REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

INSTITUTE OF GRADUATE SCHOOL
DEPARTMENT OF INDUSTRIAL ENGINEERING

A PERFORMANCE EVALUATION MODEL FOR RAILWAY TRANSPORTATION COMPANIES USING MULTI-CRITERIA DECISION MAKING METHODS

ÇAĞDAŞ YÜKSEL

MASTER OF SCIENCE

ADANA 2023

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ASST. PROF. DR. NUŞİN UNCU

ADANA, 2023

DECLARATION OF CONFORMITY

In this thesis study, which was prepared following the thesis writing rules of Adana Alparslan Türkeş Science and Technology University Institute of Graduate School, I declare that I provide all the information, documents, evaluations and results in accordance with scientific ethics and moral codes without resorting to any means or assistance that would be contrary to scientific ethics and traditions. I also declare that I refer to all of the articles I used in this study with appropriate references and accept all moral and legal consequences if a situation is found contrary to my statement regarding my work.

18/04/2023

[İmza]

Çağdaş YÜKSEL

ÖZET

DEMİRYOLU TAŞIMA ŞİRKETLERİ İÇİN ÇOK KRİTERLİ KARAR VERME YÖNTEMLERİNİ KULLANARAK BİR PERFORMANS DEĞERLENDİRME MODELİ

Çağdaş YÜKSEL

Yüksek Lisans, Endüstri Mühendisliği Anabilim Dalı

Danışman: Dr. Öğr. Üyesi Nuşin UNCU

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Performans değerlendirme, yönetimsel kararların alınması ve performansı iyileştirmeyi desteklemek amacıyla bir organizasyonun ortaya koyduğu performansa ilişkin objektif ve nicel bilgiler üretmeyi amaçlar. Bu çalışmada, Türkiye'de 2013 yılında yürürlüğe giren 6461 sayılı yasa ile serbestleşen demiryolu taşımacılığı sektöründe faaliyet gösteren demiryolu yük tren işletmecisi şirketlerin (DTİ) performans değerlendirmesi amaçlanmıştır.

Çalışmada ilk olarak demiryollarındaki performans kavramı analiz edilmiş ve demiryolu yük treni işletme şirketlerinin performansının değerlendirmesinde kullanılacak olan Temel Performans Göstergeleri (TPG'ler) belirlenmiştir. Belirlenen TPG'lerin göreli ağırlıklarını belirlemek için AHP ve bulanık AHP'den yararlanılmıştır. Çalışmanın son aşamasında belirlenen TPG ağırlıkları kullanılarak Çok Kriterli Karar Verme (ÇKKV) yöntemlerinden biri olan EDAS yöntemi kullanılarak Türkiye'de faaliyet gösteren yük treni işletme şirketlerinin performansları değerlendirilmiştir. Diğer ÇKKV yöntemleri olan TOPSIS, PROMETHEE II ve COPRAS da EDAS'ın sonuçlarını desteklemek için uygulanmıştır. TPG'lerin göreli ağırlıklarındaki değişikliklerin sonuçları nasıl etkilediğini değerlendirmek için duyarlılık analizi yapılmıştır.

Anahtar Kelimeler: çok kriterli karar verme, demiryolları, performans değerlendirme, temel performans göstergesi

ABSTRACT

A PERFORMANCE EVALUATION MODEL FOR RAILWAY TRANSPORTATION COMPANIES USING MULTI-CRITERIA DECISION MAKING METHODS

Çağdaş YÜKSEL
M.Sc., Department of Industrial Engineering
Supervisor: Asst. Prof. Dr. Nuşin UNCU

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Performance evaluation aims to produce objective and quantitative information about the performance of an organization to support making managerial decisions and improving performance. In this study, it is targeted to evaluate the performance of the freight train operating companies (TOC) in the railway transportation sector which was liberalized with Law No. 6461 entering into force in 2013 in Turkey.

In the study, firstly, the concept of performance in railways is analyzed, and the Key Performance Indicators (KPIs) to be used in evaluating the performance of railway freight train operating companies are determined. AHP and fuzzy AHP methods are utilized to determine the relative weights of the specified KPIs. In the last stage of the study, by using the KPI weights determined, the performances of freight train operating companies in Turkey are evaluated using the EDAS method which is one of the Multi-Criteria Decision Making (MCDM) methods. Other MCDM methods, TOPSIS, PROMETHEE II and COPRAS, are applied to support the results of EDAS. Sensitivity analysis was performed to evaluate how the changes in the relative weights of the KPIs effect results.

Keywords: key performance indicator, multi-criteria decision making, performance evaluation, railways

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LIST OF ABBREVIATIONS

AHP	: Analytical Hierarchy Process
CI	: Consistency index
COPRAS	: Complex Proportional Assessment
CR	: Consistency ratio
CRITIC	: Criteria importance through inter-criteria correlation
ÇKKV	: Çok Kriterli Karar Verme
DTİ	: Demiryolu tren işletmecisi
EDAS	: Evaluation Based on Distance from Average Solution
FAHP	: Fuzzy Analytical Hierarchy Process
IM	: Infrastructure manager
IMPROVERAIL	: Improved tools for railway capacity and access management
KPI	: Key performance indicator
MADM	: Multi-attribute decision making
MCDM	: Multi-criteria decision making
MODM	: Multi-objective decision making
OECD	: Organization for Economic Co-Operation and Development
PRIME	: Platform of Railway Infrastructure Managers in Europe
PROMETHEE	: Preference Ranking Organization Method for Enrichment Evaluation
RI	: Random index
TCDD	: Türkiye Cumhuriyeti Devlet Demiryolları
TOC	: Train operating company
TOPSIS	: Technique for Order of Preference by Similarity to Ideal Solution
UIC	: International Union of Railways

LIST OF SYMBOLS

$\mathbf{A^-}$	: Negative ideal solution
$\mathbf{A^+}$	: Positive ideal solution
A	: Pairwise comparison matrix
$\mathbf{a_{ij}}$	: Value of row i and column j of matrix A
$\mathbf{AS_i}$	: Appraisal score of i^{th} alternative
$\mathbf{AV_j}$	: Average solution for j^{th} criterion
$\mathbf{b_{ij}}$	: Normalized value of row i and column j of B vector
B	: B vector
$\mathbf{C_i^*}$	: Relative closeness of the i^{th} alternative
C	: C matrix
$\mathbf{d_j}$	: Differences of i^{th} alternative with respect to the other alternatives
D	: Decision matrix
DC	: Vector DC
$\mathbf{E_i}$	: E value for i^{th} alternative
$\mathbf{g_j(a), g_j(b)}$	: Performance of alternatives a and b respectively
$\mathbf{I, m, u}$	: Members of a triangular fuzzy number
n	: Number of elements
$\mathbf{NSN_i}$	: Normalized weighted sum of the negative distance from the average solution for i^{th} alternative
$\mathbf{NSP_i}$	: Normalized weighted sum of the positive distance from the average solution for i^{th} alternative
NDA	: Negative distance from the average
$\mathbf{P_i}$	: Performance index of i^{th} alternative
$\mathbf{P_j}$	: Preference value for j^{th} criterion
PDA	: Positive distance from the average
$\mathbf{Q_i}$	: Relative importance of i^{th} alternative
$\mathbf{r_{ij}}$	: Normalized value of row i and column j
R	: Normalized decision matrix

$\mathbf{S_i}$: Fuzzy synthetic extent value of ith alternative

$\mathbf{S_i^-}$: Negative ideal separation measure for i^{th} alternative

$\mathbf{S_i^+}$: Positive ideal separation measure for i^{th} alternative

$\mathbf{S_{+i}}, \mathbf{S_{-i}}$: Total weighted normalized values

$\mathbf{SN_i}$: Weighted sum of the negative distance from the average solution for i^{th} alternative

$\mathbf{SP_i}$: Weighted sum of the positive distance from the average solution for i^{th} alternative

$\mathbf{v_{ij}}$: Weighted value of row i and column j

$\mathbf{V}$: Weighted normalized decision matrix

$\mathbf{w_j}$: Weight of the j^{th} criteria

$\mathbf{W'}$: Weight vector

$\mathbf{W}$: Normalized weight vector

$\mathbf{WC}$: Criteria weighted matrix

$\mathbf{WP}$: Priority vector

$\mathbf{x_{ij}}$: The performance value of i^{th} alternative with respect to j^{th} criterion

$\boldsymbol{\lambda}$: Arithmetic mean of E values

$\boldsymbol{\pi}(\mathbf{a}, \mathbf{b})$: Aggregated preference function of alternatives a and b

$\boldsymbol{\varphi}^-$: Entering outranking flow

$\boldsymbol{\varphi}^+$: Leaving outranking flow

$\boldsymbol{\varphi}$: Net outranking flow

1. INTRODUCTION

Railway transportation, one of the inventions that changed the course of history and contributed greatly to the shaping of the modern world, continues to increase its global impact on development and change in parallel with safety, environment, energy, and economic needs. It is becoming more and more critical in the transportation sector. Railways play an important role in stimulating economic growth, reducing road congestion, and limiting the climate change impact on transport networks (Ison, Frost and Watson, 2012).

In parallel with the development of global trade, railways have become very important not only within the borders of a country but also between countries and even between continents, in the transportation of products and goods, especially in terms of mass, and raw materials, due to their safety, longevity, low cost of construction, environmentally friendliness and not dependent on petroleum.

Investments in the railway sector in our country have increased in the last 19 years. Although our country is located between the continents of Asia and Europe, it is not possible to say that it can sufficiently benefit from the geographical advantages created by its inter-regional position in terms of railway networks. It is aimed that our country will reach the desired position with the completion of the ongoing investments and future investments (TCDD, 2020).

Social and economic growth has increased the demand for more train paths and services. At the same time, existing railways are becoming more and more congested. Therefore, using the existing railway network and railway services most efficiently is a central task for all railway stakeholders (e.g., infrastructure managers, train operators, regulatory agencies, etc.) either by upgrading the infrastructure, or developing better management strategies, to provide better service to customers.

1.1. The concept of performance in railways

Railways around the world are dealing with growing demand and limited infrastructure. Using the existing railway network most efficiently is a central task for railway infrastructure managers. It is important to react to infrastructure users' requests and provide capacity at the right moment in the right place to them.

Performance evaluation aims to produce objective, quantitative information about the performance of organizations that will support management, decision making, and performance improvement (Poister, 2003).

Efficiency and effectiveness are key terms used in evaluating the performance of organizations and processes. Effectiveness is the ability to produce the desired result; efficiency is the ability to do something or produce something without wasting materials, time, or energy: the quality or degree of being efficient (Wilson, Wnuk, Silvander and Gorschek, 2018). There are many definitions of efficiency and effectiveness in the literature used in organizational, manufacturing, operational, product development, etc.

Neely, Gregory, and Platts (2005) describe performance evaluation as quantifying the efficiency and effectiveness of action. According to them, some questions should be answered before the performance evaluation process. Those are;

- Which measurements of performance are used?
- Why are they being used?
- How much will they cost?
- What benefits can they offer?

Performance measurement is used in some way or another in every business and industry, but the form and extent of the measurement systems vary. In railways, performance indicates the capability of a railway system to fulfill its claim to transport passengers and freight (Lu, 2016). Performance from the aspect of capacity is viewed differently from the market, infrastructure planning, timetable planning and operations, as stated by the UIC (UIC, 2004).

Table 1.1. Performance from the aspect of capacity (UIC, 2004).

Market (customer needs)	Infrastructure planning	Timetable planning	Operations
Expected number of train paths (peak)	Expected number of train paths (average)	Requested number of train paths	Actual number of trains
Expected mix of traffic and speed (peak)	Expected mix of traffic and speed (average)	Requested mix of traffic and speed	Actual mix of traffic and speed
Infrastructure quality need	Expected conditions of infrastructure	Existing conditions of infrastructure	Actual conditions of infrastructure
Journey times as short as possible	Time supplements for expected disruptions	Time supplements for expected disruptions	Delays caused by operational disruptions
Translation of all short and long-term market induced demands to reach optimized load	Maintenance strategies	Time supplements for maintenance	Delays caused by track works
		Connecting services in stations	Delays caused by missed connections

A key performance indicator (KPI) is a measurable value that demonstrates how effectively a company achieves key business objectives. Organizations use KPIs to evaluate success at reaching targets. KPIs are vital for monitoring the performance in the industry, and they can be used to identify poor performance and improvement potential (Lindberg, Tan, Yan, and Starfelt, 2015). The KPI concept can also be used for performance evaluation in the railway freight transport sector.

1.2. Railways in Turkey

In 2013, with the Law No. 6461 purposing to increase transparency, cost-efficiency, neutrality, and competition in the railway sector, railway infrastructure management and train operation were separated from each other in Turkey. In 2017, TCDD was authorized as railway infrastructure manager (IM) on the railway infrastructure involved in the national railway infrastructure network and on the sections of the railway infrastructure in possession of the state, and a new company TCDD Taşımacılık was established for passenger and freight transportation as train operating company (TOC) (TCDD, 2020). The law opened the Turkish rail transport sector to competition, and this meant that TCDD Taşımacılık had to compete with the private train operating companies that would enter the sector (Cebeci, Tüydeş-Yaman and Islam, 2022). Today, there are five certificated TOCs in the field of railway transportation, and those are displayed in Table 1.2 below.

Table 1.2. Certificated TOCs (UAB, 2022).

TOC name	Type of transportation
TCDD Taşımacılık A.Ş.	Freight and passenger
Körfez Ulaştırma A.Ş.	Freight
Omsan Lojistik A.Ş.	Freight
İzban Banliyö Taşımacılığı A.Ş.	Passenger
Sun Tren Sanayi Ticaret LTD ŞTİ.	Freight

TCDD Taşımacılık performs both passenger and freight transportation, Omsan Lojistik and Körfez Ulaştırma perform only freight transportation (UAB, 2022). Sun Tren Sanayi Ticaret LTD ŞTİ. has not started transportation activities yet.

Table 1.3. Lengths of lines in kilometers operated by TCDD (TCDD, 2022).

	Length	Electrified lines	Signalled lines
Conventional lines	**11.590**	**5.919**	**4.718**
Total main lines	9.194	5.124	4.166
1st main line or single line	8438	4.465	3.393
2nd, 3rd, 4th main lines	756	659	773
Branch lines and station lines	2.396	795	552
High speed lines	**1.213**	**1.213**	**1.213**
Total main lines	1.184	1.184	1184
1st main line	594	594	594
2nd main line	590	590	590
Station lines	29	29	29
Total lines	**12.803**	**7.132**	**5.931**

The lengths of the lines operated by TCDD, the railway infrastructure manager (IM), are in Table 1.3 above.

On the national railway network, the amount of freight of tonnes transported by TCDD Taşımacılık, Omsan Lojistik and Körfez Ulaştırma, and the tonne-kilometer information are as in Table 1.4 below year by year. Tonne-kilometer is a unit of freight transport measure representing the transport of one tonne over a distance of one kilometer.

Table 1.4. Freight transport data on the Turkish national railway network (TCDD, 2020).

Unit	Year				
	2016	**2017**	**2018**	**2019**	**2020**
Tonnes *(1000 tonnes)*	25.886	28.469	31.673	33.535	34.549
Tonne kilometers *(million tonne km)*	11.661	12.794	14.481	14.707	15.428

2. LITERATURE REVIEW

In Turkey, since 2013, with Law No. 6461 railway sector has been opened to private train operating and private train operating companies with their owned rolling stocks entered the railway freight train operating sector. It means private and public train operating companies compete with each other. Thus, performance has become important for these companies in this competitive environment.

Performance evaluation of railway freight train operating companies is the main focus of this study. In order to better understand the concept of performance in railway train operation companies, some studies in the literature are examined. The examined studies on this subject are given below.

Jose, Agarwal, Zhuang and Swaminathan (2022) used the hierarchical fuzzy axiomatic design method is a novel multi-criteria decision making method to evaluate the performance of several railway zones split into regions for operational reasons. Researchers stated that the study aimed to identify railway zones' strengths and shortcomings and improve their performance.

Stoilova, Munier, Kendra and Skrúcaný (2020) proposed a methodology to assess and classify railway network performance. The study presented twenty-two infrastructural, economic and technological criteria for assessing railway transport. Using MCDM methods, selected countries' railway performance was ranked. Furthermore, a cluster analysis was conducted to verify the results, classifying countries.

Stoilova (2019) focused on assessing the development level of railway transport in different railway transport markets using multi-criteria decision making methods. There are three steps in the study. In the first step, quantitative and qualitative criteria were identified to evaluate the railway transport development level's social, economic, infrastructural, and technological impact. In the second step, the criteria weights were determined using the Shannon Entropy method and the Stepwise Weight Assessment Ratio Analysis (SWARA) method. In the last step, the markets were ranked using VIKOR, WASPAS, and PROMETHEE multi-criteria decision making methods.

Lu (2017) reviewed and analyzed the existing performance measures used in industries, including railway passenger transportation. A framework for the measurement and improvement of railway network performance was proposed based on the concept of quality of service. The key factors affecting the quality of service were identified and analyzed. Multi-criteria decision making was applied to determine the weights of each key performance indicator in the framework.

Frederico and Cavenaghi (2017) aimed to elaborate a performance measurement system framework for railroad companies, and a case study method was applied to a large Brazilian railroad company. This study used semi-structured interviews and documental data collection to get evidence related to the processes, environment, customers, and strategic objectives as perspectives needed to elaborate a PMS based on balanced scorecards.

Ranjan, Chatterjee and Chakraborty (2016) proposed the application of a decision making tool for the performance evaluation of railway zones. Researchers sought to analyze the effects of various evaluation criteria on the performance of railway zones using a combined multi-criteria decision making approach that employs DEMATEL and VIKOR methods.

Sharma, Debnath, Oloruntoba and Sharma (2016) focused on measuring the performance of Indian Railways in terms of service efficiency. The study has an operational perspective only using DEA methodology. Researchers incorporated the quality of service dimensions in performance measurement and benchmarking of the railway zones that make up a national railway system under the public domain.

Fraszczyk, Lamb and Marinov (2016) compared statistical data on various parameters of the railway system in selected European countries and revealed their performance level compared to the European average. According to the researchers, the analyses made in this paper will allow identifying key performance indicators for accurately assessing the railway systems.

Bureika (2011) assessed the effectiveness of the operation of freight locomotives by multi-criteria evaluation methods, and the most efficient locomotive is determined based on a set of criteria. The study used the sum of ranks, simple additive weighting, and geometric mean.

Yu and Lin (2008) proposed a multi-activity data envelopment analysis model, both in production and consumption, to be used to simultaneously estimate passenger and freight technical efficiency, service effectiveness, and technical effectiveness on selected railways. The study results stated that the results estimated using the proposed model could be used to improve operational performance.

