteli sürücü eğitimine olan talep, trafik güvenliği açısından giderek daha acil hale gelmektedir. Trafik kazaları sonucu ülkenin ekonomisine ve toplumuna verilen maddi ve manevi zararın boyutu nedeniyle, trafik güvenliği ve yönetimi, hükümetin en önemli girişimlerinden biridir. Türkiye'de trafik güvenliği ve yönetiminden sorumlu birimlerden biri trafik jandarmasıdır. Bu çalışma, Türkiye'deki bir ilin trafik jandarmasının sorumluluk alanında meydana gelen trafik kazalarının kategorilerini, kaza sayısını ve yol ağını dikkate alarak o ildeki trafik jandarmalarının sayısı ile ilişkilendirmektedir. Çalışmada, belirlenen prensiplere göre, Çok Kriterli Karar Verme yöntemine dayalı Karışık Tam Sayılı Programlama yöntemi kullanılarak trafik jandarmalarının hangi alanlara görevlendirileceğini belirlenmiştir.

Anahtar Kelimeler
trafik; trafik güvenliği; trafik jandarmaları; çok kriterli karar verme; CRITIC; karışık tam sayılı programlama.