ENVIRONMENTAL RISK ASSESSMENT OF E-WASTE IN REVERSE LOGISTICS SYSTEMS USING MCDM METHODS

(ÇKKV YÖNTEMLERİ KULLANARAK TERSİNE LOJİSTİK KAPSAMINDAKİ ELEKTRONİK ATIKLARIN ÇEVRESEL RİSK DEĞERLENDİRMESİ)

by

Ferhat DURAN, B.S.

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

Supervisor: Dr. Öğr. Üyesi İlke BEREKETLI ZAFEIRAKOPOULOS

Mar 2019

This is to certify that the thesis entitled

ENVIRONMENTAL RISK ASSESSMENT OF E-WASTE IN REVERSE LOGISTICS SYSTEMS USING MCDM METHODS

prepared by **Ferhat DURAN** in partial fulfillment of the requirements for the degree of **Master of Science in Industrial Engineering** at the **Galatasaray University** is approved by the

Examining Committee:

Dr. Öğr. Üyesi İlke BEREKETLİ ZAFEIRAKOPOULOS (Supervisor)
Department of Industrial Engineering
Galatasaray University -------------------------

Dr. Öğr. Üyesi Mehtap DURSUN
Department of Industrial Engineering
Galatasaray University -------------------------

Doç. Dr. Sinan APAK
Department of Industrial Engineering
Maltepe University -------------------------

Date: -------------------------

ACKNOWLEDGEMENTS

I would like to express my gratitude to my advisor Dr. Öğr. Üyesi İlke BEREKETLI ZAFEIRAKOPOULOS for her guidance, endless help, patience, knowledge, and precious support. This work would not have been possible without her eternal patience and tolerance.

Especially, I would like to give my special thanks to my dear friend Esin MUKUL for her friendship, fraternity, and all her support.

Finally, I would like to thank my family for their love, encouragement and trust in me.

Mar 2019
Ferhat DURAN

TABLE OF CONTENTS

LIST OF SYMBOLS

AHP	: Analytical Hierarchy Process
ANP	: Analytical Network Process
CFLs	: Compact Fluorescent Lamps
COPRAS	: Complex Proportional Assessment
ELECTRE	: Elimination and Choice Translating Reality
E-WASTE	: Electrical and Electronic Waste
HOQ	: House of Quality
MCDM	: Multi Criteria Decision Making
QFD	: Quality Function Deployment
RFID	: Radio Frequency Identification
RL	: Reverse Logistics
SWARA	: Step-wise Weight Assessment Ratio Analysis
TOPSIS	: The Order of Preference By Similarity to The Ideal Solution
UV	: Ultraviolet Light
WEEE	: Waste Electrical and Electronic Equipment

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Due to technological developments, industrialization, rapid urbanization and population growth, the effects of human activities on the environment are increasing day by day all over the world. The expansion of production and consumption activities leads to more intensive use of natural resources. Hence resulting wastes have reached a level that threatens both the environment and human health. As a consequence of this threat, reverse logistics concept gains importance.

Reverse logistics is part of the concept of sustainability, which is the ability to meet the needs of our present needs while using resources without ignoring future generations. Reverse logistics involves processes for the final consumer or depot receipt of products to be recycled, reused, and / or properly disposed of to avoid damage to the environment.

The aim of reverse logistics is to avoid any activity that can harm the environment by focusing on the efficient use of natural resources and more liveable and cleaner world for future generations.

Due to rapidly diminishing raw material resources and the pressure on the natural environment, companies must adapt to some preventive regulations enforced by governments and demanded by societies. As a result of this consciousness, many companies have begun to understand the importance of advanced supply chains. In many industries, the importance of reverse logistics and closed loop systems is recognized as a vital need. Such practices are more commonly observed in the electrical and electronic waste (e-waste), batteries / accumulators and motor vehicles sectors. Similarly, reverse logistics activities have been observed in the collection and recycling of glass, metal

plastic and composite packaging waste. Recovery of these products is more advantageous than destruction.

Consumers tend to change their electrical and electronic products before they have completed their lives, making them one of the main responsibles of the e-waste problem.

End users should therefore be directed to take more eco-conscious decisions about e-waste problem or be deterred from their environmentally harmful behavior. For this reason, the e-waste sector is one of the areas which is frequently used in reverse logistics approach.

E-waste includes all electrical and electronic waste dispossessed by the user without intent to reuse. E-waste includes all electronic products that operate with an electric circuit, power system, or pail.

E-waste definition includes the following varieties:

- Large and small household products (dishwasher, washing machine, electric vacuum cleaner, toaster, etc.)
- Information and media transmission equipment (Computers, phones, etc.)
- Consumer equipment (camcorders, musical instruments, etc.)
- Lighting equipment (Fluorescent, saving bulbs, etc.)
- Electrical and electronic tools (drills, saws, etc., except big and stationary mechanical tools)
- Toys, entertainment and sports equipment (video games, coin-operated machines, etc.)
- Monitoring and control instruments (thermostats, thermostats, etc.)
- Automats (Money, beverage dispensers, etc.)

However, there are many environmental risk factors related to reverse logistics in the e-waste field that need to be analyzed. Electronic wastes contain more than 1000 substances in their bodies, and a significant number of them is hazardous. Fluorescent lamps are a type of lighting tool that requires mercury (Hg) as an ultraviolet radiation source to produce visible light. In almost all chemical forms, mercury is the most poisonous of all heavy metals. The mercury becomes volatile at room temperature due to the vapor pressure that it has, and immediately turns into mercury vapor.

Negative effects on the central nervous system, lungs, kidneys, skin and reproductive system can be seen as a result of penetration of the mercury vapor by respiration or by pass through the human skin. In addition, mercury leaking from fluorescent lamps affects nature in a negative way by easily penetrating into air, infiltrating waterways, and joining as a toxic waste in the biological processes.

Fluorescent lamps and saving bulbs, which have become increasingly widespread in recent years due to their particularly energy-saving features, present many hazards when they come to waste. For this reason, environmental risk assessment is carried out in the reverse logistics processes of fluorescent lamps from our lighting equipment products in our work.

In this study, the assessment of the "environmental risks" in reverse logistics of fluorescent lamps, such as CO_2 emissions, warehouse energy consumption, soil pollution risk etc. are considered as a multi criteria decision making (MCDM) problem. The Analytical Network Process (ANP) based on data collection from the experts, is used to determine the ranking of the criteria by calculating their weights. Complex Proportional Assessment (COPRAS) is applied for evaluating possible precaution strategies against environmental risks. In order to compare the results obtained by COPRAS method, Elimination and Choice Translating Reality (ELECTRE) method has been used. After the results of these two methods have been the same, the second phase of the thesis has been started. In the second phase of the thesis, a model has been developed to provide a solution to the strategy chosen by the decision-makers. In this model, alternative solutions have been produced for the strategy chosen by Step-wise Weight Assessment Ratio Analysis (SWARA) and House of Quality (HOQ) from MCDM methods.

The major contribution of this work to the literature is that the environmental risk factors in the reverse logistics of fluorescent lamps will be examined and prioritized, and the possible precautions in reverse logistics risk factors will be proposed.

ÖZET

Teknolojik gelişmeler, sanayileşme, hızlı kentleşme ve nüfus artışı nedeniyle insan faaliyetlerinin çevre üzerindeki etkileri tüm dünyada gün geçtikçe artmaktadır. Üretim ve tüketim faaliyetlerinin genişlemesi, doğal kaynakların daha yoğun kullanılmasına yol açar. Bu yönelimin sonucu olarak ortaya çıkan atıklar, hem çevreyi ve hem de insan sağlığını tehdit eden bir seviyeye ulaşmıştır. Oluşan bu tehdidin sonucu olarak ise tersine lojistik kavramı gün geçtikçe önem kazanmaktadır.

Tersine lojistik, ürünlerin son tüketiciden veya depodan iadesini, yeniden üretilmesini, geri dönüştürülmesini ve / veya çevreye zarar vermemek için bu ürünlerin uygun şekilde bertaraf edilmesi süreçlerini içerir. Tersine lojistik, mevcut ihtiyaçlarımızı karşılarken gelecek nesilleri göz ardı etmeden kaynakları kullanabilme yeteneği olan sürdürülebilirlik kavramının bir parçasıdır. Tersine lojistik kavramının amacı, doğal kaynakların verimli kullanımına odaklanarak, çevreye zarar verebilecek her türlü faaliyetten kaçınmak ve gelecek nesiller için daha temiz, daha yaşanabilir bir dünya bırakmaktır.

Birçok endüstride tersine lojistik ve kapalı devre sistemlerinin önemi, hayati bir ihtiyaç olarak kabul edilmektedir. Bu tür uygulamalar; üreticilerin geri dönüşümden sorumlu olduğu ambalaj atıkları, elektrikli ve elektronik atıklarda (e-atık), pil / akümülatörlerde ve motorlu taşıtlarda daha yaygın olarak görülmektedir. Özellikle ileri teknoloji ürünlerin ürün ömrü dolmadan kullanım ömrünün dolması problemi, çözmeye yönelik gayretleri daha da fazlalaştırmaktadır. Bu sebeple e-atık sektörü, atık yönetiminde tersine lojistik yaklaşımının sıklıkla kullanıldığı alanlardan biridir.

E-atık, yeniden kullanım niyeti olmadan e-atık kullanıcısı tarafından atılan tüm elektrikli ve elektronik atıklardan oluşmaktadır. Özellikle enerji tasarrufu sağlamaları sebebiyle son yıllarda kullanımı giderek yaygınlaşan floresan lambalar ve tasarruflu ampuller, atık konumuna geldiklerinde birçok tehlike arz etmektedir. Bu sebeple çalışmamızda aydınlatma ekipmanları ürünlerinden floresan lambalarının tersine lojistik süreçlerindeki çevresel risk değerlendirmesi yapılmaktadır.

Bu çalışmada, tersine lojistik kapsamında taşıma süreçlerinin CO_2 emisyonları, yakıt tüketimleri veya atıkların imha sürecindeki hava, su toprak kirliliği riski vb. faktörlerin çevreye yaratabileceği olası zararlı etkilerin değerlendirilmesi çok kriterli bir karar verme (ÇKKV) problemi olarak ele alınmaktadır. Çok kriterli karar analizi, çoklu ve genellikle birbiriyle uyuşmayan kriterlerin olduğu durumda bir probleme çözüm getirecek karar verme sürecini tanımlar.

Literatürde risk değerlendirmesi üzerine yapılan çalışmalar incelendiğinde, ÇKKV yöntemlerinden özellikle AHP, ANP, TOPSIS, ELECTRE ve COPRAS metotları karar problemlerinin çözümünde yoğun bir şekilde kullanılmaktadır. Yapılan çalışmada, karar destek modeli için iki araştırma görevlisi ve özel sektörde çalışan bir uzmandan oluşan 3 ayrı kişinin görüşlerinden yararlanılmıştır. Araştırma görevlileri, sürdürülebilirlik, enerji, lojistik konularında akademik çalışmalar yapmaktadır. Çalışmamızda görüşlerini aldığımız uzman ise tersine lojistik kavramı ile yakından ilgili olan özel bir kurum altında çalışan bir temsilcidir. Bu çalışmada karar vericilerin bir araya getirilerek çeşitli ÇKKV modelleri kapsamında ortak kararlar alınması sağlanarak bir uygulama sağlanmıştır.

Uzmanlardan veri toplamaya dayalı ANP, risk faktörlerinin ağırlıklarının hesaplanmasında kullanılmaktadır. ANP karar vericilerin karmaşık problemleri, problemin ana hedefi, kriterleri alt kriterler ve alternatifleri arasındaki ilişkiyi gösteren bir ağ yapısında modellemelerine olanak verir. Belirlenen çevresel risklere karşı olası önlem stratejilerini değerlendirmek için COPRAS uygulanmaktadır. COPRAS yönteminin diğer ÇKKV yöntemlerinden üstünlüğü alternatiflerin yarar derecelerini gösteriyor olmasıdır. Ayrıca yöntem hem kalitatif hem de kantitatif kriterleri değerlendirme imkânı sağlar. Diğer ÇKKV yöntemleri ile karşılaştırıldığında ise daha az hesaplama zamanı gerektiren kullanımı basit bir yöntemdir.

COPRAS metodu sonucu elde edilen sonuçları karşılaştırmak adına ELECTRE metodu denenmiştir. Yöntem, her bir değerlendirme faktörü için alternatif karar noktaları arasında ikili üstünlük kıyaslamalarına dayanır. Aynı zamanda bu yöntem öne geçme veya baskınlık ilişkisine dayanan bir yöntemdir, her bir ölçüt için bir verimlilik bir de önem ölçüsü tespit edilir. Tayin edilen verimlilik ölçüleri üzerinden her bir seçeneğe not verilir.

Aynı girdi değerleri kullanılarak bu iki model sonucunda çıkan sonuçlar karşılaştırılmıştır. Burada amaç, farklı çözüm yaklaşımlarına sahip iki farklı metot ile çıkan sonucun karşılaştırılması ve olası farklılaşmanın incelenmesidir. Bu iki metodolojiden çıkan sonuçların aynı çıkmasının ardından tezin ikinci aşamasına geçilmiştir. Tezin ikinci aşamasında ise karar vericiler tarafından seçilen strateji konusunda çözüm sağlayabilmek için bir model geliştirilmiştir. Bu modelde ÇKVV metotlarından SWARA ve Kalite evi yaklaşımı (HOQ) ile seçilen strateji için alternatif çözümler üretilmiştir.

HOQ, pazar araştırmaları ve kıyaslama verilerinden elde edilen bir dizi müşteri isteklerini, yeni bir ürün veya hizmet tasarımıyla karşılanacak makul sayıda önceliklendirilmiş mühendislik hedeflerine dönüştürmek için kullanılan bir yöntemdir. Bu çalışmada, Kalite Evi yaklaşımının uygulanma aşamalarından bahsedilmekte ve floresan lamba ürünü için bu uygulama gerçekleştirilerek sonuçların nasıl değerlendirileceği gösterilmektedir.

Yapılan çalışmalar incelendiğinde, tersine lojistik kavramı ile ilgili yakın dönemde çevresel kaygının da artmasıyla birlikte birçok çalışmanın yapıldığı görülmüştür. Öte yandan tersine lojistik kavramının güncel bir konu olması sebebiyle halen birçok konu hakkında yeterli çalışmayı barındırmamaktadır. Bu konulardan biri de tersine lojistik sürecinin çevreyle olan ilişkisi ve bu ilişkinin değerlendirilmesidir. Bu çalışmanın literatüre olan en önemli katkısı, tersine lojistiğin yaratabileceği çevresel riskin ve bu risk oluşturan faktörlerinin belirlenmesi, değerlendirilmesi, önceliklendirilmesidir. Elde edilen sonuçlar ışığında önerilen, risk faktörleri ile ilgili olası önlemlerin belirlenmesi ve bu önlemlerin bir model kapsamında incelenmesidir.

1. INTRODUCTION

Twenty to thirty years ago, the concept of supply chain was known to be efficient in the logistics of goods from raw material to final consumer. In today's flow system, some changes have occurred due to the environmental sensitivity of the consumers. So, consumer products are now starting to flow back to the origin point. These flows back cover electronic products, textile, pharmaceutical, industrial products, food etc. as well as many other sectors.

Due to the increasing world population, technological developments and the degree of consumption, the economic use and natural resources' recovery became critical for the sustainability of industrialized society's life. Also, as the number of products used increases, natural resources decrease. Because of these two problems, the recovery of used products process, reverse logistics become more important (Kilic, 2015). Reverse logistics is part of the concept of sustainability which is the ability to use resources while meeting our present needs without ignoring the future generations' ones. In reverse logistics, firms are known to be able to use product values effectively and efficiently and to reuse them with recovery activities (De Brito & Dekker, 2002). The common aim in two concepts is leaving a cleaner, more liveable world for future generations by focusing on the efficient use of natural resources, avoiding all kinds of activities that might harm the environment.

The WEEE is one of the important materials considered within reverse logistics. The WEEE amount has been augmenting according to the technological improvements and the population. Worldwide, the annual quantity of WEEE disposed was about 30–50 million tons in and it is expected to reach 40–70 million tons by 2015 (Menikpura et al., 2014). The constant increase in the quality of the electrical and electronic devices and the shortening of their use time have accelerated the formation of e-waste (Puckett et al. 2002; Hester & Harrison, 2009). Therefore, the increase in the amount of e-waste causes a significant waste of resources.

Besides, e-waste that cannot be recycled to the desired extent makes it difficult for reverse logistics processes to work effectively. Therefore, the amount of treated e-waste is directly related to the capacity of the reverse logistics systems. The number of products returned by consumers and/or companies for recycling or disposal are affected by this amount of waste.

Compact Fluorescent Lamp (CFLs) are considered more environmental and energy friendly than electric bulbs. Fluorescent lamps are being used more and more in the houses around the world as part of energy efficiency improvement trend. CFLs consume about 75% less energy than electric bulb. At first glance this seems like a good way to conserve energy and to keep the environment safe. However, there are several serious problems associated with CFL bulbs that need to be examined and corrected. Because the fluorescent lamps contain mercury and they must be examined as e-waste in reverse logistics processes.

Moreover, there are many environmental risk factors related to the reverse logistics in the e-waste field that must be analyzed. Because e-waste contains both dangerous and valuable materials that require special recycling methods to prevent environmental pollution and harmful effects on human health, and loss of value (Robinson, 2009). Therefore, it is crucial to evaluate those environmental risk factors.

MCDM is a strong approach, which is extensively used for evaluating problems containing multiple and conflicting criteria. MCDM refers to find the best option from all the feasible alternatives. Priority based, outranking, distance-based and mixed methods could be considered as the primary classes of the current methods (Pomerol et al., 2000).

Multi-criteria decision analysis defines the decision-making process that will bring a solution to a problem where there are multiple and often incompatible criteria. MCDM has a structure that can solve the problem by combining many criteria and alternatives.

This is an important advantage that gives the chance to make the right decision in the face of complex problems encountered in real life. It provides the possibility to carry out application studies in many areas with different methods.