Lan and Lin (2006) attempted to measure the performance of railways by two stochastic distance function approaches. By researchers, a stochastic input distance function with an inefficiency effect was defined to evaluate technical efficiency, whereas a stochastic consumption distance function with an ineffectiveness effect was introduced to assess service effectiveness. The empirical analysis examined some worldwide railway systems over o period where inputs contain the number of passenger cars, the number of freight cars, and the number of employees. The outputs are passenger train kilometers, freight train kilometers, and consumptions passenger kilometers and ton-kilometers.

3. MATERIALS AND METHODS

3.1. Determination of KPIs

Indicators are used to measure the performance of an organization or a system. Key Performance Indicators (KPIs) are tools to measure and benchmark the performance of an organization (Finger, Bert and Kupfer, 2016). These are; financial, organizational, technical, HSE (health, safety, and environment), etc. (Stenström, Parida and Galar, 2012). Key Performance Indicators measure what is critical to the company's success (IMPROVERAIL, 2001). The KPI concept will be used to evaluate the performance of railway freight transportation and train operating companies.

According to Finger et al. (2016), different railway transportation actors have different aims for evaluating performance.

- As per companies, KPIs are related to improving financial and operational performance.
- Per customers, performance indicates low price, availability, and reliability of services.
- Regulators are concerned with the safety performance and accessibility of the national rail system.
- Transport authorities are mainly concerned with the state of the network and the service quality.

Lu (2016) measured railways performance in terms of quality of service using eight KPIs. Lu (2016) produced KPIs based on expert opinions about the structure of railway operations and stakeholder needs. These eight KPIs are passenger comfort, punctuality, journey time, resource usage, accommodation, energy, resilience, and connectivity.

PRIME (Platform of Railway Infrastructure Managers in Europe) is a forum that aims to enhance rail infrastructure managers' collaboration, support the implementation of European rail policy and develop performance benchmarking (European Commission, 2020). PRIME (2019) has determined twelve KPIs in five dimensions that reflect the needs and priorities of railway infrastructure managers and respond to the demands of stakeholders and customers. These are shown in Table 3.1.

Table 3.1. PRIME KPI categories (PRIME, 2019).

Dimension	KIPs		
Safety and Environment	Safety	Security	Environment
Performance	Punctuality	Reliability	
Delivery	Capacity	Condition	
Financial	Costs	Revenues	
Growth	Utilization	Asset Capability & ERTMS	Intermodality

The two-year project, known as IMPROVERAIL, commissioned by the European Commission in 2001, whose aim was to support the establishment of railway infrastructure management, was carried out. As a result of the project, seven indicators called the ‘success dimension’, which can be accepted as KPIs, have been developed. Those are; efficiency, accessibility, financial effectiveness, asset utilization, innovation & growth, service quality & reliability, and safety (Anderson, Hirsch, Trompet and Adeney, 2003).

Focus group technique is a qualitative data collection technique that has been frequently used in researches. The aim of the focus group technique is to obtain qualitative information based on the perspectives, experiences, tendencies, thoughts, and perceptions of the participants about a determined subject (Çokluk, Yılmaz and Oğuz, 2011).

Focus group technique was used to determine the KPIs to be used in the performance evaluation of railway freight TOCs, which is the subject of this study. The information of the experts involved in the process is as in Table 3.2. Each of the experts has substantial knowledge about the railway industry and its operation, and is able to identify the requirements of different stakeholders.

Table 3.2. Information of experts.

Expert	Title	Specialty	Experience
Expert 1	Department manager	Railway capacity management	36 years
Expert 2	Department assistant manager	Railway capacity management	35 years
Expert 3	Department manager	Railway traffic management	25 years
Expert 4	Department assistant manager	Railway traffic management	30 years
Expert 5	Department assistant manager	Railway traffic management	28 years
Expert 6	Department assistant manager	Railway traffic management	28 years
Expert 7	Department manager	Railway infrastructure maintenance	25 years
Expert 8	Department manager	Railway infrastructure modernization	24 years

In the focus group meeting held, the KPIs in the literature and KPIs determined by the railway authorities were evaluated considering whether they are suitable for the performance evaluation of freight TOCs. It was concluded that the evaluated KPIs were more appropriate towards the performance of railway infrastructure management and general railway system. After evaluation, also considering the structure of the Turkish railway sector, seven KPIs were determined. The KPIs selected to evaluate the performance of freight train operating companies (TOCs) in Turkey are listed below.

- Punctuality
- Journey time
- Resource usage
- Profitability
- Safety
- Innovation & growth
- Environment

3.1.1. Punctuality

Punctuality is usually measured as the percentage of trains leaving or arriving at stations within a predefined delay time tolerance (Parbo, Nielsen, Landex and Prato, 2013). There are several definitions of punctuality linked to railways in the literature. Hansen (2001) defines punctuality as a percentage of railway journeys arriving or departing in a specified railway station no later than a specified time tolerance. Olsson and Haugland (2004) describe train non-punctuality as a negative deviation from the predefined timetable.

Timetables are published periodically in railways to plan and schedule train operations. These timetables may be published at different periods by different railway infrastructure managers. In TCDD, timetables are published annually by Turkey's railway infrastructure manager (IM). When minor adjustments are to be made to the timetable, they must be made in advance of a particular time before operations, and the actors in the railway system that will be affected by the adjustments must be notified.

The timetable includes the following information about active trains that will be operated daily (Goverde, 2005).

- Departure station, arrival station and passing stations;
- Planned departure and arrival time at each station;
- Tracks to be used including station lines;
- Passage times at station intervals and certain location;
- Rolling stock connections at main stations;
- Timetable speed and sometimes overtaking speed.

The punctuality of the trains is directly related to how well they operate according to the timetable. Commonly, punctuality is calculated by dividing the number of punctual trains in a specified period by the total number of trains and is expressed as a percentage of punctual trains (Olsson and Haugland, 2004).

In this study, the ratio of the number of trains departing on scheduled time and prior to scheduled time, divided by the total number of trains of a TOC is used as a performance indicator.

3.1.2. Journey time

A train timetable shows the planned arrival and departure time of trains at each station. Journey time can be defined as the total practical time spent by trains to complete their route, and it is the actual time spent rather than the scheduled time on the timetable (Lu, 2016). However, the planned times are usually affected by different types of disturbances. These disturbances may occur due to railway infrastructure managers, railway train operators, and various reasons.

In this study, in a given time period, the ratio of total actual journey time divided by total scheduled journey time is used as a measure of the “journey time” performance KPI of a TOC.

3.1.3. Resource usage

The essential resources that railway train operators have on hand are rolling stocks and human resources. Human and vehicle resources are not well utilized if a scheduled train does not run due to a railway train operator-caused cancellation. If a scheduled train on the timetable is not running due to a cancellation caused by the railway train operator means; poor usage of human and vehicle resources for the train operating company.

In this study, for a freight train operating company, in a given time period, the ratio of the number of trains operated divided by the number of trains scheduled on the timetable; is determined measure of “resource usage” KPI.

3.1.4. Profitability

Profit is the positive difference between the income and expenses of companies in a certain period of time. Profit is a significant concept for companies and is one of the tools used to measure the performance of companies. While profit is an absolute size, profitability is a relative concept (Cavlak, 2021).

Profitability is the results obtained as a result of the operation of a company. While profit is an absolute indicator, profitability is a relative indicator and reflects the degree of profitability of the company. As an effective indicator, profitability characterizes the growth or decrease in the volume of activity and efficiency of a company (Filatov, 2022).

In this study, profitability is determined as a performance evaluation KPI for railway freight train operating companies.

3.1.5. Safety

Safety is one of the most important and essential elements in the performance of a train operating company (TOC), and it affects customers, railway infrastructure manager (IM), stakeholders plus the reputation of the TOC. The safety performance level of train operating companies is an important topic for all stakeholders in the railway sector. Although railways provide safe and sustainable transportation worldwide, accidents occur, which have vital and economic effects and are caused by various reasons (Vedasingha, Perera, Hathurusinghe, Akalanka, Amarasena and Dissanayake, 2021).

An undesirable, unexpected, sudden, and unintentional event or chain of events with harmful consequences such as material damage, death, or injury is defined as an accident in railways (TCDD, 2019). According to TCDD - Safety Management Report (2019), there are six main types of accidents: collision, level crossing accidents, fire, derailment, accidents that people are exposed to due to the railway vehicles moving, and the category of other accidents.

In this study, the number of accidents caused by TOC-related issues per million train kilometers is used as a measure of safety KPI. The lower this ratio, the higher the safety performance. The train kilometer is a unit of measure representing the movement of a train over one kilometer.

3.1.6. Innovation & growth

For each organization, innovation must be a key issue, and its role in growth should be addressed by companies of all sizes, small or large. There are many definitions related to innovation in different contexts in literature. In contrast, all definitions state that innovation has a common sense of changing or improving the process or product (Tohidi and Jabbari, 2012). According to the OECD Oslo Manuel textbook (2005); All technological, organizational, financial, and commercial activities prompting innovation are recognized as innovative activities. A railway freight TOC can perform innovative activities to increase digitalization in operational processes, enhance the safety of operations, improve rolling stock maintenance operations, modernize rolling stocks, etc.

In this study, “innovation & growth” is specified as a performance evaluation KPI for railway freight train operating companies.

3.1.7. Environment

Greenhouse gas consists of a combination of gases that create a greenhouse effect in the atmosphere (Krezo, Mirza, He, Makim and Kaewunruen, 2016). The entire transportation sector makes a contribution crucially to environmental pollution by generating around 14% of greenhouse gas emissions globally (Ogochukwu, Ogochukwu, Ogorchukwu and Ebuka, 2022).

Although railway freight transportation is seen as an environmentally friendly transportation system globally, some greenhouse gas is released into the atmosphere depending on the engine types used. Freight trains are hauled with diesel, electric, or hybrid engine locomotives. In railways, freight transporting using diesel locomotives means emitting thousands of tons of pollutants into the atmosphere (Carvalhaes, de Alvarenga Rosa, de Almeida D’Agosto and Ribeiro, 2017). On the other hand, there are no visible pollutant emissions from electric locomotives (Gangwar and Sharma, 2014).

Hybrid locomotives operating in electric and diesel modes have the same characteristics of being environment friendly as electric locomotives operating on electrified lines. Therefore, both locomotives are placed in the same category in this study.

In this study, for the environmental friendliness measure of a freight train operating company, the ratio of total hybrid and electric locomotives divided by the total locomotives in its rolling stock is used.

3.2. Determination of relative weights of KPIs

In this chapter, methods and approaches for deriving criteria weights are reviewed. Determining weights of criteria is necessary in many multi-criteria decision making (MCDM) techniques. Weighting methods aim to assign values to different criteria to indicate their relative importance in a MCDM method (Zardari, Ahmed, Shirazi and Yusop, 2014). In this study, criteria correspond to KPIs.

In literature, several methods have been proposed to determine weights to the criteria. The simplest way to assign weights to criteria is with the equal weights method, which distributes the weights equally among all criteria. However, it has been criticized because it ignores the relative importance of criteria (Wang, Jing, Zhang and Zhao, 2009).

There are also rank order methods and these are divided into three groups; subjective weighting methods, objective weighting methods and combination weighting methods (Odu, 2019). In the revised Figure 3.1 below these methods are classified.

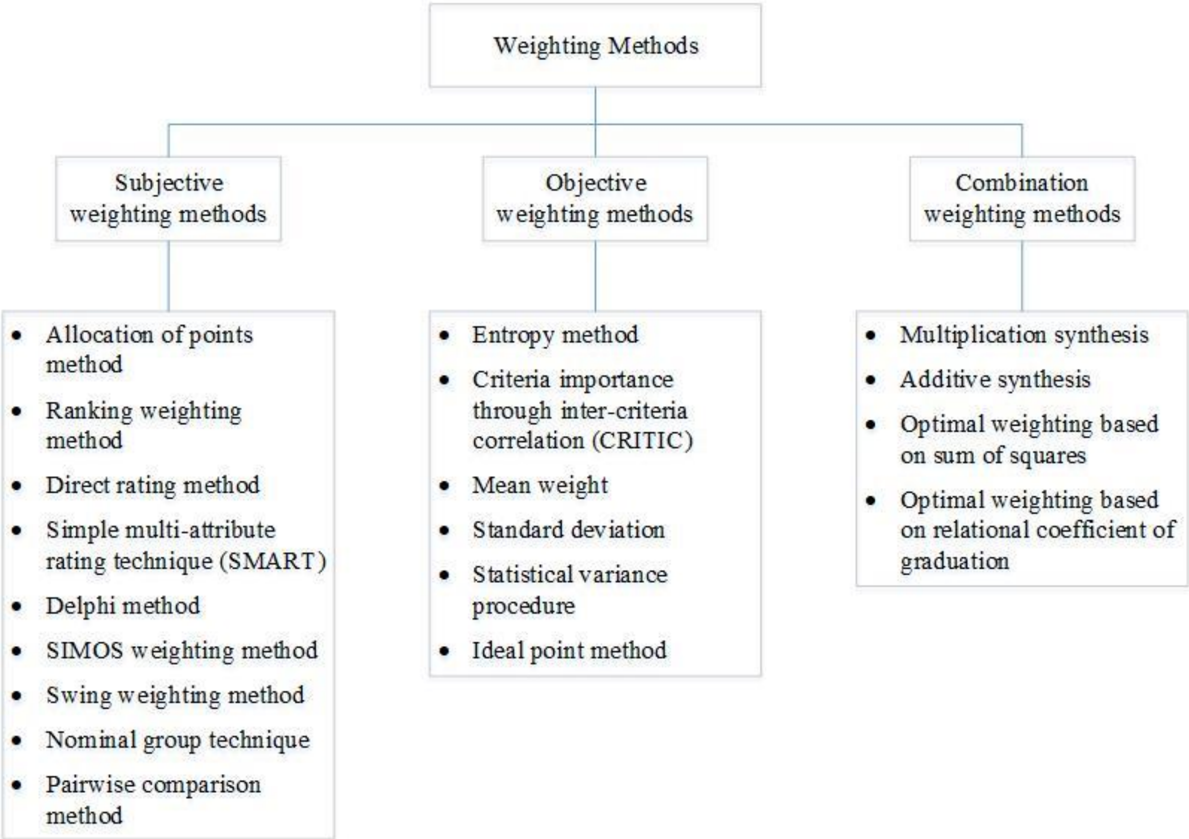

Figure 3.1. Classification of weighting methods (Odu, 2019; Zardari et al., 2014).

Subjective weighting methods determine the criteria weights according to the expert opinions while, objective weighting methods use statistical evaluation of data in decision matrix to determine criteria weights.

Combined weighting methods are derived from both subjective and objective information about criteria weights. Evaluations of decision makers are dependent on experience and knowledge so this can affect the decision process to some extent. Hence, the literature is of the opinion that neither of the two approaches (subjective and objective methods) are perfect and the combined method may be the most appropriate for determining criteria weights (Odu, 2019).

Rao and Patel (2010) have proposed a model that considering the objective weights of importance of the attributes as well as the subjective preferences of the decision maker to decide the integrated weights of importance of the criteria. Al-Aomar (2010) have derived subjective and objective criteria weights by combining the AHP and Shannon's entropy method. These studies mentioned are examples of combined weighting methods.

3.2.1. Popular Subjective Weighting Methods

Allocation of points, this is a simple method in which a decision maker is asked to divide 100 points among the criteria (Golaszewski, Sheth, Helledy and Gutierrez-Nolasco, 2012).

Ranking weighting method, this method uses a simple approach like allocation of points method to determine criteria weights. Fundamentally, the criteria are ranked according to decision maker’s opinion in order from most important to least important. Then, with using rank sum, rank reciprocal or the rank exponent method criteria weights are calculated (Malczewski, 1999).

Direct rating method, in this method decision maker ranks all criteria according to their importance. Like Likert-scale questionnaire, number ranges 1-5, 1-7, 1-10 can be used to scaling. It is possible in this method that changing the importance of one criterion without adjusting the weight of the others (Nijkamp, Rietveld and Voogd, 1990).

Simple multi-attribute rating technique (SMART), developed by Edwards in 1971, in this technique, expert is asked to rank the criteria in terms of their importance. The most important criteria take 100 points; with decreasing number of points the least important criteria take 10 points. Then, to calculate the criteria weights the sum of the points assigned to criteria is normalized to one (Patel, Vashi and Bhatt, 2017). On this basis, Edwards and Barron (1994) have introduced new versions of this technique such as SMARTS and SMARTER.

Delphi method, can be defined as a multi-stage process, each stage of which is built on the data of the previous stage. The Delphi process begins with a starting questionnaire. This stage can be defined an idea gathering strategy and aims to identify all topics related to the research topic. The feedback of the first round is given as the second questionnaire and opinions are asked about the mentioned issues. This process continues in subsequent rounds until consensus is reached. Delphi technique aims to reconcile a group of experts who look at a problem from different angles without coming face to face (Torağay and Arıkan, 2015).

SIMOS method, first proposed by Jean Simos in 1990, was further developed by Figueira and Roy (2002). The developed method can be summed up into four stages (Zardari et al., 2014). In first stage, n colored cards with the name of the criteria and purpose of the criteria as many as the number of criteria are given to each decision makers. A number of white cards are also given. In the second stage, the decision makers are asked to rank the cards from the least important to the most important. In the third stage, decision makers are asked to place the white cards between two consecutive colored cards to express their strong preference among the criteria. The number of white cards is proportional to the difference in the importance of the criteria considered. In the last step, the decision makers are asked to answer the question of how many times the first ranked criterion is more important than the last ranked criterion.

3.2.2. Popular Objective Weighting Methods

Entropy method, the concept of entropy is used to mean that measuring the uncertainty associated with a random variable (Karaca and Ulutaş, 2018). In MCDM the entropy measure is a way used for the objective calculation of criteria weights (Atan and Altan, 2020). The high entropy value calculated for a criterion is due to the small differences between the alternatives and it is means that this criterion provides little information for the decision. Therefore, the entropy value is small (Wang and Lee, 2009). This method is applied with the following steps respectively, formation of decision matrix, normalizing decision matrix, calculation of entropy values and, determination of criteria weights (Karakaş, Kıngır and Öztel, 2016).

CRITIC (Criteria importance through inter-criteria correlation) method, was introduced to the literature by Diakoulaki, Mavrotas and Papayannakis (1995), performs an objective weighting by using the standard deviations of the criteria and the correlation between the criteria (Demircioğlu and Çoşkun, 2018).

