Artvin Çoruh Üniversitesi
Doğal Afetler Uygulama ve Araştırma Merkezi
Doğal Afetler ve Çevre Dergisi

Artvin Çoruh University
Natural Hazards Application and Research Center
Journal of Natural Hazards and Environment

Araştırma Makalesi / Research Article, Doğ Afet Çev Derg, 2023; 9(1): 71-80, DOI: 10.21324/dacd.1121301

A Decision-Making Model for the Transportation of Municipal Solid Wastes

Fatih Kamaoğlu[1], Nesli Aydın[2,*]

[1]*Istanbul Metropolitan Municipality Environmental Protection Department Waste Management Branch Office, Beyoğlu, İstanbul, Turkey.*
[2]*Tekirdağ Namık Kemal University, Faculty of Engineering, Department of Environmental Engineering, Tekirdağ, Turkey.*

Abstract

The management of waste with minimum cost and the environmental burden has recently gained importance in the circular economy. In this study, alternatives for the transportation of wastes by rail and road were compared in terms of cost, environment and personnel requirement benchmarks by using the multi-criteria decision-making software - Right Choice (2.0). The transportation of waste by road is shown with Alternative 1, while the transportation by rail is represented by Alternative 2 (by loading waste-carrying trucks and trailers on the train), Alternative 3 (by loading only trailers on the train) and Alternative 4 (by loading only wastes on the train). As a result, it was determined that the optimum option to transfer the wastes is as specified in Alternative 4, to load only the wastes on the wagons. Importantly, the low operation-maintenance cost of Alternative 4, in other words, its high performance on this benchmark and the high relative importance of the operation-maintenance cost attributed by the stakeholders play a vital role. According to the sensitivity analysis results, Alternative 3 appears as another option close to Alternative 4 while Alternatives 1 and 2, however, remain as options to be evaluated where Alternatives 3 and 4 are not included in decision-making at all. The results of this study show that, depending on the scoring of the criteria in the decision tree, Alternative 4 or 3 could be a better option than the other alternatives, by reducing the number of alternatives and highlighting the good performers.

Keywords
Environmental Burden, Circular Economy, Cost, Decision-Making Software, Waste Management

Evsel Katı Atıkların Taşınması İçin Karar Verme Modeli

Özet

Son zamanlarda, atıkların minimum maliyet ve çevresel yük ile yönetimi döngüsel ekonomi açısından önem kazanmaktadır. Bu çalışmada, çok kriterli karar verme yazılımı - Right Choice (2.0), kullanılarak, atıkların demiryolu ve karayolu ile taşınması alternatifleri, maliyet, çevre ve personel ihtiyacı ölçütleri açısından karşılaştırılmıştır. Atıkların karayolu ile taşınması, Alternatif 1 ile gösterilirken, demiryolu ile taşıma, Alternatif 2 (atık kamyonu ve treylerin trene yüklenmesi), Alternatif 3 (sadece treylerin trene yüklenmesi) ve Alternatif 4 (sadece atıkların trene yüklenmesi) ile temsil edilmektedir. Sonuç olarak atıkların taşınması için en uygun seçeneğin Alternatif 4'te belirtildiği gibi sadece atıkların vagonlara yüklenmesi olduğu belirlenmiştir. Bu kapsamda, Alternatif 4'ün düşük işletme-bakım maliyeti, diğer bir deyişle, bu kıyaslamadaki yüksek performansı ve paydaşlar tarafından atfedilen işletme-bakım maliyetinin yüksek göreceli önemi rol oynamaktadır. Hassasiyet analizi sonuçlarına göre, Alternatif 3, Alternatif 4'e yakın bir başka seçenek olarak ortaya çıkarken, Alternatif 1 ve 2, Alternatif 3 ve 4'ün karar vermede hiç yer almadığı durumlarda değerlendirilecek seçenekler olarak kalmaktadır. Bu çalışmanın sonuçları, alternatiflerin sayısının azaltılarak iyi performans gösterenlerin öne çıkartılmasıyla, karar ağacındaki ölçütlerin puanlanmasına bağlı olarak Alternatif 4 veya 3'ün diğer alternatiflere göre daha iyi birer seçenek olabileceğini göstermektedir.

Anahtar Sözcükler
Çevresel Yük, Döngüsel Ekonomi, Maliyet, Karar Verme Yazılımı, Atık Yönetimi

1. Introduction

An increase in urbanisation and economic development, as well as changes in socio-economic factors, such as lifestyle and income level, has led to complicated characteristics in managing solid wastes. These complex management requirements to assess the overall performance of the system are better handled if supported by tools (Coelho et al. 2017; Morrissey and Browne 2004). It is noted that the most important benefits of waste management models are their ability to handle complexity and uncertainty (Eriksson et al. 2003; Keirstead et al. 2012). A wide variety of models has been developed in waste management to support decision-making in municipal waste management. Previously, the aim of the waste management models was straightforward, such as optimising the locations of waste transfer stations (Yadav et al. 2020) and minimising waste management system costs (Somplak et al. 2013).

