AN INTEGRATED GREY ANALYTICAL APPROACH TO EVALUATE TRANSPORTATION MODE

(TAŞIMACILIK TÜRÜNÜ DEĞERLENDİRMEDE ENTEGRE GRİ ANALİTİK YAKLAŞIMI)

by

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Thesis

Submitted in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

in

INDUSTRIAL ENGINEERING

in the

GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

of

GALATASARAY UNIVERSITY

June 2017

This is to certify that the thesis entitled

AN INTEGRATED GREY ANALYTICAL APPROACH TO EVALUATE TRANSPORTATION MODE

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ACKNOWLEDGEMENTS

I would like to thank the following people for their contributions which this thesis could not be accomplished without:

- Prof. Dr. Gülçin BÜYÜKÖZKAN FEYZİOĞLU, whom I am grateful not only for her guidance in my study but also for her positive attitude and confidence in me. This work would not have been possible without her unique counsel, eternal patience and tolerance,

- The experts, for their contributions, envisioning instructions and guidance during my study,

- Gizem KÜKREKOL KARADAĞ, My beloved wife, for her pure love, patience, encouragement, support and trust in me.

Uğur KARADAĞ
June 2017

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LIST OF SYMBOLS

AHP	: Analytic Hierarchy Process
ANFIS	: Adaptive Network Based Fuzzy Inference Systems
ANN	: Artificial Neural Network
ANP	: Analytic Network Process
CI	: Consistency Index
COPRAS	: Complex Proportional Assessment
CPLEX	: Optimization Software Program
CR	: Consistency Ratio
DEMATEL	: The Decision Making Trial and Evaluation Laboratory
DM	: Decision Maker
F-	: Fuzzy
GIS	: Geographic Information Systems
GRA	: Grey Relation Analysis
GSCM	: Green Supply Chain Management
GSDP	: Green Supplier Development Program
IT	: Information Technology
MCDM	: Multi Criteria Decision Making
MMULT	: Matrix Multiplication
Ph.D.	: Doctor of Philosophy
RI	: Random Consistency Index
RER	: Renewable Energy Sources
RoHS	: The Restriction of the use of [certain] Hazardous Substances
SAW	: Simple Additive Weighting
TOPSIS	: The Technique for Order Preference by Similarity to an Ideal Solution
TSP	: Traveling Salesman Problem
VIKOR	: Vise Kriterijumska Optimizacija I Kompromisno Resenje
WOE	: Weight of Evidence

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ABSTRACT

To maintain sustainable competitive advantage in the global marketplace, the magnitude of financial and/or intangible assets owned by international transportation service providers is considerably no longer significant. The ability to use these assets in the most rational and optimal way in creating added value is seen as an important power factor. The implementation of Multi Criteria Decision Making (MCDM) methods, which enables companies to select the most appropriate customer-oriented transportation modes, has become indispensable for logistics service providers.

In this study, to establish the main and sub-criteria affecting international logistics service provider companies' choice of transportation mode and to evaluate the existing transportation mode alternatives; DEMATEL (The Decision Making Trial and Evaluation Laboratory), ANP (Analytic Network Process) and TOPSIS (The Technique for Order Preference by Similarity to an Ideal Solution) methods of MCDM integrated with grey theory are applied over the data obtained by Delphi based Group Decision Making (Delphi based GDM).

Grey DEMATEL is applied to establish relationships between and within criteria sets. Criteria weights are determined by Grey ANP. Then, Grey TOPSIS is applied to select the most appropriate transportation mode alternative.

It is determined from literature survey that very few studies have been carried out grey based MCDM methods and have not yet been utilized in the evaluation of transportation mode. In this context, it can be said that grey based MCDM methods may be developed to be applied in different areas, based on the integrated analytical grey approach presented in this study.

ÖZET

Küresel pazarda sürdürülebilir rekabet üstünlüğünün sağlaması için, uluslararası taşımacılık hizmeti sunan işletmelerin sahip olduğu somut ve/veya soyut varlıkların büyüklüğü artık önem arz etmemektedir. Söz konusu varlıkların, katma değer yaratacak en akılcı şekilde kullanma kabiliyetine sahip olunması ise önemli bir güç çarpanı olarak görülmektedir. Müşteri odaklı uygulanabilir taşımacılık alternatifleri arasından en uygun olanın belirlenmesine olanak sağlayan Çok Kriterli Karar Verme (ÇKKV) yöntemlerinin kullanılması, lojistik işletmeleri için vazgeçilmez olmuştur.

Bu çalışmada, uluslararası taşımacılık hizmeti sunan işletmelerin taşımacılık türü tercihlerinde etkili olan ana ve alt kriterler ile mevcut alternatif taşımacılık türlerinin değerlendirilmesi maksadıyla; Delphi tabanlı grup karar verme sistemi (Delphi tabanlı GKV) ile elde edilen veriler, ÇKKV yöntemlerinden DEMATEL (The Decision Making Trial and Evaluation Laboratory), ANP (Analytic Network Process) ve TOPSIS (The Technique for Order Preference by Similarity to an Ideal Solution) yöntemleri ile gri teori bütünleştirilerek analiz edilmiştir.

Kriterler arasındaki ilişkilerin belirlenmesinde Gri DEMATEL yöntemi kullanılmıştır. Gri ANP yöntemi ile kriter ağırlıkları belirlenmiştir. Alternatif taşıma türleri değerlendirilerek, en uygun taşıma türü seçimi için Gri TOPSIS yöntemi uygulanmıştır.

Yapılan yazın taramasında, gri teori tabanlı ÇKKV yöntemleri ile çok az sayıda çalışmanın yapıldığı ve taşımacılık türünün değerlendirilmesinde ise henüz kullanılmadığı tespit edilmiştir. Bu bağlamda, çalışmada sunulan entegre gri analitik yaklaşımdan yola çıkarak, gri teori tabanlı ÇKKV yöntemlerinin başka alanlarda da kullanılacak şekilde geliştirilebileceği değerlendirilmektedir.

1. INTRODUCTION

Logistics has become a prioritized business area for global business managers due to its complex and sophisticated nature and seems it will hold its popularity for a long time. It is not just about being in the right place at the right time but flexibly managing the whole process.

Over the last few decades, globalization enables multinational companies to influence trading trends and also needs of customers. The dynamic characteristics of business economy force managers to decide from the view of costs and benefits. Companies attempt to design their supply chains on micro-rehabilitations. The process of this attempt starts from the decision making phase but not concludes at the delivery of goods, it works in a sustainable cycle including the return of customers' voice.

Logistics companies accelerate their efforts especially on cost reducing and risk decreasing issues to challenge globally. The challenge has come to a point that the first and/or the fast carrier is the most preferable even it may not be a necessity for the customer as a receiver. This perception pushes the logistics society to seek for new alternatives of transportation, especially in terms of mode, that provide speed up in transportation time and also make an admissible cost for both the customer and the company. Transportation mode selection has become a main problem for logistics.

Expanding markets' challenges attract the academic attention too. This leads to improvements upon logistics decision support systems; the decision of *Wh*- and *How*-questions: what, when, where, why, who, whom, whose, which and how, how much, how many, how long, how far etc. As a result, *Wh*- and *How*- oriented decision problem objectives and targets are emerged to be handled optimally by different approaches.

Multi criteria decision making (MCDM) methods often allow the decision makers (DMs) to overcome the complex nature of problem characteristics. MCDM based approaches are effectively applied techniques for dealing *Wh*- and *How*- oriented problems due to its objective-ensuring and optimal-solution-achieving convenience lying within the background of it and its ability in taking conflicting parameters into consideration simultaneously.

There are numerous MCDM methods available in the literature that can be classified in four main groups: outranking methods, distance based methods, pair-wise comparisons based methods and other methods (Kahraman et al., 2015). Most methods are preferred to be integrated with different theories such as fuzzy sets, grey sets, rough sets etc. The grey based approaches have the advantage of containing less computational complexity according to the determination necessity of only lower and upper bounds and no need to assign a distribution for this interval (Çelikbilek & Tüysüz, 2016).

In this study, an integrated grey analytical approach towards transportation mode selection in logistics is presented at three main stages regarding with real world business life conditions, by using mainly three MCDM techniques integrated with grey theory: DEMATEL – The Decision Making Trial and Evaluation Laboratory, ANP – Analytic Network Process and TOPSIS – The Technique for Order Preference by Similarity to an Ideal Solution.

After gathering data from experts over criteria and alternatives those obtained from literature survey and experts, Delphi based Group Decision Making approach – GDM is utilized for aggregating information to involve DMs' different opinions.

In literature, consensus reaching, geometric average and arithmetic average methods are usually applied for aggregating information. Geometric average provides a slightly smaller eigenvalue of the whitened matrix λ_{max} rather than arithmetic average but a slightly bigger consistency index value (CI) (Lee, 2002). The geometric average is usually used on a ratio scale measurement in MCDM, because it guaranties the reciprocity property of the multiplicative preference relations used to provide ratio preferences (Rosanisah et al., 2017). Due to the easiness in calculations, arithmetic average method is a very common and traditionally preferred operator where a plethora of decision makers is concerned for aggregation, but geometric average method provides us more meaningful results according to the judgments established especially by a few number of decision makers.

The grey theory is based on interval judgments with a lower and an upper limit between zero (0) and one (1). To get rid of complexity in grey calculations and to obtain meaningful pairwise comparison results based on Saaty's 1-9 scale made by a few number of decision makers, as a typical method of consensus, Delphi based GDM method is applied.

Based on the decision matrix, Grey DEMATEL is applied to identify the relations between and within criteria, Grey ANP for establishing the weights of criteria and finally the ranking of the transportation mode alternatives are evaluated by Grey TOPSIS.

The proposed method is applied on a case study of an international logistics company of Turkey to evaluate the transportation mode selection, due to the experts' willingness to cooperate.

The originality of this thesis comes from its ability to provide an overall insight on the transportation mode selection criteria. In addition to the methodological contribution, another contribution is to adapt grey based integrated MCDM techniques with DEMATEL, ANP and TOPSIS over transportation mode selection.

The rest of this study is organized as follows: Section 2 provides insight on related literature review. Section 3 explains the proposed methods, techniques and model while Section 4 presents a case study that the proposed methodology applied on. Finally, the study is concluded in Section 5 giving some concluding remarks.

2. LITERATURE REVIEW

The performance improving measurements of logistics in the frame of transportation evaluation has been thoroughly and extensively investigated in recent years. Besides, a huge diversity of studies have focused on transportation mode selection by means of various techniques and models, proposed in order to monitor affecting factors, attributes and criteria, especially over targeted transportation costs. However, a few of them introduced grey MCDM approach over transportation mode criteria.

Vannieuwenhuyse et al. (2003) provide a through insight into transportation mode selection criteria based on relative importance of 11 criteria with criterion weights. The results show that some performance criteria are more preferred by the shippers and logistics service providers regarding with the transportation modes.

Through the first decade of 21st century, as the concept of supply chain management widens its business content, so the transportation mode criteria are defined over main criteria, sub-criteria, and alternatives. The process of defining the previously mentioned attributes proceeds with the phase of determining the interactions between and within clusters, main criteria, sub-criteria, elements, and alternatives. The results significantly emphasize that choosing the optimal transportation mode selection not only depends on the effects of the main criteria or sub-criteria on the alternatives but also depends on the interactions between some main criteria and sub-criteria (Tuzkaya & Önüt, 2008).

Literature review covers the primary studies published between 1997 and 2017. Among 17 crucial studies that have addressed the relationship between transportation modes and selection criteria over logistics, those discuss the transportation mode evaluation criteria are shown in **bold** and *italic* font in Table 2.1a, Table 2.1b and Table 2.1c, also those are discussed at Section 2.2.

2.1 Transportation Mode Selection Problem

The reviews of 17 crucial studies that handle transportation mode selection problem are shown in Table 2.1a, Table 2.1b and Table 2.1c. The one shown in **bold** and *italic* are also discuss the transportation mode evaluation criteria.

Table 2.1a: Literature review on transportation mode selection problem

Author(s)	Objective(s)	Technique(s)	Application Type
Nam (1997)	***To present a new approach to improve understanding of mode selection concerned with railway service and route trucking in Korea by assessing the desirability of the aggregation over commodity groups.***	***Logit Modelling***	***Real Case***
Southworth & Peterson (2000)	To describe the development and application of a single, integrated digital representation of freight transportation network based on multimodal and transcontinental, over sequencing mode and selecting route.	Modelling with GIS	Illustrative Example
Vannieuwenhuyse et al. (2003)	***To present the outcome of research about the logistics decision maker's perception concerning the transportation modes in Belgian Industry.***	***Consensus Theory***	***Real Case***
Eskigün et al. (2005)	To develop a design of an outbound supply chain network regarding with lead times, distribution facilities' locations and transportation mode choices.	Lagrangian Heuristics	Illustrative Example
Kiesmüller et al. (2005)	To propose a dual supply model concerning manufacturing lead time that suggests postponing the decision making of transportation mode until the freights are available for shipping.	Numerical Analysis	Illustrative Example

Table 2.1b: Literature review on transportation mode selection problem

Author(s)	Objective(s)	Technique(s)	Application Type
Wang & Lee (2005)	To provide a new class of scheduling problems arising in logistics in which two different modes of transportation are available at the stage of freight delivery.	Branch and Bound Algorithm	Illustrative Example
Zhao et al. (2005)	***To analyze the characteristics of shippers and carriers' choice of transportation mode providing the thinking and the basis for using potential transportation system sources efficiently in China.***	***Discrete Choice Theory***	***Real Case***
Bielli et al. (2006)	To propose a multimodal shortest path algorithm to provide a tool for detecting the facilities of using different travel modes through a transportation network.	Network Algorithms with GIS	Illustrative Example
Blauwens et al. (2006)	***To analyze the effectiveness of policy measures aiming to trigger a modal shift in the freight transportation based on the inventory-theoretic framework that studies transportation mode choice.***	***Inventory Theoretic based Cost Analysis***	***Illustrative Example***
Punakivi & Hinkka (2006)	***To analyze the mode selection criteria of transportation services from the industrial point of view of four Finnish industrial sectors.***	***Research Analysis***	***Real Case***
Ülengin et al. (2007)	To propose a decision support system that guides logistics policy makers' strategic decisions and enables them to facilitate the analysis of the possible consequences of a specific policy on changing the share of transportation modes for both passenger and freight.	Artificial Neural Network (ANN)	Illustrative Example

Table 2.1c: Literature review on transportation mode selection problem

Author(s)	**Objective(s)**	**Technique(s)**	**Application Type**
Kutanoğlu & Lohiya (2008)	To develop a tactical optimization-based model to gain insights into the integrated inventory/transportation.	Integer Programming	Illustrative Example
Sheu (2008)	To present a hybrid neuro-fuzzy methodology to identify optimal logistics operational modes applied at Taiwan IT technology industry's global supply chain management.	F-AHP F-MCDM TOPSIS ANFIS	Real Case
Tuzkaya & Önüt (2008)	***To propose a fuzzy decision support framework to determine the transportation mode priorities, combining many detailed criteria, applied in Turkey.***	***F-ANP***	***Real Case***
Köfteci et al. (2010)	***To present the results of a conjoint analysis experiment performed in two Turkish Regions that estimates decision makers' preferences for freight service attributes.***	***Statistical Analysis***	***Real Case***
Tadić et al. (2014)	***To demonstrate a model supporting decision makers when selecting city logistics concept alternatives over a sustainable point of view performed in Belgrade, Serbia.***	***F-DEMATEL*** ***F-ANP*** ***F-VIKOR***	***Real Case***
Ghane-Ezabadi & Vergara (2016)	To develop an algorithm determining terminal locations and selecting regular routes and transportation modes for loads at intermodal logistics network.	Computational Algorithms	Illustrative Example

Nam (1997) presents logit modelling approach on variables (constant/distance, accessibility, transit time, frequency, rate, and weight) to improve understanding of mode selection concerned with railway service and route trucking in Korea by assessing the desirability of the aggregation over commodity groups. The evaluation of the model is applied over data gathered from six commodity groups; textiles, paper, chemicals, basic metal, earthenware and electrical housewares. Nam states that the appropriate level of disaggregation may differ depending on circumstances and high aggregation may be adequate for broad predictions of mode shares, but disaggregation would be necessary for more specific market shares.