Statistical variance procedure is a not subjective weighting method assigning weights to each criterion by means of variances objectively (Tayalı and Timor, 2017).

Mean weight, this method grounds on the assumption that all criteria are of equal importance. When there is no sufficient information to make a decision this method can be harnessed (Vavrek, 2019).

3.2.3. Analytical Hierarchy Process (AHP) Method

The Analytical Hierarchy Process (AHP), developed by Thomas L. Saaty in the 1970s, offers solutions to multi-criteria decision making problems. The method simplifies complex problems by analyzing the relationship between criteria, sub-criteria and alternatives. (Polat, 2016).

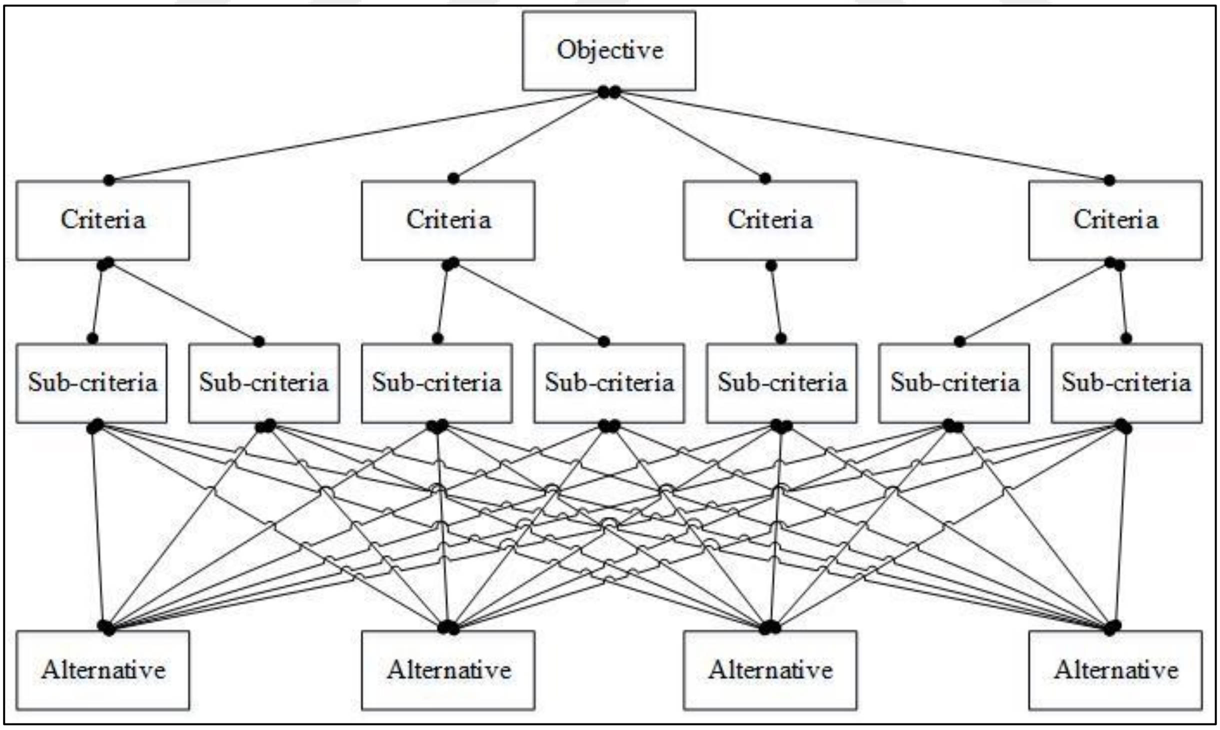

Figure 3.2. Hierarchical structure of AHP.

AHP is based on three basic principles: creating hierarchies, determining advantages, and ensuring logical and numerical consistency (Aydın, Öznehir and Akçalı, 2009). Figure 3.2 above represents hierarchical structure of AHP.

AHP is a technique of evaluation through pairwise comparisons and based on the judgments of experts to derive priority scales. AHP's steps are as follows (Saaty, 1980; Saaty, 2008).

In the first step of AHP, the problem is defined. In this step, the decision points and the factors affecting these points are determined. It is important to determine these criteria correctly in order to obtain consistent and logical results.

In the second step, the comparison matrix is formed. At this stage, factors are evaluated according to their importance. It is a critical step and considered as a backbone of AHP. The intensity of this scale ranges from one to nine. The pairwise comparison scale used in the AHP method to measure relative importance of the items is shown in the Table 3.3.

Table 3.3. Pairwise comparison scale in AHP method (Saaty, 1980).

Intensity of importance	Definition	Explanation
1	Equal importance	Judgment favors both criteria equally
3	Moderate importance	Judgment slightly favors one criterion over another
5	Strong importance	Judgment strongly favors one criterion over another
7	Very strong importance	One criterion is favored strongly over the another
9	Extreme importance	There is evidence affirming that one criterion is favored over another
2, 4, 6, 8	Intermediate values between above scale values	Absolute judgment cannot be given and a compromise is required

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \dots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \tag{3.1}$$

The above matrix A represents the relative importance of alternatives as $n * n$ matrix, where "n" is the number of items being evaluated. In the matrix to be formed, the points on the diagonals to be 1. Because the relevant factor is compared with itself. And the other components must have $a_{ij} = 1/a_{ji}$.

In the third step, each element in the pairwise comparison matrix is divided by its column sum. Thus, B column vectors are formed, n times B vectors form the C matrix.

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} aij} \tag{3.2}$$

$$B = \begin{bmatrix} b_{11} \\ b_{12} \\ \vdots \\ b_{1n} \end{bmatrix} \tag{3.3}$$

$$C = \begin{bmatrix} c_{11} & c_{12} & \dots & c_{1n} \\ c_{21} & c_{22} & \dots & c_{2n} \\ \vdots & \vdots & \dots & \vdots \\ c_{n1} & c_{n2} & \dots & c_{nn} \end{bmatrix} \tag{3.4}$$

In the obtained C matrix, the arithmetic mean of each row is calculated and the priority vector denoted by WP matrix is formed.

$$w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n} \tag{3.5}$$

$$WP = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \tag{3.6}$$

After this stage, consistency analysis to be done. While performing the consistency analysis, firstly the A matrix and the WP priority vector are multiplied to obtain the DC column vector.

$$DC = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \dots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} * \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \tag{3.7}$$

The E value is obtained by dividing the elements of the D matrix and the w vector. The arithmetic mean of sum of these E values gives us the value of λ.

$$E_i = \frac{d_i}{w_i} \qquad i = 1, 2, \dots, n \tag{3.8}$$

$$\lambda = \frac{\sum_{i=1}^{n} E_i}{n} \tag{3.9}$$

After obtaining the λ value, the consistency index (CI) and consistency ratio (CR) are calculated. The RI value in the equation used for calculating CR is the random index and it is can be found in the Table 3.4.

$$CI = \frac{\lambda - n}{n - 1} \tag{3.10}$$

$$CR = \frac{CI}{RI} \tag{3.11}$$

Table 3.4. Random index (RI) values in AHP (Saaty, 1980).

	n											
	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49	1,51	1,48

For the comparisons to be consistent, CR value should be equal to or less than 0,10. If not, a revision in the pairwise comparison is required (Saaty, Vargas and Kearns, 1991). If the consistency ratio is equal to 0, it means that a completely consistent matrix has been obtained. However, complete consistency is often not possible (Aydın et al., 2009).

3.2.4. Fuzzy Analytical Hierarchy Process (FAHP) Methods

AHP method is generally used in nearly crisp decision applications; does not take into account the uncertainty associated with the mapping of human judgment to a number; the subjective judgment, selection and preference of decision makers have great influence on the AHP results (Yang and Chen, 2004). In order to overcome these shortcomings, AHP method is combined with fuzzy logic and the fuzzy AHP approach is used as a new method. In the classical AHP method, decision makers cannot fully express their uncertainty because they use numerical values while making their evaluations. With FAHP methods, uncertainties arising from decision makers' preferences are minimized (Koç Ustalı and Tosun, 2019).

In this study, Buckley's and Chang's fuzzy AHP methods have been utilized.

3.2.4.1. Buckley's Method

Buckley (1985) extended the pure AHP method by using fuzzy triangular numbers in comparison ratios (Ayhan, 2013).

The steps of Buckley's fuzzy AHP approach are as follows (Ayhan, 2013).

In the first step, fuzzy comparison matrix is formed. If there are more than one decision makers, preferences of each decision maker is combined via geometric mean method.

In the second step, the geometric mean of fuzzy comparison values of each criterion is calculated via following formula. In the formula below, $\tilde{r}_i$ is still a fuzzy number.

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij} \right)^{1/n} \quad i = 1, 2, \dots, n \tag{3.12}$$

In the third step, with following formula, the triangular fuzzy weights of each criterion is calculated.

$$\widetilde{w}_i = \tilde{r}_i * (\tilde{r}_1 + \tilde{r}_2 + \cdots + \tilde{r}_n)^{-1} = (lw_i, mw_i, uw_i) \tag{3.13}$$

In the fourth step, the obtained triangular fuzzy weights are defuzzified using the center of area method with the following formula.

$$M_i = \frac{lw_i + mw_i + uw_i}{3} \tag{3.14}$$

In the last step, the obtained crisp values are normalized using the following formula. The N_i values here are the relative weights of each criterion.

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \tag{3.15}$$

3.2.4.2. Chang's Method

Chang (1996) introduced an approach to the literature using triangular fuzzy numbers for pairwise comparison scale of fuzzy AHP and extent analysis method for synthetic extent values of pairwise comparisons. The corresponding triangular fuzzy values for the linguistic variables obtained from decision makers are placed and the pairwise comparison matrix is constructed (Özdağoğlu & Özdağoğlu, 2007). A scale for pairwise comparisons in fuzzy AHP method is presented in the Table 3.5.

Table 3.5. Pairwise comparison scale in fuzzy AHP method (Zaki Mohamed Noor et al., 2017).

Pure AHP scale	Linguistic statement	Triangular fuzzy AHP scale
1	Equal importance	(1,1,1)
2	Intermediate value between 1 and 3	(1,2,3)
3	Moderate importance	(2,3,4)
4	intermediate value between 3 and 5	(3,4,5)
5	Strong importance	(4,5,6)
6	intermediate value between 5 and 7	(5,6,7)
7	Very strong importance	(6,7,8)
8	intermediate value between 7 and 9	(7,8,9)
9	Extreme importance	(8,9,9)

The steps of the extent analysis fuzzy AHP method proposed by Chang (1996) are as follows.

Let $\tilde{A} = (\tilde{a}_{ij})_{n*m}$ be a fuzzy pairwise comparison matrix, where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$.

In the first step, the value of the fuzzy synthetic extent, S_i is calculated with following formulas:

$$S_i = \sum_{j=1}^{m} M_{ij} * \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{ij}\right]^{-1} \tag{3.16a}$$

$$\sum_{j=1}^{m} M_{ij} = \left(\sum_{j=1}^{m} l_{ij}, \sum_{j=1}^{m} m_{ij}, \sum_{j=1}^{m} u_{ij}\right) \quad , i = 1, 2, \ldots, n \tag{3.16b}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{ij} = \left(\sum_{i=1}^{n}\sum_{j=1}^{m} l_{ij}, \sum_{i=1}^{n}\sum_{j=1}^{m} m_{ij}, \sum_{i=1}^{n}\sum_{j=1}^{m} u_{ij}\right) \tag{3.16c}$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{ij}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} u_{ij}}, \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} m_{ij}}, \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} l_{ij}}\right) \tag{3.16d}$$

In the second step, the values of S_i are compared with each other. Both values $V(S_j \geq S_i)$ and $V(S_i \geq S_j)$ are needed to be compared each other (Kılınççı and Önal, 2011). The degree of possibility of $S_j = (l_j, m_j, u_j) \geq S_i = (l_i, m_i, u_i)$ is calculated with following formula:

$$V(S_j \geq S_i) = \text{height}\,(S_i \cap S_j) = \begin{cases} 1 & \text{if } m_j \geq m_i \\ 0 & \text{if } l_i \geq u_j \\ \dfrac{l_i - u_j}{(m_j - u_j) - (m_i - l_i)} & \text{otherwise} \end{cases} \tag{3.17}$$

Figure 3.3 below represents the intersection between S_j and S_i values.

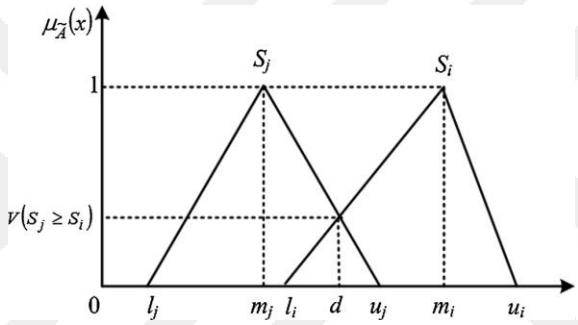

Figure 3.3. The intersection between S_j and S_i (Chen, Hsieh and Do, 2014).

In the third step, the minimum degree of possibility $d\,(i)$ of $V(S_j \geq S_i)$ for i, and $j = 1, 2, \ldots, k$; $k \neq n$ is calculated as following formula:

$$V(S \geq S_1, S_2, S_3, \ldots, S_k) \\ = V[(S \geq S_1) \textit{ and } (S \geq S_2) \textit{ and } \ldots (S \geq S_k)] = \min V\,(S \geq S_i) \quad i = 1, 2, \ldots, k \tag{3.18}$$

Then in the fourth step, assuming that $d'(A_i) = \min V(S \geq S_i)$, for $i = 1, 2, \ldots, k$; the weight vector is defined as following equation:

$$W' = \left(d'(A_1), d'(A_2), \ldots, d'(A_n)\right)^T \tag{3.19}$$

where A_i for $i = 1, 2, 3, \ldots, n$; comprises n elements.

Finally, in the last step, the weight vectors are normalized as follows:

$$W = \left(d(A_1), d(A_2), \ldots, d(A_n)\right)^T \tag{3.20a}$$

$$W = (W_1, W_2, \ldots, W_n)^T \tag{3.20b}$$

where $W_1, W_2, \ldots, W_n$ are non-fuzzy numbers. They are the priority weights of one alternative over another.

3.2.5. Application of AHP and fuzzy AHP Methods

While there are many problem solving techniques that can be used in the presence of quantitative variables and criteria, different approaches are needed when there is a necessity to make a decision with qualitative variables. In such cases, one of the most preferred techniques is the Analytical Hierarchy Process (Özdağoğlu & Özdağoğlu, 2007).

AHP provides opportunity that overcoming decision makers bias to validate decision makers' evaluation via consistency ratio calculation (Hamidah, Mohd Hasmadi, Chua, Yong, Lau, Faridah-Hanum and Pakhriazad, 2022). AHP produce clear and distinctive results for MCDM methods to be used in the evaluation of alternatives. When there is no available quantitative data about criteria, AHP is the one of the weighting method to be used. AHP is the most transparent and scientifically sound method for determining weights that represent the relative importance of criteria (Zardari et al., 2014). In the AHP method, more than one decision maker can be involved in the decision making process. The experience and knowledge of decision makers are also included in evaluation process along with the data about criteria used in decision making. For the reasons mentioned above, this method is preferable.

FAHP is a synthetic approach developed as an extension of AHP, which emerges when it is considered that there is a certain fuzziness in the comments and evaluations of decision makers (Özdağoğlu & Özdağoğlu, 2007).

In this study, AHP and FAHP methods has been used to determine the KPI weights.

3.2.5.1. Application of AHP Method

In order to construct the pairwise comparison matrices, a questionnaire form was designed and conducted to eight experts in interviews face to face. The questionnaire form designed is provided in Appendix A.

The experts are working as department manager or department assistant manager at TCDD. Each of the experts has substantial knowledge about the railway industry and its operation, and is able to identify the requirements of different stakeholders. The information of the experts involved in the process is as in Table 3.2. In this process Saaty's pairwise comparison scale provided in Table 3.3 was used.

The AHP methodology and the purpose of the process had been explained to experts before the interview questions were answered. Pairwise comparison scale introduced by Saaty should be known for answering the questionnaire. So it has been clarified for experts how linguistic expressions are converted to numerical values in the mechanism.

Table 3.6. AHP aggregated pairwise comparison matrix.

	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
Punctuality	1,00	2,24	2,30	3,69	0,25	2,80	2,95
Journey time	0,45	1,00	1,22	2,41	0,27	2,18	1,33
Resource usage	0,43	0,82	1,00	2,13	0,30	1,87	1,51
Profitability	0,27	0,42	0,47	1,00	0,19	0,89	0,82
Safety	4,00	3,69	3,38	5,27	1,00	5,11	4,12
Innovation & growth	0,36	0,46	0,53	1,13	0,20	1,00	1,00
Environment	0,34	0,75	0,66	1,21	0,24	1,00	1,00
Sum	6,85	9,37	9,56	16,84	2,45	14,84	12,74

After experts were asked to evaluate KPIs through the designed questionnaire, their linguistic expressions have been converted to numerical values and pairwise comparison matrices have been formed for each expert. Pairwise comparison matrices formed based on eight experts' evaluations of KPIs have been aggregated in one comparison matrix by geometric mean method and shown in the Table 3.6 above. The questionnaire forms answered by experts and pairwise comparison matrices formed are provided in Appendix A. All these operations and calculations have been performed in Microsoft Excel 2016.

Using Formula 3.2 each element in the matrix has been divided by its column sum in order to be normalized. The sum of each column of the normalized matrix is 1. The normalized matrix is presented in the Table 3.7 below.

Table 3.7. AHP normalized comparison matrix.

	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
Punctuality	0,15	0,24	0,24	0,22	0,10	0,19	0,23
Journey time	0,07	0,11	0,13	0,14	0,11	0,15	0,10
Resource usage	0,06	0,09	0,10	0,13	0,12	0,13	0,12
Profitability	0,04	0,04	0,05	0,06	0,08	0,06	0,06
Safety	0,58	0,39	0,35	0,31	0,41	0,34	0,32
Innovation & growth	0,05	0,05	0,06	0,07	0,08	0,07	0,08
Environment	0,05	0,08	0,07	0,07	0,10	0,07	0,08

Using Formula 3.5 mean of each row has been calculated and relative weights of the KPIs (criteria) have determined as shown in the Table 3.8 below.

Table 3.8. Relative weights of KPIs obtained by AHP.

KPI	Relative weight
Punctuality	0,1952
Journey time	0,1149
Resource usage	0,1068
Profitability	0,0564
Safety	0,3886
Innovation & growth	0,0643
Environment	0,0737

After determining KPI weights, the consistency analysis should be done. Using Formulas 3.10 and 3.11 the consistency index (CI) and consistency ratio (CR) have been calculated. The calculations are shown in the Table 3.9 below. In here according to Table 3.4 random index (RI) is 1,32 because there are seven criteria in the decision matrix.