As a result of examination of the studies on the risk assessment in the literature; it is found that the AHP, ANP, TOPSIS, ELECTRE and COPRAS methods are widely used for solving the decision problems.

The purpose of this study is twofold: to assess the environmental risks of the reverse logistics of the fluorescent lamps, and to provide a solution for the improvement of the system. As a result of the literature review and expert opinions, environmental risk factors have been identified and analytical techniques have been applied for evaluation of these factors.

The studied problem is considered as a MCDM problem. First, environmental risk factors obtained from the relevant experts and the literature are evaluated by ANP to find which factors are more likely to impact the environmental risk-causing process. In this study, ANP is chosen because there is a dependence relationship.

Secondly, COPRAS is applied to rank and evaluate alternatives in terms of importance and benefit ratings. Criterion values are used to maximize the benefit criterion in evaluating the criterion and to evaluate the most useless criteria for the lowest cost. Compared with other MCDM methods such as AHP and TOPSIS, it is a very simple method to use with less calculation time (Yardım & Akyıldız, 2005). The method allows evaluation of both qualitative and quantitative criteria.

In order to compare the results obtained by COPRAS method, ELECTRE method has been used. This method is based on the binary superiority comparisons between alternative decision points for each assessment factor. At the same time, this method is a method based on the relationship of pre-dominance or dominance, a measure of importance for each criterion and a measure of importance. Each option is graded over the assigned efficiency measures. The purpose of this step is to compare the result of two different methods with different solution approaches and to examine possible differentiation. After the results of these two methodologies were the same, the second phase of the thesis was started.

In the second phase of the thesis, a model has been developed to provide a solution to the strategy chosen by the decision-makers. In this model, alternative solutions have been produced for the strategy chosen by SWARA and HOQ from MCDM methods. The SWARA method used for weighting the customer requirements (CRs). Based weighted CRs, the house of quality (HOQ) methodology was applied to select the engineering metric that should be changed.

The HOQ approach is a method used to convert different customer requirements that are obtained from market research and benchmarking into a new product or service design. This approach is a concept that is frequently used in environmentally sensitive re-planning / production of products’ process.

The SWARA method was used to calculate the weights of each criterion related to the selection problem. The SWARA method is known as a specialist-oriented method that allows decision makers to choose their priorities. The main feature of this method is the ability to estimate expert opinions about the importance ratios of criteria in the determination of the criteria weight. In addition, the method is important for gathering information from experts and bringing them together (Aghdaie et al., 2013). The method can decide directly on the criteria and priorities; therefore, it is also appropriate for situations where the criteria weights are already known.

Lastly, based on weighted CRs, the HOQ methodology was applied to select the engineering metrics for fluorescent lamp that should be changed. The application is provided to demonstrate the potential of the proposed approach.

As a result of the literature research, it is seen that many studies have been done about the reverse logistics concept with the increase of the environmental anxiety. Due to the fact that the concept of reverse logistics is a current issue, there is still not enough work on many subjects. One of the areas where the studies are insufficient is the studies to evaluate the relationship between the reverse logistics process and the environmental risks.

This thesis contributes to the literature being the first study which proposes an integrated environmental risk assessment for reverse logistics with MCDM methods and a case study on e-waste to select the most appropriate environmental precautions strategy.

The proposed evaluation methodology as well as its application to a real case study has also contributions to the practical field by providing guidance to the managers who seek the most appropriate environmental precautions for reverse logistics

2. LITERATURE REVIEW

This section aims to provide a complete review of the literature on the Reverse Logistics (RL) issues. Literature review was performed in three subjects. The reverse logistics, reverse logistics-e-waste and reverse logistics-MCDM subjects were reviewed. Table 2.1, 2.2 and 2.3 lists some of several studies related with these topics.

The literature review shows that past research is only examining a small reverse logistics system such as network design, production planning or environmental issues. However, there is not much research on environmental risk management related to logistics, rather than e-waste.

Also, as a result of the literature the review, it was concluded that fluorescent lamps are not used as a case study in the scope of reverse logistics' environmental risk assessment.

Existing research aims to fill this gap and explore opportunities for greater environmental gain.

2.1. Literature Review of Reverse Logistics

In contrast to the forward logistics, known as shipment of the product to the consumer in the 1980s, reverse logistics was defined in a limited way as the movement of the product from the end user to the manufacturer as opposed to the primary flow (Rogers & Tibben-Lembke, 2001). In 1998, Stock reversed the logistics as the return of the product, reduction of resources, recovery, replacement of materials, reuse of materials, waste disposal and incineration, repair and reproduction in the role of logistics .

Table 2.1a: Literature Review on Reverse Logistics

Year	Author	Objective of Study
2013	Khor, S.W. and Zulkifli, M.U	Green product design on reverse logistics disposition e-waste firms.
2013	Mahmoudzadeh, M. and et al.	Identify appropriate assumptions model the problem as a third-party reverse logistics network in Iran.
2013	Souza, C.D.B. and Agosto, M.A	Verifying the likelihood of distributing financial benefits for a joint operation in the cement industries.
2013	Alfonso-Lizarazo E.H et al.	How to apply the potential of managing reverse logistics flows in the agricultural industry sector.
2013	Keyvanshokooh E. et al.	Multi-stage/period/commodity and capacitive integrated logistics network for forward / backward design and planning problem solving
2013	Kim J.K and Lee D.H	Determination of collection and demand points to the collection points with the capacity and maximum permissible collection requirements.
2013	Baia C. and Sarkisb J.	The basis for significant future research in reverse logistics flexibility.
2013	Singh. S.R. and Saxena N.	Decaying items with a mathematical model to determine the optimal replacement cycle.
2013	Jonrinaldia and Zhanga, D.Z.	A model and arrangement strategy for planning coordinated creation and stock cycles.
2013	Nikolaoua I. E. et al	A coordinated model for presenting CSR and supportability issues backward coordination’s frameworks
2013	Bogataja M. and Grubbströmb R. W.	Extending and applying MRP theory towards reverse logistics including the considerations of transportation consequences
2013	Zerhouni H. et al.	A numerical report on numerous situations to research the effect of disregarding reliance among requests and returns
2014	Jayant A. et al. (2014).	Development of a decision support system for the evaluation of assessment 3PRL service organizations using a hybrid approach using MCDM.
2014	Suyabatmaz A.Ç. (2014).	A model to solve 3PL reverse logistics network design issue with supply vulnerability by using hybrid simulation-analytical modeling approaches
2014	Shaik M. N. et al.	A complete RL performance estimation model development by integrating the BSC.

Table 2.1b: Literature Review on Reverse Logistics

Year	Author	Objective of Study
2014	Senthil S. et al. (2014).	Solving 3PL reverse logistics provider selection with hybrid method using MCDM is proposed
2014	Roghaniana E. and Pazhoheshfarb P.	Determination of multiple product / stage reverse logistics network issue for return items.
2014	Ramos T.R.P et al. (2014).	MILP models for tactical and operational planning decisions of reverse logistics systems
2014	Niknejad A. and Petrovic D.	Network optimization for an integrated reverse logistics network with a two-phase model
2014	Bansia M. et al.	An integrated system for performance of reverse logistics of an organization by BSC approach and fuzzy AHP.
2014	Filho O. S. and Salviano I.R.	Determination of a rate of return leading to the minimum cost to operate reverse logistics
2014	Hatefi S.M. and Jolai F.	A model for robust optimization approach to protect the network against uncertainty.
2015	Agrawal S. et al.	A literature review on reverse logistics issues with selected 242 articles
2015	Santos R. F. et al.	A management model for integration to all stages of supply chains of electronic products and their components.
2015	Guimarães J. L. S. and Salomon V. A. P.	Prioritization of the indicators of reverse logistics in Ceara area.
2015	Araujo et al.	Evaluation of the costs and benefits of using electronic waste in reverse logistics (e-waste), especially in Brazil.
2015	Hazen B. T. et al.	A goal setting theory and the B2B context, both for the supplier and the client.
2015	Moghaddam K. S.	Assessment the rank of candidate suppliers for end products in reverse logistics.
2015	Alshamsi A and Diabat A.	A complex network configuration of an RL system by mixed integer linear program (MILP)
2015	Prakash C. and Barua M.K.	A methodology based on fuzzy AHP and fuzzy TOPSIS to identify and sort RL adoption solutions
2015	Rezaei J.	A complete review of the application of various MCDM methods on various reverse logistics problems
2015	Kilic H. S. et al.	A proposed model for a design of reverse logistics system is in Turkey WEEE
2016	Tavana M. et al.	A hybrid SWOT and intuitive fuzzy AHP model assess the strategic factors in ORL
2016	Bouzon M. et al.	An analyze the significance level of RL barriers by fuzzy Delphi and AHP methods

Table 2.1c: Literature Review on Reverse Logistics

Year	Author	Objective of Study
2016	Agrawal S. et al.	A system for outsourcing choices in reverse logistics utilizing a graphical approach to graphs
2016	Bazan E. et al.	Literature related to modeling of reverse logistics inventory systems.
2016	Govindan K. et al.	Designs an objective model for fuzzy mathematical programming, multistage / periodic design and reverse logistics network.
2016	Sudarto S. et al.	The single-product system dynamics model of the supply chain with the reverse logistics social responsibility
2016	Guarnieri P. et al.	A Strategic Option Development Analysis based on the creation of cognitive mapping techniques.
2017	Batarfi R. et al.	A supply chain system of production, renovation, collection and waste disposal.
2017	Govindan K. and Soleimani H.	Review, classify and evaluate an appropriate vision for past studies and future studies.
2017	Sudarto S. et al.	Optimal sustainability dimensions to achieve performance cycle with inheritance uncertainty.
2017	Sifaleras A. and Konstantaras I.	An effective variable neighborhood descent intuitive algorithm to solve this problem.
2017	Kumar V.N.S.A. et al.	Forward-looking, multi-stage, vehicle routing, forward a model of the forward-backward logistics system.
2017	Giri B.C. et al.	A closed-loop supply chain with two dual channels through conventional retail and e-tail channel.
2017	Sangwan K. S	Development of various activities, decision variables and performance indicators based on the four main activities in reverse logistics.
2017	Chinda T.	Examination of the key components influencing the effective execution of invert coordination in the construction sector
2017	Zhikang L.	The SWOT analysis method to analyze problems of the reverse logistics of the automobile industry in China.
2017	Guo S. et al.	In this paper, the review the recent literature on supply chain contracts (2006-2016) focusing on reverse logistics systems.
2018	Wang et al.	A mixed method (AHP-EW) and gray MABAC are used to sort the collection modes.
2018	Sirisawat and Kiatcharoenpol	A methodology for reverse logistics application which is based on fuzzy AHP and fuzzy TOPSIS.
2018	Senthil et al.	Risks used in reverse logistics were given priority by using hybrid MCDM methods.
2018	Govindan et al.	History of sustainable triple bottom line theory under 3PRL concerns.

Table 2.1d: Literature Review on Reverse Logistics

Year	Author	Objective of Study
2018	Han and Trimi	Design and evaluation of reverse logistics processes based on social commerce.
2018	Shaik and Abdul-Kader	Multi-criteria performance measurement model to evaluate the performance of reverse logistics organization.
2018	Li et al.	Develop an effective HI-MCDM method that includes CPT to make the decision of risky 3PL choice
2018	Gardas, B. B. et al.	An interpretive structural modeling methodology for sorting obstacles according to driving forces.
2018	Tosarkani and Amin	Multi-purpose programming model for an electronic RL network
2018	Cole, C. et al.	Improved reverse logistics, which may contribute to the prolongation of product life by facilitating reuse.
2018	John, S. T. et al.	Design of product recovery system for a multi-stage reverse logistics network for
2018	Elia, V. et al.	A mixed simulation model for assessing the quantitative effects of dynamic programming adoption in the WEEE collection.
2018	Börner, L., and Hegger, D. L.	Contribute to the literature on e-waste governance to analyze the success of e-waste management approaches.
2018	Tong, X. et al.	A spatial interaction model demonstrating the formal WEEE regulation in China and the inter-regional flows of e-waste.
2018	Islam, M. T., & Huda, N.	A literature review of the reverse logistics and closed loop supply chain of WEEE / E-wastes
2018	Flygansvær et al.	Explains a Norwegian reverse supply chain for the recycling of electronic products and components
2018	Hao et al.	A multi-factor model is better able to manage the reverse supply chain of the automotive industry
2018	Bal & Satoglu	WEEE products collection process from service points to recycling and recovery facilities.
2018	Casper & Sundin	Framework for the management of reverse flow of materials in the automotive industry
2018	Rahimi & Ghezavati	Multithreading to design and plan a reverse logistics network by multi-cycle mixed integer linear programming
2018	Zarbakhshnia et al.	Mixed integer linear programming model for the design and planning of green forward and reverse logistics network
2018	Chen et al.	Reverse the logistics pricing strategy for the green supply chain: the perspective of customers' environmental awareness

2.2. Literature Review of Reverse Logistics and E-Waste

The rapid increase in the conversion of electrical and electronic goods into waste and the low stringency of recycling has become very important in recent years in terms of environmental sensitivity and responsibility. These regulations, which limit the use of harmful substances during the production of electrical and electronic products, provide for the collection and recycling of e-wastes, are designed to facilitate the recycling of e-waste by consumers. These processes, which create free recycling for consumers, aim to expand the recycling of e-wastes and to ensure a broad social participation in these activities (European Commission, 2016; Toprak et al., 2013).

Recycling of e-wastes provides a significant gain in terms of prevention of waste of resources and utilization of existing resources by recycling of precious metals in human health (Yazıcı & Deveci, 2009). Therefore, the concept of reverse logistics is used frequently to solve the problem of waste. The reverse logistics applications in e-waste industrial sectors are given in Table 2.2.

Table 2.2a: Literature Review on Reverse Logistics and E-waste

Year	Author	Objective of Study
2013	Khor, S.W. and Zulkifli, M.U	Resource commitment and green product design on reverse logistics product disposition e-waste firms in Malaysia.
2014	Jayant, Arvind, et al.	Hybrid approach of different 3PRL service providers using AHP and TOPSIS method.
2015	Malik, S., Kumari, A., and Agrawal, S	Discussion of the GTMA to find the location of collection sites for an efficient reverse supply chain.
2015	Kilic, H. S., Cebeci, U., and Ayhan, M. B.	The logistics system of the most suitable storage locations for WEEE is designed.
2015	Fernando, A. S., and Muniz Jorge Jr.	Evaluation cost and benefits of RFID usage in reverse logistics of e-waste
2015	Aras, Necati, et al.	Determination of optimum areas for storage and disposal / recycling facilities for returned products.

Table 2.2b: Literature Review on Reverse Logistics and E-waste

Year	Author	Objective of Study
2015	Ayvaz, et al.	A model to minimize costs involved in transport and reverse logistics.
2016	Liu et al.	Develop a price competitive model based on quality among formal and informal sectors.
2016	Prakash & Barua	Determination of assessment criteria for 3rd party partner choice in reverse supply systems.
2016	Cao et al.	Treatments and recommendations for improvement of WEEE reuse in China
2016	Foelster et al.	Introducing and creating WEEE recycling as a precautionary measure to PROPEE.
2016	Sinha, R. Et al.	The study explored the closure of material flow in the global mobile phone product system.
2016	Guarnieri et al.	Analysis and structuring of reverse logistics problem of e-waste
2017	Alvarez-de-los-Mozos & Renteria	Optimization of the recycling process of electronic devices
2017	Ghisolfi et al.	Measuring the effect of collected waste on waste collectors.
2017	Oliveira Neto, G. C. et al.	Evaluate the economic and environmental advantages of WEEE reverse logistics adoption
2017	Moura, J. M. B. M. et al.	Analyze the relationships between electronic equipment (EEs) and waste in Blumenau.
2018	Cole, C. et al.	A framework for contribution has improved reverse logistics to extend product life by facilitating reuse.
2018	John, S. T. et al.	The design of a multi-stage reverse logistics network
2018	Elia, V. et al.	Assessing the quantitative effects of dynamic scheduling with a hybrid simulation model in the WEEE collection.
2018	Börner, L., and Hegger, D. L.	Contribute to the literature on e-waste governance to analyze the success of e-waste management approaches.
2018	Tong, X. et al.	A spatial interaction model demonstrating the formal WEEE regulation in China and the inter-regional flows of e-waste.
2018	Islam, M. T., & Huda, N.	A literature review of the reverse logistics and closed loop supply chain of WEEE / E-wastes
2018	Gardas, B. B. et al.	An interpretive structural modeling methodology for sorting obstacles according to driving forces.

2.3. Literature Review of Reverse Logistics and MCDM

The logistics sector is one of the areas where the MCDM techniques are used for performance measurement purposes. When the literature related to the performance measurement of logistics companies is examined, it is seen that many of the studies are the choice of third-party logistics (3PL) service provider. According to the evaluation (performance) criteria determined in these studies, the most suitable among alternative firms is chosen by using the MCDM techniques. In the literature, it is seen that the studies aiming only performance measurement in 3PL companies are relatively few.

In the majority of these studies, DEA was used as the analysis method. Min and Joo (2006), Hamdan and Rogers (2007), Wang et al. (2007), Zhou et al. (2008), Min and Joo (2009) and Wanke (2009) 's work can be given. As a result, studies involving the use of smart cities and MCDM methods are given in Table 2.3.