Southworth & Peterson (2000) describe the development and application of a single, integrated digital representation of freight transportation network based on multimodal and transcontinental operations. As it is stated in their study, selection of optimal intermodal routes required procedures for linking freight origins and destinations to the transportation network, as well as procedures for modeling terminal transfers on intermodal and inter-carrier interlining practices, and a procedure for generating multimodal impedance functions to reflect the relative costs of suitable alternatives, survey reported sequencing mode. And also, while commercial GIS software is found to be invaluable for displaying, checking and editing the network, it is also found to be most efficient to construct and process shipment routes outside this environment.

Vannieuwenhuyse et al. (2003) present the outcome of surveys conducted in Belgian industry about the perception of logistics decision maker's concerning the transportation modes, further more an interactive Internet tool (invalid now) is presented in order to support the process of transportation mode decision making. The results show that following performance criteria are the top five among 11 transportation mode criteria; transportation cost, reliability, flexibility, transportation time and safety.

Eskigün et al. (2005) develop a Lagrangian heuristic based large-scale network design model for the outbound supply chain network of an automotive company that operating the same transportation mode to take advantage of economies of scale and to simplify the delivery process of the vehicles including loading, unloading, tracking, etc.; taking lead times, location of distribution facilities and choice of transportation mode into consideration. The algorithm results that the rise in the percentage of the truck usage also concludes in higher average transportation cost due to the higher cost of the trucks when compared to rail.

Kiesmüller et al. (2005) propose a dual supply model concerning manufacturing lead time, and conduct a numerical analysis to suggest postponing the decision making of transportation mode selection until the freight are available for shipping. The proposed model enables decision maker to quantify the value of the postponement of the transportation mode decision and the value of using an additional slow mode instead of only using the existing fast mode. The results showed that selecting a slow mode can be economically beneficial, especially in cases where the manufacturing lead time is long and the difference in cost between fast and slow modes is big and the lead time difference is large, the added value of including the manufacturing lead time in the model is substantial.

Wang & Lee (2005) study a new type of scheduling problem arising in logistics management where the manufacturing and delivery of the ordered products are considered simultaneously, which is beneficial for a company. Their approach based on the integration of the machine scheduling problem in the manufacturing stage with the transportation mode selection problem in the delivery stage to achieve the global maximum benefit using branch and bound algorithm. The results showed that proposed branch and bound algorithm is superior to CPLEX for the case when tardy jobs are accepted but are charged penalty costs.

Zhao et al. (2005) analyze the characteristic of transportation mode selection using discrete choice model. By utilizing questionnaire method aiming to find the most important factors at choosing transportation mode, they state that discrete choice model has good applicability in transportation mode selection due to the result accords with the characteristic of shippers and carriers’ choice of transportation mode.

Bielli et al. (2006) focus on adaptive multimodal routing model at trip planning from travelers' point of view in their study. They propose a multimodal shortest path algorithm to provide a tool for detecting the facilities of using different travel modes through a transportation network based on algorithms and Geographic Information Systems (GIS). The results point out the advantages of merging the graph concepts and the object oriented paradigm to describe data models, and nodes and links are efficient concepts to represent several elements of the multimodal transit networks.

Blauwens et al. (2006) analyze the effectiveness of logistics policy measures aimed at triggering a modal shift in the market of freight transportation based on the inventory-theoretic framework that studies modal choice from a business logistics viewpoint. The results over combinations of some transport policy measures show that: road freight transportation will continue to grow considerably in the future if no measures are taken. But this will lead to an increase at freight transport's impact on the environment and hamper the accessibility of Europe's main economic and population centers even more. Achieving a modal shift is, however, not an easy task. The alternative freight transportation modes can only challenge with road transportation mode and its dominant characteristic if they can fulfill shippers' logistical requirements and fit well into their supply chains, due to not only of transportation costs, but also of logistics costs in a broader sense.

Punakivi & Hinkka (2006) take a closer look at the basics of logistics and analyze the selection criteria of transportation services from the industrial point of view of four Finnish industrial sectors; electronics, pharmaceutical, machinery and construction, also trying to establish a better understanding of which industrial sectors are using which mode of logistics services and why. The research results show that being strongly dependent on the industry sector, different ranking of criteria are important due to the different industrial sectors' point of view, but service price, speed, reliability, accuracy, scheduling, convenience and safety are typically the most important general factors.

Ülengin et al. (2007) propose a decision support system that guides logistics policy makers in their future strategic decisions. The proposed model facilitates the analysis of the possible consequences of a specific policy on changing the share of transportation modes for both passenger and freight transportation in the case of Turkey. The model is set on a macro-structural causal map of affecting and affected variables such as, population, foreign trade, oil consumption, inflation, number of airlines, investments, freight transportation rates etc. The scenario analyses show that if the railways and maritime lines are expected to play an expanding role in the future of the Turkish transportation system, the investment required for this purpose is much higher than current status values and their share in the total invest budget should thus be increased.

Kutanoğlu & Lohiya (2008) designed a tactical optimization-based model using integer programming to gain insights into the integrated inventory/transportation and to study how inventory decisions and mode choices are affected by changes in required time-based service levels and in penalty level in service parts logistics. The results obtained over computational analysis and observations showed that a slight generalization toward multiple modes (even for a single facility with a known stock level) leads to a hard Knapsack type problem due to the increased complexity and size of transportation mode and inventory integration.

Sheu (2008) presents a hybrid neuro-fuzzy methodology to identify optimal logistics operational modes used for global supply chain management. The proposed method, integrated with FAHP, fuzzy MCDM, TOPSIS and Adaptive Neuro-Fuzzy Inference System (ANFIS) techniques, applied on IT industries of Taiwan, have revealed the distinctive features of these global logistics operational modes and corresponding ranking order to explore the relative significance of these operational features among these global logistics modes.

Tuzkaya & Önüt (2008) proposed a fuzzy decision support framework based fuzzy-ANP (FANP) method to transportation mode selection of freight, combining many detailed criteria with their inter-related effects to obtain the most convenient transportation mode for logistics service-provider company. The proposed FANP model is applied to a large-scaled real business life problem related to the transportation project between Turkey and Germany. The results show that FANP succeeds in deriving priorities from both consistent and inconsistent human decision makers judgments where most of the transportation mode selection parameters can not be given precisely, and the required data for the suitability of the alternative modes with respect to various subjective criteria and the weights of the criteria are usually expressed in linguistic terms by decision makers.

Köfteci et al. (2010) presented the results of a conjoint analysis experiment performed in two Turkish Regions that estimates decision makers' preferences for freight service attributes. Acquired from the empirical results of the study, time reliability is an important criteria determining transportation mode choice. Valuation of cost and time are generally lower than expected.

Tadić et al. (2014) propose a novel hybrid MCDM model combining fuzzy DEMATEL, fuzzy ANP and fuzzy VIKOR, to support decision makers when selecting city logistics concept alternatives complying with the attributes of the surroundings. Successfully performed for the city of Belgrade, Serbia in accordance with the current state and development plans of the city, logistics and business environment, four potential complex logistics concepts are ranked to analyze their applicability in all aspects, especially from a sustainable point of view.

Ghane-Ezabadi & Vergara (2016) intended to develop a computational algorithm determining terminal locations and selecting regular routes and transportation modes for loads at intermodal logistics network. The results showed that this approach is able to obtain optimal solutions for non-trivial problem instances of up to 150 nodes in reasonable computational times.

2.2. Transportation Mode Evaluation Criteria

The problem of transportation mode selection requires specifically identified variables to decide over. In transportation route/mode choice literature, there has been a wide range of terms, criteria, constructs, measures, attributes, variables etc. used to define or build the evaluation model. Besides, each variable has different usage in statement but similar meaning or identification in content.

In their research, Cullinane & Toy (2000) discuss the transportation mode selection criteria obtained by a content analysis methodology to the (mostly Western) freight route/mode choice literature, thereby providing a formal approach to the identification and justification of the attributes that are to be utilized within experiments based on Stated Preference. The implications for criteria selection in empirical studies are discussed, with particular reference to the Eastern European context. Cullinane & Toy's content analysis covers 75 articles in a database of literature deemed relevant to the subject of freight transportation route/mode choice decisions. Not only the definitions are stated, but also manifest analysis of number of mentions and appearance, latent analysis as being dominance theme, meta-analysis of usage in models, for each variable category. To set a sufficiently well-defined variable frame, Cullinane & Toy's category constructs and their variables/terms coverage are adopted as a guideline to provide the integrity of criteria used in transportation mode evaluation.

Table 2.2 shows the overview of criteria used by authors on transportation mode evaluation. It can be seen that especially Cullinane & Toy (2000) and Vannieuwenhuyse et al. (2003) contribute to the literature with their studies.

Table 2.2: Overview of authors' criteria on transportation mode evaluation

Evaluation Criteria	**Author(s)**												
	Nam (1997)	**Cullinane & Toy (2000)**	**Vannieuwenhuyse et al. (2003)**	**Zhao et al. (2005)**	**Blauwens et al. (2006)**	**Punakivi & Hinkka (2006)**	**Erkayman (2007)**	**Tuzkaya (2007)**	**Tuzkaya & Önüt (2008)**	**Köfteci et al. (2010)**	**Ütücüler (2015)**	**Akay (2016)**	**Total Scores**
Cost/Price/Rate	+	+	+	+	+	+	+	+	+	+	+	+	**12**
Speed	+	+	+	+	+	+	+	+	+	+	+	+	**12**
Transit Time Reliability	-	+	+	-	-	+	+	+	+	+	+	+	**9**
Flexibility	-	+	+	+	-	-	+	+	+	-	+	+	**8**
Loss/Damage	-	+	+	-	-	+	+	+	+	+	-	+	**8**
Capability	-	+	+	+	+	+	-	-	-	-	+	-	**6**
Controllability / Traceability	-	+	+	-	-	-	+	+	+	-	-	+	**6**
Characteristics of Goods	+	+	-	+	-	-	-	+	+	-	-	-	**5**
Frequency	+	+	-	+	-	+	-	-	-	-	-	-	**4**
Infrastructure Availability	+	+	-	+	-	-	-	-	-	-	-	-	**3**
Distance	+	+	-	+	-	-	-	-	-	-	-	-	**3**
Regulation and Legislation	-	-	+	+	-	-	-	-	-	-	-	+	**3**
Strategic Elements	-	-	+	-	-	-	-	+	+	-	-	-	**3**
Previous Experience	-	+	+	-	-	-	-	-	-	-	-	+	**3**
Density of Network	-	-	+	+	-	-	-	-	-	-	-	-	**2**
Service (non-specified)	-	+	-	-	-	+	-	-	-	-	-	-	**2**
Inventory	-	+	-	-	-	-	-	-	-	-	-	-	**1**
Sales per year	-	+	-	-	-	-	-	-	-	-	-	-	**1**

Nam (1997) focuses on variables as, constant/distance/length of haul, accessibility, transit time, frequency, rate, and weight. The results shows that transit time exerts the greatest influence on the shippers' transportation mode choice response for all commodity groups for both modes; rate and accessibility have some influences for rail and truck users, respectively, while the one with less of an influence for both modes is service frequency. Users of the truck mode seem less sensitive to any change in the attributes, except for accessibility, than do the users of the rail mode.

Cullinane & Toy (2000) presents the application of a content analysis methodology to the (mostly Western) freight transportation route/mode choice literature, thereby providing a formal approach to the identification and justification of the attributes that are to be utilized within experiments based on Stated Preference. The results of the various forms of content analysis undertaken within this study generally confirm what most would expect to be the most often considered facts or influences in freight route/mode choice decision making. It is also stated that the attributes most often included as influential variables in Stated Preference experiments of transportation freight route/mode choice were found to be most strongly confirmed through the application of the more mechanistic, less subjective and rather more easily implemented approaches to content analysis, such as those based on simple frequency counts of words or terms.

Based on four transportation alternatives, road haulage, rail transport, inland navigation and intermodal transport, Vannieuwenhuyse et al. (2003) provide insight into transportation mode selection criteria. The results show that following performance criteria are the top five among 11 transportation mode criteria; transportation cost, reliability, flexibility, transportation time and safety.

Zhao et al. (2005) find transportation cost and time factor as the most important factors, reliability and trade contract as the more important factors, and distance and transportation frequency as the easy to neglect factors at the analysis on the investigation result.

Blauwens et al. (2006) characterize transportation modes by four logistics criteria: transportation costs, loading capacity, average lead-time and variance of lead-time. The goods flow itself is characterized by six parameters: annual volume, average daily demand, variance in daily demand, value of the goods, holding cost and the service level required by the receiver. The results show that certain policy measures, e.g. measures leading to an increase in the transportation costs of road transportation or measures resulting in a better lead-time performance of combined transportation, can trigger significant modal shifts from road transportation to the alternative freight transportation modes.

Punakivi & Hinkka (2006) present the prioritization of the selection criteria for the transportation modes from each industrial sector's points of view of four Finnish industrial sectors; electronics, pharmaceutical, machinery and construction. The findings show that first important criteria are quality for electronics industry; speed for pharmaceutical industry; price for machinery and construction industry.

In his thesis study, Erkayman (2007) handles the transportation problem in Turkey, especially discussing pros and cons of combined/intermodal transportation mode. An optimization software model based on Genetic Algorithms is proposed to be applied on a case, kind of Traveling Salesman Problem (TSP).

Tuzkaya (2007) focuses on transportation modes considering the affects as well in his thesis. The selection of transportation modes is emphasized applying ANP and multi level programming integrated with fuzzy approach over criteria those are obtained over related literature. The results acquired over by applying the proposed model on a transportation project of a logistic service provider, provide us insight into comparing the model by using different scenarios.

Tuzkaya & Önüt (2008) applied a FANP model over a transportation project between Turkey and Germany. The findings show that rail, sea and road modes have the similar priorities but have different advantages and disadvantages due to the characteristics of selected mode.

As a result of their conjoint analysis experiment, Köfteci et al. (2010) find that only under the cost aspect the intermodal transportation is perceived better than the road transportation, but based on the criteria as transportation time, time reliability, damages and losses, intermodal transportation is considered not convenient.