* Sorumlu Yazar: +90 (282) 2502300 Fax: +90 (282) 2509924
E-posta: fatihkamaoglu@gmail.com (Kamaoğlu F), naydin@nku.edu.tr (Aydın N)
Gönderim Tarihi / Received : 25/05/2022
Kabul Tarihi / Accepted : 20/09/2022

In this context, multi-criteria decision-making was often applied to help the decision-making in municipal waste management. Some of the multi-criteria decision-making methods were further developed for simulation modelling, such as ANP and ELECTRE (Özkan 2008), as well as PROMETHEE and GAIA (Vego et al. 2008). The principle of multi-criteria decision making is that it facilitates choosing the best scenario among several scenarios by assessing numerous criteria/benchmarks (Hung et al. 2007). In recent years, multi-criteria decision-making models have focused on ''sustainability,'' by stressing that sustainable multi-criteria decision-making models should be ecologically effective, budget-friendly and socially acceptable (Hung et al. 2007). The most frequently applied decision support models in waste management are life-cycle assessment which focuses on environmental aspects, cost-benefit analysis which aims the maximisation of economic efficiency, and multi-criteria decision making which allows consideration of the factors of sustainability, such as budgetary, technical, and ecological benchmarks (Coelho et al. 2017; Morrissey and Browne 2004).

Transportation of waste is one of the most costly stages in waste management (Özkan 2008). In this context, it reveals the need to produce and compare various alternatives in order to reduce the burden of transportation. The moving of the wastes collected from the residential or industrial area to the waste disposal facility by waste collection vehicles, directly or indirectly, with large-capacity transport vehicles, is mostly conducted by road transport in Turkey. However, the attractiveness of railway transportation has recently begun to be noticed in Turkey and investments have gained momentum in this direction (İnan and Demir 2017). Moreover, worldwide examples of the transport of waste by rail have been seen for a long time (Peterson 1996; Peirce and Pierson 1983; Bauerlein and King 2018). Lower air emissions decreased energy requirements and reduced traffic caused to growing interest in rail transport of waste in the USA (Peterson, 1996). In North Carolina, design and cost considerations for rail systems were discussed in detail to find an optimum waste transfer alternative (Peirce and Pierson 1983). Another method is the transportation of waste by water. However, international principles and regulations on water transportation underline that the impact of possible accidents on water resources (surface water and groundwater) could cause consequences that cover a wide area (URL-1 2006; van Hengel and Kruitwagen 1994).

For this reason, the aim of this study is to determine the alternatives of waste transportation, which is one of the most costly stages of waste management, and to compare these alternatives within the scope of multi-criteria decision-making, taking into account benchmarks such as environmental load, cost, and technical features. The scope of the study covers the transportation of wastes collected at a certain transfer station to a regular landfill facility at a certain distance. The degree of the relative importance of these benchmarks was obtained by applying a Likert scale questionnaire to the stakeholders in the sector. All these data, obtained by calculating the performance of the scenarios on the criteria, were entered into the decision-making model built by using the software-Right Choice, which is based on a multi-criteria decision analysis. With the model, the effect of the decisions to be made on the results was measured by sensitivity analysis and the optimum alternative(s) were determined.

2. Methodology

Solid waste management is a complicated task involving the interaction of several factors. Its analysis, therefore, inherits challenges for decision-makers. As multi-criteria decision-making models could address problems involving various dimensions and conflicting factors, they have become widely-used decision-supporting tools in solid waste management.

Analysis was conducted by using Right Choice (version 2.0), a computer programme designed for situations where there is more than one option/alternative and it is necessary to determine the most appropriate solution according to certain criteria. Right Choice, a multi-criteria decision analysis programme, was designed and supported by Ventana Systems, UK and it is freely available academically. By using this decision-making software, the data entered by the user can be converted into information necessary for the use of stakeholders. In this context, the performance of the alternatives created for the solution of the problem on the determined criteria (investment cost, electricity savings, water requirement, etc.) can be determined by performing score and sensitivity analysis. The steps followed in this study are listed below (Kamaoğlu 2022):

(1) According to the results of the literature review (Apaydın and Gonullu 2007; Or and Curi 1993; Rızvanoğlu et al. 2019; Yıldız-Geyhan et al. 2017), a decision tree was created and benchmarks were determined.
(2) Four different alternatives involving various waste transportation modes have been produced.
(3) The performance of these alternatives for each benchmark in the decision tree was measured. Measurements were scored in the range of 0-100%.
(4) To bring the benchmark in the decision tree to a comparable level, relative importance grading was carried out by using a questionnaire.

2.1. Building a Decision Tree

As mentioned in the literature review, environmental factors (global warming potential, etc.) and cost are at the top of the criteria determined by the researchers to determine the most appropriate scenario for the transportation of wastes (Apaydın and Gonullu 2007; Or and Curi 1993; Rızvanoğlu et al. 2019).

In addition, among these factors, some studies include social and cultural criteria depending on the characteristics of the study region (Yıldız-Geyhan et al. 2017). The decision tree created by considering these factors is given in Figure 1.