Table 2.3a: Literature Review on Reverse Logistics and MCDM

Year	Author	Objective of Study	MCDM Methods
2012	Senthil et al.	A fuzzy hybrid MCDM methodology for the evaluation and selection of reverse logistics channels.	AHP and TOPSIS
2014	Jayant et al.	Hybrid approach of different 3PRL service providers using AHP and TOPSIS method.	AHP and TOPSIS
2014	Shaik & Abdul-Kader	Developed a comprehensive reverse logistics enterprise performance measurement system with DEMATEL	DEMATEL
2015	Rezaei	A complete review of the application of various MCDM methods on various reverse logistics problems	-
2015	Guimarães & Salomon	Prioritization of the indicators of reverse logistics in Ceara area.	ANP
2015	Prakash & Barua	Advanced decision support tool for stepwise implementation	AHP and TOPSIS
2015	Vahabzadeh et al.	FUZZY-VIKOR method for green decision-making model in reverse logistics	Fuzzy VIKOR

Table 2.3b: Literature Review on Reverse Logistics and MCDM

Year	Author	Objective of Study	MCDM Methods
2016	Tavana et al.	MCDM-based model evaluates strategic factors in providing reverse logistics outsourcing.	AHP and SWOT
2016	Prakash & Barua	Determination of assessment criteria for 3rd party partner choice in reverse supply systems.	F-AHP and F-TOPSIS
2016	Bouzon et al.	A new framework for analyzing the importance level of RL barriers with MCDM.	Fuzzy DELPHI and AHP
2016	Mangla et al.	A structural model to evaluate the CSFs in RL adoption with MCDM.	AHP and DEMATEL
2016	Uygun and Dede	A model based on integrated fuzzy MCDM methods to assess GSCM performance	Fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS
2018	Wang et al.	A mixed method (AHP-EW) and gray MABAC are used to sort the collection modes.	AHP, EW and MABAC
2018	Sirisawat and Kiatcharoenpol	A methodology for reverse logistics application which is based on fuzzy AHP and fuzzy TOPSIS.	Fuzzy AHP and Fuzzy TOPSIS
2018	Senthil et al.	Risks used in reverse logistics were given priority by MCDM methods	Fuzzy AHP and Fuzzy TOPSIS
2018	Govindan et al.	History of sustainable triple bottom line theory under 3PRL concerns.	ELECTRE
2018	Han and Trimi	Design and evaluation of reverse logistics processes based on social commerce.	Fuzzy TOPSIS
2018	Shaik andAbdul-Kader	Multi-criteria performance measurement model to assess the performance of reverse logistics organization	DEMATEL, Fuzzy ANP and AHP
2018	Li et al.	Develop an effective HI-MCDM method that includes CPT to make the decision of risky 3PL choice	FTOPSIS
2018	Gardas, B. B. et al.	An interpretive structural modeling methodology for sorting obstacles according to driving forces.	ISM
2018	Tosarkani and Amin	A model for an electronic RL network by multi-purpose programming	Fuzzy ANP

3. REVERSE LOGISTICS

In recent years, RL has become an important area for all organizations due to increased environmental concerns, legislation, corporate social responsibility and sustainable competitiveness. RL refers to the sequence of activities required to reuse or repair, reproduce, or recycle or dispose of the used product from the customer. Reverse logistics is an inverse movement of raw materials, semi-finished products, end products and related information from point of consumption to point of origin. Since reverse logistics is considered a relatively new area of research in the literature; different concepts and namings such as reverse logistics, return logistics and retro logistics are encountered.

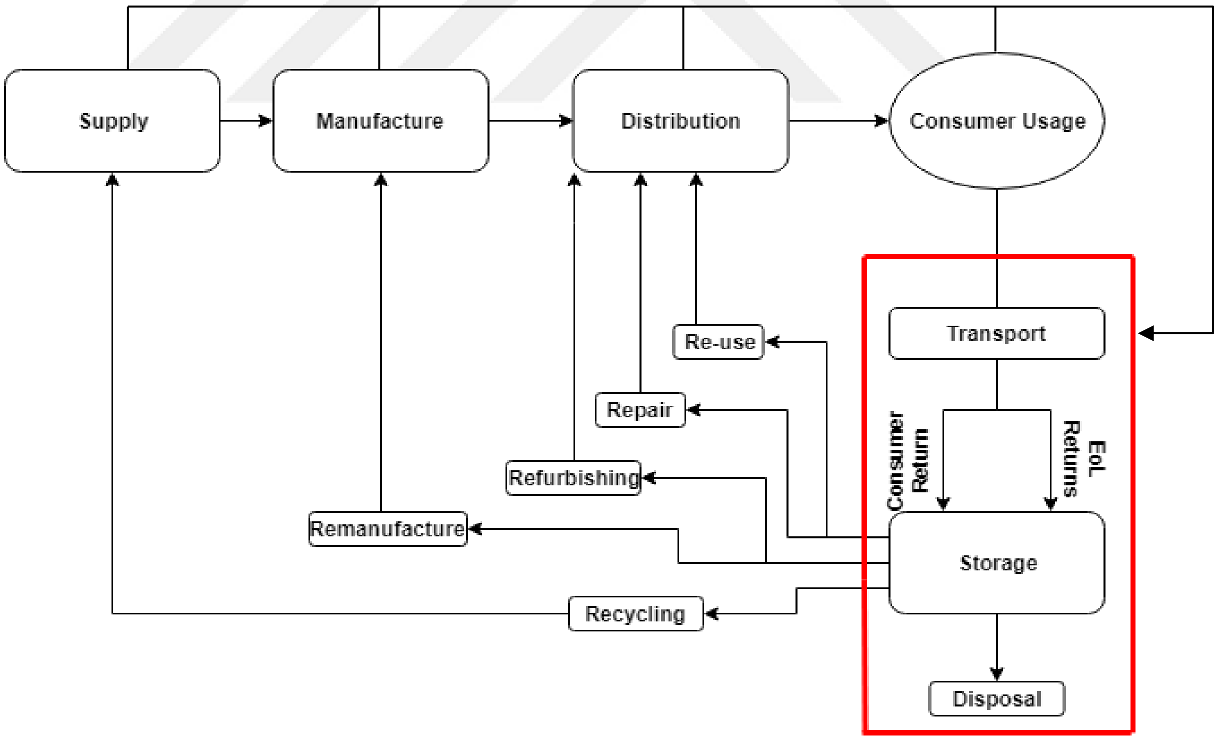

Figure 3.1: Reverse Logistics Process

The options of "repair, reuse, reprocessing, recycling and disposal", which constitute the reverse logistics process, are shown in Figure 3.1. (Thierry et al., 1995). In this study; transport, storage and disposal processes will be examined.

Research on RL has evolved over the years and the authors have described RL in different ways. The earliest definition of RL is stated by Murphy and Poist (1989) to refer to the inverse flow of goods. Lateron Carter and Ellram (1998) used the term environment in the definition of RL. Rogers and Tibben-Lembke (1999) stressed the purpose of RL and the most widely accepted definition RL completed the process inventory in the process of planning, implementing and controlling the efficient, cost-effective flow of raw materials. Goods from the point of consumption, up to the point of origin for revaluation or proper disposal, and related information. Stock (1998), Dowlatshahi (2000) and Srivastava (2008) describe RL from different perspectives. The definition of RL changes over time and extends its scope with the interest of researchers.

The two important reasons behind the increasing importance of reverse logistics applications are economic and environmental concerns. These goals are not contradictory but overlapping. Adding new value to used products or reusing certain materials saves cost and consequently increases profitability rates (Erol et al. 2006).

The importance of advanced supply chain management has begun to be understood by many companies (Kannan, 2009). The importance of reverse logistics and closed loop systems in many sectors is regarded as a basic need (Govindan and Soleimani, 2017). Recycling networks require appropriate logistics systems to reverse the products from users to manufacturers (Giannotti, 2013).

4. ELECTRICAL AND ELECTRONIC WASTE

Electronic waste, or e-waste, is a term for electronic products that have become unwanted, non-working or obsolete, and have essentially reached the end of their useful life. Since technology advances at such a high rate, many electronic devices become “trash” after a few short years of use (Grünbergen & Mark-Berglung, 2003). The devices that generate these wastes are classified in ten main categories like white goods, small household appliances, information and telecommunications equipment, consumer equipment such as camera, sound system, lighting equipment, electrical and electronic tools, entertainment-sports appliances and toys, medical devices, monitoring and control equipment and vending machines. (Grünbergen & Mark-Berglung, 2003; Puckett et al., 2002).

Based on “Global E-waste Monitoring Report 2018” by the United Nations University, almost 48.9 million tons of e-waste is producing annually around the world, while this figure is 17th in Turkey with an average of 503 thousand tons per year (EAGD, 2018). There is a common view that computers and mobile phones make the most contribution to these wastes (Robinson, 2009).

This rapid increase in the conversion of electrical and electronic goods into waste and the low stringency of recycling has become very important in recent years in terms of environmental awareness, sensitivity and responsibility. The regulations, which limit the use of harmful substances during the production of electrical and electronic products, provide the opportunities for the collection of e-wastes, and are designed to facilitate their recycling. These processes, which create ways for free recycling for consumers, aim to expand the recycling of e-wastes and to ensure a broad social participation in the environmental activities (European Commission, 2016; Toprak et al., 2013).

Recycling of e-wastes provides a significant gain in terms of prevention of waste and of resource consumption by recycling of precious metals in waste (Yazıcı & Deveci, 2009). The European Commission has made the recycling of e-waste mandatory with WEEE (Directive 2002/96/EC).

Lots of requirements are needed to achieve these objectives. Widmer et al. (2005) stated that these requirements were the necessary infrastructure and technical competence, level of industrialization, recycling culture of social and cultural structure, and environmental awareness, to ensure the e-waste recycling and effectiveness of central and local governments. In particular, conditions such as the low level of knowledge and awareness of the recycling of e-wastes and the low number of facilities to realize the transformation of e-waste make the current situation more difficult. Therefore, informing the individuals who are the end users will make a significant contribution to the evaluation of the existing e-waste potential (Toprak et al., 2013). In this context, it is necessary to take a closer look at the behavior of consumers. Eliminating this need will be possible by resorting to behavioral change strategies that encourage individuals to recycle, encourage them to adopt more environmentally sound decisions, or discourage them from environmentally harmful behavior.

4.1. Florescent Lambs

The first entry of fluorescent lamps into our lives dates back to 1935. The first fluorescent lamp was found by American General Electric and introduced its products at the Lighting Engineering Association meetings in Cincinnati, September 1935. The first fluorescent lamp gave a green light around it and the fluorescent lamps had to be tested in a variety of environments to be used by the public.

The first of these experiments was held for the anniversary of the founding of the US Patent Institute for dinner at the ballroom. After successful results, the fluorescent lamps, which were made suitable for domestic use, were launched on April 1, 1938 at the same time by both General Electric and Westinghouse companies. (Johnson et al., 2012).

Three sizes of 45, 60 and 90 centimeters were offered to the market. Mercury-containing fluorescent lamps consume about 80 percent less energy than incandescent lamps, and their lighting efficiency is 3 to 6 times and their functional life is 4 to 15 times higher. In this respect, fluorescent lamps have become the most preferred indoor lighting product in all kinds of closed areas (housing, office, hospital, school etc.).

The CFLs are developed versions of the conventional fluorescent lights that have been utilized in business structures since the 1940s. The standard fluorescent light has a different counterweight that controls the vitality gave to the bulb(s) in that installation. The CFLs joins the balance and knob into one piece by substituting electronic controls at the base of the globule for a customary balance. In that capacity, CFLs can be in a bad way into standard light attachments that are not wired to a counterbalance (Rodi et al., 2014).

Nowadays, we should use energy efficiently to save energy and protect resources. Based on research's, 70% of the lighting equipment which consists of 10% of the energy used consists of fluorescent lamps. Lighting equipment: Fluorescent lamps, compact fluorescent lamps, high-pressure mercury vapor lamps, metal lamp, sodium lamp and gas discharge lamps (all contain mercury). They use 4 times less energy than other incandescent lamps and last 8 times longer. Most of the fluorescent lamps for recycling are rod-shaped. Depending on the developing technology and usage conditions, many types of fluorescence have been produced and these fluorescents must be processed when they become waste (Rodi et al., 2014).

4.2. Hazards of Florescent Lambs

Fluorescent appears to be helpful in reducing energy consumption at first glance, but heavy metals such as mercury contained in the product harm living beings and nature. A fluorescent lamp contains mercury at the magnitude of milligrams; it is the essential component for generating ultraviolet radiation, which is then is converted into visible light by ultraviolet light excitation of a fluorescent phosphors coating on the glass envelope of the lamp.

Mercury is one of the heavy metals of high toxicity and can cause serious damage to various human organs. Once released into the atmosphere or water supplies, mercury can remain there for a long time, and be transported over long distances, before being deposited on the ground via precipitation.

Mercury in fluorescent lamps has many negative effects on humans. Civic nervous system disorders are known for the damage to DNA, chromosomes and brain functions. Care must be taken in every phase of the process, from the storage to the recycling process, of waste fluorescents containing an element that damages nature and nature.

Therefore, it is necessary to show the sensitivity required for the collection, recovery or disposal of fluorescents. Also, CFL bulbs have other serious problems like emission of UV radiation, generation of dirty electricity etc. (Havas, 2008).

As a result of the problems given above, the waste fluorescent lamps must be collected separately from other waste in the reverse logistics phase, and the mercury must be removed in a controlled manner. Also, the used glass should be re-used after being rendered harmless with the appropriate technology.

5. PROPOSED METODOLOGY

In this study, the environmental risk factors that may occur in the logistic processes of fluorescent lamps will be determined and these risk factors will be weighted by MCDM methods.

Then, potential improvement measures will be developed, and the most suitable alternative strategy will be selected.

Finally, a quality house study will be applied to show which technical characteristics should be examined to apply this strategy.

5.1. Description of Evaluation Framework

The methodology proposed in this study consists of two phases and six basic steps:

Phase I: The aim of this phase is to assess the environmental risks of the reverse logistics of the fluorescent lamps

Step 1. Research about environmental risk management in reverse logistics of fluorescent lamp that gives us the risk factors and the possible precautions strategies.

Step 2. Determining the importance of the evaluation criteria for the risk factors by ANP.

Step 3. Determining the ranking of the alternative precaution strategies with COPRAS

Step 4. Determining the robustness of the results with an alternative application ELECTRE

Phase II: The aim of this phase is to realise precaution strategies for the improvement of the system

Step 5. Determining the importance of the evaluation criteria for the customer requirements by SWARA method.

Step 6. Determining the most important engineering metric by HOQ method.

5.2. Phase I: Environmental Risk Assessment based on MCDM

5.2.1. ANP Method for Weighting of Criteria

AHP is the most widely decision-making model which is developed by Saaty's (Saaty, T.L., 1980). AHP is utilized to decide the needs among various criteria. ANP is a MCDM tool considered to be an extension of AHP. While AHP models a decision-making framework using a unidirectional hierarchical connection between decision levels, the ANP grants for more complex relationships between components and decision levels (Chatterjee & Bose, 2012).

The ANP method is based on data collection from experts is used to calculate the weights of risk factors. The ANP allows the modeling of complex structure problems by using a network structure that shows the relationship between the main and sub-criteria. In this study, ANP is chosen because there is a dependence relationship.

To decide in an organized way to generate priorities we need to decompose the decision procedure into the following steps:

Step 1: Identify the decision problem with criteria and sub-criteria.

Step 2: Find the general network of components

Step 3: Find all dependencies that exist in the decision problem

Step 4: Make pairwise comparisons on clusters to find the toper matrix.

Step 5: Make consistency analysis of all the pairwise comparisons.

Step 6: Rate the alternatives according all the criteria and sub-criteria.

Step 7: Compute and find the weighted super matrix and the limit super matrix

Step 8: Determine the final decision to reach the final evaluation of the alternatives.

Table 5.1: Saaty's Fundamental Scale

Value of a_{jk}	**Explanation**
1	*j* and *k* are equally important
3	*j* is slightly more important than *k*
5	*j* is more important than *k*
7	*j* is strongly more important than *k*
9	*j* is absolutely more important than *k*
2, 4, 6, 8	Intermediate values

In ANP, relative priorities are constituted as in AHP according to Saaty's fundamental scale as given in Table 5.1

Using the ratings given in Table 5.1, the pairwise comparison matrices A=(aij) are formed as seen below, to calculate the relative priorities of the elements forming these matrices in further steps:

$$A \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \text{where } a_{ij} = \frac{1}{a_{ij}} \forall i, j = 1, \dots., a_{ii} = 1 \forall i = 1, \dots., n$$

If the matrix A wouldn't contain errors and the judgments were perfectly consistent, then:

$$a_{kj} a_{kj} = a_{ij} \quad \forall i, j, k = 1, \dots \dots .., n \tag{1}$$

Therefore, all the elements in this matrix could be expressed as follows:

$$a_{ij} = {}^{w_i}/_{w_j} \forall i, j = 1, \dots \dots .., n \tag{2}$$

And this would yield to the following equality:

$$\begin{bmatrix} {}^{w_1}/_{w_1} & {}^{w_1}/_{w_2} & \cdots & {}^{w_1}/_{w_n} \\ {}^{w_2}/_{w_1} & {}^{w_2}/_{w_2} & \cdots & {}^{w_2}/_{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ {}^{w_n}/_{w_1} & {}^{w_n}/_{w_2} & \cdots & {}^{w_n}/_{w_n} \end{bmatrix} \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} = \text{n} \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} \quad (3)$$

An easy way to get an approximation of the relative priority vector is to make a column normalization of the matrix A and then take the arithmetic mean of the rows. Hence:

$$w_i = \sum_{k=1}^{n} [a_{ij} / \sum_{k=1}^{n} a_{ij}] \,/\text{n} \quad (4)$$

$$and$$

$$\lambda_{\text{max}} = \frac{1}{n} \sum_{i=1}^{n} \frac{\sum_{j=1}^{n} a_{ij} . w_j}{w_i} \quad (5)$$

It must be underlined that for important application; only the eigenvector derivation procedure has to be used because approximations can lead to a wrong ranking of the alternatives.