Ütücüler (2015) applies AHP methodology to determine which transportation mode is suitable, based on the case study of an international logistics company, Vestel. Pairwise comparisons are presented at conclusion by evaluating the transportation mode in terms of mode selection criteria.

Akay (2016) discusses the transportation system in Turkey, questioning the logistics companies' single transportation mode preferences rather than considering the advantageous sides of the integrated transportation based on all available modes in a logical way. The perception of companies in Konya, those getting service over international logistics service providers, is statistically analyzed.

Even though these studies form a basis for transportation mode evaluation, they do not exactly present the optimum solution due to the fuzzy and grey environment of logistics. Nevertheless, attempts to develop new approaches are still worked over and not hold off. Different integrated fuzzy and grey approaches of MCDM techniques are developed but none of them apply integrated grey approaches to evaluate transportation mode selection. In this study, we contribute to the literature proposing a new grey framework for transportation mode selection problems.

3. METHODOLOGY

3.1 The Proposed Integrated Grey Approach

Numerous approaches are developed and presented in literature to solve real world complex decision making problems. Integrated MCDM models are applied on problems to assess the alternatives with respect to the criteria, sub-criteria, attributes predetermined, considering the importance and influence weights of each of them in the evaluation. The proposed methodological background of this study consists of three phases: Grey DEMATEL, Grey ANP and Grey TOPSIS as shown at Figure 3.1.

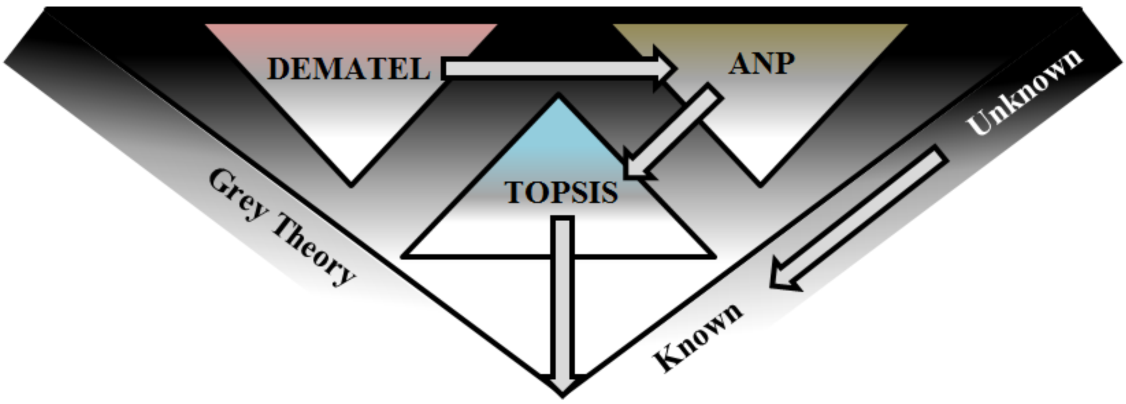


Figure 3.1: The proposed integrated grey approach

DEMATEL, widely accepted one of the best tools to establish cause-effect relationship between and within the criteria clusters, enables DMs to visualize the relation into an intelligible structural model. ANP, organizing the model for quantifying relative priorities, establishes the weights of criteria according to the pairwise judgments made by experts based on different scales as well as handles the inconsistencies in the decision making process. TOPSIS, providing the distance-based optimal solution ranking, is developed to assist DMs to choose among alternatives according to the weights of importance.

There are various methodologies in literature but, fuzzy sets theory and grey systems theory are the most important ones with respect to the ability to enable DMs to integrate uncertainty and ambiguity into the evaluation process. However, it can be said that the grey based approach has the advantage of containing less computational complexity in comparison to the fuzzy one (Çelikbilek & Tüysüz, 2016). The following sub-sections provide information about each MCDM approaches including grey theory, obtained from literature survey and related articles.

3.2 Grey Theory

Grey theory is a mathematical theory, first proposed by Professor Julong Deng (Deng, 1982), that stems from the grey set. This efficient approach addresses problems with uncertainty/partially unknown and discrete/partially known data (Tseng, 2009).

The theory consists of those five main parts as: grey prediction, Grey Relation Analysis – GRA, grey decision, grey programming and grey control (Kose et al., 2011). A grey system contains uncertain information presented by grey numbers and grey variables. A grey number $\otimes \mathbf{x}$ is described as an interval with established upper ($\overline{x}$) and lower ($\underline{x}$) limits but unknown distribution information for **x** (Deng, 1982; Deng, 1989) whose exact value is unknown, but an estimated range which comprises its value is known (Lin, et al., 2004). The concept of a grey system is shown in Figure 3.2.

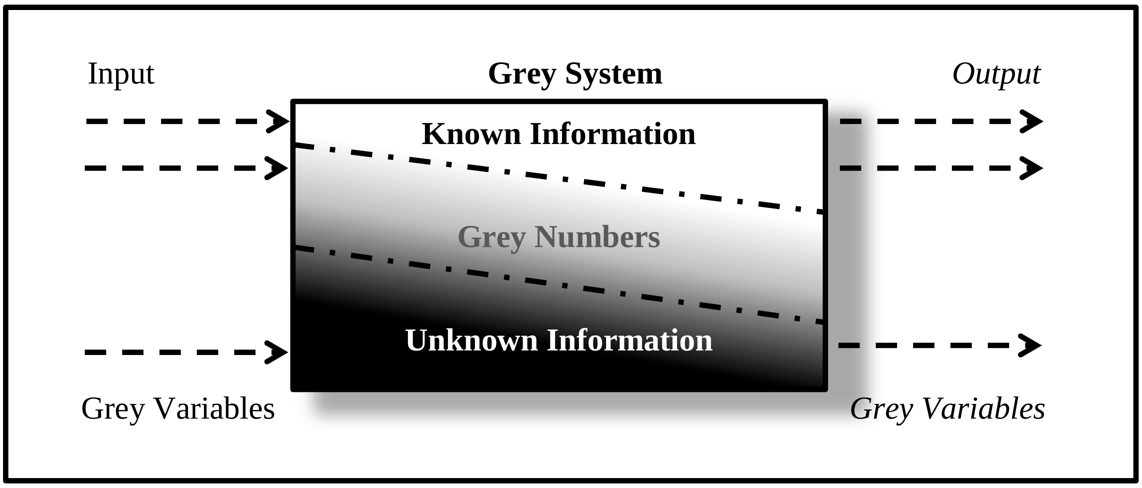


Figure 3.2: The concept of a grey system

The main general notation and elementary operations with basic essential definitions for grey numbers, grey sets and grey systems are hereby briefly presented at Table 3.1, with reference to studies of relative articles (Lin et al., 2004; Lin, Y.T. et al., 2011; Chithambaranathan et al., 2015; Ren et al., 2017):

Table 3.1: Grey Systems notations and operations

$\otimes x = [\otimes \underline{x}, \otimes \overline{x}] : \underline{x}, \overline{x} \in [0,1], \underline{x} \leq \overline{x}$

where $\underline{x}$ is the lower limit and $\overline{x}$ is the upper limit of the grey set.

Operation	Formulas and Explanation
ADDITION	$\otimes x_1 + \otimes x_2 = [\underline{x}_1, \overline{x}_1] + [\underline{x}_2, \overline{x}_2] = [\underline{x}_1 + \underline{x}_2, \overline{x}_1 + \overline{x}_2]$
SUBTRACTION	$\otimes x_1 - \otimes x_2 = [\underline{x}_1, \overline{x}_1] - [\underline{x}_2, \overline{x}_2] = [\underline{x}_1 - \underline{x}_2, \overline{x}_1 - \overline{x}_2]$
MULTIPLICATION	$\otimes x_1 \times \otimes x_2 = [\underline{x}_1, \overline{x}_1] \times [\underline{x}_2, \overline{x}_2] = \begin{bmatrix} \min\{\underline{x}_1 * \underline{x}_2, \underline{x}_1 * \overline{x}_2, \overline{x}_1 * \underline{x}_2, \overline{x}_1 * \overline{x}_2\}, \\ \max\{\underline{x}_1 * \underline{x}_2, \underline{x}_1 * \overline{x}_2, \overline{x}_1 * \underline{x}_2, \overline{x}_1 * \overline{x}_2\} \end{bmatrix}$
MULTIPLICATION	$\otimes x_1 \times k = k \times \otimes x_1 = k \times [\underline{x}_1, \overline{x}_1] = [k\underline{x}_1, k\overline{x}_1]$
DIVISION	$\frac{\otimes x_1}{\otimes x_2} = \left[\min\left\{\frac{\underline{x}_1}{\underline{x}_2}, \frac{\underline{x}_1}{\overline{x}_2}, \frac{\overline{x}_1}{\underline{x}_2}, \frac{\overline{x}_1}{\overline{x}_2}\right\}, \max\left\{\frac{\underline{x}_1}{\underline{x}_2}, \frac{\underline{x}_1}{\overline{x}_2}, \frac{\overline{x}_1}{\underline{x}_2}, \frac{\overline{x}_1}{\overline{x}_2}\right\}\right]$
WHITENED MID-VALUE	$x^M = (\underline{x} + \overline{x}) / 2$

3.3 Grey DEMATEL

Decision Making Trial and Evaluation Laboratory (DEMATEL) method, is a systematic analysis method based on matrix calculations and graph theory, was originally developed by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva Research Center between 1972 and 1976 (Gabus & Fontela, 1972).

DEMATEL method aims at finding direct and indirect causal relationships, and the strength of influence between the factors of a system. At first, DEMATEL was used for finding the cause-effect relations within a system, but it can be also used as a MCDM method for an integrated solution, as an important set of tools for addressing challenging decisions. These tools enable the decision maker handle uncertainty and complexity within a system as well as conflicting objectives. DEMATEL structures a model for analyzing the influential relation among criteria.

DEMATEL method can effectively build the structure of a relationships map with clear interrelations between within sub-criteria for each criterion. Establishing causal diagrams enable decision makers to visualize the causal relationship of sub-systems, that it can also be applied for that purpose (Büyüközkan & Çifçi, 2012).

Reviewing the former studies in literature, DEMATEL has been adapted for different topics, widely and successfully applied in many diverse application areas such as:

(i) *Business & management* (Yazdani et al., 2017; Shen et al., 2017; Govindan et al., 2016a; Altuntaş & Dereli, 2015; Liou et al., 2014b; Tsai & Cheng, 2012),

(ii) *Social sciences* (Supeekit et al., 2016; Cheng et al., 2016; Büyüközkan & Öztürkcan , 2010),

(iii) *Environmental sciences* (Sen et al., 2017; Muchangos et al., 2015; Zhou et al., 2014) and,

(iv) *Energy* (Gigović et al., 2017; Büyüközkan & Güleryüz, 2016; Ren et al., 2013).

Shaik & Abdul-Kader (2014) provide us a summary of for which three reasons the application of the DEMATEL approach is preferred as follows:

(i) It provides mutual and effective relations of factors by using graph theory: it scores the rate of each relation by a number,

(ii) It uses a feedback of relations where each factor can affect other factors at all levels (same, upper, and lower),

(iii) The importance of each factor is determined by all available factors in the system.

Although DEMATEL is a good technique for evaluating problems, the relationships of systems are generally given by crisp values in establishing a structural model. However, crisp values are inadequate in this real world. Many evaluation criteria are surely imperfect and probably uncertain factors (Büyüközkan & Çifçi, 2012).

Nevertheless, DEMATEL has its limitations and weaknesses. DEMATEL is very effective in revealing the cause and effect relationships among factors and prioritizing them, but it may have some difficulties in describing uncertainty (Bai & Sarkis, 2013). It is unable to deal with uncertainty, conflicts among experts, and lack of information. It also cannot express ambiguous values around a given discrete value (Bai & Sarkis, 2013).

In order to increase its capabilities while overcoming the mentioned problem, some extensions of DEMATEL method have been recently developed, especially integrated with;

(i) *Fuzzy set theory* (Zhan et al., 2017; Uygun & Dede, 2016; Wang, 2015; Govindan et al., 2014; Baykasoğlu et al., 2013; Tseng et al., 2012; Büyüközkan & Çifçi, 2012; Tseng, 2009a; Liou et al., 2008; Wu & Lee, 2007) and,

(ii) *Grey set theory* (Ren et al., 2017; Çelikbilek & Tüysüz, 2016; Su et al., 2016; Liang et al., 2016; Shao et al., 2016; Asad et al., 2016a; Asad et al., 2016b; Rajesh & Ravi, 2015; Zhu et al., 2015; Xia et al., 2015; Zhu et al., 2014; Dou & Sarkis, 2013; Bai & Sarkis, 2013; Fu et al., 2012; Tseng, 2009b).

When compared with fuzzy set theory and probability theory, the major benefit of a grey system is its little necessity on sample data and flexible ability in pattern recognition (Yang and John, 2003).

A grey system is a system that contains uncertain information represented by a grey number. For ordering the preference ranking, a grey possibility degree is proposed (Tseng, 2010). The ranking of criteria or alternatives as a decision-making problem is uncertain, itself.

In grey theory, if the system information is *fully known*, then the system is called a ***white system*** while the information is *unknown*, it is called a ***black system,*** according to the degree of information. A system with information *known partially* is called a ***grey system*** (Köse et al., 2013).

As a result of these significant advantages, a grey theory is integrated with DEMATEL for the aim of dealing with imperfect and incomplete information.

Obtained over the literature survey, a few numbers of integrated grey approaches of DEMATEL are developed in literature and 18 related studies are presented in Table 3.2.

The computational steps of the grey-based DEMATEL method used in this study are given below and described as follows, with reference to studies of relative articles **bolded** in Table 3.2 (Dou & Sarkis, 2013; Rajesh & Ravi, 2015; Çelikbilek & Tüysüz, 2016; Ren et al., 2017):

Table 3.2: Grey DEMATEL studies (the years between 2009 and January 2017)

Author(s)	Integrated Method(s)	Application		
		Country	Area	Type
Ren et al. (2017)	Grey DEMATEL	China	Sludge-to-energy Sustainability	Real Case
Çelikbilek & Tüysüz (2016)	Grey DEMATEL Grey ANP Grey VIKOR	Turkey	RER Selection	Real Case
Su et al. (2016)	Grey DEMATEL	Taiwan	Electronics Supplier Selection.	Real Case
Liang et al. (2016)	Grey DEMATEL	China	Biofuel Industry	Real Case
Shao et al. (2016)	Grey DEMATEL	Europe	Automobile Industry	Real Case
Asad et al. (2016a)	Grey DEMATEL	-	Internet Banking	Real Case
Asad et al. (2016b)	Grey DEMATEL	-	IT Supply Chain	Real Case
Özdemir & Tüysüz (2015)	Grey DEMATEL	Turkey	University Strategy	Real Case
Rajesh & Ravi (2015)	Grey DEMATEL	India	Electronics Risk Analysis	Real Case
Zhu et al. (2015)	Grey DEMATEL	China	Truck Engine	Real Case
Xia et al. (2015)	Grey DEMATEL	China	Automotive Industry	Real Case
Zhu et al. (2014)	Grey DEMATEL	China	Truck engine remanufacturing	Real Case
Azar & Ardakani (2014)	Grey DEMATEL	Iran	Iron Steel GSCM	Real Case
Dou & Sarkis (2013)	Grey DEMATEL	China	RoHS regulations	Real Case
Bai & Sarkis (2013)	Grey DEMATEL	China	Business process management	Real Case
Fu et al. (2012)	Grey DEMATEL	China	TELECOM GSDP evaluation	Real Case
Gao yan et al. (2009)	Grey DEMATEL	China	Defence Technology	Real Case
Tseng (2009b)	Grey DEMATEL Fuzzy DEMATEL	Taiwan	Service quality	Real Case

Step 1 : ***Constructing initial direct-relation matrix***

Step 1.1 Measuring the relationship between criteria requires a grey linguistic comparison scale designed as four integer levels: No Effect (0), Low Effect (1), Medium Effect (2), High Effect (3), Very High Effect (4); shown at Table 3.3.