Table 3.9. AHP consistency analysis result.

RI	CI	CR
1,32	0,0237	0,0180

The aggregated pairwise comparison matrix is consistent because the CR value is less than 0,10.

3.2.5.2. Application of Chang's fuzzy AHP (FAHP) method

According to the responses of the experts in the AHP method applied to determine the KPI weights, triangular fuzzy values corresponding to the linguistic variables were placed and pairwise comparison matrices were created. In this process, matrices with consistency ratio of less than 0.1 have been used. The scale provided in the Table 3.5 have been used in this process.

Pairwise comparison matrices formed based on eight experts' evaluations of KPIs have been aggregated in one comparison matrix by geometric mean method and shown in the Table 3.10. The pairwise comparison matrices based on triangular fuzzy numbers are provided in Appendix B. All these operations and calculations have been performed in Microsoft Excel 2016.

Table 3.10. Fuzzy AHP aggregated comparison matrix.

	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
	(l, m, u)	(l, m, u)	(l, m, u)	(l, m, u)	(l, m, u)	(l, m, u)	(l, m, u)
Punctuality	(1, 1, 1)	(1,77, 2,24, 2,63)	(1,83, 2,3, 2,87)	(2,77, 3,69, 4,49)	(0,21, 0,25, 0,32)	(2,1, 2,8, 3,34)	(2,29, 2,95, 3,46)
Journey time	(0,38, 0,45, 0,57)	(1, 1, 1)	(0,87, 1,22, 1,51)	(1,77, 2,41, 3,02)	(0,24, 0,27, 0,37)	(1,49, 2,18, 2,77)	(1,09, 1,33, 1,57)
Resource usage	(0,35, 0,43, 0,68)	(0,66, 0,82, 1,15)	(1, 1, 1)	(1,62, 2,13, 2,54)	(0,26, 0,3, 0,35)	(1,54, 1,87, 2,14)	(1,3, 1,51, 1,68)
Profitability	(0,22, 0,27, 0,36)	(0,33, 0,42, 0,57)	(0,39, 0,47, 0,62)	(1, 1, 1)	(0,17, 0,19, 0,25)	(0,65, 0,89, 1,11)	(0,73, 0,82, 0,95)
Safety	(3,13, 4, 4,73)	(2,73, 3,69, 4,12)	(2,83, 3,38, 3,83)	(4,06, 5,27, 5,91)	(1, 1, 1)	(3,92, 5,11, 6,13)	(3,59, 4,12, 4,49)
Innovation & growth	(0,3, 0,36, 0,48)	(0,36, 0,46, 0,67)	(0,47, 0,53, 0,65)	(0,9, 1,13, 1,54)	(0,16, 0,2, 0,26)	(1, 1, 1)	(0,87, 1, 1,15)
Environment	(0,29, 0,34, 0,44)	(0,64, 0,75, 0,92)	(0,59, 0,66, 0,77)	(1,05, 1,21, 1,36)	(0,22, 0,24, 0,28)	(0,87, 1, 1,15)	(1, 1, 1)

Using Formula 3.16a fuzzy synthetic extent values *(S_i)* have been calculated for each KPI as in the Table 3.11 below.

Table 3.11. Fuzzy synthetic extent values.

KPI	$\mathbf{S_i}$
	(l, m, u)
Punctuality	(0,1407, 0,2096, 0,3069)
Journey time	(0,0803, 0,1219, 0,1828)
Resource usage	(0,0791, 0,1110, 0,1616)
Profitability	(0,0411, 0,0558, 0,0821)
Safety	(0,2495, 0,3657, 0,5117)
Innovation & growth	(0,0478, 0,0644, 0,0972)
Environment	(0,0548, 0,0717, 0,1002)

Using Formula 3.17, fuzzy synthetic extent values have been compared with each other and the degree of possibilities have been calculated. Then using Formula 3.18, the minimum degree of possibilities has been determined for each KPI as in the Table 3.12 below.

Table 3.12. Fuzzy AHP minimum degree of possibilities.

KPI	$\mathbf{min\ V\ (S \geq S_i)}$
Punctuality	0,269
Journey time	0,000
Resource usage	0,000
Profitability	0,000
Safety	1,000
Innovation & growth	0,000
Environment	0,000

Finally, the weight vectors have been normalized and KPI weights have been determined as in the Table 3.13 below.

Table 3.13. Relative weights of KPIs obtained by Chang's fuzzy AHP approach.

KPI	Relative weight
Punctuality	0,2118
Journey time	0,0000
Resource usage	0,0000
Profitability	0,0000
Safety	0,7882
Innovation & growth	0,0000
Environment	0,0000

3.2.5.3. Application of Buckley's fuzzy AHP (FAHP) method

Using Formula 3.12 the geometric mean of fuzzy comparison values of each criterion have been calculated as in the Table 3.14 below.

Table 3.14. Geometric means of fuzzy comparison values.

KPI	$\tilde{r}_i$
	(l, m, u)
Punctuality	(1,3726, 1,6886, 1,9944)
Journey time	(0,8110, 1,0044, 1,2230)
Resource usage	(0,7919, 0,9373, 1,1413)
Profitability	(0,4207, 0,4955, 0,6132)
Safety	(2,8087, 3,4250, 3,8327)
Innovation & growth	(0,4871, 0,5693, 0,7129)
Environment	(0,5811, 0,6511, 0,7507)

Using Formula 3.13 triangular fuzzy weights of each KPI has been calculated as in the Table 3.15 below.

Table 3.15. Relative triangular fuzzy weights of KPIs.

KPI	$\tilde{w}_i$
	(l, m, u)
Punctuality	(0,1337, 0,1925, 0,2742)
Journey time	(0,0790, 0,1145, 0,1682)
Resource usage	(0,0771, 0,1069, 0,1569)
Profitability	(0,0410, 0,0565, 0,0843)
Safety	(0,2735, 0,3905, 0,5270)
Innovation & growth	(0,0474, 0,0649, 0,0980)
Environment	(0,0566, 0,0742, 0,1032)

Then, using Formula 3.14 triangular fuzzy weights have been defuzzified and crisp weights of each KPI has been obtained as in the Table 3.16. The relative crisp weight of each KPI (M_i) has been calculated by taking the average of fuzzy numbers for each KPI.

Table 3.16. Averaged relative weights (M_i) of KPIs.

KPI	$\mathbf{M_i}$
Punctuality	0,2001
Journey time	0,1205
Resource usage	0,1136
Profitability	0,0606
Safety	0,3970
Innovation & growth	0,0701
Environment	0,0780

Finally, with Formula 3.15, by using M_i values the normalized weights of each KPI have been calculated and normalized relative weights (N_i) obtained are as in the Table 3.17 below.

Table 3.17. Relative weights of KPIs obtained by Buckley's fuzzy AHP approach.

KPI	N_i
Punctuality	0,1924
Journey time	0,1159
Resource usage	0,1093
Profitability	0,0583
Safety	0,3817
Innovation & growth	0,0674
Environment	0,0750

3.2.5.4. Comparison of AHP and fuzzy AHP results

When classical AHP is applied to determine the weight of KPIs, safety and punctuality are the two most important KPIs, as in the fuzzy AHP methods. However, as seen in the Table 3.18, remaining KPIs' weights are calculated as zero in the Chang's fuzzy AHP method.

Table 3.18. KPI weights obtained with pure AHP and fuzzy AHP methods.

KPI	AHP	Chang's FAHP	Buckley's FAHP
Punctuality	0,1952	0,2118	0,1924
Journey time	0,1149	0,0000	0,1159
Resource usage	0,1068	0,0000	0,1093
Profitability	0,0564	0,0000	0,0583
Safety	0,3886	0,7882	0,3817
Innovation & growth	0,0643	0,0000	0,0674
Environment	0,0737	0,0000	0,0750

Since the Chang's fuzzy AHP approach takes the minimum degree of possibility from the degree of possibilities of pairwise comparisons of the alternatives, the KPI weights are calculated as zero except for safety and punctuality. According to this result, it was concluded that the Chang's fuzzy AHP approach is not suitable for this study and the KPI weights obtained by the Buckley's fuzzy AHP approach should be used for performance evaluation.

3.3. Data Collection

In this study, the data of the TOCs' operations in 2021 obtained through the TCDD Enterprise Resource Planning system is used. The data from these operations have been used to determine the performance values of punctuality, journey time, resource usage, safety and environment KPIs.

The data to be used to determine the performance values of "innovation & growth" and "profitability" KPIs could not be obtained because of having strategic importance for companies. Therefore, in order to determine these KPIs' performance values, AHP technique has been used. In order to determine the performance values of these KPIs for each TOC, face to face interviews have been held with the same experts group in the focus group process and KPI weight determination process in Section 3.2.5 and Section 3.1. Experts were informed about the purpose of the process first and asked to evaluate three freight TOCs in terms of "innovation & growth" and "profitability" KPIs separately. Through this process, "innovation & growth" and "profitability" KPI performance values have been generated respectively. The questionnaire forms designed, all questionnaire forms answered and pairwise comparison matrices are provided in the Appendix C and D.

Pairwise comparison matrices formed based on eight experts' evaluations on "profitability" of each TOC have been aggregated in one comparison matrix by geometric mean method and shown in the Table 3.19 below.

Table 3.19. Aggregated pairwise comparison matrix for profitability KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	0,32	0,28
TOC 2	3,11	1,00	1,44
TOC 3	3,53	0,69	1,00
Sum	**7,65**	**2,01**	**2,72**

Using Formula 3.2 each element in the matrix has been divided by its column sum in order to be normalized. The sum of each column of the normalized matrix is 1. The normalized matrix is shown in the Table 3.20 below.

Table 3.20. Normalized comparison matrix for profitability KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	0,13	0,16	0,10
TOC 2	0,41	0,50	0,53
TOC 3	0,46	0,34	0,37

Using Formula 3.5 mean of each row has been calculated and performance values of "profitability" KPI of TOCs have been determined as in the Table 3.21 below.

Table 3.21. Performance values of profitability KPI of TOCs.

TOC	**Profitability KPI performance value**
TOC 1	0,1314
TOC 2	0,4775
TOC 3	0,3911

Using Formulas 3.10 and 3.11, the consistency index (CI) and consistency ratio (CR) have been calculated. The calculations are shown in the Table 3.22 below. In here, according to Table 3.4, random index (RI) is 0,58 because there are three criteria in the decision matrix.

Table 3.22. Consistency analysis result for profitability KPI.

RI	**CI**	**CR**
0,58	0,0135	0,0233

The aggregated pairwise comparison matrix is consistent because the CR value is less than 0,10.

As “profitability” KPI performance values were obtained, “innovation and growth” KPI performance values were obtained in the similar way. Pairwise comparison matrices formed based on eight experts’ evaluations on “innovation and growth” related performance of each TOC have been aggregated in one comparison matrix by geometric mean method and shown in the Table 3.23 below.

Table 3.23. Aggregated pairwise comparison matrix for innovation & growth KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	0,49	0,41
TOC 2	2,04	1,00	1,25
TOC 3	2,46	0,80	1,00
Sum	**5,50**	**2,29**	**2,66**

Using Formula 3.2 each element in the matrix has been divided by its column sum in order to be normalized. The sum of each column of the normalized matrix is 1. The normalized matrix is shown in the Table 3.24 below.

Table 3.24. Normalized comparison matrix for innovation & growth KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	0,18	0,21	0,15
TOC 2	0,37	0,44	0,47
TOC 3	0,45	0,35	0,38

Table 3.25. Performance values of innovation & growth KPI of TOCs.

TOC	**Innovation & growth KPI performance value**
TOC 1	0,1314
TOC 2	0,4775
TOC 3	0,3911

Using Formula 3.5 mean of each row has been calculated and performance values of "innovation & growth" KPI of TOCs have been determined as in the Table 3.25 above.

Using Formulas 3.10 and 3.11, the consistency index (CI) and consistency ratio (CR) have been calculated. The calculations are shown in the Table 3.26 below. In here, according to Table 3.4 random index (RI) is 0,58 because there are three criteria in the decision matrix.

Table 3.26. AHP consistency analysis result for innovation & growth KPI.

RI	CI	CR
0,58	0,0095	0,0163

The aggregated pairwise comparison matrix is consistent because the CR value is less than 0,10.

The tables below present the all performance values of KPIs of each TOC.

Table 3.27. Punctuality KPI performance values.

TOC	On time train number	Total train number	KPI performance value
TOC 1	37612	81737	0,4602
TOC 2	394	2608	0,1511
TOC 3	1211	1871	0,6472

Table 3.28. Journey time KPI performance values.

	Journey times in minutes		
TOC	Total planned	Total actual	KPI performance value
TOC 1	50.106.982	57.676.397	0,8688
TOC 2	2.458.469	3.646.099	0,6743
TOC 3	2.484.700	2.681.821	0,9265

Table 3.29. Resource usage KPI performance values.

TOC	Total planned trains	Total operated trains	KPI performance value
TOC 1	109.544	81.737	0,7462
TOC 2	2.879	2.608	0,9059
TOC 3	2.343	1.871	0,7985

Table 3.30. Safety KPI performance values.

TOC	Accident number	Train-kilometers	KPI performance value
TOC 1	72	24.041.038	2,9949
TOC 2	6	1.410.520	4,2538
TOC 3	2	1.573.451	1,2711

Table 3.31. Environment KPI performance values.

TOC	Number of locomotives by types			KPI performance value
	Diesel locomotives	Hybrid locomotives	Electric locomotives	
TOC 1	266	0	70	0,2083
TOC 2	0	0	15	1,0000
TOC 3	5	7	0	0,5833

Table 3.32. Innovation & growth KPI performance values.

TOC	KPI performance value
TOC 1	0,1829
TOC 2	0,4261
TOC 3	0,3910

Table 3.33. Profitability KPI performance values.

TOC	KPI performance value
TOC 1	0,1314
TOC 2	0,4775
TOC 3	0,3911

3.4. MCDM methods used in performance evaluation

MCDM methods have been developed to select the best among a certain number of alternatives or to rank the alternatives, and can also be used to compare or rank companies. (Şahin and Karaoğlan, 2018). MCDM methods are used in many fields, including evaluation of investment alternatives, selecting of delivery plans, rating companies, supplier selection, performance evaluation, location selection, determining, evaluation and selection of materials in production and many others (Stojčić, Zavadskas, Pamučar, Stević and Mardani, 2019).

MCDM splits into two branches: multi-attribute decision making (MADM) and multi-objective decision making (MODM), there are a limited number of alternatives in MADM, while in MODM, the number of alternatives is unlimited (Yalçın, Kılınç and Delen, 2022). The subject of this thesis study is related to MADM. Moreover, according to their common characteristics, MADM techniques are divided into six subgroups: outranking, distance-based, pairwise comparison, utility-based, interaction-based and other techniques.

There are many MCDM methods in the literature. Some of important methods are these: ELECTRE (Elimination and Choice Translating Reality English) method, an outranking approach, first introduced by Beneyoun in 1966; SAW (Simple Additive Weighting) which is an old and simple method summarized by MacCrimmon in 1968; AHP which is a pairwise comparison approach introduced by Saaty in 1980; TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) developed by Hwang and Yoon in 1981; PROMETHEE (Preference Ranking Organization METHod for enrichment evaluation) which has six extensions today, first developed by Brans in 1982 and then extended by Vencke and Brans in 1985; ANP (Analytic Network Process) introduced by Saaty in 1996 which takes into account relationships between the criteria in the decision-making process unlike AHP; COPRAS (Complex Proportional Assessment) method developed by Zavadskas and Kaklauskas in 1996; VIKOR (VIekriterijumsko KOmpromisno Rangiranje) method which proposed by Opricovic in 1998; WASPAS (Weighted Aggregated Sum Product Assessment) method introduced by Zavadskas in 2012; EDAS (Evaluation based on Distance from Average Solution) method proposed in 2015; CODAS (Combinative Distance-based Assessment) method proposed in 2016 (Ayan and Abacıoğlu, 2022; Hwang and Yoon, 1981; Keshavarz Ghorabaee, Zavadskas, Olfat and Turskis, 2015; Muhammad Akram et al., 2019; Nedjati and Izbirak, 2013; Oubahman and Duleba, 2021; Yu and Cheng, 2007; Yücel and Ulutaş, 2009).

Problems in which MCDM methods are used are divided into three groups: selection problems, classification problems and ranking problems (Dalbudak and Rençber, 2020). In this study, EDAS method, a relatively new method, which allows companies to be compared and ranked according to certain criteria, is used as the main method in the performance evaluation of TOCs. The study is supported by using different types of MCDM methods. TOPSIS which is a distance-based approach as EDAS, PROMETHEE II which is an outranking type and COPRAS which is utility-based approach are also used to support the study.

3.4.1. EDAS Method

EDAS (Evaluation Based on Distance from Average Solution) method introduced by Keshavarz Ghorabaee et al. (2015) is a relatively new MCDM method.

The method is a distance based approach using positive and negative distances from the average solution (Mathew and Sahu, 2018). In this method the desirable alternative is related to distance from the average solution. There is no need to calculate ideal and the nadir solution in EDAS method. (Keshavarz Ghorabaee et al., 2015). The authors who developed the method compared the EDAS method with other MCDM methods and tested the validity of the method (Özbek and Engür, 2018).

Steps of applying EDAS method are as follows (Mitra, 2022; Yalçın and Uncu, 2019):

In the first step, the decision matrix with n alternative and m criteria, $D = [x_{ij}]_{n*m}$ is formed. Where x_{ij} is the performance value of i^{th} alternative on j^{th} criterion.

In the second step, AV, the average solution is calculated for each criterion with following equation.

$$AV_j = \frac{\sum_{i=1}^{n} x_{ij}}{n} \tag{3.21}$$

In the third step, PDA, the positive distance from the average values and NDA, the negative distance from the average values are calculated with following equations.