The consistency index (CI) of a comparison matrix is given by:

$$\text{CI} = \frac{\lambda max - n}{n-1} \quad (6)$$

And the consistency ratio (CR) is obtained by comparing the CI values given in the Table 5.2. With λmax value, consistency index (CI) and consistency ratio (CR) are found. A value of CR < 0,1 is typically considered acceptable, larger values require the decision maker to reduce inconsistencies in reviewing judgments. Using these values, the CR value is calculated as follows:

$$\text{CR} = CI/CR \quad (7)$$

$$\lim_{n \to \infty} (W)^{2k+1} \quad (8)$$

Table 5.2: Saaty's CI Values for Matrices

Size of Matrix	**Random Consistency (CI)**
1	0
2	0
3	0,58
4	0,90
5	1,12
6	1,24
7	1,32
8	1,41
9	1,45
10	1,49
11	1,51
12	1,54

5.2.2. COPRAS Method for Evaluating RL Strategy Alternatives

The COPRAS method is a method of evaluating alternatives by making step-by-step sequencing of alternatives in terms of importance and utility ratings. The COPRAS is one of the notable MCDM methods, which select the best alternative among of plausible choices by determining a solution to the best solution to the ratio with the ideal-worst solution (Chatterjee, N.C. and Bose, G. K., 2012). The procedure of the COPRAS method includes the following steps:

Step 1. The decision matrix is formed.

Step 2. Normalize the decision matrix using the following formula

$$x_{ij}^{*} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \qquad \text{for (j= 1,2, …, n)} \tag{20}$$

Step 3. Determine the weighted normalized decision matrix

$$d_{ij} = x_{ij}^{*}.w_j \tag{21}$$

Step 4. The sums Si- and Si+ of weighted standardized values are calculated using the following equations for both beneficial and non-beneficial criteria separately:

$$S_{i+} = \sum_{j=1}^{k} d_{ij} \tag{22}$$

$$S_{i-} = \sum_{j=k+1}^{n} d_{ij} \quad (23)$$

Step 5. The Qi values are relative importance values for each alternative and are calculated using the equation (9). The result of the calculations is determined as the best alternative with the highest relative importance value.

$$Q_i = S_{i+} + \frac{\sum_{i=1}^{m} S_{i-}}{S_{i-} * \sum_{i=1}^{m} \frac{1}{S_{i-}}} \quad (24)$$

Step 6. The highest relative priority (Qmax) value is found.

Step 7. Calculate the performance index (Pi) of each alternative with this equation:

$$P_i = \left[\frac{Q_i}{Q_{max}}\right] \times 100\% \quad (25)$$

5.2.2.1. ELECTRE Method for Evaluating RL Strategy Alternatives

ELECTRE MCDM method was first introduced in 1966 by Benayoun. The technique depends on the paired predominance examinations between elective choice focuses for every evaluation factor. The method goes to the solution in step 8 (Triantaphyllou, 2000). The steps of the ELECTRE method are described below.

Step 1: The decision matrix (A) is formed.

A matrix is the beginning network made by the leader. The choice grid is appeared as pursues:

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \quad (9)$$

Step 2: Creating the Standard Decision Matrix (X)

The Standard Decision Matrix is determined utilizing the components of matrix A and the given equation:

$$x_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \qquad (10)$$

At the end of the calculations, the matrix X is obtained as follows:

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \qquad (11)$$

Step 3: Forming the Weighted Standard Decision Matrix (Y)

The importance of evaluation factors for decision-makers may be different. In order to reflect these significance differences to the ELECTRE solution, the Y matrix is calculated. The decision-maker must first determine the (w_i) weight of the evaluation factors ($\sum_{i=1}^{n} w_i = 1$).

Then the elements in each column of the X matrix are multiplied by the respective value to form the Y matrix. The Y matrix is shown below:

$$Y_{ij} = \begin{bmatrix} w_1 x_{11} & w_2 x_{12} & \dots & w_n x_{1n} \\ w_1 x_{21} & w_2 x_{22} & \dots & w_n x_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ w_1 x_{m1} & w_2 x_{m2} & \dots & w_n x_{mn} \end{bmatrix} \qquad (12)$$

Step 4: Determination of Compliance and Incompatibility Sets

In order to determine the adaptation sets, the Y matrix is used, the decision points are compared with each other in terms of evaluation factors and the sets are determined by the relationship shown in the following formula:

$$C_{kl} = \{j, y_{kj} \geq y_{lj}\} \tag{13}$$

The formula is based on the comparison of the size of the line elements relative to each other. The number of fit sets $(m.m - m)$ in a multiple decision problem. Because k and l indices must be $k \neq l$ when creating compliance sets. The number of elements in a fit set can be the maximum number of evaluation factors (n).

In the ELECTRE method, each set of conformances (n) corresponds to a set of mismatches (m). In other words, there are a number of mismatches set up to the number of fit sets. The non-compliance set elements consist of values that do not belong to the corresponding compliance set.

In the ELECTRE method, attention should be paid to the meaning of the evaluation factors when creating adaptation sets. For example, if the relevant evaluation factor is profit, then $C_{kl} = \{j, y_{kj} \geq y_{lj}\}$ formula will be used for compliance set. However, the evaluation factor cost is the condition $y_{kj} < y_{ij}$ inequality for the adaptation set.

Step 5: Formation of Compliance (C) and Incompatibility Matrices (D)

Adaptation sets are used to create the fit matrix (C). The matrix C is mxm and does not have a value for $k = l$. The elements of the C matrix are calculated by the relationship shown in the following formula. The matrix C is shown below:

$$c_{kl} = \sum_{j \in C_{kl}} w_j \tag{14}$$

$$C = \begin{bmatrix} - & c_{12} & c_{13} & \dots & c_{1m} \\ c_{21} & - & c_{23} & \dots & c_{2m} \\ . & & & & . \\ . & & & & . \\ . & & & & . \\ c_{m1} & c_{m2} & c_{m3} & \dots & - \end{bmatrix} \tag{15}$$

The elements of the mismatch matrix (D) are calculated by the following formula:

$$d_{kl} = \frac{\max_{j \in D_{kl}} \left| y_{kj} - y_{lj} \right|}{\max_{j} \left| y_{kj} - y_{lj} \right|} \tag{16}$$

As the C matrix, the D matrix is also mxm in size and does not take any value for $k = l$. The matrix D is shown below:

$$D = \begin{bmatrix} - & d_{12} & d_{13} & \dots & d_{1m} \\ d_{21} & - & d_{23} & \dots & d_{2m} \\ . & & & & . \\ . & & & & . \\ . & & & & . \\ d_{m1} & d_{m2} & d_{m3} & \dots & - \end{bmatrix} \tag{17}$$

Step 6: Formation of Compliance Advantage (F) and Disparity Superiority (G) Matrices

The alignment superiority matrix (F) is mxm sized and the elements of the matrix are obtained by comparing the fit threshold value ($\underline{c}$) with the elements of the fit matrix (C_{kl}). The compliance threshold value ($\underline{c}$) is obtained by the following formula:

$$\underline{c} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} c_{kl} \tag{18}$$

Parameter m shows the number of decision points in the formula. More precisely, the value of $\underline{c}$ is equal to the sum of the sum of the elements that make up the matrix $\frac{1}{m\,(m-1)}$ and C.

The elements (f_{kl}) of the matrix F take either the value of 1 or 0, and there is no value because it shows the same decision points on the diagonal of the matrix. If $c_{kl} \geq \underline{c} \Rightarrow f_{kl} = 1$ and if $c_{kl} < \underline{c} \Rightarrow f_{kl} = 0$.

The mismatch advantage matrix (G) is also mxm sized and is formed in a similar manner to the F matrix. The mismatch threshold value ($\underline{d}$) is obtained by the following formula:

$$\underline{d} = \frac{1}{m(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} d_{kl} \tag{19}$$

In other words, the $\underline{d}$ value is equal to the product of the sum of the elements that make up the $\frac{1}{m\,(m-1)}$ and the D matrix.

The elements of the G matrix (g_{kl}) are either 1 or 0, and there is no value, since they represent the same decision points on the diagonal of the matrix. If $d_{kl} \geq \underline{d} \rightarrow g_{kl} = 1$ else $g_{kl} = 0$.

Step 7: Creating the Total Dominance Matrix (E)

The elements (e_{kl}) of the Total Dominance Matrix (E) are equal to the reciprocal of the elements f_{kl} and g_{kl}, as shown in the following formula. Here, the E matrix is mxm sized depending on the C and D matrices and it is also composed of 1 or 0 values.

Step 8: Determining the order of importance of decision points

The rows and columns of the E matrix represent the decision points.

$$S_{i+} = \sum_{j=1}^{k} d_{ij}\, S_{i-} = \sum_{j=k+1}^{n} d_{ij}$$

5.3. Phase II: Realising precaution strategies for the improvement of the system based on SWARA and HOQ

5.3.1. SWARA Method for Weighting the Customer Requirements

The SWARA method gives DMs an opportunity to choose their own priorities, taking into account the current environmental and economic situation. Moreover, the role of DMs is even more important in this method (Hashemkhani & Bahrami, 2014). The

SWARA method has been used to solve many problems in the literature. Some of these studies are dispute resolution (Keršuliene et al., 2010), architect selection (Keršulienė & Turskis, 2011), machine tool selection (Hasan et al.,2013), personnel selection (Zolfani & Banihashemi, 2014), priority for implementation of solar projects (Vafaeipour et al., 2014), assessment of regional landslide hazard (Dehnavi et al., 2015), selection of candidates in the mining industry (Karabasevic et al.,2015), ranking of companies according to the indicators of corporate social responsibility (Karabašević, et al. 2016), ERP system selection (Shukla et al. 2016), evaluation of construction projects of hotels (Zolfani et al. 2018) and residential house element and material selection (Zavadskas et al., 2018).

The procedure of the SWARA method includes the following steps:
Step 1. The factors are sorted in descending order based on their expected significances.

Step 2. Beginning with the second factor, relative importance levels are determined for each factor. For this, the factor j and the previous factor (j-1) are compared. Keršulienė et al. [8] call it "comparative importance of average value" and show it with the symbol s_j.

Step 3. The coefficient *kj* is determined as follows:

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \tag{26}$$

Step 4. The significance vector q_j is calculated by the following equation:

$$q_j = \begin{cases} 1 & j = 1 \\ \frac{k_{j-1}}{k_j} & j > 1 \end{cases} \tag{27}$$

Step 5. Determine the relative weights of the evaluation factors as follows:

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \tag{28}$$

where w_j indicates the relative weight of factor j.

5.3.2. HOQ Method for Prioritization the Engineering Metrics

QFD is a systematic approach that is often used by the design teams for the development of new products and services that considers the expectations of the various stakeholders. QFD was developed by Yoji Akao in 1966, and demonstrated at the Mitsubishi Heavy Industries (Sullivan, 1986). The aim of QFD is to make the products and services better and responsive to the requirements of the stakeholders. It starts with identifying the needs of the stakeholders. The requirements of the stakeholders are then translated into design characteristics (Dursun & Karsak, 2013). Four phases of QFD are namely product planning, product design, process planning, and process control. Main advantages of QFD includes the customer satisfaction, shorter lead time, better flexibility, quality promotion, reduced time for marketing and knowledge preservation (Khademi-Zare et al., 2010).

HOQ or planning matrix is the relationship matrix where the interconnection between customer requirements and engineering metrics are displayed. House of quality (Hauser and Clausing, 1988) is given in Figure 5.1, and its steps are described in the following (Akao, 1990).

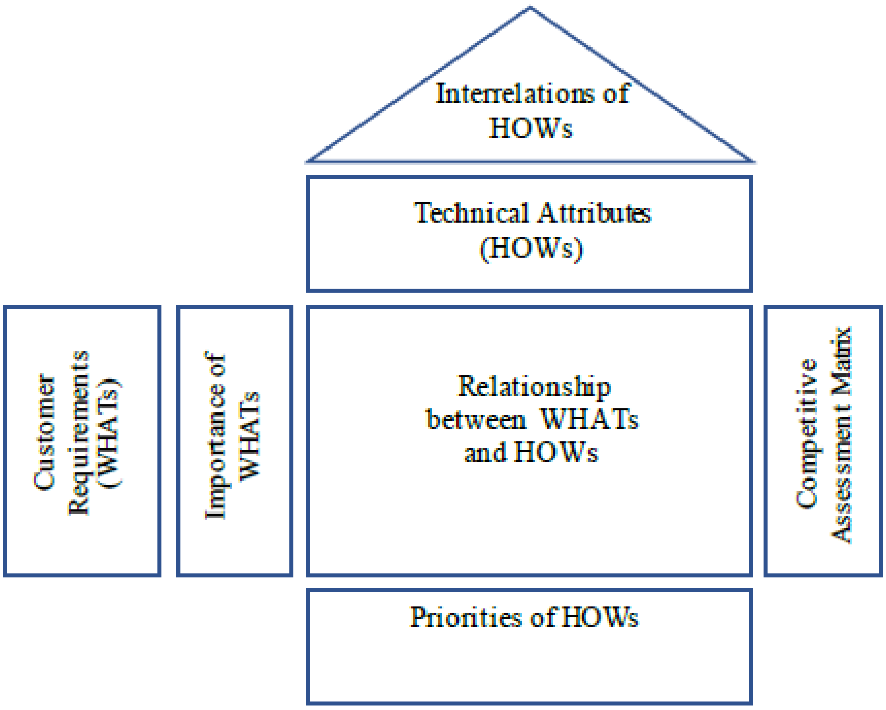

Figure 5.1: House of quality (Hauser & Clausing, 1988)

i. CRs (WHATs): Customer requirements are also known as voice of stakeholders, customer needs or customer attributes. The first step of constructing HOQ is the collection of customer requirements for the corresponding product or service. CRs guide the designers about the characteristics of the product or service to be developed.

ii. EMs (HOWs): EMs are also known as design attributes, design requirements, engineering characteristics or engineering attributes. HOW is the answer of how the customer requirements will be satisfied, and thus HOWs are closely associated with customer needs. Engineering metrics have a highly important role in producing a product or service, which satisfies the needs of the customers.

iii. Importance of WHATs: This part represents the rating or weights of customer requirements (WHATs). The input gathered from the stakeholders must be weighted in order to be able to disqualify comparatively less important needs and have the chance to focus the more important ones.

iv. Relationship between WHATs and HOWs: The relationship matrix is the essential part of HOQ since it demonstrates whether EMs influence CRs, and in which level each EM affects each CR. In this part, decision makers (DMs) are asked to evaluate the relationship. The question might be as “What is the strength of the relationship between the engineering metrics and the customer requirements?” A determined scale is used to measure the relationship.

v. Competitive assessment matrix: Comparative position of the company’s product or service is analysed in terms of CRs by conducting a competitive analysis of the domestic product with main rival’s products. The customers are asked to rank the performance of both products by using a fixed scale.

vi. Interrelations of HOWs: Interrelations of the engineering metrics are indicated in the roof matrix of the house. This matrix considers how the EMs impact each other. This part is often not used.

vii. Priorities of HOWs: The importance is calculated for each technical attribute (HOW), also called EM weights. This is counted as the last step of the HOQ.

Definition 1 (Tavana et al., 2016):

Suppose that there are n EMs satisfying m CRs. The raw score, Wj is calculated by the total of the sum multiplied by the weights of the customer requirement, Ci with the relational strength, Rij. It is given in Eq. (29) as follows:

$$Wj = \sum_{i=1}^{m} RijCi \tag{29}$$

where,

W_j the importance or "raw score" of the j_{th} technical attribute (j = 1, 2,..., n);

R_{ij} the relational strength between i_{th} customer requirement, and jth technical attribute (i = 1, 2,..., m; j = 1, 2,..., n);

C_i the weight of the i_{th} customer requirement (i = 1, 2,..., m).

Definition 2:

Suppose that there are n EMs satisfying m CRs. The normalised weight, ϖj is calculated by dividing the raw score of j_{th} technical attribute, W_j to the sum of total raw scores. It is given in Eq. (30) as follows:

$$\varpi j = \frac{Wj}{\sum_{J=1}^{n} WJ} \tag{30}$$

where,

ϖj the normalised weight of the j_{th} technical attribute (j = 1, 2,..., n);

Wj the importance or "raw score" of the j_{th} technical attribute (j = 1, 2,..., n).

6. APPLICATION

6.1. Background

The assessment of the "environmental risks" in the reverse logistics of the florescent lamp, such as CO_2 emissions, warehouse energy consumption, soil pollution risk etc. are considered as a MCDM problem with two phases.

In this study, the opinions of a group of two research assistants and experts were used for the ANP model. Research assistants make academic studies on sustainability, energy and logistics. The expert is a representative working under a special institution which is closely related to the concept of reverse logistics. In this study, decision-makers worked together to make common decisions with CONSENSUS method in various MCDM models.

First phase contains an ANP based on data collection from the experts, is used to determine the ranking of the criteria by calculating their weights. COPRAS is applied for evaluating possible precaution strategies against environmental risks. Also, the ELECTRE method was successfully applied to compare the results of COPRAS as a decision support model between various alternatives. Second phase aims to realize a solution stage according to the strategy chosen as a result of COPRAS with SWARA to weight customer expectations and HOQ method to determine the area that needs improvement by comparing customer expectations with engineering expectations.

Our goal for the study is selecting the best strategy for reverse logistics system. There are five possible alternatives in which to select the strategy: Re-engineering strategy for product (A1), monitoring and control management strategy for RL processes (A2), increasing operational safety strategy (A3), waste management strategy for RL disposal process (A4), environmental strategy for RL transportation process (A5).

In the first phase, the company must take a decision according to the following seven criteria: CO_2 transportation emissions factor per unit of returned product in G/Km (T11), miles per gallon of fuel (T12), release of hazardous chemicals of damaged products (T13), storage and warehouse energy consumption (S11), risks of unexpected situations (fire, natural disasters etc.) (S12), release of hazardous chemicals of damaged products (S13), amount of mercury released to water supply (water pollution) (D11), the amount of mercury particles in the air (air pollution) (D12), amount of mercury released to the soil and land (soil pollution) (D13). The five possible alternatives A_i ($i = 1, 2, 3, 4, 5$) are to be evaluated using the ANP, COPRAS and ELECTRE methods.

In the second phase, the company must take a decision according to the following sixteen customer requirements: low price (CR1), led lamp quality (luminance) (CR2), material for head lamp (CR3), environmentally safe (CR4), chromaticity (CR5), viewing angle (CR6), low power consumption (CR7), response time (CR8), brightness uniformity (CR9), easy to clean (CR10), quiet (CR11), easy to recycle (CR12), visually attractive appearance (CR13), safe to use (CR14), free of hazardous substances (CR15), durable (CR16). Those CRs are to be weighted using SWARA method.