Table 3.3 : Linguistic terms and corresponding grey values for Grey DEMATEL

Linguistic Terms	Abbreviations	Crisp Values	Grey Values
No Effect	NO	0	[0 , 0]
Low Effect	LE	1	[0 , 0.25]
Medium Effect	ME	2	[0.25 , 0.50]
High Effect	HE	3	[0.50 , 0.75]
Very High Effect	VH	4	[0.75 , 1]

Step 1.2 A team of ***k*** experts is asked to make pairwise comparisons in terms of influence and direction between ***n*** criteria with crisp values.

The integer results of these evaluations form a ***nxn*** non-negative matrix called direct-relation matrix ***X***, in which $\boldsymbol{x_{ij}}$ is denoted as the degree to which the criterion ***i*** affects the criterion ***j***, according to the expert ***k***. Then, the direct relation matrices are converted into grey direct relation matrices represented in Eq. (3.1) and Eq. (3.2).

$$\boldsymbol{X^k} = \begin{bmatrix} 0 & \cdots & \boldsymbol{x_{1j}^k} \\ \vdots & \ddots & \vdots \\ \boldsymbol{x_{i1}^k} & \cdots & 0 \end{bmatrix}_{nxn} \tag{3.1}$$

$$\otimes\boldsymbol{X^k} = \begin{bmatrix} 0 & \cdots & \otimes\boldsymbol{x_{1j}^k} \\ \vdots & \ddots & \vdots \\ \otimes\boldsymbol{x_{i1}^k} & \cdots & 0 \end{bmatrix}_{nxn} \tag{3.2}$$

Step 1.3 All grey direct relation matrices of $\boldsymbol{k}$ experts are averaged by using Eq. (3.3) and the $\boldsymbol{nxn}$ initial grey direct relation matrix $\otimes\boldsymbol{Z}$ is obtained, represented in Eq. (3.4).

$$\otimes\boldsymbol{z_{ij}} = \left(\sum_{i=1}^{k} \otimes\boldsymbol{x_{ij}^{k}}\right) /k \tag{3.3}$$

$$\otimes\boldsymbol{Z} = \begin{bmatrix} 0 & \cdots & \otimes\boldsymbol{z_{1j}} \\ \vdots & \ddots & \vdots \\ \otimes\boldsymbol{z_{i1}} & \cdots & 0 \end{bmatrix}_{nxn} \tag{3.4}$$

Step 2 : ***Obtaining normalized grey direct relation matrix***

The normalized grey direct relation matrix $\otimes\boldsymbol{N}$ as in Eq. (3.7) is obtained through the initial grey direct relation matrix $\otimes\boldsymbol{Z}$**,** normalized by Eq. (3.5) and Eq. (3.6).

$$\boldsymbol{r} = \max_{1 \le i \le n} \left(\sum_{j=1}^{n} \otimes\boldsymbol{z_{ij}}\right) \tag{3.5}$$

$$\otimes\boldsymbol{N} = \boldsymbol{r}^{-1} * \otimes\, \boldsymbol{Z} \tag{3.6}$$

$$\otimes\boldsymbol{N} = \begin{bmatrix} 0 & \cdots & \otimes\boldsymbol{n_{1j}} \\ \vdots & \ddots & \vdots \\ \otimes\boldsymbol{n_{i1}} & \cdots & 0 \end{bmatrix}_{nxn} \tag{3.7}$$

Step 3 : ***Constructing grey total relation matrix***

Once, $\otimes\boldsymbol{N}$ - the normalized grey direct relation matrix - is obtained, the grey total relation matrix $\otimes\boldsymbol{T}$ as in Eq. (3.9) is calculated by using the Eq. (3.8), in which $\otimes\boldsymbol{I}$ is the identity matrix.

$$\otimes\boldsymbol{T} = \otimes\boldsymbol{N} * (\otimes\boldsymbol{I} - \otimes\boldsymbol{N})^{-1} \tag{3.8}$$

$$\otimes\boldsymbol{T} = \begin{bmatrix} 0 & \cdots & \otimes\boldsymbol{t_{1j}} \\ \vdots & \ddots & \vdots \\ \otimes\boldsymbol{t_{i1}} & \cdots & 0 \end{bmatrix}_{nxn} \tag{3.9}$$

Step 4 : ***Whitenization and Calculating the Dispatcher, Receiver, Prominence (D+R) and Relation (D-R).***

Step 4.1 Whitenization

To find crisp scores as $\boldsymbol{z_{ij}}$ represented in Eq. (3.14), the grey total relation matrix $\otimes\boldsymbol{T}$ is whitened by using Eq. (3.10), Eq. (3.11), Eq. (3.12) and Eq. (3.13). The grey numbers are converted into crisp values by modified **Converting Fuzzy data into Crisp Scores (CFCS)** method (Wu & Lee, 2007) given below.

$$\otimes\underline{\boldsymbol{t}}_{\boldsymbol{ij}} = \left(\otimes\underline{\boldsymbol{t}}_{\boldsymbol{ij}} - \min_j \otimes\underline{\boldsymbol{t}}_{\boldsymbol{ij}}\right) / \Delta_{\boldsymbol{min}}^{\boldsymbol{max}} \tag{3.10}$$

$$\otimes\bar{\boldsymbol{t}}_{\boldsymbol{ij}} = \left(\otimes\bar{\boldsymbol{t}}_{\boldsymbol{ij}} - \min_j \otimes\underline{\boldsymbol{t}}_{\boldsymbol{ij}}\right) / \Delta_{\boldsymbol{min}}^{\boldsymbol{max}} \tag{3.11}$$

where: $$\Delta_{\boldsymbol{min}}^{\boldsymbol{max}} = max \ \otimes\bar{\boldsymbol{t}}_{\boldsymbol{ij}} - min \ \otimes\underline{\boldsymbol{t}}_{\boldsymbol{ij}} \tag{3.12}$$

$$\boldsymbol{Y_{ij}} = \frac{\left[\otimes\underline{\boldsymbol{t}}_{\boldsymbol{ij}} \times \left(1 - \otimes\underline{\boldsymbol{t}}_{\boldsymbol{ij}}\right)\right] + \left[\otimes\bar{\boldsymbol{t}}_{\boldsymbol{ij}} \times \otimes\bar{\boldsymbol{t}}_{\boldsymbol{ij}}\right]}{1 - \otimes\underline{\boldsymbol{t}}_{\boldsymbol{ij}} + \otimes\bar{\boldsymbol{t}}_{\boldsymbol{ij}}} \tag{3.13}$$

$$\boldsymbol{z_{ij}} = \min_j \otimes\underline{\boldsymbol{t}}_{\boldsymbol{ij}} + \left(\boldsymbol{Y_{ij}} \times \Delta_{\boldsymbol{min}}^{\boldsymbol{max}}\right) \tag{3.14}$$

Step 4.2 Calculating the Dispatcher, Receiver, Prominence (D+R) and Relation (D-R)

The integer results ***D*** is the sum of rows and ***R*** is the sum of columns in whitened matrix ***T***, calculated by using Eq. (3.15) and Eq. (3.16)

$$\boldsymbol{D} = [\boldsymbol{d_i}]_{nx1} = \left(\sum_{\boldsymbol{j=1}}^{\boldsymbol{n}} \boldsymbol{t_{ij}}\right)_{nx1} \tag{3.15}$$

$$\boldsymbol{R} = [\boldsymbol{r_j}]_{1xn} = \left(\sum_{\boldsymbol{j=1}}^{\boldsymbol{n}} \boldsymbol{t_{ij}}\right)_{1xn} \tag{3.16}$$

(D+R), called as ***''Prominence''***, shows the effects among criteria and the importance of the criterion. Those criteria that are exhibiting higher positive D+R values mean they affect the others to a greater impact than affected by them.

(D-R), called as ***"Relation"***, shows the causal relations among criteria. If ***(D-R)*** is positive, it means that criterion or factor has a cause effect on others so it is from the cause group as a dispatcher; otherwise, if ***(D-R)*** is negative then the criterion or the factor is affected by the others so it is from the effect group as a receiver.

Step 5 : *Setting up the threshold value (α) and obtaining the impact diagraph map*

In order to have an appropriate diagram, influence level threshold value must be set by decision makers. The average of elements in whitened matrix ***T*** is calculated by using Eq. (3.17).

$$\boldsymbol{\alpha} = \left(\sum_{i=1}^{n} \sum_{j=1}^{n} \boldsymbol{t_{ij}}\right) / n^2 \tag{3.17}$$

3.4 Grey AHP – Grey ANP

Analytic Hierarchy Process (AHP) is developed by Saaty (1980) and still effectively used quantitative technique for determining the priorities among different criteria due to its simplicity and ability to overcome complex real world decision problems.

AHP method has some disadvantages at providing information over the interrelationships within the criteria clusters rather than between the criteria clusters. So, ANP method is developed to overcome the disadvantage of AHP. Recent studies applied ANP to allow for more complex relationship among the decision levels. However, ANP requires more calculations and formation of additional pair-wise comparison matrices (Li et al., 2015). Therefore, the complexity of ANP is higher than AHP and its accuracy may be affected by the expertise of evaluation experts (Chen et al., 2009).

Even though the conventional AHP has difficulties in handling the expert's knowledge, especially fuzzy and grey extensions of AHP are developed to overcome this problem. For example, an extension of Grey AHP, being an improved grey clustering measurement method, uses the weights obtained by AHP and provides a grey evaluation grade by using the explicit weight functions which do not depend excessively on the experience of experts (Hao et al., 2010).

Applying extensions of Grey AHP based Grey ANP on MCDM problem may overcome the constraints of evaluation consistency and better handle the perception uncertainty of evaluators' matrices (Li et al., 2015). Acquired over the literature survey, a few numbers of integrated grey approaches of ANP are developed in literature and 13 related studies are presented in Table 3.4.

The computational steps of the Grey AHP – Grey ANP method used in this study are given below and described as follows, with reference to studies of relative articles **bolded** in Table 3.4:

Table 3.4 : Grey AHP and Grey ANP studies (the years between 2002 and January 2017)

Author(s)	Integrated Method(s)	Application		
		Country	Area	Type
Mathivathanan et al. (2017)	Grey AHP	India	Performance Evaluation	Real Case
Çelikbilek & Tüysüz (2016)	Grey DEMATEL Grey ANP Grey VIKOR	Turkey	RER Selection	Real Case
Sahoo et al. (2016)	Grey AHP	India	Environmental Vulnerability Assessment	Real Case
Li et al. (2015)	Grey AHP	China	Safety Management Evaluation	Real Case
Tianshui & Gang (2014)	Grey Theory & DEMATEL-ANP	China	Security and Privacy Risk Assessment	Illustrative Example
Dou et al. (2014)	Grey ANP	China	Green Supplier Evaluation	Real Case
Köse et al. (2013)	Grey ANP	Turkey	Sniper-Personnel Selection	Real Case
Tseng & Chiu (2012)	Grey-Entropy ANP	Taiwan	Green Innovation Practice	Real Case
Wang et al. (2011)	Grey ANP	China	Target Value Sequencing	Illustrative Example
Hao et al. (2010)	Grey AHP	China	Crime Prevention System Evaluation	Real Case
Zhang et al. (2009)	Grey ANP	China	Storm Tide Risk Identification	Real Case
Jin & Zhang (2007)	Grey AHP	China	Knowledge Management Performance Evaluation	Illustrative Example
Lee Y.-M. (2002)	Grey AHP	Taiwan	Factor Analysis	Illustrative Example

Step 1 : ***Defining the Problem***

After establishing the inner and outer dependencies by DEMATEL between and within the criteria clusters, the network structure is constructed.

Step 2 : ***Determining the grey linguistic scale and making the pairwise comparisons***

The process of making pairwise comparisons between and within criteria clusters in ANP is similar as in AHP method. The linguistic terms and corresponding grey numbers are given at Table 3.5.

Table 3.5 : Linguistic terms and corresponding grey values for Grey AHP

Linguistic Terms	**Abb.**	**Crisp Values**	**Grey Values**	**Reciprocal Crisp Values**	**Reciprocal Grey Values**
Extremely Influencing	EI	9	[8,9]	0.11	[0.1110, 0.1250]
Very Strongly Influencing	VS	7	[6,8]	0.14	[0.1250, 0.1667]
Strongly Influencing	S	5	[4,6]	0.2	[0.1667, 0.2500]
Moderately Influencing	M	3	[2,4]	0.33	[0.2500, 0.5000]
Equally Influencing	E	1	[1,2]	1	[0.5000, 1.0000]

Based on the values according to the linguistic terms presented at Table 3.5, the pairwise comparisons matrix is obtained as the matrix given at Eq. (3.18)

$$\otimes\boldsymbol{A} = \begin{bmatrix} \otimes\boldsymbol{a_{11}} & \cdots & \otimes\boldsymbol{a_{1n}} \\ \vdots & \ddots & \vdots \\ \otimes\boldsymbol{a_{n1}} & \cdots & \otimes\boldsymbol{a_{nn}} \end{bmatrix}_{nxn} \qquad (3.18)$$

Step 3 : *Combining all pairwise comparisons.*

The comparison matrices are averaged by using preferred aggregation method, as below arithmetic average method is presented at Eq. (3.19) for giving an example.

$$\otimes \boldsymbol{a_{ij}} = \left(\sum_{i=1}^{k} \otimes \boldsymbol{a_{ij}^{k}}\right) / k \tag{3.19}$$

Step 4 : *Whitenization of the grey all pairwise comparisons.*

To find crisp scores as $\boldsymbol{a}$ represented in Eq. (3.9), the matrix is whitened by using Eq. (3.10), Eq. (3.11), Eq. (3.12) and Eq. (3.13) presented as in Section 3.3. The grey numbers are converted into crisp values by modified **Converting Fuzzy data into Crisp Scores (CFCS)** method (Wu & Lee, 2007) given below.