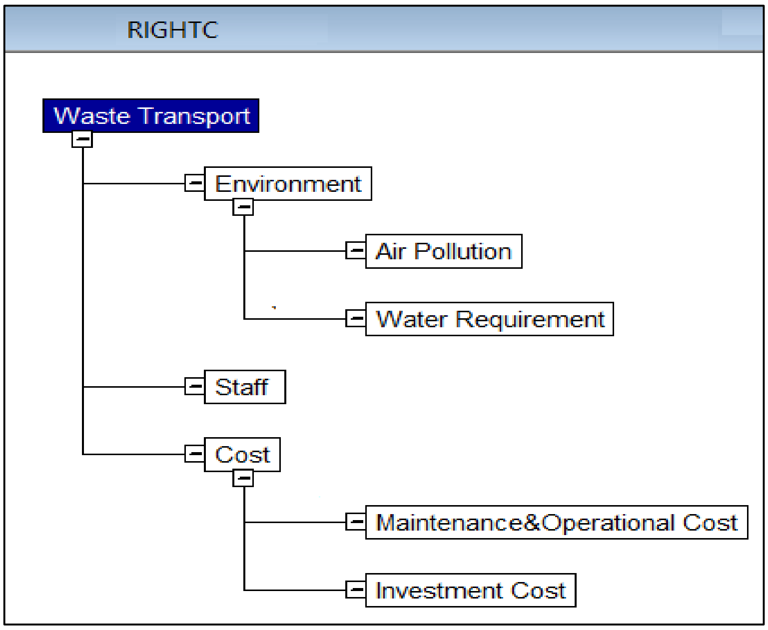

Figure 1: Decision tree

2.2 Determination of Alternatives

Four static alternatives were determined within the scope of the multi-criteria decision-making analysis. In each of these alternatives, different waste transportation modes were chosen. While Alternative-1 is based on road transport, Alternative-2, 3 and 4 include different types of rail transport. In these alternatives with railway content, it is considered that electric trains will be used because the operating cost of electric trains is low compared to diesel ones.

In general, the use of rail is suitable for areas that are difficult to reach by road and where the construction of railways is suitable. In case the round-trip distance is more than 100 km and at least 1000 tonnes of waste are transported per day, it is recommended to use transfer stations to compress the waste before disposal (Mısır 2015). In the alternatives, it was assumed that the distance of transportation is up to 100 km and approximately 1000 wastes are transported directly to a disposal facility.

In addition, calculations were made on the basis that the disposal sites are located next to the railway or in areas where train access can be made. The data used in the calculations were obtained from official reports and databases (URL-2 2011; URL-3 2012; URL-4 2013; URL-5 2009; URL-6 2019), and also the literature review (Yaşar and Eren 2008; Sezer 2019).

2.2.1 Alternative 1

In this context, wastes are transported to the disposal site by waste-carrying trucks on the road (Figure 2a)

2.2.2 Alternative 2

This alternative includes loading the waste-carrying truck and the trailer onto the train and taking it to the disposal site (Figure 2b). Carrying the truck and the trailer together by loading them on the wagon has advantages over loading the trailer only on the wagon. In the case of a possible accident or breakdown, the operation could continue with the help of other vehicles without loss of time in waste transportation. Assuming that the locomotive, in which only the wastes are transported in the wagons, breaks down, the operation will have to stop until the problem is resolved. In addition, the advantage of Alternative 2 comes to the fore when the danger of a long-term interruption of the operation arises during the maintenance of the railway.

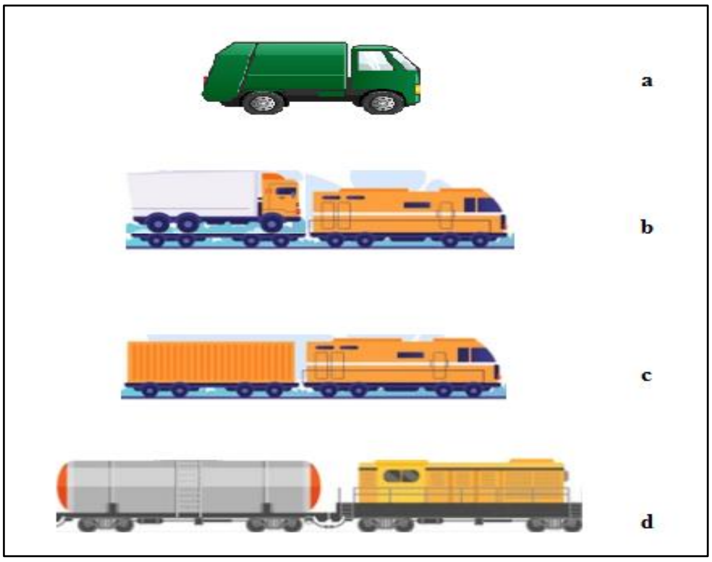

Figure 2: Waste transportation modes

2.2.3 Alternative 3

Alternative 3 represents only the loading of the trailer on the train and transporting it to the disposal site (Figure 2c). In Alternative 3, only trailer loads are included, saving around 7.5 tonnes of truckload compared to Alternative 2. It also comes to the fore that the number of trips is lower since less weight will be transported compared to Alternative 2, and therefore, the emission values and cost are lower. In Alternative 3, in case of a possible rail accident or malfunction, the waste transport operation could continue on the highway, as the trailers are loaded on the train.