The twenty possible engineering metrics material weight (EM1), material size (EM2), tube control (EM3), inverter control (EM4), low-power IC design (EM5), packaging process (EM6), transportation process (EM7), quality control (EM8), power consumption (EM9), material development (EM10), noise control (EM11), product lifetime (EM12), emissions in use (EM13), environmental performance (EM14), production functionality (EM15), production waste (EM16), usability (EM17), end of life waste (EM18), time for disassembly (EM19), recyclability ratio (EM20); are to be evaluated using the HOQ method. Detailed information about those variables will be given in the sections below.

6.2. Phase I: Environmental Risk Assessment based on MCDM

6.2.1. Proposed Evaluation Criteria and Alternatives

There are three main criteria Transport, Storage and Disposal as mentioned in “Figure 3.1: Reverse Logistics Process” that must be taken into consideration to assess reverse logistics in terms of environmental risks. The goal of the evaluation, the three criteria and their sub-criteria are as in Figure 6.1.

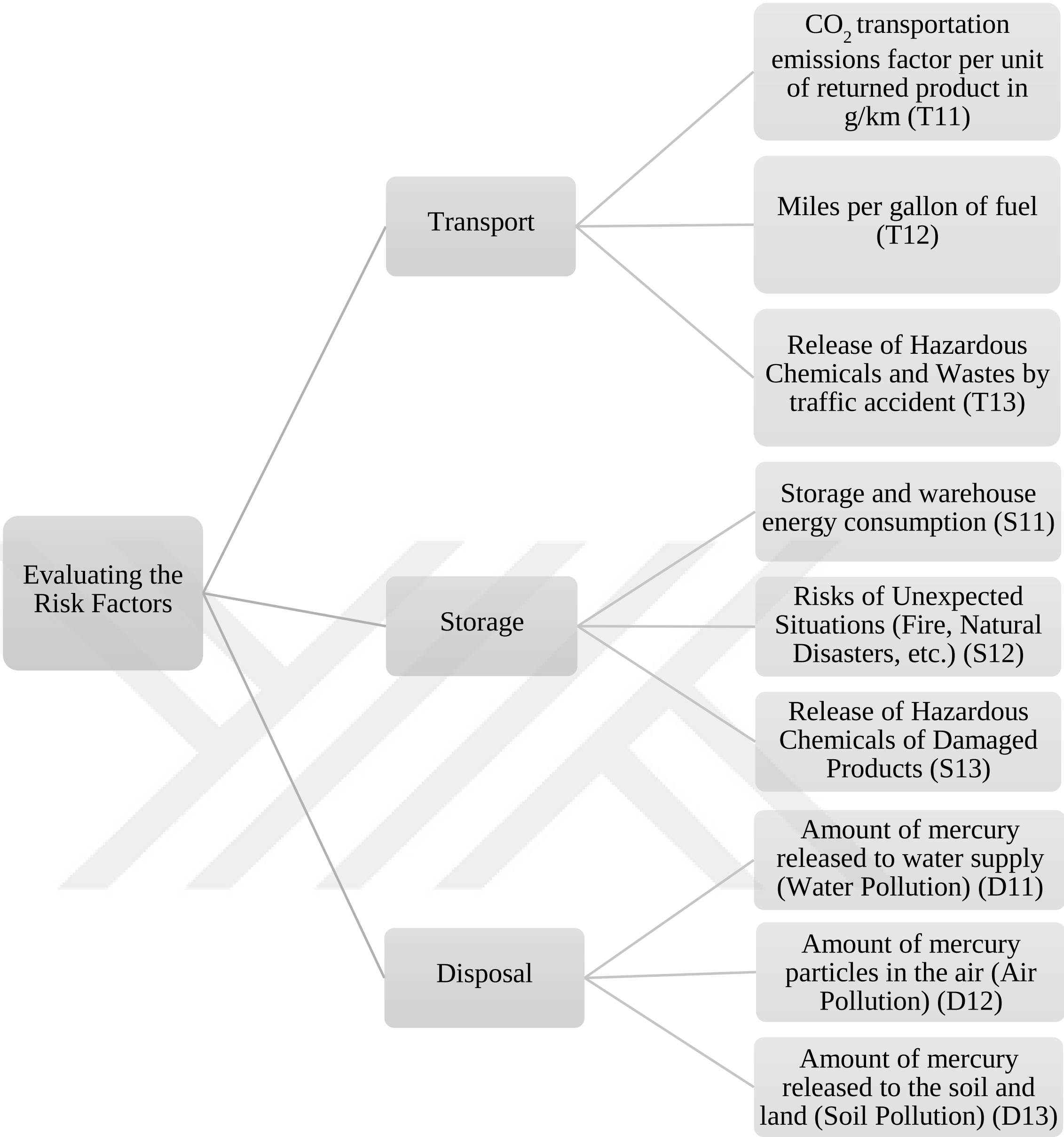

Figure 6.1*: The goal of the evaluation, the three criteria and their sub-criteria*

• *Criteria 1 - Transport:*

(T11) - CO_2 Transportation Emissions Factor Per Unit of Returned Product In g/km: The simplest of companies to calculate transport emissions is to use standard emission conversion factors to record energy and / or fuel use and convert energy or fuel values into CO_2 emissions. Each liter of fuel consumed will result in a certain amount of CO_2 emissions. (McKinnon & Piecyk, 2010).

(T12) - Miles Per Gallon of Fuel: Gallons per 100 miles. This relates directly to the amount of fuel used and resource depletion (Waters &Laker,1980).

(T13) - Release of Hazardous Chemicals and Wastes by traffic accident: Mercury in a fluorescent lamp can be released as both dust and vapor when the lamp is accidentally broken. This heavy metal is dangerous to people and animals, and easily migrates through the environment in the air, water, and soil (Taghipour et al., 2014).

- *Criteria 2 - Storage:*

(S11) - Storage and Warehouse Energy Consumption: Many products require controlled storage conditions. Therefore, warehouse buildings are equipped with devices that create an appropriate microclimate inside. Thus, these will be cold, air conditioned and heated warehouses. Warehouse operations are clearly linked to energy consumption in its various forms. Among the different forms and varieties of warehouses, cold and heated warehouses are characterized by a relatively high energy demand (Taghipour et al., 2014). As a result, companies need to learn how to save energy while reducing the carbon footprint of the warehouse.

(S12) - Risks of Unexpected Situations (Fire, Natural Disasters, etc.) : Explosion and/or sudden release of pressure because of unexpected situations such as fire, natural disasters, etc. (Payzan-LeNestour and Bossaerts, 2011).

(S13) - Release of Hazardous Chemicals of Damaged Products : Release of hazardous chemicals which poses substantial or potential threats to workers' health in the warehouse and/or the environment (Taghipour et al., 2014). The products can be damaged in the warehouses by several reasons.

- *Criteria 3 - Disposal:*

(D11) - Amount of mercury released to water supply (Water Pollution): Release of hazardous water pollutants into the water by landfill. (Lim et al., 2012)

(D12) - Amount of mercury particles in the air (Air Pollution): Burning of all kinds of air pollutants containing chemicals, particulate matter or biological substances (mercury etc.) to the atmosphere (Nance et al., 2012).

(D13) - Amount of mercury released to the soil and land (Soil Pollution): Release of hazardous soil pollutants into the soil by landfill. [(Lim et al., 2012).

Many strategies can be considered to improve the reverse logistics system. In this case, it is important to choose the strategy that will be most successful and most appropriate for the system. These strategies are as follows:

- *Alternative 1 - Re-engineering strategy for product (A1):*

First, because mercury can be dangerous to human health, it is important to dispose of fluorescent tubes properly. When collecting used fluorescent bulbs, it is recommended to store and packaging to minimize lamp breakage. Along with this strategy, organizational arrangements are carried out in order to ensure the systematic planning, coordination and implementation of the reverse logistics system. The implementation of legislative arrangements for the implementation and integration of the reverse logistics system is among the foundations of this strategy (Kilic et al., 2015). Fluorescent lamps carry potential risks throughout the production process. For this reason; starting from product design, all processes including production technology, packaging process, stocking must be re-engineered with the view of eco-design.

- *Alternative 2 - Monitoring and control management strategy for RL processes (A2):*

The main purpose of this strategy is to increase the control and monitoring of practitioners of reverse logistics of fluorescent lamps. So, companies and users will realize that sustainable reverse logistics strategies provide additional benefits that cannot be listed such as eliminating fines from government organization from improper disposal or improving the public perception of the company etc.

- *Alternative 3 - Increasing operational safety strategy (A3):*

This strategy focuses on the operational health and safety regulations for the reverse logistics systems. With this strategy, it is aimed to redesign logistics system components for safer reverse logistics processes with lower probability of accidents, and to increase the training of company logistics personnel.

- *Alternative 4 - Waste management strategy for RL disposal process (A4)*:

Besides harmful effects on human health, wrong recycling of fluorescent bulbs can also threaten the environment. Metals and other toxic substances can be released into the environment when CFLs are damaged such as broken, burned, or buried. Mercury in the air can be deposited in soil and water bodies and can be transferred to the methyl-mercury by microbial activity. This harmful element not only contaminates water, but also affects fish and eaters. This strategy is environmentally oriented and ensures that all work in the waste management is environmentally friendly. With this strategy, it is aimed to reduce the hazardous substances in the lamp that may harm the environment and the human health (Kilic et al., 2015).

- *Alternative 5 - Environmental strategy for RL transportation process (A5):*

Strategy aims to reduce emissions in transportation are produced, such as using less fuel-consuming vehicles, switching to electric vehicles, optimized routes etc.

6.2.2. Weighting the Criteria with ANP Method

ANP-Stage 1. Evaluation criteria, definitions and network structures are given in Figure 6.2.

ANP-Stage 2. Experts agree on a binary comparison of the criteria underlying the ANP method. A binary comparison matrix has been established for the implementation of ANP. The decision matrix, which is based on Saaty's nine-point scale. The DMs use the fundamental 1–9 scale defined by Saaty's to assess the priority score. The Consensus results of DMs' are as given in appendix tables from Table A.1.1 to A.1.4.

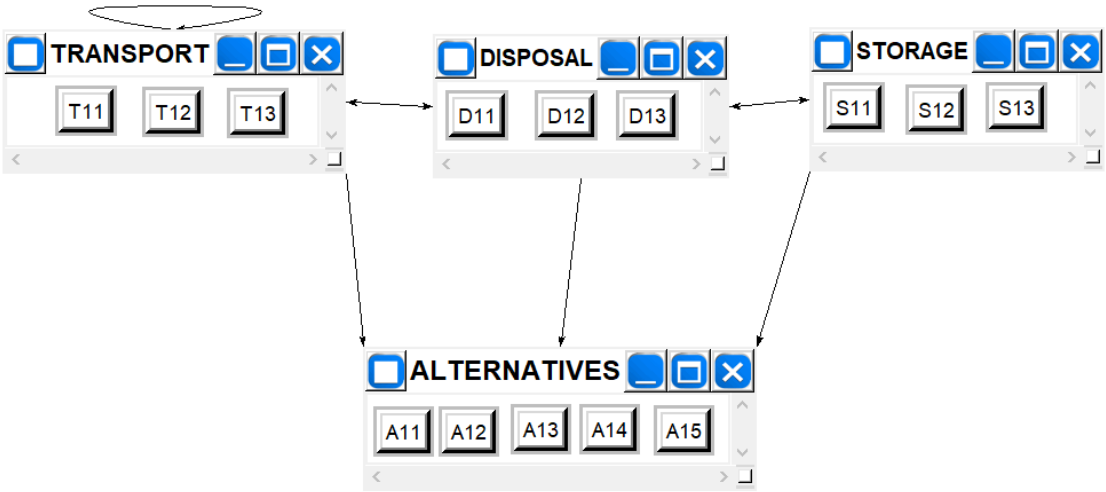

Figure 6.2: ANP Network Structures

The network given above contains dependent variables from each different node. Gallon of fuel per miles (T12) effects CO_2 transportation emissions factor per unit of returned product in g/km (T11), release of hazardous chemicals and wastes by traffic accident (T13) effects the mount of mercury released to the soil and land (Soil Pollution) (D13) and release of hazardous chemicals of damaged products (S13).

In ANP method, the decision-making problem is modeled by a network structure as shown in the application. In the modeling phase, dependencies between factors and internal dependencies within the factor are also examined.

The super decision tool was used for ANP calculation. Super Decisions is decision making software based on the AHP and the ANP.

In the calculation of ANP method, superiority comparison is made between main criteria and sub criteria based on all alternatives. After all the benchmarks are evaluated, the weighted super matrix is generated. As a result of all processes, weights are determined for all sub-criteria. Comparison results of main criteria and super-matrix are as given below in Table 6.1 and 6.2.

Table 6.1: The Comparison Results of Main Criteria

	Weights
Transport	0,3022
Storage	0,0896
Disposal	0,6082

Table 6.2: The Super-Matrix

	A11	A12	A13	A14	A15
T11	0.00000	0.18643	0.00000	0.31149	0.52784
T12	0.00000	0.08012	0.00000	0.00000	0.33252
T13	0.00000	0.02066	0.28720	0.00000	0.13965
S11	0.00000	0.04554	0.00000	0.00000	0.00000
S12	0.00000	0.02189	0.01949	0.00000	0.00000
S13	0.10937	0.01053	0.05847	0.00000	0.00000
D11	0.43942	0.30513	0.27207	0.31669	0.00000
D12	0.17439	0.07235	0.27207	0.15225	0.00000
D13	0.27682	0.25736	0.09069	0.21958	0.00000

ANP-Stage 3. The ANP method was applied to the mathematical model, which was the result of the common opinion of the experts, and the criteria weights were calculated as in Table 6.3.

Table 6.3: The Standardized Matrix

Criteria	Normalized by Cluster	ANP Weights
T11	0,62097	0,250282
T12	0,16697	0,065841
T13	0,21206	0,082516
S11	0,16246	0,008232
S12	0,15321	0,007353
S13	0,68432	0,035413
D11	0,46781	0,252128
D12	0,2376	0,134063
D13	0,29459	0,164172

ANP-Stage 4. At this level of the application, the consistency ratio is measured.

Since the numeric values are derived from the subjective preferences of individuals, it is impossible to avoid some inconsistencies in the final matrix of judgments. The question is how much inconsistency is acceptable. For this purpose, ANP calculates a consistency ratio (CR) comparing the consistency index (CI) of the matrix in question (the one with our judgments) versus the consistency index of a random-like matrix (RI). A random matrix is one where the judgments have been entered randomly and therefore it is expected to be highly inconsistent. More specifically, RI is the average CI of 500 randomly filled in matrices.

As stated in chapter 5.2.1, if the consistency ratio is greater than 0.10, it is necessary to revise the judgments to locate the cause of the inconsistency and correct it. In our study, Saaty's constant is defined as 0,58 and CR has found 0,082063641 which is less than 0,1 which means acceptable to continue the ANP analysis.

Table 6.4: The Consistency Ratio

Count =	3
λ_{max} =	3,095193823
CI= 0,047596912	
Constant = 0,58	
CR= 0,082063641 < 0,1	

6.2.3. Evaluating of RL Strategy Alternatives with COPRAS Method

By using the criteria weights found with ANP, five alternative precaution strategies are evaluated with the COPRAS method.

COPRAS-Stage 1. The decision matrix is established as given in appendix Table A.2.1 and Table A.2.2

COPRAS-Stage 2-3. The weighted normalized decision matrix of the alternatives computed by multiplying the normalized decision matrix and the weights is represented in Table 6.5. The normalized decision matrix is calculated.

Table 6.5: The Weighted Normalized Matrix

	T11	**T12**	**T13**	**S11**	**S12**	**S13**	**D11**	**D12**	**D13**
A1	0,051	0,016	0,020	0,004	0,002	0,015	0,115	0,059	0,076
A2	0,120	0,038	0,034	0,004	0,004	0,015	0,115	0,059	0,076
A3	0,051	0,016	0,061	0,003	0,006	0,022	0,115	0,059	0,055
A4	0,120	0,027	0,020	0,004	0,002	0,015	0,148	0,075	0,098
A5	0,154	0,038	0,034	0,003	0,002	0,009	0,082	0,042	0,055

COPRAS-Stage 4-5-6-7. The values of Qi, Si+, Si-, Pi were calculated using equations (22), (23), (24) and (25) by COPRAS method. Table 6.6. shows the results. In view of the proposed model, every option has the preferable values for the maximizing and minimizing indices.

Table 6.6: The Final Results of COPRAS

	Si+	Si-	Qi	Pi	Rank
A1	0,000	0,360	0,502	100	1
A2	0,000	0,466	0,388	77,36	4
A3	0,000	0,387	0,468	93,23	2
A4	0,000	0,512	0,354	70,47	5
A5	0,000	0,419	0,432	85,98	3

Ultimately, re-engineering of production system strategy (A1) has become the most suitable strategy among five alternatives with the final results; while the strategy increasing operational (A3), the decreasing environmental impacts of transportation strategy (A5), the strategy for rising the awareness reverse logistics (A2), the strategy for decreasing environmental impacts of waste management strategy (A4) have positioned at the second, third, fourth and fifth ranks with 93.23, 85.98, 77.36 and 70.47 as the final performance values, respectively.

6.2.4. Evaluating the RL Strategy Alternatives with ELECTRE Method

By using the criteria weights found with ANP, five alternative precaution strategies are evaluated with the ELECTRE method.

ELECTRE-Stage 1: Normalize the decision matrix as given in appendix Table A.3.

ELECTRE-Stage 2: Multiply the weight of the criteria according to the normal value of each criterion of each alternative.

Table 6.7: The Weighted Normalized Matrix

Criteria Weights	0,2503	0,0658	0,0825	0,0082	0,0074	0,0354	0,2521	0,1341	0,1642
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
A1	0,051	0,016	0,020	0,004	0,002	0,015	0,115	0,059	0,076
A2	0,120	0,038	0,034	0,004	0,004	0,015	0,115	0,059	0,076
A3	0,051	0,016	0,061	0,003	0,006	0,022	0,115	0,059	0,055
A4	0,120	0,027	0,020	0,004	0,002	0,015	0,148	0,075	0,098
A5	0,154	0,038	0,034	0,003	0,002	0,009	0,082	0,042	0,055

ELECTRE-Stage 3: Determine the mismatch or incompatibility of each criterion for each paired comparison of different alternatives.