If j^{th} criterion is beneficial;

$$PDA_{ij} = \frac{\max\left(0, \left(x_{ij} - AV_j\right)\right)}{AV_j} \tag{3.22a}$$

$$NDA_{ij} = \frac{\max\left(0, \left(AV_j - x_{ij}\right)\right)}{AV_j} \tag{3.22b}$$

If j^{th} criterion is non-beneficial;

$$PDA_{ij} = \frac{\max\left(0, \left(AV_j - x_{ij}\right)\right)}{AV_j} \tag{3.23a}$$

$$NDA_{ij} = \frac{\max\left(0, \left(x_{ij} - AV_j\right)\right)}{AV_j} \tag{3.23b}$$

In the fourth step, SP_i, weighted sum of the positive distance from the average solution values and SN_i, weighted sum of the negative distance from the average solution values for each alternative are calculated with following formulas, where w_j is the weight of j^{th} criterion.

$$SP_i = \sum_{j=1}^{m} w_j * PDA_{ij} \tag{3.24a}$$

$$SN_i = \sum_{j=1}^{m} w_j * NDA_{ij} \tag{3.24b}$$

In the fifth step, SP_i and SN_i values are normalized using following equations for each alternative.

$$NSP_i = \frac{SP_i}{\max SP_i} \tag{3.25a}$$

$$NSN_i = 1 - \frac{SN_i}{\max SN_i} \tag{3.25b}$$

In the final step, the appraisal score, AS is calculated with using equation 3.40 for each alternative, where $0 \leq AS_i \leq 1$.

$$AS_i = \frac{1}{2} * (NSP_i + NSN_i) \tag{3.26}$$

3.4.2. TOPSIS method

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is one of the MCDM methods developed by Hwang and Yoon (1981). The method is based on the concept that the chosen alternative is the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution. TOPSIS method is a distance-based method like EDAS method. TOPSIS not only reveals the distance of the chosen alternative from the positive and negative ideal solution, but also reveals ideal and non-ideal solutions (Wang et al., 2009).

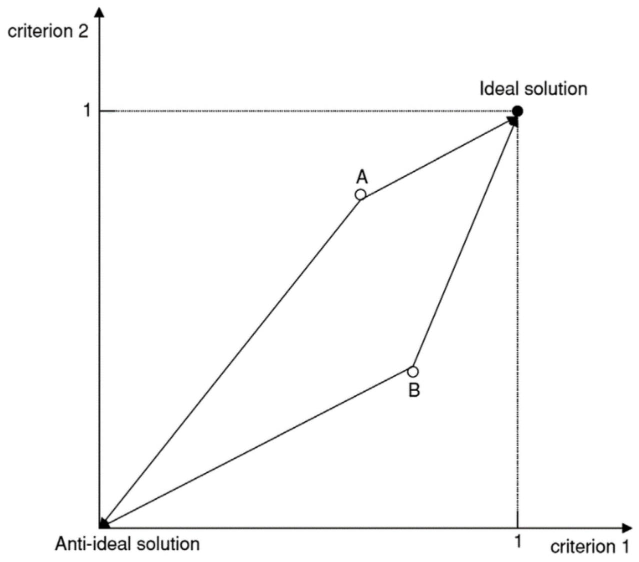

Figure 3.4. TOPSIS illustration with two alternatives and two criteria (Ishizaka and Nemery, 2013).

In the Figure 3.4 above, x being close to the ideal solution and far from the negative ideal solution, is the reason why x should be preferred over y.

The steps followed in the implementation of the TOPSIS method are given below (Monjezi, Dehghani, Singh, Sayadi and Gholinejad, 2012).

In the first step of the method, the decision matrix D is formed. There are m alternatives, $A_1, \dots, A_m$ and n decision criteria, $C_1, \dots, C_n$ in the matrix, then each alternative is evaluated with respect to the n criteria.

$$D = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \dots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \tag{3.27}$$

In the second step, the normalized decision matrix R is calculated with r_{ij} as the normalized value.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n \tag{3.28a}$$

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \vdots & \vdots & \dots & \vdots \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix} \tag{3.28b}$$

In the third step, assuming the criteria weighted matrix WC is as follows.

$$WC = \begin{bmatrix} w_1 & 0 & \dots & 0 \\ & w_2 & \dots & 0 \\ \vdots & \vdots & \dots & \vdots \\ 0 & 0 & \dots & w_n \end{bmatrix} \tag{3.29}$$

The weighted normalized decision matrix V with v_{ij} as weighted normalized value is calculated as follows, w_j is the weight of the j criteria.

$$v_{ij} = w_i * r_{ij} = W * R = V \qquad j = 1, \dots, n; \qquad i = 1, \dots, m; \qquad \sum_{i=1}^{n} w_i = 1 \tag{3.30a}$$

$$V = \begin{bmatrix} w_1 * r_{11} & w_2 * r_{12} & \dots & w_n * r_{1n} \\ w_1 * r_{21} & w_2 * r_{22} & \dots & w_n * r_{2n} \\ \vdots & \vdots & \dots & \vdots \\ w_1 * r_{m1} & w_2 * r_{m2} & \dots & w_n * r_{mn} \end{bmatrix} \tag{3.30b}$$

In the fourth step, the positive ideal solution A^+ and the negative ideal solution A^- are calculated for each criterion. The positive ideal solution consists of the best performance values of the weighted normalized decision matrix and the negative ideal solution consists of the worst values. J and $\hat{J}$ are associated with benefit and cost criteria, respectively (Shyjith, Ilangkumaran and Kumanan, 2008).

$$A^+ = \{v_1^+, \dots, v_n^+\} = \left\{\left(\max_i v_{ij} \,|j \in J\right), \left(\min_j v_{ij} \,|j \in \hat{J}\right)\right\} \tag{3.31a}$$

$$A^- = \{v_1^-, \dots, v_n^-\} = \left\{\left(\min_i v_{ij} \,|j \in J\right), \left(\max_j v_{ij} \,|j \in \hat{J}\right)\right\} \tag{3.31b}$$

In the fifth step, separation measures are calculated. TOPSIS benefits from the Euclidean norm in order to convert the values of each criteria and Euclidean distance to measure how far the alternatives are from both the ideal and negative ideal solutions (Parkan and Wu, 1999). The n-dimensional Euclidean distance of each alternative from the positive ideal solution (S_i^+) and the distance of each alternative from the negative ideal solution (S_i^-) are calculated with the following formulas.

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2} \qquad i = 1, 2, \dots, m \tag{3.32a}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2} \quad i = 1, 2, \dots, m \tag{3.32b}$$

In the sixth step, relative closeness to the ideal solution denoted with C_i^* values for each alternative are calculated via following formula.

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-} \quad i = 1, 2, \dots, m \tag{3.33}$$

In the last step, according to their relative closeness to the ideal solution the alternatives are ranked. In here $0 \leq C_i^* \leq 1$ takes values. With the higher C_i^*, the better is the alternative A_i. The best alternative is the one with the greatest relative closeness to the ideal solution (Atan and Altan, 2020).

3.4.3. PROMETHEE II method

The PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) is a multi-criteria priority determination method developed by Jean Pierre Brans in 1982 (Atan and Altan, 2020). Brans has introduced that partial preorder of the candidate alternatives can be determined within the framework of the criteria by the PROMETHEE (Maity and Chakraborty, 2015). PROMETHEE method is an outranking type method (Yalçın et al., 2022). PROMETHEE II is a version of PROMETHEE and it enables a decision maker to make complete ranking of all alternatives (Abedi, Ali Torabi, Norouzi, Hamzeh and Elyasi, 2012).

The basic principle of PROMETHEE II is based on pairwise comparison of alternatives along each selected criterion. PROMETHEE II requires two additional types of information; these are information about the weights of the criteria and a decision maker's preference functions used to compare alternatives (Dağdeviren and Eraslan, 2008).

The PROMETHEE II method basically involves six steps, these are as follows (Maity and Chakraborty, 2015):

In the first step, the decision matrix consisting of m alternatives and n criteria is formed and normalized with following equations. The weight and type (cost or benefit) for each criterion is chosen. Where $\min_j(x_{ij})$ and $max_j(x_{ij})$ are the minimum and maximum values of x_{ij} respectively.

For benefit criteria:

$$r_{ij} = \frac{x_{ij} - \min(x_{ij})}{max(x_{ij}) - \min(x_{ij})} \qquad (i = 1, 2, \dots, m; j = 1, 2, \dots, n) \tag{3.34a}$$

For cost criteria:

$$r_{ij} = \frac{max(x_{ij}) - x_{ij}}{max(x_{ij}) - \min(x_{ij})} \qquad (i = 1, 2, \dots, m; j = 1, 2, \dots, n) \tag{3.34b}$$

In the second step, the differences d_j of alternative i^{th} with respect to the other alternatives is calculated for each criterion as following formula:

$$d_j(a, b) = g_j(a) - g_j(b) \tag{3.35}$$

where $g_j(a)$ and $g_j(b)$ show the performance of alternatives a and b respectively, with regard to criterion j, and $d_j(a, b)$ denotes the difference between these performances (Abedi et al., 2012).

In the third step, considering the determined preference function, pairwise comparisons of the alternatives are made for each criterion and preference value, $P_j(a, b)$ is calculated.

In this method, there are six main types of preference functions, such as usual criterion, U shape criterion, V shape criterion, level criterion, V shape with indifference criterion and the Gaussian criterion preference functions (Kabir and Sumi, 2014). On the other hand, they require the definition of some parameters, such as indifference and preference thresholds. Hence, the following simplified preference function is preferred generally by researchers (Palczewski and Salabun, 2019).

$$P_j(a,b) = 0 \quad if\ R_{aj} \leq R_{bj}$$
$$P_j(a,b) = (R_{aj} - R_{bj}) \quad if\ R_{aj} > R_{bj} \tag{3.36}$$

In the fourth step, aggregated preference function, $\pi(a,b)$ is calculated taking into account the criteria weights (w_j) via following formula.

$$\pi(a,b) = \left[\sum_{j=1}^{n} w_j * P_j(a,b)\right] / \sum_{j=1}^{n} w_j \tag{3.37}$$

In the fifth step, the leaving and the entering outranking flows respectively; $\varphi^+(a)$ and $\varphi^-(b)$ are determined as follows:

$$\varphi^+(a) = \frac{1}{m-1}\sum_{b=1}^{m} \pi(a,b) \qquad (a \neq b) \tag{3.38a}$$

$$\varphi^-(a) = \frac{1}{m-1}\sum_{b=1}^{m} \pi(b,a) \qquad (a \neq b) \tag{3.38b}$$

Then in the last step, net outranking flow, $\varphi(a)$ for each alternative is calculated with equation 3.29 and the ranking of all the considered alternatives depending on the values of $\varphi(a)$ is determined. The higher the value of $\varphi(a)$, the better is the alternative.

$$\varphi(a) = \varphi^+(a) - \varphi^-(a) \tag{3.39}$$

3.4.4. COPRAS Method

COPRAS (Complex Proportional Assessment) method introduced by the researchers of the Vilnius Gediminas Technical University, Zavadskas and Kaklauskas evaluates the alternatives step by step in terms of their degree of importance and utility on a set of criteria (Yıldırım and Timor, 2019). COPRAS is a utility-based approach (Yalçın et al., 2022). The method examines the effect of maximizing and minimizing criteria on the evaluation result (Altın, 2021). The method determines the degree of significance of alternatives considering both the ideal and the ideal-worst solutions (Görgülü, Özceylan and Özkan, 2021).

The determination of priority and importance of the alternatives according to the COPRAS method is performed in following steps (Bakhouyi, Dehbi and Talea, 2016; Özdağoğlu, Keleş, Altınata and Ulutaş, 2021).

In the first step, the decision matrix is formed and normalized with following formula. R is the normalized decision matrix with n criteria and m alternatives. Where a_{ij} is the performance of the i^{th} alternative with respect to the j^{th} criterion.

$$R = r_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}} \tag{3.40}$$

In the second step, weighted normalized decision matrix is formed; v_{ij}, weighted normalized value is calculated with using the following formula. Where w_j represents the weight of the j^{th} criterion and $\sum_{j=1}^{n} w_j = 1$.

$$v_{ij} = w_j * r_{ij} \qquad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n \tag{3.41}$$

In the third step, total weighted normalized values based on benefit and cost criteria are calculated. In terms of showing the benefit or cost feature of the criterion, the criteria based total weighted normalized values are calculated with the following formulas to show S_{+i} the total of the benefit criteria and S_{-i} the total of the cost criteria.

$$S_{+i} = \sum_{j=1}^{k} v_{ij} \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n \tag{3.42a}$$

$$S_{-i} = \sum_{j=k+1}^{m} v_{ij} \quad i = 1, 2, \dots, m; \quad j = k+1, k+2, \dots, n \tag{3.42b}$$

In the fourth step, relative importance of each alternative (Q_i) is calculated with following formula.

$$Q_i = S_{+i} + \frac{\min S_{-i} * \sum_{i=1}^{m} S_{-i}}{S_{-i} * \sum_{i=1}^{m} \left(\frac{\min S_{-i}}{S_{-i}}\right)} \quad i = 1, 2, \dots, m \tag{3.43}$$

In the last step, the performance index, P_i value of each alternative is calculated with following Formula 3.34. The P_i values obtained are ordered from the largest to the smallest, and the preference order of the alternatives is attained.

$$P_i = \left(\frac{Q_i}{Q_{max}}\right) * 100 \quad i = 1, 2, \dots, m \tag{3.44}$$

3.5. Application of MCDM methods for performance evaluation

3.5.1. Application of EDAS method

For three TOCs (alternatives) and seven KPIs (criteria) the decision matrix formed is as shown in the Table 3.34 below. Using Formula 3.21 average solution (AV_j) has been calculated for each alternative and showed in the Table 3.34. Relative weights of the KPIs contained in the table are obtained via Buckley's FAHP approach as described in Section 3.2.5.3. Safety KPI is non-beneficial criterion and the other KPIs are beneficial criteria.

Table 3.34. EDAS decision matrix and average solutions.

Weightage	0,1924	0,1159	0,1093	0,0583	0,3817	0,0674	0,0750
TOC	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
TOC 1	0,4602	0,8688	0,7462	0,1314	2,9949	0,1829	0,2083
TOC 2	0,1511	0,6743	0,9059	0,4775	4,2538	0,4261	1,0000
TOC 3	0,6472	0,9265	0,7985	0,3911	1,2711	0,3910	0,5833
AV_j	0,4195	0,8232	0,8169	0,3333	2,8399	0,3333	0,5972

(PDA) the positive distance from the average values have been calculated. For safety KPI which is cost criterion, Formula 3.23a has been used and for the benefit criteria Formula 3.22a has been used. Calculations are as in the table below.

Table 3.35. EDAS (PDA) values.

TOC	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
TOC 1	0,0187	0,0064	0,0000	0,0000	0,0000	0,0000	0,0000
TOC 2	0,0000	0,0000	0,0119	0,0252	0,0000	0,0188	0,0506
TOC 3	0,1045	0,0145	0,0000	0,0101	0,2109	0,0117	0,0000

(NDA) the negative distance from the average values have been calculated. For safety KPI which is cost criterion, Formula 3.23b has been used and for the benefit criteria Formula 3.22b has been used. Calculations are as in the tables below.

Table 3.36. EDAS (NDA) values.

TOC	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
TOC 1	0,0000	0,0000	0,0095	0,0353	0,0208	0,0304	0,0488
TOC 2	0,1231	0,0210	0,0000	0,0000	0,1900	0,0000	0,0000
TOC 3	0,0000	0,0000	0,0024	0,0000	0,0000	0,0000	0,0017

With using Formulas 3.24a and 3.24b, (SP_i) weighted sum of the positive distance from the average solution values and (SN_i) weighted sum of the negative distance from the average solution values for each alternative have been calculated as in the table below.

Table 3.37. EDAS (SP_i) and (SN_i) values.

TOC	SP_i	SN_i
TOC 1	0,0251	0,1449
TOC 2	0,1065	0,3341
TOC 3	0,3516	0,0042

Using Formulas 3.25a and 3.25b, (SP_i) weighted sum of the positive distance from the average solution values and (SN_i) weighted sum of the negative distance from the average solution values have been normalized. Then in the final step, appraisal score (AS) has been calculated using Formula 3.26 for each alternative. Calculations are as in the table below.

Table 3.38. EDAS (NSP_i), (NSN_i) values and appraisal scores.

TOC	NSP_i	NSN_i	AS_i	Rank
TOC 1	0,0713	0,5665	0,6378	2
TOC 2	0,3028	0,0000	0,3028	3
TOC 3	1,0000	0,9874	1,9874	1

The higher the value of (AS_i) means the better performance.

3.5.2. Application of TOPSIS method

The decision matrix is same as in the EDAS method and shown in the Table 3.39 below. Safety KPI is cost criterion and the other KPIs are benefit criteria.

Table 3.39. TOPSIS decision matrix.

Weightage	0,1924	0,1159	0,1093	0,0583	0,3817	0,0674	0,0750
TOC	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
TOC 1	0,4602	0,8688	0,7462	0,1314	2,9949	0,1829	0,2083
TOC 2	0,1511	0,6743	0,9059	0,4775	4,2538	0,4261	1,0000
TOC 3	0,6472	0,9265	0,7985	0,3911	1,2711	0,3910	0,5833

The normalized decision matrix has been formed as in the table below via Formulas 3.28a and 3.28b.

Table 3.40. TOPSIS normalized decision matrix.

TOC	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
TOC 1	0,5692	0,6042	0,5256	0,2082	0,4408	0,3015	0,1771
TOC 2	0,1869	0,4689	0,6382	0,7567	0,2057	0,7025	0,8501
TOC 3	0,8007	0,6443	0,5625	0,6198	0,7626	0,6446	0,4959

With Formulas 3.30a and 3.30b, the weighted normalized decision matrix has been formed as in the table below.

Table 3.41. TOPSIS weighted normalized decision matrix.

TOC	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
TOC 1	0,1095	0,0700	0,0574	0,0121	0,1682	0,0203	0,0133
TOC 2	0,0360	0,0543	0,0697	0,0441	0,0785	0,0474	0,0638
TOC 3	0,1541	0,0747	0,0615	0,0361	0,2911	0,0435	0,0372

With Formulas 3.31a and 3.31b, the positive ideal solution (A^{+}) and the negative ideal solution (A^{-}) have been calculated for each KPI as in the Table 3.42 below.

Table 3.42. Positive and negative ideal solutions.

	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
A^{+}	0,1541	0,0747	0,0697	0,0441	0,2911	0,0474	0,0638
A^{-}	0,0360	0,0543	0,0574	0,0121	0,0785	0,0203	0,0133

Table 3.43. Separation measures and (C_i^{*}) values of alternatives.

TOC	S_i^{+}	S_i^{-}	C_i^{*}	**Rank**
TOC 1	0,1468	0,1171	0,4437	2
TOC 2	0,2440	0,0667	0,2147	3
TOC 3	0,0292	0,2475	0,8944	1

Via Formulas 3.32a and 3.32b, positive ideal separation measure (S_i^{+}) and negative ideal separation measure (S_i^{-}) of each alternative based on Euclidean distance to both the positive ideal and negative ideal solutions have been calculated. Using separation measures relative closeness (C_i^*) of each alternative to the ideal solution has been calculated via Formula 3.33. Calculations are as in the Table 3.43 above.