$$\otimes \underline{\boldsymbol{t}}_{\boldsymbol{ij}} = \left(\otimes \underline{\boldsymbol{t}}_{\boldsymbol{ij}} - \min_j \otimes \underline{\boldsymbol{t}}_{\boldsymbol{ij}}\right) / \Delta_{\boldsymbol{min}}^{\boldsymbol{max}} \tag{3.10}$$

$$\otimes \bar{\boldsymbol{t}}_{\boldsymbol{ij}} = \left(\otimes \bar{\boldsymbol{t}}_{\boldsymbol{ij}} - \min_j \otimes \underline{\boldsymbol{t}}_{\boldsymbol{ij}}\right) / \Delta_{\boldsymbol{min}}^{\boldsymbol{max}} \tag{3.11}$$

where: $\Delta_{\boldsymbol{min}}^{\boldsymbol{max}} = max \otimes \bar{\boldsymbol{t}}_{\boldsymbol{ij}} - min \otimes \underline{\boldsymbol{t}}_{\boldsymbol{ij}}$ (3.12)

$$\boldsymbol{Y_{ij}} = \frac{\left[\otimes \underline{\boldsymbol{t}}_{\boldsymbol{ij}} \times \left(1 - \otimes \underline{\boldsymbol{t}}_{\boldsymbol{ij}}\right)\right] + \left[\otimes \bar{\boldsymbol{t}}_{\boldsymbol{ij}} \times \otimes \bar{\boldsymbol{t}}_{\boldsymbol{ij}}\right]}{1 - \otimes \underline{\boldsymbol{t}}_{\boldsymbol{ij}} + \otimes \bar{\boldsymbol{t}}_{\boldsymbol{ij}}} \tag{3.13}$$

$$\boldsymbol{a_{ij}} = \min_j \otimes \underline{\boldsymbol{t}}_{\boldsymbol{ij}} + \left(\boldsymbol{Y_{ij}} \times \Delta_{\boldsymbol{min}}^{\boldsymbol{max}}\right) \tag{3.14}$$

Step 5 : *Generating the super matrix*

The super matrix is formed as presented below at Eq. (3.20), with the weights obtained both from Grey DEMATEL for criteria those have inner dependencies and Grey AHP for the other criteria.

$$W = \begin{array}{cc} & \begin{array}{ccccccccccccc} & C_1 & & & C_2 & & \cdots & & C_N & & \\ e_{11} & e_{12} & \cdots & e_{1n_1} & e_{21} & \cdots & e_{2n_2} & \cdots & e_{N1} & \cdots & e_{Nn_n} \end{array} \\ \begin{array}{cc} C_1 & \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1n_1} \end{array} \\ C_2 & \begin{array}{c} e_{21} \\ \vdots \\ e_{2n_2} \end{array} \\ \vdots & \vdots \\ C_N & \begin{array}{c} e_{N1} \\ \vdots \\ e_{Nn_n} \end{array} \end{array} & \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ W_{21} & W_{22} & \cdots & W_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ W_{N1} & W_{N2} & \cdots & W_{NN} \end{bmatrix} \end{array} \quad (3.20)$$

Step 6 : *Calculating the limit super matrix*

The super matrix must be normalized for the process of raising the super matrix to the limit matrix. Then, the matrix is inspected at each power-raising process for having nearly same values for each column. Reaching the limit matrix will provide us the weights of criteria.

As the limit matrix is obtained, the normalization controls of each criteria cluster are done. If there is a column with not normalized values, the normalization is applied for that. So, the weights of criteria, are obtained through the limit matrix all having normalized values.

3.5 Grey TOPSIS

The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) is a multiple criteria method to identify solutions by ranking from finite set of alternatives. The underlying logic is proposed by Hwang and Yoon (1981) and developed by Chen and Hwang (1992).

The TOPSIS method is basically based on the concept of relative-distance-ranking within the set of various alternatives choosing the optimal alternative with the shortest distance from the positive ideal solution and the farthest distance to the negative-ideal solution. There are various TOPSIS studies developed and applications integrated with several MCDM approaches in various areas such as:

(i) *Supply chain management and logistics* (Awasthi et al., 2011; Huang & Li, 2010; Önüt et al., 2009; Büyüközkan et al., 2008; Ertuğrul & Karakaşoğlu, 2008),

(ii) *Design, engineering and manufacturing systems* (Azadeh et al., 2011; Kahraman et al., 2007, Huang & Tang, 2006),

(iii) *Business and marketing* (Aydoğan, 2011; Ertuğrul & Karakaşoğlu, 2009; Işıklar & Büyüközkan, 2007, Feng & Wang, 2000),

(iv) *Health, safety and environment management* (Huang et al., 2011; Kabak & Ruan, 2010; Shi et al., 2009; Zavadskas & Antucheviciene, 2006) and,

(v) *Energy* (Boran et al., 2012; Yan et al., 2011; Amiri, 2010; Huang & Huang, 2003).

Due to its effectiveness and adaptability in solving various decision problems, some extensions of TOPSIS method have been recently developed, especially integrated with;

(i) *Fuzzy set theory* (Önüt et al., 2009; Büyüközkan et al., 2008; Wang & Chang, 2007) and,

(ii) *Grey set theory* (Jiang et al., 2015; Öztayşi, 2014; Zavadskas et al., 2010a; Zavadskas et al., 2010b, Lin et al., 2008a; Lin et al., 2008b).

Obtained over the literature survey, a few numbers of integrated grey approaches of TOPSIS are developed in literature and 6 related studies are presented in Table 3.6.

Based on the grey theory definitions and operations, the computational steps of the grey-based TOPSIS method used in this study are given below and described as follows, with reference to studies of relative articles **bolded** in Table 3.6 (Jiang et al., 2015; Öztayşi, 2014; Zavadskas et al., 2010b; Zavadskas et al., 2010a, Lin et al., 2008b; Lin et al., 2008a):

Table 3.6 : Grey TOPSIS studies (the years between 2008 and January 2017)

Author(s)	**Integrated Method(s)**	**Application**		
		Country	**Area**	**Type**
Jiang et al. (2015)	WOE	China	Sediment quality	Real Case
Öztayşi (2014)	AHP	Turkey	IT selection	Real Case
Zavadskas et al. (2010b)	Grey SAW	Lithuania	Contractor selection	Real Case
Zavadskas et al. (2010a)	Grey COPRAS	Lithuania	Risk assessment	Real Case
Lin et al. (2008b)	-	Taiwan	Subcontractor selection	Illustrative Example
Lin et al. (2008a)	-	Taiwan	Subcontractor selection	Illustrative Example

Step 1 : ***Determining the decision criteria, the set of most important attributes and describing the alternatives***

Based on the literature survey, the sets of criteria and alternatives are determined.

Step ***2 : Determining the decision making matrix D***

$$\boldsymbol{D} = \begin{bmatrix} \otimes \boldsymbol{x_{11}} & \cdots & \otimes \boldsymbol{x_{1m}} \\ \vdots & \ddots & \vdots \\ \otimes \boldsymbol{x_{n1}} & \cdots & \otimes \boldsymbol{x_{nm}} \end{bmatrix}_{nxm} ; \quad \boldsymbol{i}:1,..,n; \quad \boldsymbol{j}: 1,..,m \qquad (3.21)$$

where $\otimes \boldsymbol{x_{ij}}$ denotes the grey evaluations made by the decision makers for the ***i***th alternative with respect to the ***j***th attribute. An example of the criteria properties and corresponding characteristics used for the grey evaluation scale is given at Table 3.7.

Table 3.7 : Criteria properties and corresponding characteristics for Grey TOPSIS

Criteria	**Assessment**	**Values**	**Type**
Criteria A	Intangible	1-5 Scale	Benefit
Criteria B	Tangible	Weeks	Cost
Criteria C	Tangible	Dollars	Benefit
Criteria D	Intangible	1-10 Scale	Cost

Step 3 : Determining the weights of the attributes $\boldsymbol{w_j}$

In this study, Grey ANP method is used to determine the weights of the criteria, by generating the super matrix to the power for limit matrix.

Step 4 : Constructing the normalized grey decision matrices according to the type of criteria: Benefit (larger the better) or Cost (smaller the better)

$$\otimes \boldsymbol{r_{ij}} = \frac{\otimes \boldsymbol{x_{ij}}}{\boldsymbol{max_i}(\boldsymbol{\bar{x}_{ij}})} = \left(\frac{\underline{x}_{ij}}{max_i(\bar{x}_{ij})} \; ; \; \frac{\bar{x}_{ij}}{max_i(\bar{x}_{ij})}\right) \quad \textbf{:} \textit{ for Benefit type} \tag{3.22}$$

$$\otimes \boldsymbol{r_{ij}} = \boldsymbol{1} - \frac{\otimes \boldsymbol{x_{ij}}}{\boldsymbol{max_i}(\boldsymbol{\bar{x}_{ij}})} = \left(1 - \frac{\bar{x}_{ij}}{max_i(\bar{x}_{ij})} \; ; \; 1 - \frac{\underline{x}_{ij}}{max_i(\bar{x}_{ij})}\right) \quad \textbf{:} \textit{ for Cost type} \tag{3.23}$$

where $\underline{\boldsymbol{x}}_{\boldsymbol{ij}}$ represents the lower value of the interval and $\boldsymbol{\bar{x}_{ij}}$ represents the higher value of the interval. For benefit type Eq. (3.22) and for cost type Eq. (3.23) is applied.

Step 5 : Determining the positive A^+ and negative A^- ideal alternatives by Eq. (3.24) and Eq. (3.25)

$$\boldsymbol{A^+} = \left\{ \left(\boldsymbol{max_i}\, \boldsymbol{\bar{r}_{ij}} \,|j \in J \right), \left(\boldsymbol{min_i}\, \underline{r}_{ij} \,|j \in J' \right) \middle| i \in n \right\} = \left[\boldsymbol{r}_{\boldsymbol{1}}^{+}, \boldsymbol{r}_{\boldsymbol{2}}^{+}, \dots, \boldsymbol{r}_{\boldsymbol{m}}^{+} \right] \tag{3.24}$$

$$\boldsymbol{A^-} = \left\{ \left(\boldsymbol{min_i}\, \boldsymbol{\bar{r}_{ij}} \,|j \in J \right), \left(\boldsymbol{max_i}\, \underline{r}_{ij} \,|j \in J' \right) \middle| i \in n \right\} = \left[\boldsymbol{r}_{\boldsymbol{1}}^{-}, \boldsymbol{r}_{\boldsymbol{2}}^{-}, \dots, \boldsymbol{r}_{\boldsymbol{m}}^{-} \right] \tag{3.25}$$

where;

$J = \{j = 1, 2, \dots, n | \; j \text{ associated with benefit criteria}\}$

$J' = \{j = 1, 2, \dots, n | \; j \text{ associated with cost criteria}\}$

Step 6 : Calculating the separation measure of the positive and negative ideal alternatives, $\boldsymbol{d}_{\boldsymbol{i}}^{+}$ and $\boldsymbol{d}_{\boldsymbol{i}}^{-}$ associated with the weight of each criterion, $\boldsymbol{w}_{\boldsymbol{i}}$ by Eq. (3.26) and Eq. (3.27)

$$\boldsymbol{d}_{\boldsymbol{i}}^{+} = \sqrt{\frac{1}{2}\sum_{j=1}^{m} \boldsymbol{w}_{\boldsymbol{i}} * \left[\left| r_j^{+} - \underline{r}_{ij} \right|^2 + \left| r_j^{+} - \bar{r}_{ij} \right|^2 \right]} \tag{3.26}$$

$$\boldsymbol{d}_{\boldsymbol{i}}^{-} = \sqrt{\frac{1}{2}\sum_{j=1}^{m} \boldsymbol{w}_{\boldsymbol{i}} * \left[\left| r_j^{-} - \underline{r}_{ij} \right|^2 + \left| r_j^{-} - \bar{r}_{ij} \right|^2 \right]} \tag{3.27}$$

Step 7 : Calculating the relative closeness, C_i^+, to the positive ideal alternative and ranking the preference order by descending order of C_i^+ by Eq. (3.28)

$$\boldsymbol{C}_i^+ = \frac{d_i^-}{d_i^+ + d_i^-} \tag{3.28}$$

where $0 \leq \boldsymbol{C}_i^+ \leq 1$. The larger the index value is the better the evaluation of alternative will be.

3.6 Computational Steps of the Proposed Approach

MCDM have been applied to various logistics problems, being one of the popular methods to deal with the complicacy that exhibit high uncertainty, clashing objectives, various interests and multiple perspectives (Pomerol & Barba-Romero, 2000).

This study consists of three stages: theoretical background, the MCDM based calculations within the integrated theory and the evaluation of the results considering the limitations and recommendations for future research. Selection of a suitable methodology for the problem is a complex process itself.

Firstly, the literature on transportation mode selection problem is analyzed based on various articles in the first stage. Simultaneously, transportation mode evaluation criteria are focused, defined and re-categorized through experts' opinions. Secondly, contact is established with an international logistics company, which operates over different transportation modes: road, air, sea, railway and combined (intermodal).

In the second stage, the Grey DEMATEL, Grey ANP and Grey TOPSIS structural calculations are performed based on the related literature, as well as giving references for each step while the evaluation of results are discussed at the third stage. Due to characteristics of company's preferences, the optimal alternative will be decided by applying the proposed integrated methodology among various MCDM methods. The study is structured at three stages as shown in Fig. 3.3.

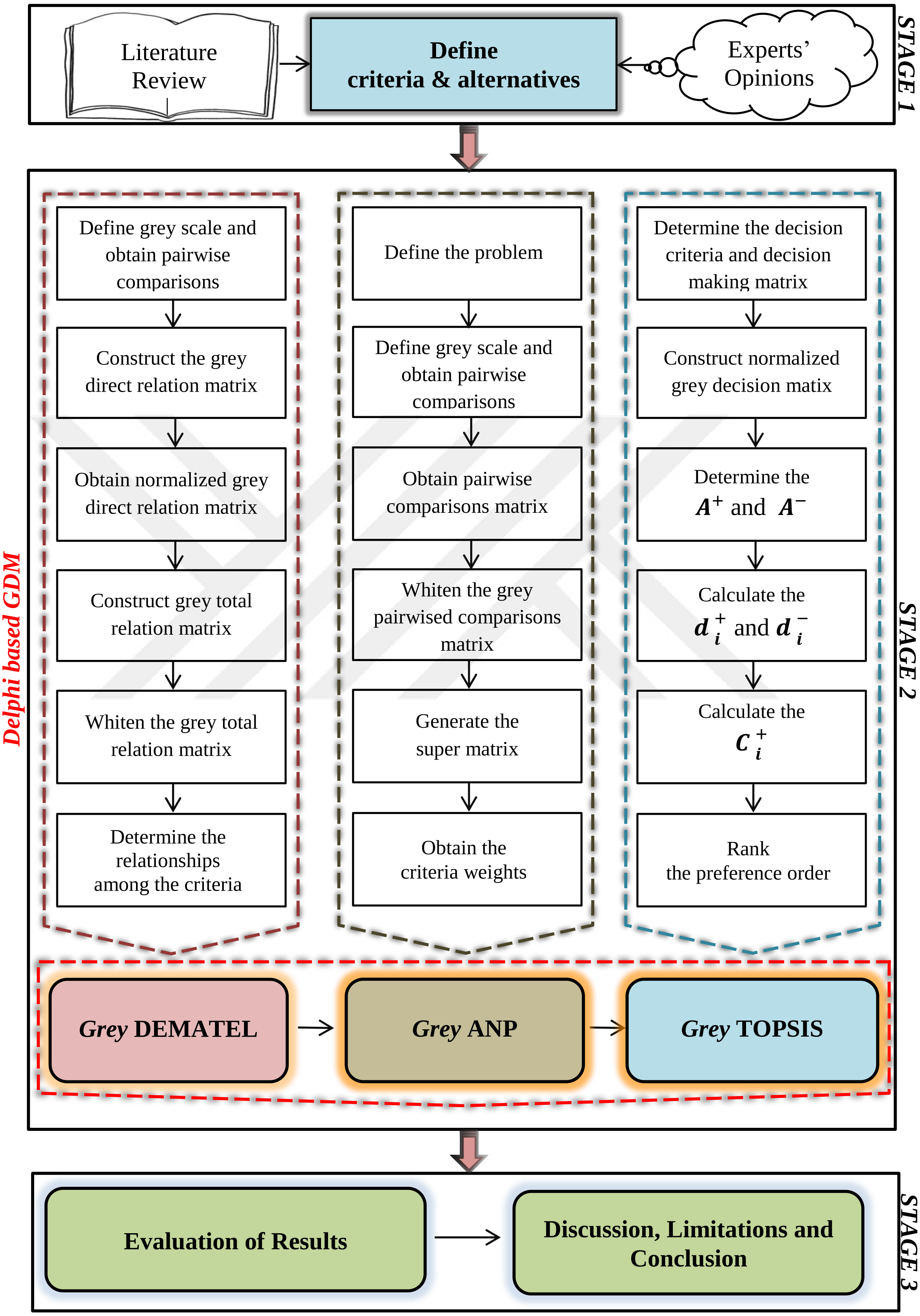


Figure 3.3 Framework of the proposed methodology

STAGE 1

Step 1 : *Literature Review :* Based on various databases, related articles on transportation mode selection criteria and transportation mode evaluation criteria are analyzed. A composition of criteria cluster is formed then.