ELECTRE-Stage 4: Calculating the fit matrix by collecting the weight of each adjustment in double comparison.

ELECTRE-Stage 5: Calculate the dissociation matrix by dividing the maximum weight of each mismatch in paired comparisons by the maximum weights of all paired comparisons.

ELECTRE-Stage 6: Determination of the active coordinate matrix with the coordination matrix.

ELECTRE-Stage 7: Identify the unique coordinate matrix with the mismatch matrix.

ELECTRE-Stage 8: Effective matrix computation with the multiplication of each of the effective coordinated and uncoordinated matrix sequences.

ELECTRE-Stage 9: Select the alternative with the maximum point in the active matrix.

Table 6.8: The Final Results for ELECTRE

	Win	**Lost**	**Final**	**Ranking**
A1	3	0	**3**	1
A2	1	2	-1	4
A3	2	1	1	2
A4	0	3	-3	5
A5	0	0	0	3

Ultimately, re-engineering of production system strategy (A1) has become the most appropriate strategy among five alternatives with the final performance; while the strategy increasing operational (A3), the decreasing environmental impacts of transportation strategy (A5), the strategy for rising the awareness reverse logistics (A2), the strategy for decreasing environmental impacts of waste management strategy (A4) have positioned at the second, third, fourth and fifth ranks with 1, 0, -1 and -3 as the final performance values, respectively.

The aim of this application, to compare and check the accuracy of the COPRAS results with another MCDM approach and method with same inputs. Based on ELECTRE method, same results have obtained with the ranking of alternatives are A1, A3, A5, A3 and A4.

As a result of these two different approaches achieving the same results, a solution application was applied for the important alternative in the second phase.

6.3. Phase II: Realising precaution strategies for the improvement of the system based on SWARA and HOQ

The customer requirements and engineering metrics which are collected from the literature review (Masui, 2003; Wimmer, 2004; Vinodh & Rathod, 2010) and DMs' reviews are presented as follows.

6.3.1. Proposed Customer Requirements and Engineering Metrics

Table 6.9: Customer Requirements

Customer Requirements	**Definitions**
Low price (CR1)	Price of the product
Led lamp quality (Luminance) (CR2)	Good quality of LED light conveys a more extensive light
Head lamp materials (CR3)	It helps LED light to work in low temp to maintain the light distribution
Environmentally safe (CR4)	To have harmless environmental effects in any of the product life cycle phases
Chromaticity (CR5)	The color intensity and quality of a color determined by the hue
Viewing angle (CR6)	The maximum angle at which a showcase seen with worthy visual execution without any changes
Low power consumption (CR7)	Power utilization alludes to the electrical energy provided overtime to work the BLU.
Response time (CR8)	The LCD optical switching time interval between ‘white’ state and ’black’ state
Brightness uniformity (CR9)	Maximum and minimum brightness ratio according to measurement points
Easy to clean (CR10)	Use of cleanable, easily separable parts
Quiet (CR11)	Less noise while operating
Easy to recycle (CR12)	Use of recyclable materials
Visually attractive appearance (CR13)	Color, shape, size, etc.
Safe to use (CR14)	Related to leakage, burning of boiled water
Free of hazardous substances (CR15)	Absence of hazardous materials and toxics
Durable (CR16)	Having robustness and long lifetime.

Table 6.10: Engineering Metrics

Engineering Metrics	**Definitions**
Material weight (EM1)	The weight of items
Material size (EM2)	The size of items
Tube material (EM3)	CFL light source such as incandescent light bulb, electroluminescent panel, light-emitting diodes, mercury content and cold cathode fluorescent lamp.
Inverter quality (EM4)	Voltage (AC) and electric current (mA) control
Low-power IC design (EM5)	Power consumption reduction with the help of IC design
Packaging process (EM6)	Proper vapor-resistant packaging
Transportation process (EM7)	The necessary levels of protection and minimizing fuel consumption
Quality control (EM8)	It utilized in developing frameworks to guarantee that items are designed and produced to meet the needs.
Power consumption (EM9)	Power consumption through materials (light sources)
Material type (EM10)	Including light guide plate (LGP), reflective sheet, prism sheet and diffusion sheet, etc. expect tube material.
Noise Control (EM11)	Sound generated during lightning process
Product Lifetime (EM12)	Life time of the product
Emissions in use (EM13)	Ultraviolet radiation efficiently produced by an electric discharge
Production functionality (EM14)	Maintaining the light distribution
Production waste (EM15)	Waste during the usage of product life
Usability (EM16)	Hardware serviceability ratio
End of life waste (EM17)	Waste after the end of product life
Time for disassembly (EM18)	Total time for vanishing of product into nature.
Recyclability ratio (EM19)	A proportional value (%) and reflects the proportion of materials recycled or recovered from waste

6.3.2. Weighting of Customer Requirements with SWARA Method

In order to determine the significance levels of the evaluation criteria in Table 6.11, three decision makers were determined. Firstly, the process of ranking the first step of the SWARA method from the most important to the least important is done separately by each decision maker. SWARA is a method that combines the decisions of three different decision makers. Therefore, consensus method is not used in this methodology. According to the table, the most important criteria for decision maker 1 (DM1) can be seen as "Led lamp quality (Luminance) (CR2) "criterion.

Table 6.11: Sequence results

	DM1	DM2	DM3
(CR1)	3	3	5
(CR2)	1	1	7
(CR3)	15	13	12
(CR4)	10	16	4
(CR5)	2	14	14
(CR6)	5	10	3
(CR7)	4	6	2
(CR8)	16	7	6
(CR9)	7	12	15
(CR10)	13	15	13
(CR11)	8	5	8
(CR12)	14	13	9
(CR13)	9	8	10
(CR14)	12	9	11
(CR15)	11	11	16
(CR16)	6	2	1

The criteria listed in Table 6.12, which is the most important one, and the relative importance levels (sj) for each criterion from the second criterion are determined separately by the decision makers. For example, the comparative severity level between the C8 criteria and the C3 criteria for the decision-maker 1 is 0.60.

Table 6.12: Comparative Severity Levels

Significance Ranking	DM1		DM2		DM3	
	Ranking	sj	Ranking	sj	Ranking	sj
1	(CR2)	-	(CR2)	-	(CR16)	-
2	(CR5)	0,4	(CR16)	0,05	(CR7)	0,6
3	(CR1)	0,1	(CR1)	0,05	(CR6)	0,8
4	(CR7)	0,15	(CR11)	0,2	(CR4)	0,5
5	(CR6)	0,25	(CR7)	0,35	(CR1)	0,4
6	(CR16)	0,1	(CR8)	0,25	(CR8)	0,3
7	(CR9)	0,4	(CR13)	0,15	(CR2)	0,1
8	(CR11)	0,05	(CR14)	0,2	(CR11)	0,2
9	(CR13)	0,3	(CR6)	0,4	(CR12)	0,2
10	(CR4)	0,35	(CR15)	0,4	(CR13)	0,35
11	(CR15)	0,25	(CR9)	0,05	(CR14)	0,25
12	(CR14)	0,15	(CR3)	0,3	(CR3)	0,15
13	(CR10)	0,2	(CR12)	0,6	(CR10)	0,2
14	(CR12)	0,4	(CR5)	0,8	(CR5)	0,4
15	(CR3)	0,3	(CR10)	0,5	(CR9)	0,5
16	(CR8)	0,6	(CR4)	0,4	(CR15)	0,5

The criteria weighting steps made by the SWARA method continue as follows; Firstly, by using Equation (26) and s_j, the coefficient (k_j) values have been reached. Then, with the help of Equation (27), the significance vector (q_j) values of each criterion were calculated. Finally, the weights (w_j) of the criteria were calculated with Equation (28). The calculated values of k_j, q_j and w_j for each criterion of the DM1 are shown in Table 6.13.

Table 6.13: The calculated values of k_j, q_j and w_j for the DM1

Order	Criteria	s_j	k_j	q_j	w_j
1	(CR2)	-	1	1	0,1917
2	(CR5)	0,4	1,4	0,714	0,1369
3	(CR1)	0,1	1,1	0,649	0,1245
4	(CR7)	0,15	1,15	0,565	0,1083
5	(CR6)	0,25	1,25	0,452	0,0866
6	(CR16)	0,1	1,1	0,411	0,0787
7	(CR9)	0,4	1,4	0,293	0,0562
8	(CR11)	0,05	1,05	0,279	0,0536
9	(CR13)	0,3	1,3	0,215	0,0412
10	(CR4)	0,35	1,35	0,159	0,0305
11	(CR15)	0,25	1,25	0,127	0,0244
12	(CR14)	0,15	1,15	0,111	0,0212
13	(CR10)	0,2	1,2	0,092	0,0177
14	(CR12)	0,4	1,4	0,066	0,0126
15	(CR3)	0,3	1,3	0,051	0,0097
16	(CR8)	0,6	1,6	0,032	0,0061

In Table 6.14, the criteria weights obtained from the decision makers as given.

Table 6.14: DM's Final Weights

Criteria	DM1	DM2	DM3
(CR1)	0,1245	0,1697	0,0547
(CR2)	0,1917	0,1870	0,0382
(CR3)	0,0097	0,0153	0,0137
(CR4)	0,0305	0,0025	0,0766
(CR5)	0,1369	0,0053	0,0081
(CR6)	0,0866	0,0293	0,1148
(CR7)	0,1083	0,0707	0,2067
(CR8)	0,0061	0,0566	0,0421
(CR9)	0,0562	0,0199	0,0054
(CR10)	0,0177	0,0035	0,0114
(CR11)	0,0536	0,1414	0,0319
(CR12)	0,0126	0,0096	0,0266
(CR13)	0,0412	0,0492	0,0197
(CR14)	0,0212	0,0410	0,0157
(CR15)	0,0244	0,0209	0,0036
(CR16)	0,0787	0,1781	0,3308

The weights obtained by taking the average of the weights of each DM are shown in Table 6.15. As a result of the evaluations of the decision makers, it was concluded that the most important criterion was "CR16 – Durable" the most important criterion with a value of 0,1959.

Table 6.15: Final weights of criteria

Criteria	w_j
(CR1)	0,1163
(CR2)	0,1390
(CR3)	0,0129
(CR4)	0,0365
(CR5)	0,0501
(CR6)	0,0769
(CR7)	0,1286
(CR8)	0,0349
(CR9)	0,0272
(CR10)	0,0109
(CR11)	0,0756
(CR12)	0,0163
(CR13)	0,0367
(CR14)	0,0260
(CR15)	0,0163
(CR16)	0,1959

Table 6.15 shows the final benchmark weights. The final criterion was reached by weighting the averages of the decision makers' evaluations. The average of expert assessments can lead researchers to the final criteria weights. Then, the evaluation of engineering metric of a fluorescent lamps is obtained by HOQ method.

6.3.3. Evaluation of Engineering Metrics with HOQ Method

The House of Quality is set up with customer requirements (CR) weights, Customer Requirements (CR) and the connections between CR and EM given by the DMs. At intersection points between CR and EM are demonstrated numbers showing the size of the two components determined by the DMs in consensus over a H-M-L (1-3-9) scale.

According to the relationship between customer requirements and weighting factors, a relative importance order is obtained. From the outcomes, it very well may be reasoned that the most essential natural EM for the florescent lambs is "Tube material" to satisfy the multi viewpoint partner prerequisites, with a significance level of 12,59%.

"Power Consumption" and "Material Type" are the most important second and third environmental parameters with 9.8% and 9.39% respectively. The overall ranking results for engineering measures are shown in Table 6.16.

Table 6.16: The overall ranking results of HOQ

	Importance	Material weight(EM1)	Material size(EM2)	Tube material(EM3)	Inverter control(EM4)	Low-power IC design(EM5)	Packaging (EM6)	Transportation (EM7)	Quality control(EM8)	Power consumption (EM9)	Material type (EM10)	Noise Control(EM11)	Product Lifetime (EM12)	Emissions in use(EM13)	Production functionality(EM14)	Production waste(EM15)	Usability(EM16)	End of life waste(EM17)	Time for disassembly(EM18)	Recyclability ratio(EM19)	**Total**
Low price(CR1)	0,116		L	M	M	M	M		M	H	H	H	H	M	M	L				L	6,977
Led lamp quality(Luminance)(CR2)	0,139			H	M	L				M	M			M	H		H				5,560
Material for head lamp(CR3)	0,013	H	H						M	M	H							H	H		0,658
Environmentally safe(CR4)	0,037					M	H	H	M	M	M		M	H		H		H	H	H	2,850
Chromaticity(CR5)	0,050			H	M				M	L	L			L	M		M				1,203
Viewing angle (CR6)	0,077			L	M				M		H				H		M				2,153
Low power consumption(CR7)	0,129			M	M	H			M	H	M			H		H	M				6,556
Response time(CR8)	0,035			H	H				M		M				M		M				1,047
Brightness uniformity(CR9)	0,027			M	M				M		M			L	M		M				0,517
Easy to clean(CR10)	0,011	M	H								L										0,141
Quiet(CR11)	0,076			H	H						M				H		H				2,948
Easy to recycle(CR12)	0,016			M			M		M		M		M					H	H	H	0,683
Visually attractive appearance(CR13)	0,037	L	H								M		H				M				0,917
Safe to use(CR14)	0,026								H		M			H		H					0,779
Free of hazardous substances(CR15)	0,016			M					M							L	M	H	H	H	0,604
Durable(CR16)	0,196			H	M	H			M	M	M		H	M	M		L	L			9,206
Total		0,185	0,661	5,450	3,196	3,517	0,726	0,329	2,369	3,407	4,066	1,047	3,298	3,150	3,897	1,852	3,239	0,934	0,738	0,738	42,800
Relative Weight (Priority)		0,43%	1,54%	12,73%	7,47%	8,22%	1,70%	0,77%	5,54%	7,96%	9,50%	2,45%	7,71%	7,36%	9,10%	4,33%	7,57%	2,18%	1,72%	1,72%	1,000

6.4. Results and Discussion

In this master thesis, environmental risk assessment of e-waste in reverse logistics systems using MCDM methods is applied in two phases for a case study in the field of reverse logistics of the fluorescent lamp in two phases.

In the first phase of the study, risk factors determined as a result of literature search were weighted by ANP method. According to ANP method results, percentage of the mercury which access to water supply (water pollution) (D11), CO2 transportation emissions factor per unit of returned product in G/Km (T11), mercury released from CFLs to the soil and land usage (soil pollution) (D13), the amount of mercury particles in the air (Air Pollution) (D12), risk of accident hazardous chemicals and wastes (T13) are the most appropriate factors with values 0,262136, 0,240784, 0,165071, 0,133139, 0,082226, 0,064743, 0,035517, 0,008432, 0,007952.

After that, the most appropriate environmental strategy in proposed reverse logistics system is obtained with COPRAS method and this is "Re-engineering strategy for product (A1)" with the final performance value of 100 while other main dimensions process have positioned with 93.23, 85.98, 77.36 and 70.47 respectively.

In order to compare the results obtained by COPRAS method, ELECTRE method has been used. The results of these two methods with same data seen exactly same and obtained strategy is "Re-engineering strategy for product (A1)"

In the second phase, alternative solutions were examined selected strategy for environmental risk of CFLs reverse logistics system which are determined with literature review and expert opinions. The weights of each customer requirements are calculated with SWARA method. At the end of the SWARA method, the most important factor is found to be the "Durable (CR16)".

Then, engineering metrics are determined based on literature review of CLF's. These metrics are evaluated with the HOQ methods. According to the HOQ method, the most appropriate EM is “Tube material (EM3)”. The second, third, fourth, fifth and sixth metrics are ranked as "Power Consumption (EM9)", “Material type (EM10)”, “Production functionality (EM14)”, “Low-power IC design (EM5)” and “Product Lifetime (EM12)”, respectively.

The results of the risk assessment of CFLs' reverse logistics process show that the problem with the CFL's is the mercury used in tube material. Mercury content become a risk to all reverse logistics processes. As a result of the risk assessment, it was decided that the product should be redesigned. Finally, it was decided to change the mercury containing area first which is the tube material.

A new material can be selected to produce mercury-free and less electricity consuming light for compact fluorescent lamps.

7. CONCLUSION

The recovery of used electronic materials is an essential task. Depending on the importance of the subject, numerous studies have been performed in the recent years. Reverse logistics managing the backward flows in a recovery system has turned out to be critical.

The purpose of this study is to estimate the strategic risk factors of reverse logistics and to evaluate alternative reverse logistics precaution strategies in terms of environmental risk assessment.

At first the basic concepts of reverse logistics are reviewed in terms of environmental risk assessment. The model is built on the criteria and the alternatives for reverse logistics strategy evaluation. As the MCDM approach, the ANP, COPRAS and ELECTRE methods are applied. Five alternative strategies for evaluation of reverse logistics of fluorescent lamp are determined, and their priority order alternatives for environmental risk assessment of reverse logistics is found. The first order in the alternatives is re-engineering of product strategy (A1).

Then, engineering metrics are determined based on literature review of CLF’s. Based on weighted customer requirements with SWARA method, these metrics are evaluated with HOQ methods. According to the HOQ method, the most appropriate strategy to work on in order to improve the RL procedure of fluorescent lamps in an environmentally friendly way is “Tube material (EM3)”.

In summary, this study proposed an integrated methodology to deal with the environmental risks occurring in the RL of florescent lamps, and the main contributions of this thesis are:

…to perform an environmental risk assessment for reverse logistics.
…to evaluate the environmental risks with COPRAS/ELECTRE methods.
…to propose integrated HOQ analysis for re-engineering of product strategy selection.

Re-engineering should be the priority for the above-mentioned system. For reverse logistics systems to be successful for the environmental risk assessment, first the existing production system must be analyzed, and the problematic parts concerning the environmental risks should be defined. Then, with a systematical planning re-engineering process of product must be applied into the current system.