2.2.4 Alternative 4

Alternative 4 is based on the fact that only the wastes are loaded on train wagons and taken to the disposal site (Figure 2d). The difference between Alternative 4 from other railway-based alternatives (Alternatives 2 and 3) is that only the wastes are transported saving the weight of the truck and trailer. The most prominent feature of Alternative 4 is that instead of trailer and truck weights, waste is transported and the number of train trips is reduced significantly by taking the wastes to the disposal site by train. In this way, both the need for personnel and air emission and cost values are reduced.

2.3 Benchmark Performances

Details regarding the data on cost and emission values used in the calculations for the transportation of wastes within the scope of this study are given in Table 1. While calculating the air emission values of the alternatives, only the emissions due to the use of trucks are taken into account in Alternative 1, where road transport is represented. Since the emission value released during the production of the fuel used by the trucks is very low compared to the emission during the operation, it is not taken into account. However, in the air performance evaluation, the emission values released during the production of electricity that will be needed by the electric train used in Alternatives 2, 3 and 4 are taken into account (URL-4 2013).

As it is known, besides the environmental and cost factors, the need for personnel is also important in transportation. In this regard, it is estimated that the need for more personnel could increase employment opportunities, while the need for less number of personnel could accelerate the mechanisation. In cases where waste transportation is carried out by road or rail, the personnel requirement is given in Table 2.

Öztürk and Öztürk (2018) compared the water requirement of road and rail transport in their study. As a result, no significant difference in water performance was observed in either type of transport. For this reason, the water requirement performances for Alternatives 1, 2, 3 and 4 are entered into the model as equivalent. In the study, it has also been observed that the road and railway have already been completed in the region where the current transportation will be made, and the construction cost is not distinctively different in this context. However, the performance of the "Maintenance & Operational Costs" benchmark in the decision tree for road and rail options with significant differences in this criterion is included in the model as explained in the following section (3. Results and Discussion).

Table 1: Details of data used in calculations

Parameter	Data and unit	Notes and Sources
Cost of diesel fuel	22.22 TL	As of 28 April 2022
Electricity production cost (Trade)	2.74 TL/kW	As of April 2022, including taxes. (URL-7 2022)
Average emission produced by burning 1 L of diesel fuel	kg CO_{2e}/L	2,68 kg CO_{2eq}/L (Yaşar and Eren 2008)
Electric train energy consumption	60.8 kW	(Sezer 2019)
Electric train energy consumption	166.5 TL/km	(Sezer 2019)
Emission for 1 KW energy production	0.49 kg CO_{2eq}/L	Coefficients were taken for energy production provided by the Energy Market Regulatory Authority (URL-4 2013)
Fuel consumption of the truck	0.5 (L/km)	Average fuel consumption depending on distance and load (URL-3 2012)
Total waste to be transported	1000 ton/day	(Mısır 2015)
The load capacity of the electric locomotive	1250 ton/unit/trip	The maximum load to be drawn by an electric locomotive (Sezer 2019)
Route length	100 km	(Mısır 2015)
Trailer weight	7.5 tonnes/unit	It varies according to the occupancy rate, so an average of 7.5 tonnes was accepted. (URL-3 2012)
The waste capacity of the truck trailer	20 tonnes	The waste capacity of the trailers by providing the average transport limit (URL-3 2012)
1 R type wagon waste capacity	69 tonnes	Wagon Guide (URL-6 2019)
Weight of truck with waste-filled trailer	40 tonnes	(URL-3 2012)
1 R type wagon tare	21 tonnes/piece	Wagon Guide (URL-6 2019)
Trailer weight of the full truck	32.5 tonnes/unit	Trailer weight is equal to the total of waste and tare it can take (URL-3 2012)
U type swing-out wagon tare	20.6 tonnes/piece	Curb weight of the wagon (URL-6 2019)
The waste capacity of U type swing wagon	52 tonnes/piece	Wagon-type waste receiving capacity selected for waste transportation (URL-6 2019)

Table 2: Required staff for waste transportation

Type/Item number for transportation	People	Notes
1 waste-carrying truck in road transport	1	A driver who is legally qualified to drive a truck is required for each vehicle to use.
1 waste carrying-train in rail transport	3	1 driver is required to use the locomotive, 2 auxiliary personnel are also needed for loading-unloading organisation and monitoring.

2.4 Assigning Relative Weighs to the Benchmarks

A relative importance rating was obtained as a result of the questionnaire (consisting of 5 questions asking the importance of cost, environment and personnel requirement benchmarks) conducted with the participation of 32 stakeholders from various environmental backgrounds including the provincial municipal waste management units and private sectors in charge of the collection, transportation, disposal of solid and medical wastes.