Step 2 : *Experts' Opinion :* As the criteria cluster is obtained over literature survey, experienced experts are asked to assess on the criteria and re-organize interrelations among criteria.

Step 3 : *Define Evaluation Criteria and Alternatives :* The area of study and criteria cluster are significantly defined by Delphi based GDM.

STAGE 2

Step 4 : *Grey DEMATEL :* The network structure of the relationships and affects among and within criteria are determined with Grey DEMATEL, as explained at Section 3.3.

Step 5 : *Grey ANP :* The global weights of the evaluation criteria are obtained by generating super matrix with grey ANP, as explained at Section 3.4.

Step 6 : *Grey TOPSIS :* The alternatives are evaluated with Grey TOPSIS, as explained at Section 3.5.

STAGE 3

Step 7 : *Evaluation Results :* The ranking of alternatives is assessed.

Step 8 : *Discussion, Limitations and Conclusion:* The applicability of proposed methodology is evaluated and recommendations are made for further research.

4. CASE STUDY

4.1 Case Background

For the implementation of the proposed methodology, a contact is established with a well-known logistics company in Turkey for further information gathering over real business life experiences. The company is an international logistics service provider that offers transportation operations by various modes as road, sea, air, railway or combined (intermodal).

The company transports freight across Europe according to customer-oriented alternative modes. The customer-oriented constraints make the logistics provider to decide by which mode to choose for transporting the freight, due to the necessities of handling characteristics of freight also regarding with the costs. Global logistics companies seek for different alternatives via their Research and Development (R&D) department to reduce the cost burden while transporting and to deliver the freight not only just in time also at flexibly preferred delivery point.

Selecting the optimal and evaluating the chosen transportation mode is the aim of this study. For this aim, establishing a well-experienced decision makers team of experts of the related fields and asking for their cooperation to re-organize the up-to-date criteria sets are vital. Delphi based GDM method that contains two or more rounds of evaluation and pairwise comparison by experts for revising their opinions, is used to reach consensus for the pairwise comparisons and evaluations.

The following sub-sections are about the implementation of the proposed methodology step by step and the obtained results.

4.2 Implementation of the proposed methodology

Step 1 : *Literature Review :* Relevant articles on transportation mode selection criteria and transportation mode evaluation criteria gathered from databases and analyzed as shown at Table 2.1a, Table 2.1b, Table 2.1c and Table 2.2.

Step 2 : *Experts' Opinion :* The decision makers team is established by 3 experts in their fields whom are shown in Table 4.1.

Table 4.1: Decision Makers team

Title	Job	Experience
Industrial Engineer, Prof.Dr.	Project Manager	42 years
Business Administration, Ph.D.	Academician	40 years
Informatics, M.Sc.	Company Manager	18 years

Expert 1 is a logistics expert with over 42 years of significant academic experience in evaluating a various aspects of transportation operations in Turkey. He works closely with local and international logistics companies during project consulting phases. *Expert 2* is an academician with business administration background, having more than 30 years of business experience in private sector agencies. *Expert 3* has gained relevant experiences in supply chain management due to his commitment on business development, project management and trading issues in logistics.

Step 3 : *Define Evaluation Criteria and Alternatives :* The literature survey related (including implied contents) to the transportation mode selection and evaluation criteria are given at Table 2.1a, Table 2.1b, Table 2.1c Table 2.2 and the definitions are specified as follows. Then, Delphi based GDM is applied upon criteria evaluation.

Not all main criteria and sub-criteria are obtained from literature survey, but also the expert team of decision makers is asked to contribute to the evaluation frame, as shown at Table 4.2a, Table 4.2b and Table 4.2c, as depicted at Figure 4.1.

Due to the decision makers' experiences in their professional areas, the team of experts is encouraged to re-structure the relationships within the evaluation frame in the context of up-to-date world competition.

(1) INFRASTRUCTURE AVAILABILITY (IA)

(IA1) *Station/Hub Accessibility :* Accessibility of the facilities both geographically and infrastructure availability including rail connection.

(IA2) *Inventory/Warehousing Capacity :* The adaptiveness of facility in storing freight with different required conditions.

(IA3) *Connection to Logistics Village :* Having access to local/central logistics hubs.

(IA4) *Combined Transportation :* The flexibility of vehicle, product and the management at carrying between different transportation types.

(2) TRACEABILITY (T)

(T1) *Vehicle Traceability :* The ability of geographical traceability of the vehicle.

(T2) *Freight Traceability :* The ability of geographical traceability of the freight.

(T3) *Potential Flow Traceability :* The ability of traceability in terms of potential flow.

(3) COST (C)

(C1) *Handling Costs :* The cost of keeping product in expected conditions.

(C2) *Defective Freight Costs :* Burdened cost in case of defective freight.

(C3) *TELECOM&Information Costs :* The cost of communication including GPS.

(C4) *Transportation Costs :* The admissible cost of carrying in terms of tons.

(C5) *Inventory Costs :* The cost of storage at any phase of the transportation.

(4) FLEXIBILITY (F)

(F1) *Convenient Scheduling :* Meeting customized schedule expectation.

(F2) *Flexible Capacity :* The ability to operate at different amount and form.

(F3) *Flexible Routing :* Adaptive routing during transportation.

(F4) *Flexible Pick-up/Delivery :* Convenience at loading and delivery.

(5) SPEED (S)

(S1) *Terminal Time :* The average elapsed time at final terminal before distribution.

(S2) *Transshipment Time :* The average elapsed time during transfers at intermediate stations

(S3) *Transportation Time :* The average elapsed time from addressing to delivery.

(S4) *Transportation Speed :* The speed of whole process in terms of time.

(S5) *Transportation Distance :* The distance of whole process in terms of time.

(6) SUSTAINABILITY (SA)

(SA1) *Environmental Friendly :* The sustainable profitability of the whole transportation process in terms of environmental consciousness.

(SA2) *Social Sustainability :* The sustainable profitability of the whole transportation process in terms of social contribution.

(SA3) *Economic Sustainability :* The sustainable profitability of the whole transportation process in terms of economic value.

(SA4) *Carbon Footage :* The emission level of carbon dioxide.

(7) CAPABILITY (CA)

(CA1) *Service Quality :* Fulfillment of expected service quality.

(CA2) *Equipments Available :* The hardware or outfit used during operations.

(CA3) *Customs Clearance :* The managerial capability at customs.

(CA4) *Delivery Frequency :* The transportation rate of recurrence.

(CA5) *Service Variety :* The service provided in case of different firm trends.

(8) RELIABILITY (R)

(R1) *Late Arrival Accountability :* Carrier’s outlined policy in case of late arrival.

(R2) *Stable Arrivals/Delivery :* The constancy of field operations at high percentage.

(R3) *Reliable Scheduling :* Reasonable just-in-time operations.

(R4) *Previous Experiences :* The acquired experiences before.

(R5) *Managerial Stability of firm :* The adaptability of management at unexpected.

(9) REGULATION & LEGISLATION (RL)

(RL1) *Claims :* The kind of damages included in contract in terms of insurance.

(RL2) *Obligations :* The conditions that the firm ought to comply with.

(RL3) *Custom Formalities :* The difficulties encountered according to freight type.

(RL4) *Trade Contract/Reassurance :* The extent of the contract in term of efficiency.

(10) SAFETY & RISKS (SR)

(SR1) *Storage Risks :* The effect of hazards and risks of storing on product.

(SR2) *Burglary&Accident Probability :* The possibility of burglary or accidental situations.

(SR3) *Loss/Damage Risks :* Regarding the reasons conclude with harm on or loss of product during transportation.

(SR4) *Environmental Risks :* The unmanageable but preventable environmental possibility.

(SR5) *Strategic Concerns :* Envisaged issues according to the preferred transportation mode.

(11) CHARACTERISTICS OF GOODS (CG)

(CG1) *Weight/Volume/Density :* The weight, volume or density of the product in the content of carriage limitations.

(CG2) *Packaging Features :* The protection level of package, the material package made of –recyclable/biodegradable–, price of packaging material, comfortable carriage, product visibility, easy-to-open/re-pack.

(CG3) *Product Life/Assurance :* Balanced integrity of product under different circumstances and the extent of assurance.

(CG4) *Product Value/weight Ratio :* Perceived overall market value of the product.

(CG5) *Shipment Size :* Proportional scale regarding product value, package and weight/volume and density.

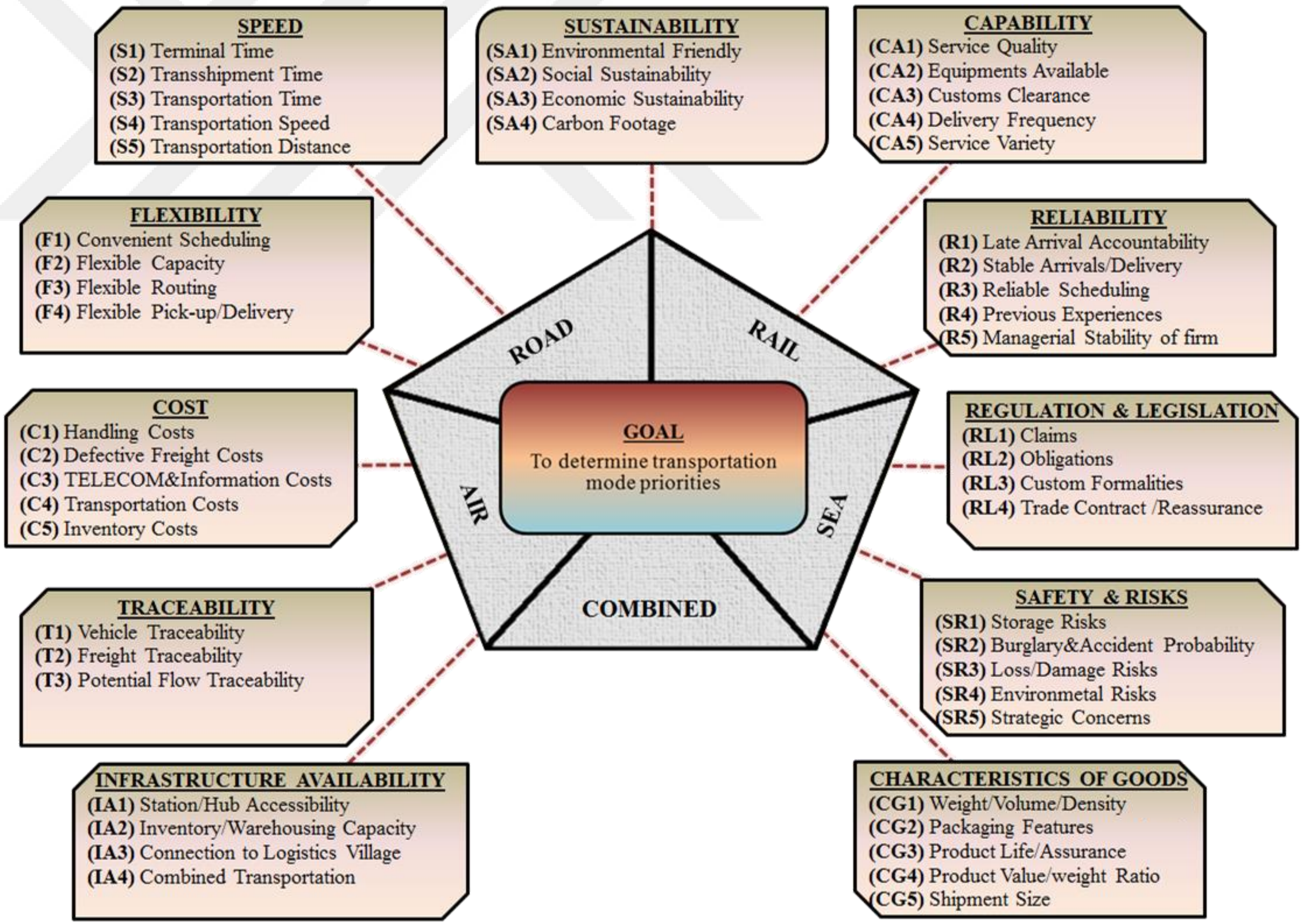


Figure 4.1: Proposed evaluation model for transportation mode selection

Table 4.2a: Transportation mode evaluation criteria related literature

Main & Sub-Criteria	References	
	Literature	**Experts**
1. INFRASTRUCTURE AVAILABILITY	Cullinane & Toy, 2000.	
(IA1) Station/Hub Accessibility	Nam, 1997; Cullinane & Toy, 2000; Zhao et al., 2005.	
(IA2) Inventory/Warehousing Capacity	Cullinane & Toy, 2000; Vannieuwenhuyse et al., 2003.	
(IA3) Connection to Logistics Village		X
(IA4) Combined Transportation		X
2. TRACEABILITY	Cullinane & Toy, 2000; Tuzkaya & Önüt, 2008.	
(T1) Vehicle Traceability	Tuzkaya & Önüt, 2008.	
(T2) Freight Traceability	Tuzkaya & Önüt, 2008.	
(T3) Potential Flow Traceability	Vannieuwenhuyse et al., 2003; Tuzkaya & Önüt, 2008.	
3. COST	Nam, 1997; Cullinane & Toy, 2000; Vannieuwenhuyse et al., 2003; Zhao et al., 2005; Blauwens et al., 2006; Punakivi & Hinkka, 2007; Tuzkaya & Önüt, 2008; Köfteci et al., 2010.	
(C1) Handling Costs	Nam, 1997; Cullinane & Toy, 2000; Vannieuwenhuyse et al., 2003; Zhao et al., 2005; Blauwens et al., 2006; Tuzkaya & Önüt, 2008.	
(C2) Defective Freight Costs	Tuzkaya & Önüt, 2008.	
(C3) TELECOM&Information Costs	Tuzkaya & Önüt, 2008.	
(C4) Transportation Costs	Nam, 1997;Cullinane & Toy, 2000; Vannieuwenhuyse et al., 2003; Zhao et al., 2005; Blauwens et al., 2006; Tuzkaya & Önüt, 2008; Köfteci et al., 2010.	
(C5) Inventory Costs	Zhao et al., 2005; Tuzkaya & Önüt, 2008.	
4. FLEXIBILITY	Cullinane & Toy, 2000; Vannieuwenhuyse et al., 2003; Zhao et al., 2005; Punakivi & Hinkka, 2007; Tuzkaya & Önüt, 2008.	
(F1) Convenient Scheduling	Cullinane & Toy, 2000; Tuzkaya & Önüt, 2008.	
(F2) Flexible Capacity	Zhao et al., 2005; Tuzkaya & Önüt, 2008.	
(F3) Flexible Routing	Vannieuwenhuyse et al., 2003; Tuzkaya & Önüt, 2008.	
(F4) Flexible Pick-up/Delivery	Cullinane & Toy, 2000; Tuzkaya & Önüt, 2008.	