Finally, a versatile SWARA/HOQ technique has led us to identify the most appropriate eco-design improvement strategies for the fluorescent lamp. Due to the relationship levels given by decision-makers, it was determined that the most important element to be improved is the tube material. Choosing the right materials has the greatest potential to achieve better environmental performance.

Mercury-containing lamps are the single largest category of products that contain mercury and a significant percentage of waste mercury-containing lamps end up in landfill each year. This high rate of mercury damages nature and human health.

Having eco-friendly lamps and light fixtures is key to produce the green lighting. Energy efficiency is not enough also product content should also be eco-friendly. So, all lamps should produce with harmless, natural, recyclable, or from reused materials.

The subject of reverse logistics strategy selection can be advanced in future studies by increasing the number of criteria and the decision makers or using different decision-making methods. Another perspective can be to consider uncertainty using fuzzy approach (Zadeh, 1965).

REFERENCES

Achillas, C., Aidonis, D., Vlachokostas, C., Moussiopoulos, N., Banias, G., & Triantafillou, D. (2012). "A Multi-Objective Decision-Making Model To Select Waste Electrical And Electronic Equipment Transportation Media". Resources, Conservation and Recycling. 66, 76-84.

Agrawal, S., Singh, R. K., & Murtaza, Q. (2015). A literature review and perspectives in reverse logistics. Resources, Conservation and Recycling, 97, pp. 76–92

Agrawal, S., Singh, R. K., & Murtaza, Q. (2016). Outsourcing decisions in reverse logistics: Sustainable balanced scorecard and graph theoretic approach. Resources, Conservation and Recycling, 108, pp. 41–53.

Akao, Y. (1990). QFD: integrating customer requirements into product design. Cambridge, MA.

Alfonso-Lizarazo E.H, Montoya-Torresa J.R, Gutiérrez-Francoa E. (2013). Modeling reverse logistics process in the agro-industrial sector: The case of the palm oil supply chain. Applied Mathematical Modelling, 37, pp. 9652–9664

Alshamsi A and Diabat A. (2015). A reverse logistics network design. Journal of Manufacturing Systems, 37, pp. 589–598.

Alvarez-de-los-Mozos, E., & Renteria, A. (2017). Collaborative robots in e-waste management. Procedia Manufacturing, 11, 55-62.

Aras, N., Korugan, A., Büyüközkan, G., Şerifoğlu, F. S., Erol, İ., & Velioğlu, M. N. (2015). Locating recycling facilities for IT-based electronic waste in Turkey. Journal of Cleaner Production, 105, 324-336.

Ayvaz, B., Bolat, B., & Aydın, N. (2015). Stochastic reverse logistics network design for waste of electrical and electronic equipment. Resources, conservation and recycling, 104, 391-404.

Babu, B. R., Parande, A. K., & Basha, C. A. (2007). "Electrical And Electronic Waste:A Global Environmental Problem". Waste Management & Research. 25(4), 307-318.

Baia C. and Sarkisb J. (2013). Flexibility in reverse logistics: a framework and evaluation approach. Journal of Cleaner Production, 47, pp. 306–318.

Bal, A., & Satoglu, S. I. (2018). A goal programming model for sustainable reverse logistics operations planning and an application. Journal of Cleaner Production, 201, 1081-1091.

Bansia, M., Varkey, J. K., & Agrawal, S. (2014). Development of a Reverse Logistics Performance Measurement System for a Battery Manufacturer. Procedia Materials Science, 6, pp. 1419-1427.

Batarfi, R., Jaber, M. Y., & Aljazzar, S. M. (2017). A profit maximization for a reverse logistics dual-channel supply chain with a return policy. Computers & Industrial Engineering, 106, pp. 58–82.

Bazan, E., Jaber, M. Y., & Zanoni, S. (2016). A review of mathematical inventory models for reverse logistics and the future of its modeling: An environmental perspective. Applied Mathematical Modelling, 40, pp. 4151–4178.

Benayoun, R., Roy, B., & Sussman, B. (1966). ELECTRE: Une méthode pour guider le choix en présence de points de vue multiples, Note de travail 49. Paris: SEMA-METRA International.

Bernon M, Cullen J (2007). An integrated approach to managing reverse logistics. Int J Logist; 10(1):41–56.

Bogataja M. and Grubbströmb R. W. (2013). Transportation delays in reverse logistics. International Journal of Production Economics,143, pp. 395–402

Bouzon, M., Govindan, K., & Rodriguez, C. M. T. (2015). Reducing the extraction of minerals: Reverse logistics in the machinery manufacturing industry sector in Brazil using ISM approach. Resources Policy, 46, 27-36.

Bouzon, M., Govindan, K., Rodriguez, C. M. T., & Campos, L. M. (2016). Identification and analysis of reverse logistics barriers using fuzzy Delphi method and AHP. Resources, Conservation and Recycling, 108, pp. 182–197.

Börner, L., & Hegger, D. L. (2018). Toward design principles for sound e-waste governance: A research approach illustrated with the case of the Netherlands. Resources, Conservation and Recycling, 134, 271-281.

Cao, J., Chen, Y., Shi, B., Lu, B., Zhang, X., Ye, X., ... & Zhou, G. (2016). WEEE recycling in Zhejiang Province, China: generation, treatment, and public awareness. Journal of Cleaner Production, 127, 311-324.

Carter CR, Ellram LM. (1998). Reverse logistics: a review of the literature and framework for future investigation. J Bus Logist ;19(1):85–102.

Casper, R., & Sundin, E. (2018). Reverse Logistic Transportation and Packaging Concepts in Automotive Remanufacturing. Procedia Manufacturing, 25, 154-160.

Chatterjee, N.C. and Bose, G. K., 2012, A COPRAS-F base multi-criteria group decision making approach for site selection of wind farm, Decision Science Letters, pp. 1-10.

Chen, D., Ignatius, J., Sun, D., Zhan, S., Zhou, C., Marra, M., & Demirbag, M. (2018). Reverse logistics pricing strategy for a green supply chain: A view of customers' environmental awareness. International Journal of Production Economics.

Chinda T. (2017). Examination of Factors Influencing the Successful Implementation of Reverse Logistics in the Construction Industry: Pilot Study. Procedia Engineering, 182, pp. 99–105.

Cole, C., Gnanapragasam, A., Singh, J., & Cooper, T. (2018). Enhancing reuse and resource recovery of electrical and electronic equipment with reverse logistics to meet carbon reduction targets. Procedia CIRP, 69, 980-985.

da Silveira Guimarães, J. L., & Salomon, V. A. P. (2015). ANP applied to the evaluation of performance indicators of reverse logistics in footwear industry. Procedia Computer Science, 55, 139-148.

De Brito, M. P., & Dekker, R. (2002). Reverse logistics-a framework (No. EI 2002-38). Erasmus School of Economics (ESE).

de Oliveira Neto, G. C., Correia, A. D. J. C., & Schroeder, A. M. (2017). Economic and environmental assessment of recycling and reuse of electronic waste: Multiple case studies in Brazil and Switzerland. Resources, Conservation and Recycling, 127, 42-55.

de Souza, R. G., Clímaco, J. C. N., Sant'Anna, A. P., Rocha, T. B., do Valle, R. D. A. B., & Quelhas, O. L. G. (2016). Sustainability assessment and prioritisation of e-waste management options in Brazil. Waste management, 57, 46-56.

Dehnavi, A., Aghdam, I. N., Pradhan, B., & Varzandeh, M. H. M. (2015). A new hybrid model using step-wise weight assessment ratio analysis (SWARA) technique and adaptive neuro-fuzzy inference system (ANFIS) for regional landslide hazard assessment in Iran. Catena, 135, 122-148.

Dos Santos, R. F., & Marins, F. A. S. (2015). Integrated model for Reverse Logistics Management of Electronic Products and Components. Procedia Computer Science, 55, pp. 575-585.

Dowlatshahi S (2000). Developing a theory of reverse logistics. Interfaces ;30(3):143–55.

Dursun, M., & Karsak, E. E. (2013). A QFD-based fuzzy MCDM approach for supplier selection. Applied Mathematical Modelling, 37(8), 5864-5875.

Elia, V., Gnoni, M. G., & Tornese, F. (2018). Improving logistic efficiency of WEEE collection through dynamic scheduling using simulation modeling. Waste Management, 72, 78-86.

Erol, I., Alehan, F., Pourbagher, M. A., Canan, O., & Yildirim, S. V. (2006). Neuroimaging findings in infantile GM1 gangliosidosis. European Journal of Paediatric Neurology, 10(5), 245-248.

Européenne, U. (2003). Directive 2002/96/EC on Waste Electrical and Electronic Equipment (WEEE). JO EU, 37, 24-38.

Fernando, A. S., & Jorge Jr, M. (2015). Cost assessment and benefits of using RFID in reverse logistics of waste electrical & electronic equipment (WEEE). Procedia Computer Science, 55, 688-697.

Filho O. S. and Salviano I.R. (2014). Choosing an optimal return rate and a reverse logistics policy from the solution of a constrained LQG problem. IFAC Proceedings Volumes, 47, pp. 8927-8932.

Fleischmann M (2001). Reverse logistics network structures and design. In: Guide VDR Jr, Van Wassenhove LN, editors. Business aspects of closed-loop supply chains. Pittsburgh, PA: Carnegie Bosch Institute; p. 117–48.

Fleischmann M, Krikke HR, Dekker R, Flapper SDP (2000). A characterization of logistics networks for product recovery. Omega ;28(6):653–66.

Flygansvær, B., Dahlstrom, R., & Nygaard, A. (2018). Exploring the pursuit of sustainability in reverse supply chains for electronics. Journal of Cleaner Production, 189, 472-484.

Foelster, A. S., Andrew, S., Kroeger, L., Bohr, P., Dettmer, T., Boehme, S., & Herrmann, C. (2016). Electronics recycling as an energy efficiency measure–a Life Cycle Assessment (LCA) study on refrigerator recycling in Brazil. Journal of cleaner production, 129, 30-42.

Gardas, B. B., Raut, R. D., & Narkhede, B. (2018). Reducing the exploration and production of oil: Reverse logistics in the automobile service sector. Sustainable Production and Consumption, 16, 141-153.

Ghisolfi, V., Chaves, G. D. L. D., Siman, R. R., & Xavier, L. H. (2017). System dynamics applied to closed loop supply chains of desktops and laptops in Brazil: A perspective for social inclusion of waste pickers. Waste Management, 60, 14-31.

Giannotti, S., Trombi, L., Bottai, V., Ghilardi, M., D'Alessandro, D., Danti, S., ... & Petrini, M. (2013). Use of autologous human mesenchymal stromal cell/fibrin clot constructs in upper limb non-unions: long-term assessment.

Giri, B. C., Chakraborty, A., & Maiti, T. (2017). Pricing and return product collection decisions in a closed-loop supply chain with dual-channel in both forward and reverse logistics. Journal of Manufacturing Systems, 42, pp. 104–123.

Govindan K, Soleimani H, Kannanc D (2013). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. European Journal of Operational Research, 240, pp. 603–626.

Govindan K. and Soleimani H. (2017). A review of reverse logistics and closed-loop supply chains: Journal of Cleaner Production, 142, pp. 371–384.

Govindan, K., Kadziński, M., Ehling, R., & Miebs, G. (2018). Selection of a sustainable third-party reverse logistics provider based on the robustness analysis of an outranking graph kernel conducted with ELECTRE I and SMAA.

Govindan, K., Paam, P., & Abtahi, A. R. (2016). A fuzzy multi-objective optimization model for sustainable reverse logistics network design. Ecological Indicators, 67, pp. 753–768.

Guarnieri, P., e Silva, L. C., & Levino, N. A. (2016). Analysis of electronic waste reverse logistics decisions using Strategic Options Development Analysis methodology: A Brazilian case. Journal of Cleaner Production, 133, pp. 1105–1117

Guide VDR, Wassenhove LN (2001). Managing product returns for remanufacturing. Prod Oper Manag ;10(2):142–55.

Guimarães J. L. S. and Salomon V. A. P. (2015). ANP Applied to the Evaluation of Performance Indicators of Reverse Logistics in Footwear Industry. Procedia Computer Science, 55, pp. 139-148.

Guo, S., Shen, B., Choi, T. M., & Jung, S. (2017). A review on supply chain contracts in reverse logistics: Supply chain structures and channel leaderships. Journal of Cleaner Production, 144, pp. 387–402

Han, H., & Trimi, S. (2018). A fuzzy TOPSIS method for performance evaluation of reverse logistics in social commerce platforms. Expert Systems with Applications, 103, 133-145.

Hao, H., Zhang, Q., Wang, Z., & Zhang, J. (2018). Forecasting the number of end-of-life vehicles using a hybrid model based on grey model and artificial neural network. Journal of Cleaner Production, 202, 684-696.

Hasan Aghdaie, M., Hashemkhani Zolfani, S., & Zavadskas, E. K. (2013). Decision making in machine tool selection: An integrated approach with SWARA and COPRAS-G methods. Engineering Economics, 24(1), 5-17.

Hashemkhani Zolfani, S., & Bahrami, M. (2014). Investment prioritizing in high tech industries based on SWARA-COPRAS approach. Technological and Economic Development of Economy, 20(3), 534-553.

Hatefi S.M. and Jolai F. (2014). Robust and reliable forward–reverse logistics network design under demand uncertainty and facility disruptions. Applied Mathematical Modelling, 38, pp. 2630–2647.

Hauser, J. R., & Clausing, D. (1988). The house of quality.

Hazen, B. T., Overstreet, R. E., Hall, D. J., Huscroft, J. R., & Hanna, J. B. (2015). Antecedents to and outcomes of reverse logistics metrics. Industrial Marketing Management, 46, pp. 160–170

He, W., Li, G., Ma, X., Wang, H., Huang, J., Xu, M., & Huang, C. (2006). “WEEE Recovery Strategies and The WEEE Treatment Status in China”. Journal of Hazardous Materials. 136(3), 502-512.

Hester, R. E., & Harrison, R. M. (2009). Electronic Waste Management: Deisgn, Analysis and Applicaiton (Vol. 27). UK, Cambridge: Royal Society of Chemistry.

Hwang, C.L., Yoon, K., 1981, “Multiple Attribute Decision Making—Methods and Applications”, Springer-Verlag, Heidelberg.

Islam, M. T., & Huda, N. (2018). Reverse logistics and closed-loop supply chain of Waste Electrical and Electronic Equipment (WEEE)/E-waste: A comprehensive literature review. Resources, Conservation and Recycling, 137, 48-75.

Jayant, A., Gupta, P., Garg, S. K., & Khan, M. (2014). TOPSIS-AHP Based Approach for Selection of Reverse Logistics Service Provider: A Case Study of Mobile Phone Industry. Procedia Engineering, 97, pp. 2147-2156

Jayaraman V, Luo Y (2007). Creating competitive advantages through new value creation: a reverse logistics perspective. Acad Manag Perspect ;21(2):56–73.

John, S. T., Sridharan, R., Kumar, P. R., & Krishnamoorthy, M. (2018). Multi-period reverse logistics network design for used refrigerators. Applied Mathematical Modelling, 54, 311-331.

Jonrinaldia and Zhanga, D.Z. (2013). An integrated production and inventory model for a whole manufacturing supply chain involving reverse logistics with finite horizon period. Omega, 41, pp. 598–620

Kannan G, Palaniappan M, Zhu Q, Kannan D (2012). Analysis of third party reverse logistics provider using interpretive structural modeling. Int Prod Res;140(1):204–11.

Kannan, G., 2009. Fuzzy Approach for the selection of third party reverse logistics provider. Asia Pac. J. Market. Logist. 21 (3), 397-416.

Karabašević, D., Paunkovic, J., & Stanujkic, D. (2016). Ranking of companies according to the indicators of corporate social responsibility based on SWARA and ARAS methods. Serbian Journal of Management, 11(1), 43-53.

Karabasevic, D., Stanujkic, D., Urosevic, S., & Maksimovic, M. (2015). Selection of candidates in the mining industry based on the application of the SWARA and the MULTIMOORA methods. Acta Montanistica Slovaca, 20(2).

Keršulienė, V., & Turskis, Z. (2011). Integrated fuzzy multiple criteria decision-making model for architect selection. Technological and Economic Development of Economy, 17(4), 645-666.

Keršuliene, V., Zavadskas, E. K., & Turskis, Z. (2010). Selection of rational dispute resolution method by applying new step-wise weight assessment ratio analysis (SWARA). Journal of business economics and management, 11(2), 243-258.

Keskin, M. H. (2008). Lojistik Tedarik Zinciri Yönetimi. Ankara, pp.39.

Keyvanshokooh E. Seyed-Hosseinia S.M, Tavakkoli-Moghaddamc R. (2013). A dynamic pricing approach for returned products in integrated forward/reverse logistics network design. Applied Mathematical Modelling, 37, pp. 10182–10202.

Khademi-Zare, H., Zarei, M., Sadeghieh, A., & Owlia, M. S. (2010). Ranking the strategic actions of Iran mobile cellular telecommunication using two models of fuzzy QFD. Telecommunications Policy, 34(11), 747-759.

Khor, K. S., & Udin, Z. M. (2013). Reverse logistics in Malaysia: Investigating the effect of green product design and resource commitment. Resources, Conservation and Recycling, 81, 71-80.

Kilic, H. S., Cebeci, U., & Ayhan, M. B. (2015). Reverse logistics system design for the waste of electrical and electronic equipment (WEEE) in Turkey. Resources, Conservation and Recycling, 95, 120-132.

Kim J.K and Lee D.H (2013). A restricted dynamic model for refuse collection network design in reverse logistics. Computers & Industrial Engineering, 66, pp. 1131–1137.

Kumar, V. N. S. A., Kumar, V., Brady, M., Garza-Reyes, J. A., & Simpson, M. (2017). Resolving forward-reverse logistics multi-period model using evolutionary algorithms. International Journal of Production Economics, 183, pp. 458–469

Li, Y. L., Ying, C. S., Chin, K. S., Yang, H. T., & Xu, J. (2018). Third-party Reverse Logistics Provider Selection Approach Based on Hybrid-Information MCDM and Cumulative Prospect Theory. Journal of Cleaner Production.