3. Results and Discussion

In this section, the transportation of wastes was examined within the scope of multi-criteria decision analysis, taking into account the need for personnel in a way that minimises air emissions at the lowest possible cost. The results were analysed using the Right Choice programme as part of a multi-criteria decision-making analysis to test how well each alternative performs and how responsive the waste transport system is to any change in the score of the set criteria/benchmark. In this context, while the advantages and disadvantages of the alternatives are evaluated in terms of more than one criterion, it is also aimed to improve the understanding of the stakeholders regarding the relevant decision-making problem.

3.1 Performances of Alternatives on Each Benchmark

Table 3 shows the performances of the alternatives in terms of benchmarks identified in the decision tree in Figure 1. The values in Table 3 were calculated by using the data provided in Table 2.

Table 3: Performances of the alternatives in terms of benchmarks

Alternatives	Air Emissions (kg CO_{2e})	Performance (%)*	Staff Requirement (person)	Performance (%)*	Maintenance & Operational Cost (TL/day)	Performance (%)*
Alternative 1	18 760	0	70	16	165 464	0
Alternative 2	238	99	82	0	12 958	92
Alternative 3	179	99.5	44	50	7 237	97
Alternative 4	119	100	6	100	1 517	100
*While calculating the performance values, for example, the alternative with the lowest air emission value was determined as 100% and the alternative with the highest value as 0%. Intermediate values were normalized to 0-100% range.						

3.2 Relative Importance of Benchmarks

The relative importance rating of the criteria in the decision tree, according to the results of the questionnaire, is 35% for the environment, 20% for the staff requirement, 45% for the cost, 50% for air emissions, 50% for water pollution, 60% for operation & maintenance costs, and 40% for investment cost.

3.3 Score Analysis

The results of the score analysis obtained by running the model with the data determined for the alternatives defined above are shown in Figure 3. Under the determined weights of cost, staff requirement and environment (cost: 0.45; staff requirement: 0.20; environment: 0.35), Alternatives 4, 2 and 3 perform well (approximately 64%, 61% and 58%, respectively), while Alternative 1 has the lowest performance with almost 17%. This indicates that Alternative 4, 3 or Alternative 2 have the potential to be the optimum solution, depending on the relative importance weights given for the benchmarks.

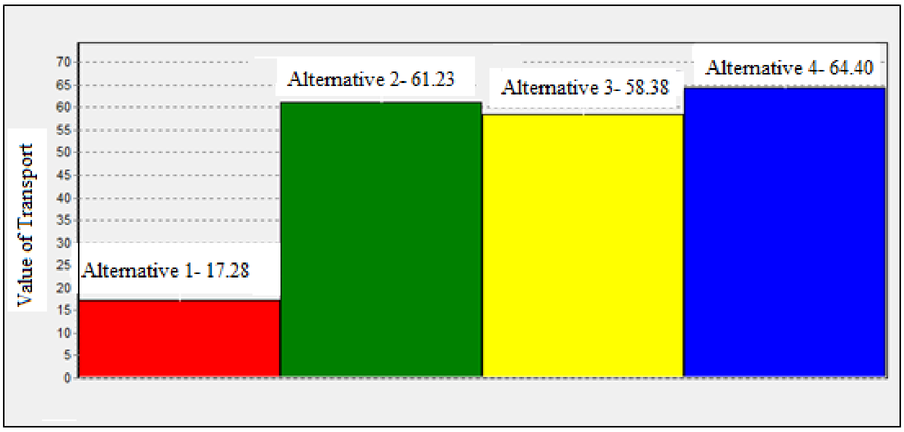

Figure 3: Results of score analysis

3.4 Sensitivity Analysis

Sensitivity analysis is performed to show the sensitivity of the final selection to any chosen criterion. The vertical white line in Figure 4a shows the environment's initial weight of 0.35 versus the economy and staffing needs. Moving to the right of this vertical line means that the environment is weighed against the other two criteria (the environment being more important than the cost and staff requirement).

It is seen in Figure 4a that Alternative 4 outperforms all other alternatives as long as the weight of the environment benchmark remains below 95% against personnel need and cost. If the weight of the environmental criterion is over 95%, Alternative 3 and 2 intersect with Alternative 4, showing the same high performance due to low air emissions and low operation-maintenance performance. Besides, it could be seen in Figure 4a that Alternative 1 will not be the appropriate solution due to the high cost and environmental burden, regardless of the relative importance of the environment to the cost and personnel needs.

Figure 4b and Figure 4c show the sensitivity analysis results of staffing needs and cost measures, respectively. Here, the relative importance of the benchmark for which the sensitivity analysis was performed changes along the y-axis, while the relative importance of the other three criteria except this benchmark remains the same concerning each other. For example, if the importance of staffing needs increases from 20% to 30%, the importance of cost and environment will decrease to 40% and 30%, respectively. In other words, the 10% increase in the personnel need criterion is reflected as an equal decrease in the other two criteria.