Table 4.2b: Transportation mode evaluation criteria related literature

Main & Sub-Criteria	References: Literature	References: Experts
5. SPEED	Cullinane & Toy, 2000; Tuzkaya & Önüt, 2008; Köfteci et al., 2010.	
(S1) Terminal Time	Cullinane & Toy, 2000; Zhao et al., 2005.	
(S2) Transshipment Time	Cullinane & Toy, 2000; Zhao et al., 2005; Tuzkaya & Önüt, 2008.	
(S3) Transportation Time	Nam, 1997; Vannieuwenhuyse et al., 2003; Zhao et al., 2005; Blauwens et al., 2006; Tuzkaya & Önüt, 2008; Köfteci et al., 2010.	
(S4) Transportation Speed	Cullinane & Toy, 2000; Zhao et al., 2005; Punakivi & Hinkka, 2007; Tuzkaya & Önüt, 2008.	
(S5) Transportation Distance	Nam, 1997; Cullinane & Toy, 2000; Zhao et al., 2005; Zhao et al., 2005; Tuzkaya & Önüt, 2008.	
6. SUSTAINABILITY		X
(SA1) Environmental Friendly	Vannieuwenhuyse et al., 2003.	
(SA2) Social Sustainability		X
(SA3) Economic Sustainability		X
(SA4) Carbon Footage		X
7. CAPABILITY	Cullinane & Toy, 2000.	
(CA1) Service Quality	Cullinane & Toy, 2000; Zhao et al., 2005; Punakivi & Hinkka, 2007.	
(CA2) Equipments Available	Cullinane & Toy, 2000.	
(CA3) Customs Clearance		X
(CA4) Delivery Frequency	Nam, 1997; Cullinane & Toy, 2000; Zhao et al., 2005; Blauwens et al., 2006.	
(CA5) Service Variety	Cullinane & Toy, 2000; Zhao et al., 2005.	
8. RELIABILITY	Vannieuwenhuyse et al., 2003; Zhao et al., 2005; Punakivi & Hinkka, 2007; Tuzkaya & Önüt, 2008; Köfteci et al., 2010.	
(R1) Late Arrival Accountability	Vannieuwenhuyse et al., 2003; Punakivi & Hinkka, 2007; Tuzkaya & Önüt, 2008.	
(R2) Stable Arrivals/Delivery	Vannieuwenhuyse et al., 2003; Tuzkaya & Önüt, 2008; Köfteci et al., 2010.	
(R3) Reliable Scheduling	Cullinane & Toy, 2000; Vannieuwenhuyse et al., 2003; Punakivi & Hinkka, 2007; Tuzkaya & Önüt, 2008; Köfteci et al., 2010.	
(R4) Previous Experiences	Cullinane & Toy, 2000.	
(R5) Managerial Stability of firm	Cullinane & Toy, 2000.	

Table 4.2c: Transportation mode evaluation criteria related literature

Main & Sub-Criteria	References	
	Literature	**Experts**
9. REGULATION & LEGISLATION	Vannieuwenhuyse et al., 2003.	
(RL1) Claims	Vannieuwenhuyse et al., 2003.	
(RL2) Obligations	Vannieuwenhuyse et al., 2003.	
(RL3) Custom Formalities	Vannieuwenhuyse et al., 2003;	
(RL4) Trade Contract /Reassurance	Vannieuwenhuyse et al., 2003; Zhao et al., 2005.	
10. SAFETY & RISKS	Blauwens et al., 2006; Punakivi & Hinkka, 2007; Tuzkaya & Önüt, 2008; Köfteci et al., 2010.	
(SR1) Storage Risks	Zhao et al., 2005; Tuzkaya & Önüt, 2008.	
(SR2) Burglary&Accident Probability	Tuzkaya & Önüt, 2008.	
(SR3) Loss/Damage Risks	Cullinane & Toy, 2000; Vannieuwenhuyse et al., 2003; Zhao et al., 2005; Tuzkaya & Önüt, 2008; Köfteci et al., 2010.	
(SR4) Environmental Risks	Tuzkaya & Önüt, 2008.	
(SR5) Strategic Concerns	Vannieuwenhuyse et al., 2003; Tuzkaya & Önüt, 2008.	
11. CHARACTERISTICS OF GOODS	Cullinane & Toy, 2000; Tuzkaya & Önüt, 2008.	
(CG1) Weight/Volume/Density	Nam, 1997; Zhao et al., 2005; Blauwens et al., 2006; Tuzkaya & Önüt, 2008.	
(CG2) Packaging Features	Tuzkaya & Önüt, 2008.	
(CG3) Product Life/Assurance	Zhao et al., 2005; Tuzkaya & Önüt, 2008.	
(CG4) Product Value/weight Ratio	Zhao et al., 2005; Blauwens et al., 2006; Tuzkaya & Önüt, 2008.	
(CG5) Shipment Size	Zhao et al., 2005; Blauwens et al., 2006; Tuzkaya & Önüt, 2008.	

Step 4 : *Grey DEMATEL :* Based on the pairwise comparisons made by experts using Delphi method and expert knowledge in their fields, inner dependencies are determined at 7 out of 11 criteria and none of them are found dependent on another criterion.

In order to establish the dependencies within these criteria, Grey DEMATEL will be applied also determining the network structure of the relationships and affects among criteria, as explained at Section 3.3.

The general sub-matrix notation is presented at Table 4.3 and the criteria with inner dependencies are highlighted with pink and loops on it.

Table 4.3 : General sub-matrix notation for Grey DEMATEL

	IA	**T**	**C**	**F**	**S**	**SA**	**CA**	**R**	**RL**	**SR**	**CG**
IA		0	0	0	0	0	0	0	0	0	0
T	0		0	0	0	0	0	0	0	0	0
C	0	0		0	0	0	0	0	0	0	0
F	0	0	0		0	0	0	0	0	0	0
S	0	0	0	0		0	0	0	0	0	0
SA	0	0	0	0	0		0	0	0	0	0
CA	0	0	0	0	0	0		0	0	0	0
R	0	0	0	0	0	0	0		0	0	0
RL	0	0	0	0	0	0	0	0		0	0
SR	0	0	0	0	0	0	0	0	0		0
CG	0	0	0	0	0	0	0	0	0	0	

First of all, DMs are asked to make pairwise comparisons as represented at Eq. (3.1) according to Table 3.3 to establish the relationships within the criteria having inner dependencies using Delphi based GDM. Then, the comparisons are inverted into corresponding grey values using Eq. (3.2).

For the reason that we apply Delphi based GDM, there is no need to apply an aggregation process. Using Eq. (3.5) and (3.6), the normalized grey direct relation matrix, represented at Eq. (3.7), is constructed.

The total relation matrix as in Eq. (3.9) is calculated over the normalized grey direct relation matrix using Eq. (3.8).

Once the total relation matrix is obtained, being a modified CFCS method – whitenization process is applied to find crisp scores to be used in Grey ANP, utilizing Eq. (3.10), (3.11), (3.12), (3.13) and (3.14).

Dispatcher and receiver sub-criteria are determined over whitened matrix. The influence threshold value is determined by averaging the elements in whitened matrix by using Eq. (3.17).

As an example, the results of Grey DEMATEL steps applied on the ***Cost*** criterion are given at Table 4.4 – Table 4.7. The sums of given and received among dimensions of ***Cost*** criterion are presented at Table 4.8.

Table 4.4: Grey direct relation matrix for ***Cost*** criterion

C	C1		C2		C3		C4		C5	
	l	***u***	***l***	***u***	***l***	***u***	***l***	***u***	***l***	***u***
C1	0.000	0.000	0.250	0.500	0.000	0.000	0.000	0.250	0.000	0.250
C2	0.000	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C3	0.000	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C4	0.500	0.750	0.750	1.000	0.750	1.000	0.000	0.000	0.250	0.500
C5	0.000	0.250	0.250	0.500	0.000	0.000	0.000	0.250	0.000	0.000

Table 4.5: Normalized grey direct relation matrix for ***Cost*** criterion

C	C1		C2		C3		C4		C5	
	l	***u***	***l***	***u***	***l***	***u***	***l***	***u***	***l***	***u***
C1	0.000	0.000	0.077	0.154	0.000	0.000	0.000	0.077	0.000	0.077
C2	0.000	0.077	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C3	0.000	0.077	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C4	0.154	0.231	0.231	0.308	0.231	0.308	0.000	0.000	0.077	0.154
C5	0.000	0.077	0.077	0.154	0.000	0.000	0.000	0.077	0.000	0.000

Table 4.6: Grey total relation matrix for ***Cost*** criterion

C	C1		C2		C3		C4		C5	
	l	***u***	***l***	***u***	***l***	***u***	***l***	***u***	***l***	***u***
C1	0.000	0.045	0.077	0.202	0.000	0.027	0.000	0.088	0.000	0.094
C2	0.000	0.080	0.000	0.016	0.000	0.002	0.000	0.007	0.000	0.007
C3	0.000	0.080	0.000	0.016	0.000	0.002	0.000	0.007	0.000	0.007
C4	0.154	0.309	0.249	0.395	0.231	0.319	0.000	0.038	0.077	0.183
C5	0.000	0.116	0.077	0.202	0.000	0.027	0.000	0.088	0.000	0.022

Table 4.7: Whitenization for ***Cost*** criterion

C	C1	C2	C3	C4	C5
C1	0.005	**0.126**	0.002	0.016	0.018
C2	0.014	0.001	0.000	0.000	0.000
C3	0.014	0.001	0.000	0.000	0.000
C4	**0.241**	**0.355**	**0.289**	0.003	**0.116**
C5	0.027	**0.126**	0.002	0.016	0.001

***** In whitened total relation matrix of ***Cost*** criterion, the values in **bold** and **red** font are equal to and greater than the median (***0.055***) – the threshold value – of ***Cost*** criterion cluster**.**

Medians of ***IA, C, F, S, CA, R, SR* and ***CG*** are respectively: ***0.140, 0.055, 0.085, 0.133, 0.072, 0,077, 0.053*** and ***0.073.***

Table 4.8: The sums of given and received for ***Cost*** criterion

COST	μ	**d**	**r**	**D+R**	**D-R**
C1	**0.055**	0.166	0.299	0.465	-0.133
C2		0.014	0.608	0.622	-0.593
C3		0.014	0.293	0.307	-0.278
C4		1.005	0.035	**1.040**	**0.969**
C5		0.171	0.135	0.306	**0.036**

The threshold for ***Cost*** criterion is found to be 0.055. The results indicate that ***Transportation Costs*** (C4) and ***Inventory Costs*** (C5) are dispatcher; ***Handling Costs*** (C1), ***Defective Freight Costs*** (C2) and ***TELECOM&Information Costs*** (C3) are receivers. It is seen that ***Transportation Cost*** (C4) has the value of (D-R=0.969) and is regarded as the most important cause as it influences all the others with a high importance (D+R=1.040). ***Inventory Costs*** (C5) has (D-R= 0.036) and is in cause group; as well as it has an importance value of (D+R=0.306). According to the results obtained, it can be said that there is an inner dependence within ***Cost*** criterion.

Step 5 : *Grey AHP – Grey ANP :* After the inner dependencies are calculated by Grey DEMATEL, Grey AHP will be applied for the rest of the criteria those not having inner dependencies, ***Traceability*** (T), ***Sustainability*** (SA) and ***Regulation & Legislation*** (RL). DMs are also asked to determine the local weights of the main criteria based on those main criteria do not have dependencies among each other.

DMs are expected to make pairwise comparisons for sub-criteria according to Table (3.5) with linguistic terms. The obtained matrix is converted into grey matrix as presented at Eq. (3.18) by using Table (3.5). Again, the Delphi based GDM is applied to construct pairwise comparison matrix so that aggregation method presented in Eq. (3.9) will not be applied.

The grey pairwise matrix constructed will be whitened by using CFCS methods mentioned in Section 3.3. So, the whitened total relation matrix obtained will be used by putting into the sub-matrix as highlighted with blue at Table 4.3 to generate the super matrix in Grey ANP. The consistency of the judgments is checked within the pairwise comparison matrix. As an example, ***Traceability*** (T) criterion is presented with the steps mentioned for Grey AHP.

The crisp values of pairwise comparison established by DMs in linguistic terms are presented at Table 4.9. Then, the matrix is constructed in grey values according to Table 3.5, shown as at Table 4.10.

To obtain the values at Table 4.11, whitenization of the grey pairwise comparison matrix is conducted on Table 4.10, by applying CFCS methods mentioned at Section 3.3.

To be used in super matrix generating, the whitened matrix is normalized as seen at Table 4.12.

To check inconsistencies while pairwise comparison, consistency analysis is applied, the results shown at Table 4.13.

Table 4.9: Crisp pairwise comparison for ***Traceability*** criterion

T	T1	T2	T3
T1	**1**	1.00	3.00
T2	1.00	**1**	5.00
T3	0.33	0.20	**1**

Table 4.10: Grey pairwise comparison for ***Traceability*** criterion

T	T1		T2		T3	
	l	***u***	***l***	***u***	***l***	***u***
T1	**1**	**1**	1.0000	2.0000	2.0000	4.0000
T2	0.5000	1.0000	**1**	**1**	4.0000	6.0000
T3	0.2500	0.5000	0.1667	0.2500	**1**	**1**

Table 4.11: Whitenization for ***Traceability*** criterion

T	T1	T2	T3
T1	**1**	1.2683	2.7660
T2	0.5592	**1**	5.2767
T3	0.2603	0.1682	**1**

Table 4.12: Normalization for ***Traceability*** criterion

T	T1	T2	T3
T1	0.5496	0.5205	0.3059
T2	0.3073	0.4104	0.5835
T3	0.1430	0.0690	0.1106

Table 4.13: Consistency Analysis for ***Traceability*** criterion

MMULT	Consistency Measure	λ_max	n	RI	Consistency Index (CI)	Consistency Ratio (CR)	Check CR ≺ 0.1 ?
1.229	3.030	3.025	3	0.580	0.0126	0.0217	**Consistent.**
1.458	3.039						
0.344	3.006						

Once the super matrix is constructed, the values are checked again to have normalized values for generating the super matrix to the converged matrix. Then, the super matrix is increased to sufficient large power until convergence in priority occurs.