3.5.3. Application of PROMETHEE II method

The decision matrix is same as in the EDAS and TOPSIS methods. Where ($\min_j x_{ij}$) and ($\max_j x_{ij}$) are the minimum and maximum values of (x_{ij}) respectively in the table below.

Table 3.44. PROMETHEE II decision matrix.

Weightage	0,1924	0,1159	0,1093	0,0583	0,3817	0,0674	0,0750
TOC	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
TOC 1	0,4602	0,8688	0,7462	0,1314	2,9949	0,1829	0,2083
TOC 2	0,1511	0,6743	0,9059	0,4775	4,2538	0,4261	1,0000
TOC 3	0,6472	0,9265	0,7985	0,3911	1,2711	0,3910	0,5833
$\mathbf{max_j\ x_{ij}}$	0,6472	0,9265	0,9059	0,4775	4,2538	0,4261	1,0000
$\mathbf{min_j\ x_{ij}}$	0,1511	0,6743	0,7462	0,1314	1,2711	0,1829	0,2083

In order to make criteria values dimensionless and comparable using Formula 3.34a for benefit criteria (punctuality, journey time, resource usage, profitability, innovation & growth, environment) and Formula 3.34b for cost criterion (safety) the decision matrix has been normalized as in the table below.

Table 3.45. PROMETHEE II normalized decision matrix.

Weightage	0,1924	0,1159	0,1093	0,0583	0,3817	0,0674	0,0750
TOC	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
TOC 1	0,6229	0,7711	0,0000	0,0000	0,4221	0,0000	0,0000
TOC 2	0,0000	0,0000	1,0000	1,0000	0,0000	1,0000	1,0000
TOC 3	1,0000	1,0000	0,3280	0,7504	1,0000	0,8555	0,4737

Using Formula 3.35 the differences d_j of alternative i^{th} with respect to the other alternatives has been calculated for each criterion as in the Table 3.46 below.

Table 3.46. PROMETHEE II differences (d_j) of alternatives.

$\mathbf{d_j(TOC\ 1, TOC\ 2)}$	0,623	0,771	-1,000	-1,000	0,422	-1,000	-1,000
$\mathbf{d_j(TOC\ 1, TOC\ 3)}$	-0,377	-0,229	-0,328	-0,750	-0,578	-0,856	-0,474
$\mathbf{d_j(TOC\ 2, TOC\ 1)}$	-0,623	-0,771	1,000	1,000	-0,422	1,000	1,000
$\mathbf{d_j(TOC\ 2, TOC\ 3)}$	-1,000	-1,000	0,672	0,250	-1,000	0,144	0,526
$\mathbf{d_j(TOC\ 3, TOC\ 1)}$	0,377	0,229	0,328	0,750	0,578	0,856	0,474
$\mathbf{d_j(TOC\ 3, TOC\ 2)}$	1,000	1,000	-0,672	-0,250	1,000	-0,144	-0,526

Table 3.47. Preference values of pairwise comparison of alternatives.

$\mathbf{P_j(TOC\ 1, TOC\ 2)}$	0,6229	0,7711	0,0000	0,0000	0,4221	0,0000	0,0000
$\mathbf{P_j(TOC\ 1, TOC\ 3)}$	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
$\mathbf{P_j(TOC\ 2, TOC\ 1)}$	0,0000	0,0000	1,0000	1,0000	0,0000	1,0000	1,0000
$\mathbf{P_j(TOC\ 2, TOC\ 3)}$	0,0000	0,0000	0,6720	0,2496	0,0000	0,1445	0,5263
$\mathbf{P_j(TOC\ 3, TOC\ 1)}$	0,3771	0,2289	0,3280	0,7504	0,5779	0,8555	0,4737
$\mathbf{P_j(TOC\ 3, TOC\ 2)}$	1,0000	1,0000	0,0000	0,0000	1,0000	0,0000	0,0000

Considering the chosen preference function, with the help of Formula 3.36, pairwise comparisons of the alternatives have been made for each criterion and preferences values (P_j) have been calculated as in the Table 3.47 above.

Using Formula 3.37, aggregated preference functions (π), taking into account the criteria weights have been calculated as in the table below.

Table 3.48. Aggregated preference values of pairwise comparison of alternatives.

$\boldsymbol{\pi}(\mathbf{TOC\ 1}, \mathbf{TOC\ 2})$	0,3704
$\boldsymbol{\pi}(\mathbf{TOC\ 1}, \mathbf{TOC\ 3})$	0,0000
$\boldsymbol{\pi}(\mathbf{TOC\ 2}, \mathbf{TOC\ 1})$	0,3100
$\boldsymbol{\pi}(\mathbf{TOC\ 2}, \mathbf{TOC\ 3})$	0,1372
$\boldsymbol{\pi}(\mathbf{TOC\ 3}, \mathbf{TOC\ 1})$	0,4925
$\boldsymbol{\pi}(\mathbf{TOC\ 3}, \mathbf{TOC\ 2})$	0,6900

Using Formulas 3.38a and 3.88b, the leaving and the entering outranking flows (φ^+) and (φ^-) have been calculated respectively. Then using Equation 3.39, net outranking flow (φ) for each alternative has been calculated as in the Table 3.49 below.

Table 3.49. PROMETHEE II outranking flows.

TOC	$\boldsymbol{\varphi}^{+}$	$\boldsymbol{\varphi}^{-}$	$\boldsymbol{\varphi}$	**Rank**
TOC 1	0,1852	0,4012	-0,2160	2
TOC 2	0,2236	0,5302	-0,3066	3
TOC 3	0,5913	0,0686	0,5227	1

The higher the value of (φ) means the better performance.

3.5.4. Application of COPRAS method

The decision matrix is same as in the EDAS, TOPSIS and PROMETHEE II methods. Using Formula 3.40, the normalized decision matrix has been formed as in the Table 3.50 below.

Table 3.50. COPRAS normalized decision matrix.

Weightage	0,1924	0,1159	0,1093	0,0583	0,3817	0,0674	0,0750
TOC	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
TOC 1	0,3656	0,3518	0,3045	0,1314	0,3515	0,1829	0,1163
TOC 2	0,1200	0,2730	0,3697	0,4775	0,4993	0,4261	0,5581
TOC 3	0,5143	0,3752	0,3259	0,3911	0,1492	0,3910	0,3256

Using Formula 3.41, the weighted normalized decision matrix has been formed as in the Table 3.51 below.

Table 3.51. COPRAS weighted normalized decision matrix.

TOC	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
TOC 1	0,0704	0,0408	0,0333	0,0077	0,1342	0,0123	0,0087
TOC 2	0,0231	0,0316	0,0404	0,0278	0,1906	0,0287	0,0419
TOC 3	0,0990	0,0435	0,0356	0,0228	0,0569	0,0264	0,0244

Using Formulas 3.42a and 3.42b, total weighted normalized values (S_{+i}) and (S_{-i}) based on benefit and cost criteria have been calculated as in the table below.

Table 3.52. COPRAS total weighted normalized values.

TOC	S_{+i}	S_{-i}
TOC 1	0,1731	0,1342
TOC 2	0,1936	0,1906
TOC 3	0,2516	0,0569

Using Formula 3.43, relative importance of each alternative (Q_i) has been calculated. Then, using Formula 3.44, performance index (P_i) of each alternative has been calculated. Calculated values have been shown in the Table 3.53 below.

Table 3.53. COPRAS relative importance and performance index values.

TOC	Q_i	P_i	Rank
TOC 1	0,2671	56,46	2
TOC 2	0,2597	54,90	3
TOC 3	0,4731	100,00	1

4. RESULTS AND DISCUSSIONS

The EDAS method described in detail in the Section 3.4 have been applied to evaluate the performance of freight TOCs in Section 3.5. Results are presented in the Table 4.1 below.

Table 4.1. Results of performance evaluation of TOCs.

TOCs	Appraisal score (Performance score)	Rank
TOC 1	0,6378	2
TOC 2	0,3028	3
TOC 3	1,9874	1

It is seen from the Table 4.1 that the company with the best performance is TOC 3 and the company with the worst performance is TOC 2.

Sensitivity analysis, with the mainlines, can be defined as the exploration of how the outputs of a system are related to and are influenced by its inputs (Razavi et al., 2021). In mathematical models; sensitivity analysis plays a significant role on analyzing the impact and dependency that inputs have on whilst determining the possible outputs of the model (Iooss and Saltelli, 2017).

In this study, sensitivity analyzes were carried out to reveal whether the alternatives are sensitive to changes in KPI weights when the fuzzy AHP application is performed with different decision makers. In addition, a sensitivity analysis was also performed to observe how the result changed in case of evaluation with different type of MCDM methods described in Section 3.4.

Firstly, sensitivity analyzes were performed on the EDAS method used in performance evaluation by changing the KPI weights obtained by the fuzzy AHP method. Sensitivity analyzes were carried out over seven different scenarios. In the scenarios, the weight of each KPI separately has been increased to 0,9, and the weights of the other KPIs have been evenly distributed. For example, In the scenario 1, it is assumed that the “punctuality” KPI is the most important criterion with 0,9 weight for performance evaluation of TOCs, and the weights of the other KPIs are evenly distributed. The KPI weights obtained using the fuzzy AHP method and the assumed KPI weights for scenarios of sensitivity analysis are shown in the Table 4.2 below.

Table 4.2. KPI weights for sensitivity analysis.

KPIs	FAHP	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
Punctuality	0,192	0,900	0,017	0,017	0,017	0,017	0,017	0,017
Journey time	0,116	0,017	0,900	0,017	0,017	0,017	0,017	0,017
Resource usage	0,109	0,017	0,017	0,900	0,017	0,017	0,017	0,017
Profitability	0,058	0,017	0,017	0,017	0,900	0,017	0,017	0,017
Safety	0,382	0,017	0,017	0,017	0,017	0,900	0,017	0,017
Innovation & growth	0,067	0,017	0,017	0,017	0,017	0,017	0,900	0,017
Environment	0,075	0,017	0,017	0,017	0,017	0,017	0,017	0,900

Table 4.3. Results of sensitivity analysis.

	Ranking			Appraisal score		
Scenario	**TOC 1**	**TOC 2**	**TOC 3**	**TOC 1**	**TOC 2**	**TOC 3**
Real case	2	3	1	0,6378	0,3028	1,9874
Scenario 1	2	3	1	1,1219	0,0492	1,9987
Scenario 2	2	3	1	1,2060	0,1818	1,9958
Scenario 3	3	1	2	0,0210	1,7951	1,0239
Scenario 4	3	1	2	0,0062	1,9612	1,4391
Scenario 5	2	3	1	0,8338	0,0484	1,9984
Scenario 6	3	1	2	0,0094	1,9488	1,6588
Scenario 7	3	1	2	0,0041	1,9637	1,0069

The results that emerged after the implementation of the scenarios are as in the Table 4.3 above. In the real case, best performing company is TOC 3 and the worst performing company is TOC 2. According to the results of the sensitivity analyzes, it is seen from the Table 4.3 that in scenario 3, 4, 6 and 7 ranking is changed and company with the best performance is TOC 2 and the company with the worst performance is TOC 1. According to these results, it is seen that TOC 1 was not the best performing company and TOC 3 was not the worst performing company in applied seven scenarios.

Secondly, the TOPSIS, COPRAS, and PROMETHEE II described in detail in the Section 3.4 have been applied to evaluate the performance of TOCs in Section 3.5. All obtained results are presented in the table below.

Table 4.4. Results of applied MCDM methods.

TOC	EDAS		TOPSIS		COPRAS		PROMETHEE II	
	Appraisal score	**Rank**	**Relative closeness to the ideal solution**	**Rank**	**Performance index**	**Rank**	**Net outranking flow**	**Rank**
TOC 1	0,6378	2	0,4437	2	56,46	2	-0,2160	2
TOC 2	0,3028	3	0,2147	3	54,90	3	-0,3066	3
TOC 3	1,9874	1	0,8944	1	100,00	1	0,5227	1

It is seen from the Table 4.4 that all of the applied MCDM methods give the same ranking with different performance scores. The company with the best performance is TOC 3 and the company with the worst performance is TOC 2.

5. CONCLUSIONS

In this study, evaluating the performance of freight train operating companies (TOCs) in railway transportation is aimed, which has a very important place on the mass transportation in our country as it has for the rest of the world. The Law No. 6461 regarding liberalization of railway transportation, enacted in 2013 in Turkey, allowed private railway train operating companies to take place into the sector. As of 2022 three freight train operating companies, two of them belonging to private sector and one to the government, are actively functioning in Turkey. In the near future, due to liberalization law, number of private train operating companies that are active on this field would increase, considering this situation; performing better in this more competitive environment will have more importance for these train operating companies.

Concept of KPI (key performance indicator) has been utilized on the topic of evaluating the performance of companies that operating on railway freight transportation. As a result of the focus group meeting involving eight experts, seven unique KPIs have been determined based on the reports of the railway transportation authorities, previous studies in literature and structure of Turkish railway transportation sector. Mentioned determined KPIs are the followings: punctuality, journey time, resource usage, profitability, safety, innovation & growth and environment.

AHP and fuzzy AHP techniques, being multi-criteria decision making methods that allow us to make decisions through qualitative variables, have been used to determine the relative weights of KPIs by including eight experts who have substantial knowledge about the railway industry and its operation, and capable to identify the requirements of different stakeholders. The relative weights of the KPIs to be used in the performance evaluation have been determined by Buckley's fuzzy AHP method. Within the specified framework, it has been revealed that the safety KPI is the criterion with the highest relative weight in terms of the performance of a freight TOC and the profitability KPI stands as having the least relative weight. The relative weights of KPIs obtained with the fuzzy AHP method are shown in the figure below.

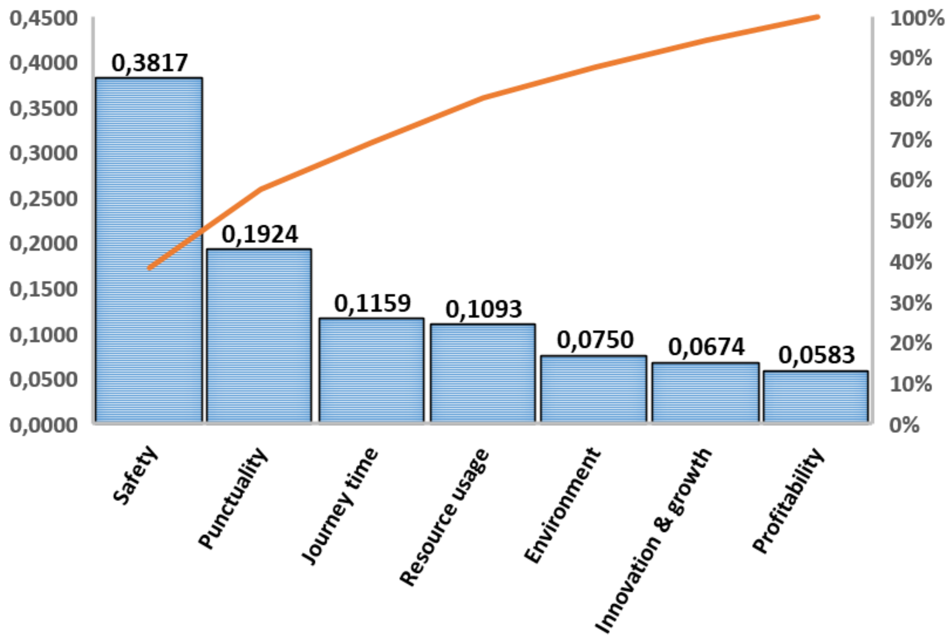

Figure 5.1. Relative weights of KPIs obtained by FAHP method.

The operational data of the TOCs acquired from the ERP (Enterprise Resource Planning) system of TCDD, the railway infrastructure manager, have been used as data for the KPIs of punctuality, journey time, resource usage, safety and environment. As the data concerning profitability and innovation & growth KPIs are of strategic importance for companies, these data could not be acquired, and values have been assigned to these two KPIs via the AHP method, in which eight experts are included.

EDAS which is a distance-based MCDM method is used as main method to evaluate performance of TOCs. TOPSIS, PROMETHEE II and COPRAS methods are also applied to the problem to support study. Even the performance scores calculated by the methods are different, all four different methods give the same performance ranking for the performance evaluation of three TOCs. It has been revealed that the company with the best performance is TOC 3, and the company with the worst performance is TOC 2. In order to reveal whether the alternatives (TOCs) are sensitive to the changes in KPI weights in the case that there are different decision makers in determining the KPI weights by fuzzy AHP method, sensitivity analyzes have been made over seven different scenarios.

When the previous studies in the literature are examined, it is seen that while there are many performance evaluation studies on the general railway systems, there are very few studies on the train operating companies level. This study has an important place in closing this gap.

The structure and performance indicators of railway freight and passenger transportation are different from each other. On the other hand, main line passenger transportation in Turkey, with the exception of suburban and metro lines, is carried out by a public owned railway train operating company. If this situation changes in the future and the number of companies in passenger transportation increase, this study can be taken one step further by including passenger train operating companies in the process.

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APPENDIX

Appendix A

Appendix Table A.1. Questionnaire form designed for weighting KPIs.

A	B	According to you which criteria is more important? (A or B?)	According to you to what extent is it more important? Scale (1 to 9)
Punctuality	Journey time		
	Resource usage		
	Profitability		
	Safety		
	Innovation & growth		
	Environment		
Journey time	Resource usage		
	Profitability		
	Safety		
	Innovation & growth		
	Environment		
Resource usage	Profitability		
	Safety		
	Innovation & growth		
	Environment		
Profitability	Safety		
	Innovation & growth		
	Environment		
Safety	Innovation & growth		
	Environment		
Innovation & growth	Environment		

Appendix Table A.2. Answered questionnaire form of expert 1 for weighting KPIs.

A	B	According to you which criteria is more important? (A or B?)	According to you to what extent is it more important? Scale (1 to 9)
Punctuality	Journey time	A	1
	Resource usage	A	3
	Profitability	A	7
	Safety	B	7
	Innovation & growth	A	9
	Environment	A	7
Journey time	Resource usage	A	3
	Profitability	A	9
	Safety	B	5
	Innovation & growth	A	7
	Environment	A	5
Resource usage	Profitability	A	2
	Safety	B	3
	Innovation & growth	A	3
	Environment	A	3
Profitability	Safety	B	5
	Innovation & growth	A	2
	Environment	A	1
Safety	Innovation & growth	A	9
	Environment	A	9
Innovation & growth	Environment	A	1

Appendix Table A.3. Answered questionnaire form of expert 2 for weighting KPIs.