Lim, S. R., Kang, D., Ogunseitan, O. A., & Schoenung, J. M. (2012). Potential environmental impacts from the metals in incandescent, compact fluorescent lamp (CFL), and light-emitting diode (LED) bulbs. Environmental science & technology, 47(2), 1040-1047.

Liu, H., Lei, M., Deng, H., Leong, G. K., & Huang, T. (2016). A dual channel, quality-based price competition model for the WEEE recycling market with government subsidy. Omega, 59, 290-302.

Mahmoudzadeh, M., Dehaene-Lambertz, G., Fournier, M., Kongolo, G., Goudjil, S., Dubois, J., ... & Wallois, F. (2013). Syllabic discrimination in premature human infants prior to complete formation of cortical layers. Proceedings of the National Academy of Sciences, 110(12), 4846-4851.

Malik, S., Kumari, A., & Agrawal, S. (2015). Selection of locations of collection centers for reverse logistics using GTMA. Materials Today: Proceedings, 2(4-5), 2538-2547.

Mangla, S. K., Govindan, K., & Luthra, S. (2016). Critical success factors for reverse logistics in Indian industries: a structural model. Journal of cleaner production, 129, 608-621.

Masui, K., Sakao, T., Kobayashi, M., & Inaba, A. (2003). Applying quality function deployment to environmentally conscious design. International Journal of Quality & Reliability Management, 20(1), 90-106.

McKinnon, A., & Piecyk, M. (2010). Measuring and managing CO_2 emissions. Edinburgh: European Chemical Industry Council.

Menikpura, S. N. M., Santo, A., & Hotta, Y. (2014). Assessing the climate co-benefits from waste electrical and electronic equipment (WEEE) recycling in Japan. Journal of Cleaner Production, 74, 183-190.

Moghaddam K. S. (2015). Fuzzy multi-objective model for supplier selection and order allocation in reverse logistics systems under supply and demand uncertainty. Expert Systems with Applications, 42, pp. 6237–6254.

Moura, J. M. B. M., Pinheiro, I. G., Lischeski, D., & Valle, J. A. B. (2017). Relation of Brazilian institutional users and technical assistances with electronics and their waste: What has changed?. Resources, Conservation and Recycling, 127, 68-75.

Murphy PR, Poist RP (1989). Managing of logistics retro movements: an empirical analysis of literature suggestions. Transp Res Forum ;29(1):177–84.

Murphy, P. R., & Poist, R. F. (2000). Green logistics strategies: an analysis of usage patterns. Transportation journal, 5-16.

Nance, P., Patterson, J., Willis, A., Foronda, N., & Dourson, M. (2012). Human health risks from mercury exposure from broken compact fluorescent lamps (CFLs). Regulatory Toxicology and Pharmacology, 62(3), 542-552.

Niknejad A. and Petrovic D. (2014). Optimisation of integrated reverse logistics networks with different product recovery routes. European Journal of Operational Research, 238, pp. 143–154.

Nikolaou, I. E., Evangelinos, K. I., & Allan, S (2013). A reverse logistics social responsibility evaluation framework based on the triple bottom line approach. Journal of Cleaner Production, 56, pp. 173–184.

Payzan-LeNestour, E., & Bossaerts, P. (2011). Risk, unexpected uncertainty, and estimation uncertainty: Bayesian learning in unstable settings. PLoS computational biology, 7(1), e1001048.

Pomerol, C., Barba Romero, S., 2000, "Multicriterion Decision in Management: Principles and Practice", 1st edition, Kluwer Academic Publishers, Norwell.

Prakash C. and Barua M.K. (2015). Integration of AHP-TOPSIS method for prioritizing the solutions of reverse logistics adoption to overcome its barriers under fuzzy environment. Journal of Manufacturing Systems, 37, pp. 599–615

Prakash, C., & Barua, M. K. (2016). A combined MCDM approach for evaluation and selection of third-party reverse logistics partner for Indian electronics industry. Sustainable Production and Consumption, 7, 66-78.

Puckett, J., Byster, L., Westervelt, S., Gutierrez, R., Davis, S., Hussain, A., & Dutta, M. (2002). “Exporting Harm: The High-Tech Trashing of Asia”.

Rahimi, M., & Ghezavati, V. (2018). Sustainable multi-period reverse logistics network design and planning under uncertainty utilizing conditional value at risk (CVaR) for recycling construction and demolition waste. Journal of Cleaner Production, 172, 1567-1581.

Ramos, T. R. P., Gomes, M. I., & Barbosa-Póvoa, A. P. (2014). Planning a sustainable reverse logistics system: Balancing costs with environmental and social concerns. Omega 48, pp. 60–74.

Rezaei J. (2015). A Systematic Review of Multicriteria Decision-making Applications in Reverse Logistics. Transportation Research Procedia, 10, pp. 766-776.

Richey, R. G., Daugherty, P. J., Genchev, S. E., & Autry, C. W. (2004). Reverse logistics: the impact of timing and resources. Journal of Business Logistics, 25(2), 229-250.

Robinson, B. H. (2009). E-waste: an assessment of global production and environmental impacts. Science of the total environment, 408(2), 183-191.

Rodi, P.M., Bocco Gianello, M.D., Gennaro, A.M., 2014. Insights about CHAPS

Rogers DS, Tibben-Lembke RS (2001). An examination of reverse logistics practices. Bus Logist ;22(2):129–48.

Rogers DS, Tibben-Lembke(1999). R. Going backwards: reverse logistics trends and practices. Reno, NV: Reverse Logistics Executive Council

Roghaniana E. and Pazhoheshfarb P. (2014). An optimization model for reverse logistics network under stochastic environment by using genetic algorithm. Journal of Manufacturing Systems, 33, pp. 348–356.

Saaty, T. L. (1980). The analytic hierarchy process: planning, priorisetting, resource allocation.

Sangwan K. S. (2017). Key Activities, Decision Variables and Performance Indicators of Reverse Logistics. Procedia CIRP, 61, pp. 257–262.

Sarkis, J. (1998). Evaluating environmentally conscious business practices. European journal of operational research, 107(1), 159-174.

Senthil, S., Murugananthan, K., & Ramesh, A. (2018). Analysis and prioritisation of risks in a reverse logistics network using hybrid multi-criteria decision making methods. Journal of Cleaner Production, 179, 716-730.

Senthil, S., Srirangacharyulu, B., & Ramesh, A. (2012). A decision making methodology for the selection of reverse logistics operating channels. Procedia Engineering, 38, 418-428.

Shaik, M. N., & Abdul-Kader, W. (2014). A robust hybrid multi-criteria decision making methodology for contractor evaluation and selection in third-party reverse logistics, Expert Systems with Applications, 41, pp. 50–58.

Shaik, M. N., & Abdul-Kader, W. (2014). Comprehensive performance measurement and causal-effect decision making model for reverse logistics enterprise. Computers & Industrial Engineering, 68, 87-103.

Shaik, M. N., & Abdul-Kader, W. (2018). A hybrid multiple criteria decision making approach for measuring comprehensive performance of reverse logistics enterprises. Computers & Industrial Engineering, 123, 9-25.

Shukla, S., Mishra, P. K., Jain, R., & Yadav, H. C. (2016). An integrated decision-making approach for ERP system selection using SWARA and PROMETHEE method. International Journal of Intelligent Enterprise, 3(2), 120-147.

Sifaleras A. and Konstantaras I. (2017). Variable neighborhood descent heuristic for solving reverse logistics multi-item dynamic lot-sizing problems. Computers & Operations Research, 78, pp. 385–392.

Singh. S.R. and Saxena N. (2013). A Closed Loop Supply Chain System with Flexible Manufacturing and Reverse Logistics Operation under Shortages for Deteriorating Items. Procedia Technology, 10, pp. 330-339

Sinha, R., Laurenti, R., Singh, J., Malmström, M. E., & Frostell, B. (2016). Identifying ways of closing the metal flow loop in the global mobile phone product system: A system dynamics modeling approach. Resources, Conservation and Recycling, 113, 65-76.

Sirisawat, P., & Kiatcharoenpol, T. (2018). Fuzzy AHP-TOPSIS approaches to prioritizing solutions for reverse logistics barriers. Computers & Industrial Engineering, 117, 303-318.

Souza C. D. R, Agosto M. A. (2013). Value chain analysis applied to the scrap tire reverse logistics chain: An applied study of co-processing in the cement industry. Resources, Conservation and Recycling, 78, pp. 15–25.

Srivastava S (2008). Network design for reverse logistics. Omega;36(4):535–48.

Stock JR, Mulki JP (2009). Product returns processing: an examination of practices of manufacturers wholesalers/distributors and retailers. J Bus Logist;30(1):33–62.

Stock JR. (1998). Development and implementation of reverse logistics program. Oak Brook, IL: Council of Logistics Management.

Sudarto, S., Takahashi, K., & Morikawa, K. (2017). Efficient flexible long-term capacity planning for optimal sustainability dimensions performance of reverse logistics social responsibility: A system dynamics approach. International Journal of Production Economics, 184, pp. 179–192

Sudarto, S., Takahashi, K., Morikawa, K., & Nagasawa, K. (2016). The impact of capacity planning on product lifecycle for performance on sustainability dimensions in Reverse Logistics Social Responsibility. Journal of Cleaner Production, 133, pp. 28–42.

Sullivan, L. P. (1986). THE 7 STAGES IN COMPANY-WIDE QUALITY-CONTROL. Quality Progress, 19(5), 77-83.

Suyabatmaz, A. Ç., Altekin, F. T., & Şahin, G. (2014). Hybrid simulation-analytical modeling approaches for the reverse logistics network design of a third-party logistics provider. Computers & Industrial Engineering. 70, pp. 74–89.

T.C. Ulaştırma, Denizcilik ve Haberleşme Bakanlığı, (2014), "Ulusal Akıllı Ulaşım Sistemleri Strateji Belgesi ve Eki Eylem Planı".

Taghipour, H., Amjad, Z., Jafarabadi, M. A., Gholampour, A., & Nowrouz, P. (2014). Determining heavy metals in spent compact fluorescent lamps (CFLs) and their waste. management challenges: some strategies for improving current conditions. Waste management, 34(7), 1251-1256.

Tavana, M., Zareinejad, M., Di Caprio, D., & Kaviani, M. A. (2016). An integrated intuitionistic fuzzy AHP and SWOT method for outsourcing reverse logistics. Applied Soft Computing, 40, 544-557.

Thierry, M., Salomon, M., Van Nunen, J., & Van Wassenhove, L. (1995). Strategic issues in product recovery management. California management review, 37(2), 114-136.

Tong, X., Wang, T., Chen, Y., & Wang, Y. (2018). Towards an inclusive circular economy: Quantifying the spatial flows of e-waste through the informal sector in China. Resources, Conservation and Recycling, 135, 163-171.

Tosarkani, B. M., & Amin, S. H. (2018). A multi-objective model to configure an electronic reverse logistics network and third party selection. Journal of Cleaner Production, 198, 662-682.

Triantaphyllou, E. (2000). Multi-criteria decision-making methods. In Multi-criteria decision-making methods: A comparative study (pp. 5-21). Springer, Boston, MA.

Uygun, Ö., & Dede, A. (2016). Performance evaluation of green supply chain management using integrated fuzzy multi-criteria decision making techniques. Computers & Industrial Engineering, 102, 502-511.

Vafaeipour, M., Zolfani, S. H., Varzandeh, M. H. M., Derakhti, A., & Eshkalag, M. K. (2014). Assessment of regions priority for implementation of solar projects in Iran: New application of a hybrid multi-criteria decision making approach. Energy Conversion and Management, 86, 653-663.

Vahabzadeh, A. H., Asiaei, A., & Zailani, S. (2015). Green decision-making model in reverse logistics using FUZZY-VIKOR method. Resources, Conservation and Recycling, 103, 125-138.

Vinodh, S., & Rathod, G. (2010). Integration of ECQFD and LCA for sustainable product design. Journal of Cleaner Production, 18(8), 833-842.

Wang, H., Jiang, Z., Wang, Y., Liu, Y., Li, F., Yan, W., & Zhang, H. (2018). A Demands-Matching Multi-Criteria Decision-Making Method for Reverse Logistics. Procedia CIRP, 72, 1398-1403.

Waters, M. H. L., & Laker, I. B. (1980). Research on fuel conservation for cars (No. TRRL LR921 Monograph).

Wilson, G. T., Smalley, G., Suckling, J. R., Lilley, D., Lee, J., & Mawle, R. (2017). The hibernating mobile phone: Dead storage as a barrier to efficient electronic waste recovery. Waste Management, 60, 521-533.

Wimmer, W., Züst, R., & Lee, K. M. (2004). Ecodesign implementation: a systematic guidance on integrating environmental considerations into product development (Vol. 6). Springer Science & Business Media.

Yardım, M. S. and Akyıldız, G., 2005, “Akıllı Ulaştırma Sistemleri ve Türkiye’deki Uygulamalar”, Ulaştırma Kongresi, Istanbul, TMMOB Inşaat Mühendisleri Odası.

Zadeh, L. A., 1965, " Fuzzy sets" Information and control, 8(3), 338-353.

Zarbakhshnia, N., Soleimani, H., Goh, M., & Razavi, S. S. (2018). A novel multi-objective model for green forward and reverse logistics network design. Journal of Cleaner Production.

Zavadskas, E. K., Bausys, R., Juodagalviene, B., & Garnyte-Sapranaviciene, I. (2017). Model for residential house element and material selection by neutrosophic MULTIMOORA method. Engineering Applications of Artificial Intelligence, 64, 315-324.

Zerhouni, H., Gayon, J. P., & Frein, Y. (2013). Influence of dependency between demands and returns in a reverse logistics system. International Journal of Production Economic, 143, pp. 62–71

Zhikang L. (2017). Research on Development Strategy of Automobile Reverse Logistics Based on SWOT Analyss. Procedia Engineering, 174, pp. 324–330.

Zolfani, S. H., & Banihashemi, S. S. A. (2014, May). Personnel selection based on a novel model of game theory and MCDM approaches. In Proc. of 8th International Scientific Conference" Business and Management (pp. 15-16).

Zolfani, S. H., Pourhossein, M., Yazdani, M., & Zavadskas, E. K. (2018). Evaluating construction projects of hotels based on environmental sustainability with MCDM framework. Alexandria engineering journal, 57(1), 357-365.

APPENDICES

Appendix A.

Table A.1.1: ANP Pairwise Comparisons Matrix (Main Criteria)

	Transport	Storage	Disposal
Transport	1,00	5,00000	0,33000
Storage	0,20	1,00	0,20000
Disposal	3,03	5,00	1,00

Table A.1.2: ANP Pairwise Comparisons Matrix (Transport sub-criteria)

	T11	T12	T13
T11	1,00	3,00	5,00
T12	0,33	1,00	5,00
T13	0,20	0,20	1,00

Table A.1.3: ANP Pairwise Comparisons Matrix (Storage sub-criteria)

	S11	S12	S13
S11	1,00	5,00	3,00
S12	0,20	1,00	0,33
S13	0,33	3,00	1,00

Table A.1.4: ANP Pairwise Comparisons Matrix (Disposal sub-criteria)

	D11	D12	D13
D11	1,00	3,00	3,00
D12	0,33	1,00	0,33
D13	0,33	3,00	1,00

Table A.2.1: COPRAS Evaluation Matrix

	CO_2 transportation emissions factor per unit of returned product in G/Km (T11)	**Miles per gallon of fuel (T12)**	**Risk of accident hazardous chemicals and wastes (T13)**	**Storage and warehouse energy consumption (S11)**	**Risks of unexpected situations (fire, natural disasters etc.) (S12)**
A1	3	3	3	5	3
A2	7	7	5	5	5
A3	3	3	9	3	7
A4	7	5	3	5	5
A5	9	7	5	3	3
WEIGHTS	0,240784	0,064743	0,082226	0,008432	0,007952

NORMA [rij]	14,03566885	11,87434209	12,20655562	9,643650761	10,81665383

Table A.2.2: COPRAS Evaluation Matrix

	Hazardous waste generation of damaged products (S13)	**Percentage of the mercury which access to water supply (Water Pollution) (D11)**	**The amount of mercury particles in the air (Air Pollution) (D12)**	**Mercury released from cfls to the soil and land usage (Soil Pollution) (D13)**
A1	5	7	7	7
A2	5	7	7	7
A3	3	7	7	5
A4	5	9	9	9
A5	3	5	5	5
WEIGHTS	0,035517	0,262136	0,133139	0,165071

NORMA [rij]	9,643650761	15,90597372	15,90597372	15,13274595

Table A.3: ELECTRE Evaluation Matrix

Weight of criteria	0,241	0,065	0,082	0,008	0,008	0,036	0,262	0,133	0,165
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
A1	3	3	3	5	3	5	7	7	7
A2	7	7	5	5	5	5	7	7	7
A3	3	3	9	3	7	7	7	7	5
A4	7	5	3	5	3	5	9	9	9
A5	9	7	5	3	3	3	5	5	5

BIOGRAPHICAL SKETCH

Ferhat Duran was born in Istanbul on December 14, 1992. He studied at Istanbul Atatürk Anatolian High School where he was graduated in 2010. He started his undergraduate studies at the Industrial Engineering Department of Galatasaray University in 2011. In 2016, he obtained the B.S. degree in Industrial Engineering. Since September 2017, he has been working as a data scientist in SAS Turkey. Currently, he is working towards master's degree in Industrial Engineering under the supervision of Dr. Öğr. Üyesi İlke BEREKETLI ZAFEIRAKOPOULOS at the Institute of Science and Engineering, Galatasaray University.

PUBLICATIONS

DURAN, Ferhat; BEREKETLİ ZAFEIRAKOPOULOS, İlke. Environmental Risk Assessment of E-waste in Reverse Logistics Systems Using MCDM Methods. In: The International Symposium for Production Research. Springer, Cham, 2018. p. 590-603.