Accordingly, regardless of the relative importance assigned to the staff requirement benchmark, it is seen that the most appropriate alternative is Alternative 4 (Figure 4b). As this degree of importance decreases, Alternative 3 approaches Alternative 4. This situation is explained by the decrease in the importance of staff needs and the increase in the importance of environment and cost, and Alternative 3's high performance compared to Alternative 4 in terms of air emissions among environmental and -operational-maintenance cost benchmarks as shown in Table 3. Figure 4b also shows that, if the importance of the staff need benchmark relative to the other criteria (environment and cost) is more than 78%, Alternative 1 could overtake the performance of Alternative 2.

According to the sensitivity analysis results of the cost criterion given in Figure 4c, Alternative 4 appears as the optimum option, while Alternative 3 appears as another option close to it. Alternatives 1 and 2, however, remain as options to be evaluated where Alternatives 3 and 4 are not included in decision-making at all.

As a result, when Figure 4a, Figure 4b and Figure 4c are evaluated together, it is seen that Alternative 4 performs best for all three benchmarks. It is seen that Alternative 3, on the other hand, approaches Alternative 4, especially with the increase in the importance of the environment, but moves away from Alternative 4 as the importance of personnel needs increases. The reason for this is that while Alternative 3 performs as well as Alternative 4 in terms of environment, it is disadvantageous in terms of personnel needs (Table 3).

Although Alternative 1 performs relatively well in terms of personnel requirement (16%-Table 3), it is seen that it cannot surpass other alternatives due to its high environmental and economical burden.

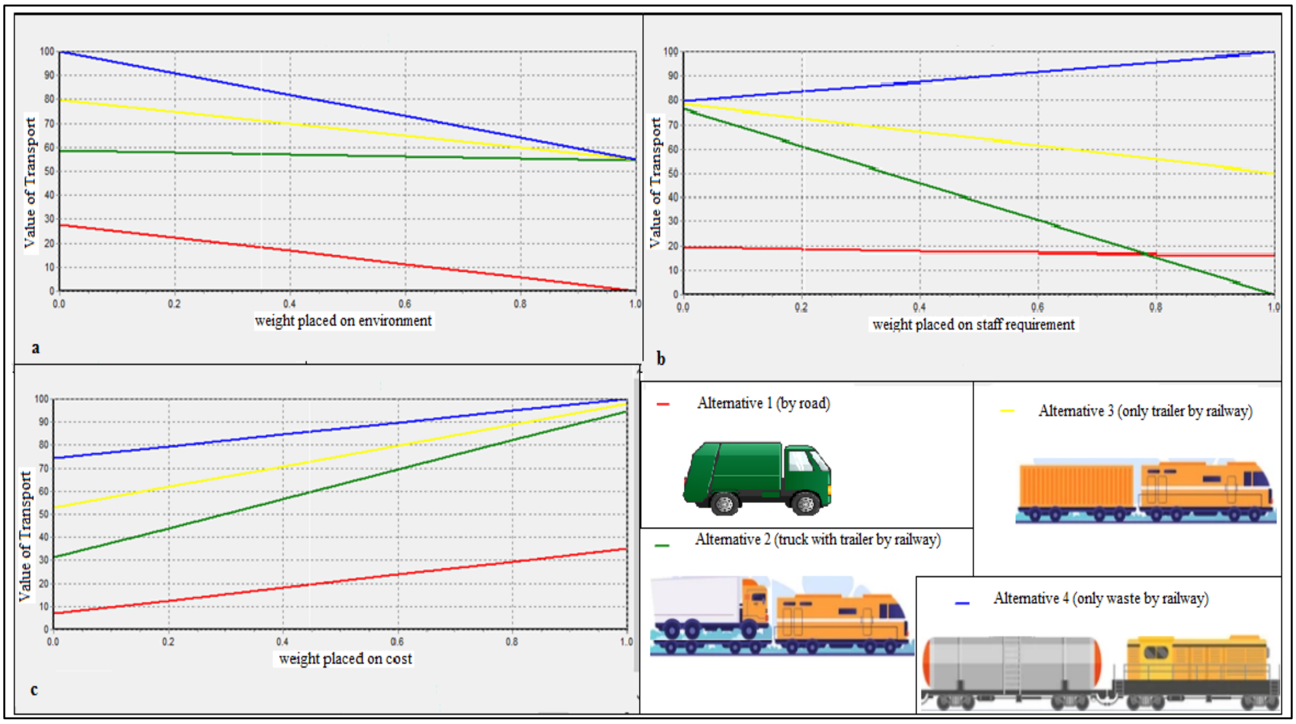

Figure 4: Results of Sensitivity Analysis

These project results show that Alternative 4 or 3 could be an optimum choice among other alternatives, depending on the scoring of the criteria in the decision tree, reducing the number of alternatives and highlighting the good performers.