A	B	According to you which criteria is more important? (A or B?)	According to you to what extent is it more important? Scale (1 to 9)
Punctuality	Journey time	A	3
	Resource usage	A	3
	Profitability	A	5
	Safety	B	3
	Innovation & growth	A	5
	Environment	A	9
Journey time	Resource usage	A	2
	Profitability	A	3
	Safety	B	3
	Innovation & growth	A	3
	Environment	A	3
Resource usage	Profitability	A	5
	Safety	B	5
	Innovation & growth	A	5
	Environment	A	3
Profitability	Safety	B	5
	Innovation & growth	B	3
	Environment	A	1
Safety	Innovation & growth	A	7
	Environment	A	7
Innovation & growth	Environment	A	1

Appendix Table A.4. Answered questionnaire form of expert 3 for weighting KPIs.

A	B	According to you which criteria is more important? (A or B?)	According to you to what extent is it more important? Scale (1 to 9)
Punctuality	Journey time	A	3
	Resource usage	A	5
	Profitability	A	7
	Safety	B	9
	Innovation & growth	A	7
	Environment	A	5
Journey time	Resource usage	A	3
	Profitability	A	3
	Safety	B	7
	Innovation & growth	A	5
	Environment	A	5
Resource usage	Profitability	A	3
	Safety	B	5
	Innovation & growth	A	5
	Environment	A	3
Profitability	Safety	B	9
	Innovation & growth	A	1
	Environment	B	2
Safety	Innovation & growth	A	7
	Environment	A	9
Innovation & growth	Environment	A	1

Appendix Table A.5. Revised answered questionnaire form of expert 3 for weighting KPIs.

A	B	According to you which criteria is more important? (A or B?)	According to you to what extent is it more important? Scale (1 to 9)
Punctuality	Journey time	A	3
	Resource usage	A	5
	Profitability	A	7
	Safety	B	5
	Innovation & growth	A	7
	Environment	A	5
Journey time	Resource usage	A	2
	Profitability	A	3
	Safety	B	9
	Innovation & growth	A	3
	Environment	A	1
Resource usage	Profitability	A	3
	Safety	B	5
	Innovation & growth	A	5
	Environment	A	3
Profitability	Safety	B	9
	Innovation & growth	A	2
	Environment	B	2
Safety	Innovation & growth	A	7
	Environment	A	9
Innovation & growth	Environment	A	1

Appendix Table A.6. Answered questionnaire form of expert 4 for weighting KPIs.

A	B	According to you which criteria is more important? (A or B?)	According to you to what extent is it more important? Scale (1 to 9)
Punctuality	Journey time	A	9
	Resource usage	B	2
	Profitability	A	7
	Safety	A	1
	Innovation & growth	A	1
	Environment	A	1
Journey time	Resource usage	A	1
	Profitability	A	7
	Safety	A	1
	Innovation & growth	A	1
	Environment	A	1
Resource usage	Profitability	A	7
	Safety	A	1
	Innovation & growth	A	1
	Environment	A	1
Profitability	Safety	B	7
	Innovation & growth	B	7
	Environment	B	7
Safety	Innovation & growth	A	5
	Environment	A	1
Innovation & growth	Environment	A	1

Appendix Table A.7. Revised answered questionnaire form of expert 4 for weighting KPIs.

A	B	According to you which criteria is more important? (A or B?)	According to you to what extent is it more important? Scale (1 to 9)
Punctuality	Journey time	A	2
	Resource usage	B	2
	Profitability	A	7
	Safety	A	1
	Innovation & growth	A	1
	Environment	A	1
Journey time	Resource usage	A	1
	Profitability	A	7
	Safety	A	1
	Innovation & growth	A	1
	Environment	A	1
Resource usage	Profitability	A	7
	Safety	A	1
	Innovation & growth	A	1
	Environment	A	1
Profitability	Safety	B	7
	Innovation & growth	B	7
	Environment	B	7
Safety	Innovation & growth	A	5
	Environment	A	1
Innovation & growth	Environment	A	1

Appendix Table A.8. Answered questionnaire form of expert 5 for weighting KPIs.

A	B	According to you which criteria is more important? (A or B?)	According to you to what extent is it more important? Scale (1 to 9)
Punctuality	Journey time	A	7
	Resource usage	A	5
	Profitability	A	2
	Safety	B	9
	Innovation & growth	A	1
	Environment	A	1
Journey time	Resource usage	B	5
	Profitability	B	3
	Safety	B	9
	Innovation & growth	A	1
	Environment	B	3
Resource usage	Profitability	A	1
	Safety	B	9
	Innovation & growth	A	2
	Environment	B	5
Profitability	Safety	B	7
	Innovation & growth	A	2
	Environment	A	3
Safety	Innovation & growth	A	7
	Environment	A	7
Innovation & growth	Environment	A	2

Appendix Table A.9. Revised answered questionnaire form of expert 5 for weighting KPIs.

A	B	According to you which criteria is more important? (A or B?)	According to you to what extent is it more important? Scale (1 to 9)
Punctuality	Journey time	A	7
	Resource usage	A	5
	Profitability	A	2
	Safety	B	9
	Innovation & growth	A	2
	Environment	A	2
Journey time	Resource usage	B	5
	Profitability	B	3
	Safety	B	9
	Innovation & growth	A	1
	Environment	B	3
Resource usage	Profitability	A	1
	Safety	B	9
	Innovation & growth	A	2
	Environment	A	1
Profitability	Safety	B	7
	Innovation & growth	A	2
	Environment	A	3
Safety	Innovation & growth	A	7
	Environment	A	7
Innovation & growth	Environment	A	2

Appendix Table A.10. Answered questionnaire form of expert 6 for weighting KPIs.

A	B	According to you which criteria is more important? (A or B?)	According to you to what extent is it more important? Scale (1 to 9)
Punctuality	Journey time	A	5
	Resource usage	A	7
	Profitability	A	5
	Safety	B	7
	Innovation & growth	A	3
	Environment	A	3
Journey time	Resource usage	A	2
	Profitability	A	3
	Safety	B	7
	Innovation & growth	A	2
	Environment	A	1
Resource usage	Profitability	A	2
	Safety	B	5
	Innovation & growth	A	1
	Environment	A	1
Profitability	Safety	B	9
	Innovation & growth	A	1
	Environment	A	1
Safety	Innovation & growth	A	5
	Environment	A	7
Innovation & growth	Environment	A	1

Appendix Table A.11. Answered questionnaire form of expert 7 for weighting KPIs.

A	B	According to you which criteria is more important? (A or B?)	According to you to what extent is it more important? Scale (1 to 9)
Punctuality	Journey time	A	1
	Resource usage	A	1
	Profitability	A	2
	Safety	B	5
	Innovation & growth	A	1
	Environment	A	1
Journey time	Resource usage	A	1
	Profitability	A	2
	Safety	B	2
	Innovation & growth	A	2
	Environment	A	1
Resource usage	Profitability	A	1
	Safety	B	5
	Innovation & growth	A	1
	Environment	A	1
Profitability	Safety	B	2
	Innovation & growth	A	1
	Environment	A	1
Safety	Innovation & growth	A	3
	Environment	A	3
Innovation & growth	Environment	B	2

Appendix Table A.12. Answered questionnaire form of expert 8 for weighting KPIs.

A	B	According to you which criteria is more important? (A or B?)	According to you to what extent is it more important? Scale (1 to 9)
Punctuality	Journey time	A	1
	Resource usage	A	1
	Profitability	A	1
	Safety	B	2
	Innovation & growth	A	2
	Environment	A	3
Journey time	Resource usage	A	1
	Profitability	A	1
	Safety	B	2
	Innovation & growth	A	2
	Environment	A	2
Resource usage	Profitability	A	1
	Safety	A	1
	Innovation & growth	A	1
	Environment	A	1
Profitability	Safety	B	3
	Innovation & growth	A	1
	Environment	A	1
Safety	Innovation & growth	A	2
	Environment	A	1
Innovation & growth	Environment	A	1

Appendix A1

Appendix Table A1.1. AHP pairwise comparison matrix for expert 1.

	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
Punctuality	1,00	1,00	3,00	7,00	0,14	9,00	7,00
Journey time	1,00	1,00	3,00	9,00	0,20	7,00	5,00
Resource usage	0,33	0,33	1,00	2,00	0,33	3,00	3,00
Profitability	0,14	0,11	0,50	1,00	0,20	2,00	1,00
Safety	7,00	5,00	3,00	5,00	1,00	9,00	9,00
Innovation & growth	0,11	0,14	0,33	0,50	0,11	1,00	1,00
Environment	0,14	0,20	0,33	1,00	0,11	1,00	1,00

Consistency Ratio (CR) = 0,08

Appendix Table A1.2. AHP pairwise comparison matrix for expert 2.

	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
Punctuality	1,00	3,00	3,00	5,00	0,33	5,00	9,00
Journey time	0,33	1,00	2,00	3,00	0,33	3,00	3,00
Resource usage	0,33	0,50	1,00	5,00	0,20	5,00	3,00
Profitability	0,20	0,33	0,20	1,00	0,20	0,33	1,00
Safety	3,00	3,00	5,00	5,00	1,00	7,00	7,00
Innovation & growth	0,20	0,33	0,20	3,00	0,14	1,00	1,00
Environment	0,11	0,33	0,33	1,00	0,14	1,00	1,00

Consistency Ratio (CR) = 0,07

Appendix Table A1.3. AHP pairwise comparison matrix for expert 3.

	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
Punctuality	1,00	3,00	5,00	7,00	0,11	7,00	5,00
Journey time	0,33	1,00	3,00	3,00	0,14	5,00	5,00
Resource usage	0,20	0,33	1,00	3,00	0,20	5,00	3,00
Profitability	0,14	0,33	0,33	1,00	0,11	1,00	0,50
Safety	9,00	7,00	5,00	9,00	1,00	7,00	9,00
Innovation & growth	0,14	0,20	0,20	1,00	0,14	1,00	1,00
Environment	0,20	0,20	0,33	2,00	0,11	1,00	1,00

Consistency Ratio (CR) = 0,11

Appendix Table A1.4. Revied AHP pairwise comparison matrix for expert 3.

	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
Punctuality	1,00	3,00	5,00	7,00	0,20	7,00	5,00
Journey time	0,33	1,00	2,00	3,00	0,11	3,00	1,00
Resource usage	0,20	0,50	1,00	3,00	0,20	5,00	3,00
Profitability	0,14	0,33	0,33	1,00	0,11	2,00	0,50
Safety	5,00	9,00	5,00	9,00	1,00	7,00	9,00
Innovation & growth	0,14	0,33	0,20	0,50	0,14	1,00	1,00
Environment	0,20	1,00	0,33	2,00	0,11	1,00	1,00

Consistency Ratio (CR) = 0,08

Appendix Table A1.5. AHP pairwise comparison matrix for expert 4.

	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
Punctuality	1,00	9,00	0,50	7,00	1,00	1,00	1,00
Journey time	0,11	1,00	1,00	7,00	1,00	1,00	1,00
Resource usage	2,00	1,00	1,00	7,00	1,00	1,00	1,00
Profitability	0,14	0,14	0,14	1,00	0,14	0,14	0,14
Safety	1,00	1,00	1,00	7,00	1,00	5,00	1,00
Innovation & growth	1,00	1,00	1,00	7,00	0,20	1,00	1,00
Environment	1,00	1,00	1,00	7,00	1,00	1,00	1,00

Consistency Ratio (CR) = 0,13

Appendix Table A1.6. Revised AHP pairwise comparison matrix for expert 4.

	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
Punctuality	1,00	2,00	0,50	7,00	1,00	1,00	1,00
Journey time	0,50	1,00	1,00	7,00	1,00	1,00	1,00
Resource usage	2,00	1,00	1,00	7,00	1,00	1,00	1,00
Profitability	0,14	0,14	0,14	1,00	0,14	0,14	0,14
Safety	1,00	1,00	1,00	7,00	1,00	5,00	1,00
Innovation & growth	1,00	1,00	1,00	7,00	0,20	1,00	1,00
Environment	1,00	1,00	1,00	7,00	1,00	1,00	1,00

Consistency Ratio (CR) = 0,05

Appendix Table A1.7. AHP pairwise comparison matrix for expert 5.

	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
Punctuality	1,00	7,00	5,00	2,00	0,11	1,00	1,00
Journey time	0,14	1,00	0,20	0,33	0,11	1,00	0,33
Resource usage	0,20	5,00	1,00	1,00	0,11	2,00	0,20
Profitability	0,50	3,00	1,00	1,00	0,14	2,00	3,00
Safety	9,00	9,00	9,00	7,00	1,00	7,00	7,00
Innovation & growth	1,00	1,00	0,50	0,50	0,14	1,00	2,00
Environment	1,00	3,00	5,00	0,33	0,14	0,50	1,00

Consistency Ratio (CR) = 0,18

Appendix Table A1.8. Revised AHP pairwise comparison matrix for expert 5.

	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
Punctuality	1,00	7,00	5,00	2,00	0,11	2,00	2,00
Journey time	0,14	1,00	0,20	0,33	0,11	1,00	0,33
Resource usage	0,20	5,00	1,00	1,00	0,11	2,00	1,00
Profitability	0,50	3,00	1,00	1,00	0,14	2,00	3,00
Safety	9,00	9,00	9,00	7,00	1,00	7,00	7,00
Innovation & growth	0,50	1,00	0,50	0,50	0,14	1,00	2,00
Environment	0,50	3,00	1,00	0,33	0,14	0,50	1,00

Consistency Ratio (CR) = 0,098

Appendix Table A1.9. AHP pairwise comparison matrix for expert 6.

	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
Punctuality	1,00	5,00	7,00	5,00	0,14	3,00	3,00
Journey time	0,20	1,00	2,00	3,00	0,14	2,00	1,00
Resource usage	0,14	0,50	1,00	2,00	0,20	1,00	1,00
Profitability	0,20	0,33	0,50	1,00	0,11	1,00	1,00
Safety	7,00	7,00	5,00	9,00	1,00	5,00	7,00
Innovation & growth	0,33	0,50	1,00	1,00	0,20	1,00	1,00
Environment	0,33	1,00	1,00	1,00	0,14	1,00	1,00

Consistency Ratio (CR) = 0,07

Appendix Table A1.10. AHP pairwise comparison matrix for expert 7.

	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
Punctuality	1,00	1,00	1,00	2,00	0,20	1,00	1,00
Journey time	1,00	1,00	1,00	2,00	0,50	2,00	1,00
Resource usage	1,00	1,00	1,00	1,00	0,20	1,00	1,00
Profitability	0,50	0,50	1,00	1,00	0,50	1,00	1,00
Safety	5,00	2,00	5,00	2,00	1,00	3,00	3,00
Innovation & growth	1,00	0,50	1,00	1,00	0,33	1,00	0,50
Environment	1,00	1,00	1,00	1,00	0,33	2,00	1,00

Consistency Ratio (CR) = 0,03

Appendix Table A1.11. AHP pairwise comparison matrix for expert 8.

	Punctuality	Journey time	Resource usage	Profitability	Safety	Innovation & growth	Environment
Punctuality	1,00	1,00	1,00	1,00	0,50	2,00	3,00
Journey time	1,00	1,00	1,00	1,00	0,50	2,00	2,00
Resource usage	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Profitability	1,00	1,00	1,00	1,00	0,33	1,00	1,00
Safety	2,00	2,00	1,00	3,00	1,00	2,00	1,00
Innovation & growth	0,50	0,50	1,00	1,00	0,50	1,00	1,00
Environment	0,33	0,50	1,00	1,00	1,00	1,00	1,00

Consistency Ratio (CR) = 0,04

Appendix B

Appendix Table B.1. Fuzzy AHP pairwise comparison matrix for expert 1.

	Punctuality			Journey time			Resource usage			Profitability			Safety			Innovation & growth			Environment		
Punctuality	1,00	1,00	1,00	1,00	1,00	1,00	2,00	3,00	4,00	6,00	7,00	8,00	0,13	0,14	0,17	8,00	9,00	9,00	6,00	7,00	8,00
Journey time	1,00	1,00	1,00	1,00	1,00	1,00	2,00	3,00	4,00	8,00	9,00	9,00	0,17	0,20	0,25	6,00	7,00	8,00	4,00	5,00	6,00
Resource usage	0,25	0,33	0,50	0,25	0,33	0,50	1,00	1,00	1,00	1,00	2,00	3,00	0,25	0,33	0,50	2,00	3,00	4,00	2,00	3,00	4,00
Profitability	0,13	0,14	0,17	0,11	0,11	0,13	0,33	0,50	1,00	1,00	1,00	1,00	0,17	0,20	0,25	1,00	2,00	3,00	1,00	1,00	1,00
Safety	6,00	7,00	8,00	4,00	5,00	6,00	2,00	3,00	4,00	4,00	5,00	6,00	1,00	1,00	1,00	8,00	9,00	9,00	8,00	9,00	9,00
Innovation & growth	0,11	0,11	0,13	0,13	0,14	0,17	0,25	0,33	0,50	0,33	0,50	1,00	0,11	0,11	0,13	1,00	1,00	1,00	1,00	1,00	1,00
Environment	0,13	0,14	0,17	0,17	0,20	0,25	0,25	0,33	0,50	1,00	1,00	1,00	0,11	0,11	0,13	1,00	1,00	1,00	1,00	1,00	1,00

Appendix Table B.2. Fuzzy AHP pairwise comparison matrix for expert 2.

	Punctuality			Journey time			Resource usage			Profitability			Safety			Innovation & growth			Environment		
Punctuality	1,00	1,00	1,00	2,00	3,00	4,00	2,00	3,00	4,00	4,00	5,00	6,00	0,25	0,33	0,50	4,00	5,00	6,00	8,00	9,00	9,00
Journey time	0,25	0,33	0,50	1,00	1,00	1,00	1,00	2,00	3,00	2,00	3,00	4,00	0,25	0,33	0,50	2,00	3,00	4,00	2,00	3,00	4,00
Resource usage	0,25	0,33	0,50	0,33	0,50	1,00	1,00	1,00	1,00	4,00	5,00	6,00	0,17	0,20	0,25	4,00	5,00	6,00	2,00	3,00	4,00
Profitability	0,17	0,20	0,25	0,25	0,33	0,50	0,17	0,20	0,25	1,00	1,00	1,00	0,17	0,20	0,25	0,25	0,33	0,50	1,00	1,00	1,00
Safety	2,00	3,00	4,00	2,00	3,00	4,00	4,00	5,00	6,00	4,00	5,00	6,00	1,00	1,00	1,00	6,00	7,00	8,00	6,00	7,00	8,00
Innovation & growth	0,17	0,20	0,25	0,25	0,33	0,50	0,17	0,20	0,25	2,00	3,00	4,00	0,13	0,14	0,17	1,00	1,00	1,00	1,00	1,00	1,00
Environment	0,11	0,11	0,13	0,25	0,33	0,50	0,25	0,33	0,50	1,00	1,00	1,00	0,13	0,14	0,17	1,00	1,00	1,00	1,00	1,00	1,00

Appendix Table B.3. Fuzzy AHP pairwise comparison matrix for expert 3.