The normalized initial super matrix is given at Table 4.14 and the converged matrix is obtained by raising the super matrix to ***64th*** power of it.

The weights of criteria are obtained from Grey ANP as presented at Table 4.15. The sum of each criteria column values is checked to be equal to 1. The criteria with a sum of column unequal to 1 are normalized within the column.

Table 4.14: Initial super matrix

INITIAL SUPER MATRIX

	IA				T			C					F				S					SA				CA					R					RL				SR					CG				
IA	0.1383	0.4656	0.4644	0.9065	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0102	0.0024	0.0482	0.0009	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.3055	0.0664	0.0230	0.0319	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.5459	0.4656	0.4644	0.0606	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
T	0.0000	0.0000	0.0000	0.0000	0.5496	0.5205	0.3059	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.3073	0.4104	0.5835	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.1430	0.0690	0.1106	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0154	0.2067	0.0059	0.4500	0.1332	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0455	0.0010	0.0000	0.0032	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0455	0.0010	0.0000	0.0032	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.8049	0.5848	0.9882	0.0936	0.8560	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0887	0.2067	0.0059	0.4500	0.0089	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006	0.0002	0.0470	0.0015	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6974	0.0734	0.8336	0.8785	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0416	0.0136	0.0046	0.1020	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2604	0.9128	0.1148	0.0180	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0029	0.0297	0.0096	0.0096	0.0422	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0442	0.0403	0.1248	0.1248	0.0945	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4543	0.4256	0.1811	0.5598	0.4116	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4543	0.4256	0.5598	0.1811	0.4116	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0442	0.0788	0.1248	0.1248	0.0401	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SA	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1546	0.0752	0.1112	0.1493	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1942	0.1329	0.0510	0.1493	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1942	0.3959	0.2224	0.1493	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4571	0.3959	0.6153	0.5520	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CA	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1559	0.4888	0.4888	0.4408	0.9593	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6996	0.0156	0.0156	0.0179	0.0347	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0008	0.0027	0.0027	0.1879	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0267	0.0732	0.0732	0.0108	0.0011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1169	0.4198	0.4198	0.3425	0.0050	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
R	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0518	0.3162	0.0023	0.0154	0.0518	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3328	0.0631	0.0197	0.1198	0.3328	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5177	0.5221	0.0342	0.1996	0.5177	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0863	0.0870	0.8196	0.0266	0.0863	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0115	0.0116	0.1242	0.6387	0.0115	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1338	0.1542	0.0881	0.1276	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0748	0.1216	0.0881	0.1276	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3957	0.3621	0.3838	0.2731	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3957	0.3621	0.4400	0.4717	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0633	0.0517	0.7877	0.1620	0.0320	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2762	0.0034	0.0609	0.1535	0.4048	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4594	0.9427	0.1095	0.5993	0.5618	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1914	0.0022	0.0403	0.0091	0.0014	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0098	0.0001	0.0017	0.0761	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
CG	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0023	0.4259	0.4324	0.1299	0.1186
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0009	0.0304	0.0001	0.0106
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0151	0.0541	0.0102	0.0080	0.7039
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0362	0.0367	0.0001	0.0130
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9822	0.4829	0.4902	0.8618	0.1539

Table 4.15: Obtained criteria weights from converged matrix with Grey ANP

w		**MAIN CRITERIA**										
		IA	**T**	**C**	**F**	**S**	**SA**	**CA**	**R**	**RL**	**SR**	**CG**
Global weights		**0.0608**	**0.0381**	**0.2973**	**0.1200**	**0.1991**	**0.0221**	**0.1200**	**0.0608**	**0.0221**	**0.0376**	**0.0221**
SUB-CRITERIA	**1**	0.0286	0.0195	**0.0755**	0.0004	0.0030	0.0029	**0.0524**	0.0040	0.0026	0.0135	0.0044
	2	0.0008	0.0144	0.0040	**0.0582**	0.0221	0.0029	0.0382	0.0087	0.0024	0.0053	0.0003
	3	0.0097	0.0042	0.0040	0.0064	**0.0761**	0.0045	0.0010	0.0176	0.0074	0.0151	0.0071
	4	0.0218		**0.1419**	**0.0550**	**0.0761**	0.0117	0.0043	0.0171	0.0097	0.0032	0.0004
	5			**0.0720**		0.0217		0.0242	0.0134		0.0004	0.0098
Σ		**1.0000**										

* The most important main and sub-criteria are highlighted with **bold** and **red** font due to their global weights.

** Respectively, ***Cost*** (C), ***Speed*** (S), ***Flexibility*** (F) and ***Capability*** (CA) criteria are the most important main criteria comparing with others.

****** Transportation Costs*** (C4), ***Transportation Time*** (S3), ***Transportation Speed*** (S4), ***Handling Costs*** (C1), ***Inventory Costs*** (C5), ***Flexible Capacity*** (F2), ***Flexible Pick-up/Delivery*** (F4) and ***Service Quality*** (CA1) sub-criteria have higher overall impact.

Step 6 : *Grey TOPSIS :* The alternatives are evaluated with Grey TOPSIS, as explained at Section 3.4.

The decision matrix is determined by 3 experts with respect to the alternatives by Eq. (3.21). The global weights of each criterion obtained from Grey ANP are used at that stage. Also, the normalization of the matrix is made according to the type of the criteria, benefit or cost type. The evaluation criteria with weights and alternatives, benefit/cost type of criteria with value type are presented at Table 4.16.

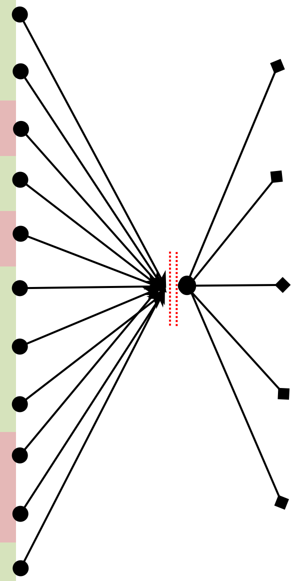
The evaluation of alternatives and grey normalized values according to ***Sustainability*** criterion, established with lower and upper limits of each sub-criteria are presented at Table 4.17.

Using Eq. (3.22) and Eq. (3.23), the weights of each attributes according to their benefit/cost type are determined with respect to their weights, and the normalized decision matrix is constructed as shown at Table 4.17.

The positive/negative ideal values of alternatives according to ***Sustainability*** criterion are determined by using Eq. (3.24) and Eq. (3.25). The separation measures of the positive and negative alternatives are calculated by using Eq. (3.26) and Eq. (3.27), as shown at Table 4.18. Then, the relative closeness to the ideal alternative of each alternative is calculated by using Eq. (3.28). According to the relative closeness values, the ranking of alternatives is determined. The values and the ranking are briefly presented at Table 4.19.

Table 4.16: Evaluation criteria and Alternatives for Grey TOPSIS

Criteria	Sub-Criteria Global Weights 1	2	3	4	5	Value	Benefit / Cost Type	Alternatives of Transportation Mode
IA	0.0286	0.0008	0.0097	0.0218	-	1-5 Scale	Benefit	
T	0.0195	0.0144	0.0042	-	-	1-5 Scale	Benefit	**A1** Road
C	0.0755	0.0040	0.0040	0.1419	0.0720	1-5 Scale	***Cost***	
F	0.0004	0.0582	0.0064	0.0550	-	1-5 Scale	Benefit	**A2** Rail
S	0.0030	0.0221	0.0761	0.0761	0.0217	1-5 Scale	***Cost*** / Benefit	
SA	0.0029	0.0029	0.0045	0.0117	-	1-5 Scale	Benefit / ***Cost***	**A3** Combined
CA	0.0524	0.0382	0.0010	0.0043	0.0242	1-5 Scale	Benefit	
R	0.0040	0.0087	0.0176	0.0171	0.0134	1-5 Scale	Benefit	**A4** Sea
RL	0.0026	0.0024	0.0074	0.0097	-	1-5 Scale	***Cost***	
SR	0.0135	0.0053	0.0151	0.0032	0.0004	1-5 Scale	***Cost***	**A5** Air
CG	0.0044	0.0003	0.0071	0.0004	0.0098	1-5 Scale	Benefit	



* The pink highlighted criteria are the cost type; those highlighted with green are benefit type.

** **S** and **SA** contain sub-criteria both benefit and cost type.

Table 4.17: Evaluation of alternatives and grey normalized values of ***Sustainability*** criterion

TYPE	BENEFIT		BENEFIT		BENEFIT		COST	
w	0.0029		0.0029		0.0045		0.0117	
	SA1		SA2		SA3		SA4	
	l	*u*	*l*	*u*	*l*	*u*	*l*	*u*
A1	3	4	3	5	3	5	3	4
A2	2	4	2	3	1	3	4	5
A3	2	4	3	5	3	5	2	3
A4	3	5	3	4	3	4	1	2
A5	3	5	1	3	1	2	2	3

TYPE	BENEFIT		BENEFIT		BENEFIT		COST	
w	0.0029		0.0029		0.0045		0.0117	
	SA1		SA2		SA3		SA4	
	l	*u*	*l*	*u*	*l*	*u*	*l*	*u*
A1	0.60	0.80	0.60	1.00	0.60	1.00	0.20	0.40
A2	0.40	0.80	0.40	0.60	0.20	0.60	0.00	0.20
A3	0.40	0.80	0.60	1.00	0.60	1.00	0.40	0.60
A4	0.60	1.00	0.60	0.80	0.60	0.80	0.60	0.80
A5	0.60	1.00	0.20	0.60	0.20	0.40	0.40	0.60
A-	0.40		0.20		0.20		0.00	
A+	1.00		1.00		1.00		0.80	

Table 4.18: +/- ideal values of ***Sustainability*** criterion

TYPE	BENEFIT	BENEFIT	BENEFIT	COST
w	0.0029	0.0029	0.0045	0.0117
d-	SA1	SA2	SA3	SA4
A1	0.0006	0.0024	0.0036	0.0023
A2	0.0005	0.0006	0.0007	0.0005
A3	0.0005	0.0024	0.0036	0.0061
A4	0.0012	0.0015	0.0023	0.0117
A5	0.0012	0.0005	0.0002	0.0061

TYPE	BENEFIT	BENEFIT	BENEFIT	COST
w	0.0029	0.0029	0.0045	0.0117
d+	SA1	SA2	SA3	SA4
A1	0.0006	0.0005	0.0007	0.0061
A2	0.0012	0.0015	0.0036	0.0117
A3	0.0012	0.0005	0.0007	0.0023
A4	0.0005	0.0006	0.0009	0.0005
A5	0.0005	0.0024	0.0045	0.0023

Table 4.19: +/- ideal values, separation measures and the relative closeness

A	Mode	d^-	d^+	C^+	# RANK
A1	Road	0.4809	0.2753	**0.6360**	**2**
A2	Rail	0.4266	0.3566	**0.5447**	3
A3	**Combined**	**0.5284**	**0.2327**	**0.6943**	**1**
A4	Sea	0.3658	0.4193	**0.4659**	4
A5	Air	0.2245	0.5415	**0.2931**	5

Step 7 : *Evaluation Results :* The ranking of alternatives is obtained with Grey TOPSIS, using the global weights which are obtained from Grey ANP.

According to the Grey DEMATEL results;

- 7 main criteria out of 11 have inner dependencies within the criteria clusters based on the D and R values and that are; ***Infrastructure Availability*** (IA), ***Cost*** (C), ***Flexibility*** (F), ***Speed*** (S), ***Capability*** (CA), ***Reliability*** (R), ***Safety & Risks*** (SR) and ***Characteristics of Goods*** (CG).
- Medians of *IA*, *C*, *F*, *S*, *CA*, *R*, *SR* and *CG* are respectively: ***0.140, 0.055, 0.085, 0.133, 0.072, 0,077, 0.053*** and ***0.073.***

According to Grey AHP – Grey ANP results;

- *C*, *S*, *F* and *CA* are the most important main criteria based on Grey AHP weight values as well as have a % 73.64 overall importance on the whole evaluation due to their global weights and the rest of the seven main criteria have % 26.36 overall importance.
- ***Transportation Costs*** (C4), ***Transportation Time*** (S3), ***Transportation Speed*** (S4), ***Handling Costs*** (C1), ***Inventory Costs*** (C5), ***Flexible Capacity*** (F2), ***Flexible Pick-up/Delivery*** (F4) ***and Service Quality*** (CA1) are found to have higher overall impact due to global weights obtained.

According to Grey TOPSIS results;

- Combined transportation mode is ranked the first preferred mode due to the highest relative closeness value (0.6943) presented at Table 4.19.

5. CONCLUSION AND PERSPECTIVES

This study presents a grey based MCDM model for the selection and evaluation of transportation mode, integrating DEMATEL, ANP and TOPSIS methods. The proposed approach allows us;

- to identify the interrelations within criteria by Grey DEMATEL,
- to establish the weights of criteria by Grey AHP and Grey ANP,
- to rank the transportation mode alternatives by Grey TOPSIS.

A cluster of 11 main criteria and a total of 49 sub-criteria are obtained from literature survey complied with the experts' opinions, that can affect the decision of transportation mode. Alternatives of mode are evaluated according to their influencing degrees by constructing pairwise comparisons over each criterion. For the calculation of all MCDM approaches, Ms. Excel is used to analyze the data and to obtain results.

The case study gives us insight into the transportation mode alternative selection and evaluation from logistics service provider companies frame. The objective is determined as: to minimize the cost, to transport the freight in an early time, to have the proactive readiness towards unexpected situations in term of flexibility and to provide service quality at every stage.

The results enables us to have better understanding of on which criteria should the company particularly concentrate, based on the customer's preferences or freight related characteristics. Basically, among the 11 main criteria; ***Cost, Speed, Flexibility*** and ***Capability*** criteria emerge as more important than other criteria, by % 73.64 overall impacts.

As alternatives, combined and road transportation are mostly preferred due to their characteristics in term of the criteria. The difference in preference in the ranking of combined and road alternative is quite acceptable since the criteria values of these two modes are different. The proposed grey methodology used in this study allows decision makers to implement analysis on their preference aspects in industry.

Although, the criteria cluster formed in this study may be generalized for all logistics service provider companies, the corresponding weights of criteria and values assigned for the alternatives would not be the same at influencing. So the ranking findings will also change.

Theoretically, the grey based approach helps decision makers to determine the decision intervals. Besides, grey approach has the advantage to provide support in making interval based comparisons rather than assigning uncertain or partially known data.

For further research, the integrated grey analytical approach presented in this study could be modified by other MCDM methods for other industrial problems at various problem fields rather than logistics. The integration of modified grey based approach seems to be an encouraging trend to be used in solving complex real world problems.

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BIOGRAPHICAL SKETCH

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