In determining Alternative 4 as optimum, the low operating-maintenance cost of this alternative, in other words, its high performance on this benchmark (Table 3) and the high relative importance of the operating-maintenance cost assigned by the stakeholders (3.2 Relative Importance of Benchmarks) play a crucial role. Accordingly, the number of personnel required for Alternative 4 is low compared to other alternatives (Table 3). The outcomes of this study are consistent with the results of the study comparing different waste transport alternatives in New Zealand (Schriiffer 2006). In the study conducted by Schriiffer (2006), it was determined that the transportation of solid wastes from the Christchurch Transfer Station to the Kate Valley Landfill by rail is more economical and environmental than by road. In the same study, it was also highlighted that one of the major merits of using the rail option for waste transfer compared to the road is its low operating cost and personnel requirement.

The determination of Alternative 4 as the optimum option coincides with the results of studies showing that the transport of waste by rail is much more environmentally friendly and economical, as explained in the literature (Bauerlein and King 2018; Peirce and Pierson 1983; Peterson 1996). The results obtained in this study indicate that the development of innovative railway wagons for the transportation of municipal wastes could also contribute to the circular economy and support the study conducted by Vidovic et al. (2022).

4. Conclusions

In this study, alternatives for the transportation of wastes by rail and road were defined, and these alternatives were compared in the Right Choice model, using multi-criteria decision-making analysis within the scope of cost, environment and staff requirement. The necessary data for the model were obtained by a questionnaire and literature review. In this context, the transportation of waste by road is shown with Alternative 1, while the transportation by rail is represented by Alternative 2 (loading trucks and trailers on the train), Alternative 3 (loading only trailers on the train) and Alternative 4 (loading only wastes on the train). As a result, the transfer of wastes specified in Alternative 4 was determined as the optimum option according to the determined criteria, by only loading the wastes on the wagons (without the use of trucks and trailers).

It is a challenging task to determine how important the factors in the decision-making activity will be in the future. It is possible for the decision tree (Figure 1) created in this study to be affected by changing and developing decision-making processes and to be restructured to include more factors in the future. For instance, as the time factor becomes more important in waste transportation or the importance of the accident risk (especially in hazardous waste transportation) is less in rail transportation, it will be inevitable to change the decision tree. Therefore, the relative weight of each criterion to be used in the evaluation of any proposed waste transport system is uncertain.

In this context, the sensitivity analysis conducted in this study is important in terms of guiding the stakeholders about the method that can be used for these changing conditions. It is estimated that the method and model structure used in this study will be useful in researching similar problems in other regions, in adapting it according to that region and reusing it, in terms of increasing the perception of the stakeholders about a complex problem such as waste transportation.

Acknowledgement

This paper was produced from the master thesis (Alternative Transport Methods for Integrated Waste Management Systems) of Fatih Kamaoğlu in the Department of Environmental Engineering, Faculty of Engineering, Tekirdağ Namık Kemal University and supervised by Nesli Aydın.

References

Apaydın O., Gonullu M. T., (2007), *Route optimization for solid waste collection: Trabzon (Turkey) Case Study*, Global NEST Journal, 9(1), 6-11. doi: 10.30955/gnj.000388.

Bauerlein V., King K., (2018), New York City's Sewage Shipment Runs Afoul in Rural South, The Wall Street Journal. https://www.wsj.com/articles/new-york-citys-sewage-shipment-runs-afoul-in-rural-south-1522402201, [Accessed 26 June 2021].

Coelho L. M. G., Lange L. C., Coelho H., (2017), *Multi-criteria decision making to support waste management: A critical review of current practices and methods*, Waste Management & Research: The Journal for a Sustainable Circular Economy, 35(1), 3-28.

Eriksson L., Jaworska J., Worth A.P., Cronin M.T.D., McDowell R.M., Gramatica P., (2003), *Methods for reliability and uncertainty assessment and for applicability evaluations of classification- and regression-based QSARs*, Environmental Health Perspectives, 111(10), 1361-1375.

Hung M. L., Ma H., Yang W. F., (2007), *A novel sustainable decision making model for municipal solid waste management*, Waste Management, 27(2), 209-219.

İnan M., Demir M., (2017), *Rail Transportation and Effects of High Speed Railway Investments in Turkey: Eskişehir - Konya Example*, The Journal of International Social Sciences, 27(1), 99-120.

Kamaoğlu F., (2022), *Alternative transport methods for integrated waste management systems*, Master Thesis, Tekirdağ Namık Kemal University, Tekirdağ, Turkey.

Keirstead J., Jennings M., Sivakumar A., (2012), *A review of urban energy system models: Approaches, challenges and opportunities*, Renewable and Sustainable Energy Reviews, 16(6), 3847-3866.

Mısır S.O., (2015), *Kentsel katı atıkların taşınması ve transferi*, Bitirme Tezi, Ondokuz Mayıs Universitesi, Mühendislik Fakültesi, Samsun. (in Turkish).

Morrissey A. J., Browne J., (2004), *Waste management models and their application to sustainable waste management*, Waste Management, 24(3), 297-308.

Or I., Curi K., (1993), *Improving the efficiency of the solid waste collection system in Izmir, Turkey,* Through Mathematical Programming, Waste Management and Research, 11(4), 297-311.