	Punctuality			Journey time			Resource usage			Profitability			Safety			Innovation & growth			Environment		
Punctuality	1,00	1,00	1,00	2,00	3,00	4,00	4,00	5,00	6,00	6,00	7,00	8,00	0,17	0,20	0,25	6,00	7,00	8,00	4,00	5,00	6,00
Journey time	0,25	0,33	0,50	1,00	1,00	1,00	1,00	2,00	3,00	2,00	3,00	4,00	0,13	0,11	0,13	2,00	3,00	4,00	1,00	1,00	1,00
Resource usage	0,17	0,20	0,25	0,33	0,50	1,00	1,00	1,00	1,00	2,00	3,00	4,00	0,17	0,20	0,25	4,00	5,00	6,00	2,00	3,00	4,00
Profitability	0,13	0,14	0,17	0,25	0,33	0,50	0,25	0,33	0,50	1,00	1,00	1,00	0,11	0,11	0,13	1,00	2,00	3,00	0,33	0,50	1,00
Safety	4,00	5,00	6,00	8,00	9,00	8,00	4,00	5,00	6,00	8,00	9,00	9,00	1,00	1,00	1,00	6,00	7,00	8,00	8,00	9,00	9,00
Innovation & growth	0,13	0,14	0,17	0,25	0,33	0,50	0,17	0,20	0,25	0,33	0,50	1,00	0,13	0,14	0,17	1,00	1,00	1,00	1,00	1,00	1,00
Environment	0,17	0,20	0,25	1,00	1,00	1,00	0,25	0,33	0,50	1,00	2,00	3,00	0,11	0,11	0,13	1,00	1,00	1,00	1,00	1,00	1,00

Appendix Table B.4. Fuzzy AHP pairwise comparison matrix for expert 4.

	Punctuality			Journey time			Resource usage			Profitability			Safety			Innovation & growth			Environment		
Punctuality	1,00	1,00	1,00	1,00	2,00	3,00	0,33	0,50	1,00	6,00	7,00	8,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Journey time	0,33	0,50	1,00	1,00	1,00	1,00	1,00	1,00	1,00	6,00	7,00	8,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Resource usage	1,00	2,00	3,00	1,00	1,00	1,00	1,00	1,00	1,00	6,00	7,00	8,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Profitability	0,13	0,14	0,17	0,13	0,14	0,17	0,13	0,14	0,17	1,00	1,00	1,00	0,13	0,14	0,17	0,13	0,14	0,17	0,13	0,14	0,17
Safety	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	6,00	7,00	8,00	1,00	1,00	1,00	4,00	5,00	6,00	1,00	1,00	1,00
Innovation & growth	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	6,00	7,00	8,00	0,17	0,20	0,25	1,00	1,00	1,00	1,00	1,00	1,00
Environment	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	6,00	7,00	8,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

Appendix Table B.5. Fuzzy AHP pairwise comparison matrix for expert 5.

	Punctuality			Journey time			Resource usage			Profitability			Safety			Innovation & growth			Environment		
Punctuality	1,00	1,00	1,00	6,00	7,00	8,00	4,00	5,00	6,00	1,00	2,00	3,00	0,11	0,11	0,13	1,00	2,00	3,00	1,00	2,00	3,00
Journey time	0,13	0,14	0,17	1,00	1,00	1,00	0,17	0,20	0,25	0,25	0,33	0,50	0,11	0,11	0,13	1,00	1,00	1,00	0,25	0,33	0,50
Resource usage	0,17	0,20	0,25	4,00	5,00	6,00	1,00	1,00	1,00	1,00	1,00	1,00	0,11	0,11	0,13	1,00	2,00	3,00	1,00	1,00	1,00
Profitability	0,33	0,50	1,00	2,00	3,00	4,00	1,00	1,00	1,00	1,00	1,00	1,00	0,13	0,14	0,17	1,00	2,00	3,00	2,00	3,00	4,00
Safety	8,00	9,00	9,00	8,00	9,00	9,00	8,00	9,00	9,00	6,00	7,00	8,00	1,00	1,00	1,00	6,00	7,00	8,00	6,00	7,00	8,00
Innovation & growth	0,33	0,50	1,00	1,00	1,00	1,00	0,33	0,50	1,00	0,33	0,50	1,00	0,13	0,14	0,17	1,00	1,00	1,00	1,00	2,00	3,00
Environment	0,33	0,50	1,00	2,00	3,00	4,00	1,00	1,00	1,00	0,25	0,33	0,50	0,13	0,14	0,17	0,33	0,50	1,00	1,00	1,00	1,00

Appendix Table B.6. Fuzzy AHP pairwise comparison matrix for expert 6.

	Punctuality			Journey time			Resource usage			Profitability			Safety			Innovation & growth			Environment		
Punctuality	1,00	1,00	1,00	4,00	5,00	6,00	6,00	7,00	8,00	4,00	5,00	6,00	0,13	0,14	0,17	2,00	3,00	4,00	2,00	3,00	4,00
Journey time	0,17	0,20	0,25	1,00	1,00	1,00	1,00	2,00	3,00	2,00	3,00	4,00	0,13	0,14	0,17	1,00	2,00	3,00	1,00	1,00	1,00
Resource usage	0,13	0,14	1,00	0,33	0,50	1,00	1,00	1,00	1,00	1,00	2,00	3,00	0,17	0,20	0,25	1,00	1,00	1,00	1,00	1,00	1,00
Profitability	0,17	0,20	0,25	0,25	0,33	0,50	0,33	0,50	1,00	1,00	1,00	1,00	0,11	0,11	0,13	1,00	1,00	1,00	1,00	1,00	1,00
Safety	6,00	7,00	8,00	6,00	7,00	8,00	4,00	5,00	6,00	8,00	9,00	9,00	1,00	1,00	1,00	4,00	5,00	6,00	6,00	7,00	8,00
Innovation & growth	0,25	0,33	0,50	0,33	0,50	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,17	0,20	0,25	1,00	1,00	1,00	1,00	1,00	1,00
Environment	0,25	0,33	0,50	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,13	0,14	0,17	1,00	1,00	1,00	1,00	1,00	1,00

Appendix Table B.7. Fuzzy AHP pairwise comparison matrix for expert 7.

	Punctuality			Journey time			Resource usage			Profitability			Safety			Innovation & growth			Environment		
Punctuality	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	2,00	3,00	0,17	0,20	0,25	1,00	1,00	1,00	1,00	1,00	1,00
Journey time	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	2,00	3,00	0,50	0,50	1,00	1,00	2,00	3,00	1,00	1,00	1,00
Resource usage	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,17	0,20	0,25	1,00	1,00	1,00	1,00	1,00	1,00
Profitability	0,33	0,50	1,00	0,33	0,50	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,50	0,50	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Safety	4,00	5,00	6,00	1,00	2,00	2,00	4,00	5,00	6,00	1,00	2,00	2,00	1,00	1,00	1,00	2,00	3,00	4,00	2,00	3,00	4,00
Innovation & growth	1,00	1,00	1,00	0,33	0,50	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,25	0,33	0,50	1,00	1,00	1,00	0,33	0,50	1,00
Environment	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,25	0,33	0,50	1,00	2,00	3,00	1,00	1,00	1,00

Appendix Table B.8. Fuzzy AHP pairwise comparison matrix for expert 8.

	Punctuality			Journey time			Resource usage			Profitability			Safety			Innovation & growth			Environment		
Punctuality	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,33	0,50	1,00	1,00	2,00	3,00	2,00	3,00	4,00
Journey time	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,33	0,50	1,00	1,00	2,00	3,00	1,00	2,00	3,00
Resource usage	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Profitability	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,25	0,33	0,50	1,00	1,00	1,00	1,00	1,00	1,00
Safety	1,00	2,00	3,00	1,00	2,00	3,00	1,00	1,00	1,00	2,00	3,00	4,00	1,00	1,00	1,00	1,00	2,00	3,00	1,00	1,00	1,00
Innovation & growth	0,33	0,50	1,00	0,33	0,50	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,33	0,50	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Environment	0,25	0,33	0,50	0,33	0,50	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

Appendix C

Appendix Table C.1. Questionnaire form designed for determining performance values of "protifibilaty" KPI for TOCs.

A	B	According to you which TOC performs best in terms of profitability?	According to you to what extent does it perform better? Scale (1 to 9)
TOC 1	TOC 2		
	TOC 3		
TOC 2	TOC 3		

Appendix Table C.2. Answered questionnaire form of expert 1 for determining performance values of "protifibilaty" KPI.

A	B	According to you which TOC performs best in terms of profitability?	According to you to what extent does it perform better? Scale (1 to 9)
TOC 1	TOC 2	B	5
	TOC 3	B	3
TOC 2	TOC 3	A	2

Appendix Table C.3. Answered questionnaire form of expert 2 for determining performance values of "protifibilaty" KPI.

A	B	According to you which TOC performs best in terms of profitability?	According to you to what extent does it perform better? Scale (1 to 9)
TOC 1	TOC 2	B	4
	TOC 3	B	5
TOC 2	TOC 3	A	1

Appendix Table C.4. Answered questionnaire form of expert 3 for determining performance values of "protifibilaty" KPI.

A	B	According to you which TOC performs best in terms of profitability?	According to you to what extent does it perform better? Scale (1 to 9)
TOC 1	TOC 2	A	2
	TOC 3	B	3
TOC 2	TOC 3	B	3

Appendix Table C.5. Answered questionnaire form of expert 4 for determining performance values of "protifibilaty" KPI.

A	B	According to you which TOC performs best in terms of profitability?	According to you to what extent does it perform better? Scale (1 to 9)
TOC 1	TOC 2	B	2
	TOC 3	B	5
TOC 2	TOC 3	A	1

Appendix Table C.6. Answered questionnaire form of expert 5 for determining performance values of "protifibilaty" KPI.

A	B	According to you which TOC performs best in terms of profitability?	According to you to what extent does it perform better? Scale (1 to 9)
TOC 1	TOC 2	B	7
	TOC 3	B	2
TOC 2	TOC 3	A	7

Appendix Table C.7. Answered questionnaire form of expert 6 for determining performance values of "protifibilaty" KPI.

A	B	According to you which TOC performs best in terms of profitability?	According to you to what extent does it perform better? Scale (1 to 9)
TOC 1	TOC 2	B	3
	TOC 3	B	6
TOC 2	TOC 3	A	1

Appendix Table C.8. Answered questionnaire form of expert 7 for determining performance values of "protifibilaty" KPI.

A	B	According to you which TOC performs best in terms of profitability?	According to you to what extent does it perform better? Scale (1 to 9)
TOC 1	TOC 2	B	3
	TOC 3	B	3
TOC 2	TOC 3	A	2

Appendix Table C.9. Answered questionnaire form of expert 8 for determining performance values of "protifibilaty" KPI.

A	B	According to you which TOC performs best in terms of profitability?	According to you to what extent does it perform better? Scale (1 to 9)
TOC 1	TOC 2	B	7
	TOC 3	B	3
TOC 2	TOC 3	A	2

Appendix C1

Appendix Table C1.1. AHP pairwise comparison matrix formed for expert 1 for the "protifibilaty" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	0,20	0,33
TOC 2	5,00	1,00	2,00
TOC 3	3,00	0,50	1,00

Consistency Ratio (CR) = 0,003

Appendix Table C1.2. AHP pairwise comparison matrix formed for expert 2 for the "protifibilaty" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	0,25	0,20
TOC 2	4,00	1,00	1,00
TOC 3	5,00	1,00	1,00

Consistency Ratio (CR) = 0,005

Appendix Table C1.3. AHP pairwise comparison matrix formed for expert 3 for the "protifibilaty" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	2,00	0,33
TOC 2	0,50	1,00	0,33
TOC 3	3,00	3,00	1,00

Consistency Ratio (CR) = 0,05

Appendix Table C1.4. AHP pairwise comparison matrix formed for expert 4 for the "protifibilaty" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	0,50	0,20
TOC 2	2,00	1,00	1,00
TOC 3	5,00	1,00	1,00

Consistency Ratio (CR) = 0,08

Appendix Table C1.5. AHP pairwise comparison matrix formed for expert 5 for the "protifibilaty" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	0,14	0,50
TOC 2	7,00	1,00	7,00
TOC 3	2,00	0,14	1,00

Consistency Ratio (CR) = 0,05

Appendix Table C1.6. AHP pairwise comparison matrix formed for expert 6 for the "protifibilaty" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	0,33	0,17
TOC 2	3,00	1,00	1,00
TOC 3	6,00	1,00	1,00

Consistency Ratio (CR) = 0,05

Appendix Table C1.7. AHP pairwise comparison matrix formed for expert 7 for the "protifibilaty" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	0,33	0,33
TOC 2	3,00	1,00	2,00
TOC 3	3,00	0,50	1,00

Consistency Ratio (CR) = 0,05

Appendix Table C1.8. AHP pairwise comparison matrix formed for expert 8 for the "protifibilaty" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	0,14	0,33
TOC 2	7,00	1,00	2,00
TOC 3	3,00	0,50	1,00

Consistency Ratio (CR) = 0,002

Appendix D

Appendix Table D.1. Questionnaire form designed for determining performance values of "innovation & growth" KPI for TOCs.

A	B	According to you which TOC is better for innovation & growth?	According to you to what extent does it better? Scale (1 to 9)
TOC 1	TOC 2		
	TOC 3		
TOC 2	TOC 3		

Appendix Table D.2. Answered questionnaire form of expert 1 for determining performance values of "innovation & growth" KPI.

A	B	According to you which TOC is better for innovation & growth?	According to you to what extent does it better? Scale (1 to 9)
TOC 1	TOC 2	A	2
	TOC 3	A	3
TOC 2	TOC 3	A	1

Appendix Table D.3. Answered questionnaire form of expert 2 for determining performance values of "innovation & growth" KPI.

A	B	According to you which TOC is better for innovation & growth?	According to you to what extent does it better? Scale (1 to 9)
TOC 1	TOC 2	A	1
	TOC 3	B	2
TOC 2	TOC 3	B	3

Appendix Table D.4. Answered questionnaire form of expert 3 for determining performance values of "innovation & growth" KPI.

A	B	According to you which TOC is better for innovation & growth?	According to you to what extent does it better? Scale (1 to 9)
TOC 1	TOC 2	B	5
	TOC 3	B	3
TOC 2	TOC 3	A	3

Appendix Table D.5. Answered questionnaire form of expert 4 for determining performance values of "innovation & growth" KPI.

A	B	According to you which TOC is better for innovation & growth?	According to you to what extent does it better? Scale (1 to 9)
TOC 1	TOC 2	B	4
	TOC 3	B	3
TOC 2	TOC 3	A	3

Appendix Table D.6. Answered questionnaire form of expert 5 for determining performance values of "innovation & growth" KPI.

A	B	According to you which TOC is better for innovation & growth?	According to you to what extent does it better? Scale (1 to 9)
TOC 1	TOC 2	B	2
	TOC 3	B	3
TOC 2	TOC 3	A	1

Appendix Table D.7. Answered questionnaire form of expert 6 for determining performance values of "innovation & growth" KPI.

A	B	According to you which TOC is better for innovation & growth?	According to you to what extent does it better? Scale (1 to 9)
TOC 1	TOC 2	B	3
	TOC 3	B	3
TOC 2	TOC 3	A	2

Appendix Table D.8. Answered questionnaire form of expert 7 for determining performance values of "innovation & growth" KPI.

A	B	According to you which TOC is better for innovation & growth?	According to you to what extent does it better? Scale (1 to 9)
TOC 1	TOC 2	B	5
	TOC 3	B	5
TOC 2	TOC 3	A	2

Appendix Table D.9. Answered questionnaire form of expert 8 for determining performance values of "innovation & growth" KPI.

A	B	According to you which TOC is better for innovation & growth?	According to you to what extent does it better? Scale (1 to 9)
TOC 1	TOC 2	A	1
	TOC 3	B	5
TOC 2	TOC 3	B	2

Appendix D1

Appendix Table D1.1. AHP pairwise comparison matrix formed for expert 1 for the "innovation & growth" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	2,00	3,00
TOC 2	0,50	1,00	1,00
TOC 3	0,33	1,00	1,00

Consistency Ratio (CR) = 0,02

Appendix Table D1.2. AHP pairwise comparison matrix formed for expert 2 for the "innovation & growth" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	1,00	0,50
TOC 2	1,00	1,00	0,33
TOC 3	2,00	3,00	1,00

Consistency Ratio (CR) = 0,02

Appendix Table D1.3. AHP pairwise comparison matrix formed for expert 3 for the "innovation & growth" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	0,20	0,33
TOC 2	5,00	1,00	3,00
TOC 3	3,00	0,33	1,00

Consistency Ratio (CR) = 0,03

Appendix Table D1.4. AHP pairwise comparison matrix formed for expert 4 for the "innovation & growth" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	0,25	0,33
TOC 2	4,00	1,00	3,00
TOC 3	3,00	0,33	1,00

Consistency Ratio (CR) = 0,06

Appendix Table D1.5. AHP pairwise comparison matrix formed for expert 5 for the "innovation & growth" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	0,50	0,33
TOC 2	2,00	1,00	1,00
TOC 3	3,00	1,00	1,00

Consistency Ratio (CR) = 0,02

Appendix Table D1.6. AHP pairwise comparison matrix formed for expert 6 for the "innovation & growth" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	0,33	0,33
TOC 2	3,00	1,00	2,00
TOC 3	3,00	0,50	1,00

Consistency Ratio (CR) = 0,05

Appendix Table D1.7. AHP pairwise comparison matrix formed for expert 7 for the "innovation & growth" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	0,20	0,20
TOC 2	5,00	1,00	2,00
TOC 3	5,00	0,50	1,00

Consistency Ratio (CR) = 0,05

Appendix Table D1.8. AHP pairwise comparison matrix formed for expert 8 for the "innovation & growth" KPI.

	TOC 1	TOC 2	TOC 3
TOC 1	1,00	1,00	0,20
TOC 2	1,00	1,00	0,50
TOC 3	5,00	2,00	1,00

Consistency Ratio (CR) = 0,08