Özkan A., (2008), *Utilization of different decision making techniques for development of municipal solid waste management systems*, Doctoral Thesis, Anadolu University, Eskişehir, Turkey.

Öztürk O., Öztürk O., (2018), *Demiryolu denizyolu ve karayolunun ülkemizde enerji tüketimi ve çevresel etkiler açılarından karşılaştırılmaları*, International Symposium on Railway System Engineering, 10-12 October, Karabük, Turkey, pp. 43-53.

Peirce J. J., Pierson B. A., (1983), *Analysis of rail transfer for solid wastes in North Carolina, U.S.A*, Waste Management and Research: The Journal for a Sustainable Circular Economy, 1(2), 127-138.

Peterson C., (1996), *Rail transport of municipal waste within the United States*, Waste Management & Research: The Journal for a Sustainable Circular Economy, 14(3), 319-325.

Rızvanoğlu O., Kaya S., Ulukavak M., Yeşilnacar M. İ., (2019), *Optimization of municipal solid waste collection and transportation routes, through linear programming and geographic information system: a case study from Şanlıurfa, Turkey*, Environmental Monitoring and Assessment, 192, 9, doi:10.1007/s10661-019-7975-1.

Schriiffer B., (2006), *Transport of Christchurch Solid Waste Road Transport Versus Rail Transport*, Master Thesis, Lincoln University, New Zealand, https://core.ac.uk/download/pdf/35463996.pdf, [Accessed 17 January 2023].

Sezer F. E. (2019), *İstanbul'un avrupa yakasında oluşan katı atıkların demiryoluyla taşınması üzerine bir araştırma*, Master Thesis. İstanbul Technical University, İstanbul.

Somplak R., Prochazkab V., Pavlasa M., Popela P., (2013), *The logistic model for decision making in waste management*, Chemical Engineering Transactions, 35, 817-822.

URL-1, (2006), *Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste*, European Parliament and of the Council, https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/? uri=CELEX:32006R1013 from=EN, [Accessed 08 August 2022].

URL-2, (2011), *Transportation in Turkey, Country Report*, Ministry of Transport, Maritime Affairs and Communications, http://www.comcec.org/wpcontent/uploads/2015/02/Turkey.pdf, [Accessed 29 June 2021].

URL-3, (2012), *Araçların Yüklenmesine İlişkin Ölçü ve Usuller ile Tartı ve Boyut Ölçüm Toleransları Hakkında Yönetmelik*, Resmi Gazete Tarih: 8 Kasım 2012, Sayı: 28461, https://www.resmigazete.gov.tr/eskiler/2012/11/20121108-7.htm, [Accessed 29 June 2021]. (in Turkish).

URL-4, (2013), *Energy Statistics*, Energy and Natural Resources Ministry, https://www.resmiistatistik.gov.tr/detail/subject/enerji-istatistikleri/ [Accessed 29 June 2021].

URL-5, (2009), *Future Projects of Our Organization*, Republic of Turkey State Railways, http://www.tcdd.gov.tr, [Accessed 29 June 2021].

URL-6, (2019), *Freight wagon handbook*, Republic of Turkey State Railways, https://www.tcddtasimacilik.gov.tr/uploads/images/ 2019/vg%20 rehberi%20d%C3%BCzenleme%2006_2019.pdf, [Accessed 29 June 2021].
URL-7, (2022), *Tariff Tables Based on Electricity Bills*, Turkish Electricity Distribution Inc., https://www.epdk.gov.tr/Detay/ Icerik/3-1327/elektrik-faturalarina-esas-tarife-tablolari [Accessed 29 June 2021].
Van Hengel W., Kruitwagen P. G., (1994), *Environmental risks of inland water transport*, Water Science and Technology, 29(3), 173–179.
Vego G., Kučar-Dragičević S., Koprivanac N., (2008), *Application of multi-criteria decision-making on strategic municipal solid waste management in Dalmatia, Croatia*, Waste Management, 28(11), 2192-2201.
Vidovic D., Niksic M., Susak M., (2022), *Development of innovative rail wagons for transport of municipal waste "EKO-VAKO"*, In M. Petrovic, L. Novacko, D. Bozic, & T. Rozic (Eds.), the Science and Development of Transport-ZIRP 2021 (155-165), Cham: Springer International Publishing.
Yadav V., Kalbar P.P., Karmakar S., Dikshit A.K., (2020), *A two-stage multi-attribute decision-making model for selecting appropriate locations of waste transfer stations in urban centers*, Waste Management, 114, 80-88.
Yaşar B., Eren Ö., (2008), *Türkiye'de tarım sektöründe kullanılan petrodizelin çevresel etkileri ve biyodizel alternatifiyle karşılaştırılması*, VII. Ulusal Temiz Enerji Sempozyumu, 17-18 Aralık, İstanbul, Turkiye. (in Turkish).
Yıldız-Geyhan E., Altun-Çiftçioğlu G. A., Kadırgan M. A. N., (2017), *Social life cycle assessment of different packaging waste collection system.* Resources, Conservation and Recycling, 124, 1-12. doi: 10.1016/j.resconrec.2017.04.003.