EVALUATION OF IFE SYSTEMS USING TRIPLE BOTTOM LINE AND MCDM APPROACHES

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LIST OF SYMBOLS

WIFE : Wireless In-Flight Entertainment
PED : Portable Electronic Devices
IFE : In-Flight Entertainment
TBL : Triple Bottom Line
MRO : Maintenance, Repair and Overhaul
SSCM : Sustainable Supply Chain Management
MCDM : Multiple Criteria Decision Making
ANP : Analytic Network Process
AHP : Analytic Hierarchical Process
TOPSIS : Technique for Order Preference by Similarity to Ideal Solution
SCOR : Supply Chain Operations Reference
CBA : Cost Benefit Analysis
EASA : European Aviation Safety Agency
FAA : Federal Aviation Administration
DGCA : Directorate General of Civil Aviation

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ABSTRACT

Supply chain management, which require doing better with less cost and with maximum quality, is one of the most prominent subjects in the developing aviation community. The aviation industry has many strict regulations, complex products and systems. In order to deal with that, aviation companies endeavour to follow recent technologies, to develop new innovation projects and to associate them in supply chain operations effectively.

Airline companies purpose to focus on sustainable development of their systems. Sustainability is getting increasing attention due to growing worldwide concerns about environmental protection and adaptation to the environmental regulations in developing industries. Especially, aviation companies are searching new ways to develop efficient products and services that can provide continuous sustainability in the sector.

Innovation in business processes and technologies show positive impact in management of sustainable supply chain functions. Sustainability on the system performance can be supported by adding values to the supply chain operations. Innovation projects contribute to value-adding activities that can support SSCM.

One of the breakthrough projects in the airline industry is Wireless In-Flight Entertainment (WIFE) system. The project is represented as the most innovative version of in-flight entertainment systems. It enables connectivity of passengers on the internet by their own portable electronic devices (PED) during the flight. Additionally, the system provides reduction of size, weight and energy consumption. The system also offers increasing passenger satisfaction, cost saving, additional revenue and functional efficiency for airlines.

The aim of the research is to assess the Wireless IFE system by comparing with Wired IFE system in respect of economical, customer and environmental viewpoints during the management of the sustainable supply chain operations.

In the thesis, multi-phase assessment is implemented. Triple Bottom Line (TBL) and Multiple Criteria Decision Making (MCDM) approaches are employed to compare two different systems in the same research efficiently. The research is applied in Turkish Airlines Technic Inc. that is a maintenance, repair and overhaul (MRO) company.

In the scope of TBL approach, cost benefit analysis, customer survey study and environmental assessment are implemented in the research. Firstly, in cost benefit analysis, wired and wireless IFE systems are compared by depending on economical criteria. The result of the analysis shows that implementing wireless IFE system is more profitable than Wired IFE system. Secondly, in customer survey study, for customer criteria, survey questions are generated and asked potential customers to understand satisfaction level of customers when using wireless and wired IFE. The outcome of survey implies that when customers use wireless IFE, the satisfaction level is greater than using wired IFE. Lastly, in the environmental assessment, environmental criteria are evaluated and competitiveness of wired and wireless IFE are measured. The result of the assessment indicates that using wireless IFE system demonstrates more positive impacts in the environment than using wired IFE.

In the scope of MCDM approach, Analytic Network Process (ANP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods are conducted. Firstly, ANP is conducted to evaluate importance weights of economical, customer and environmental criteria by gathering data from experts and literature reviews. The study analyses that customer criteria is the most important one that affects to choose the efficient IFE system. Additionally, equipment variety (C21) is resulted as the most important sub-criteria when determining preferable IFE system. Secondly, TOPSIS is employed in the study. In this part, alternatives are ranked by depending on analysis of triple bottom criteria. As a result, wireless IFE is selected as the first in the ranking.

In summary, all criteria and alternatives are evaluated by conducting multi-phase methodologies thus wireless IFE system is selected as more efficient and profitable than wired IFE system.

ÖZET

Tedarik zinciri yönetimi, daha az maliyetle ve maksimum kaliteyle daha iyisini yapmayı gerektiren, gelişmekte olan havacılık sektöründe en önemli konulardan biridir. Havacılık endüstrisinin birçok katı düzenlemesi, karmaşık ürünleri ve sistemleri vardır. Bu konularla mücadele edebilmek için havacılık şirketleri son teknolojileri takip etmeye, yenilikçi projeler geliştirmeye ve tedarik zinciri operasyonlarında bu alanları etkin bir şekilde ilişkilendirmeye çalışmaktadır.

Havayolu şirketleri sistemlerinin sürdürülebilir gelişimlerine odaklanmayı amaçlamaktadırlar. Gelişmekte olan endüstrilerdeki çevresel koruma ve düzenlemelere uyum konusundaki artan endişeler nedeniyle sürdürülebilirlik kavramı artan bir oranda dikkat çekmektedir. Özellikle havacılık şirketleri, sektörde sürekli sürdürülebilirlik sağlayabilecek verimli ürün ve hizmetler geliştirmenin yeni yollarını araştırmaktadır.

İş süreçleri ve teknolojilerindeki yenilikler sürdürülebilir tedarik zinciri işlevlerinin yönetiminde olumlu etki göstermektedir. Sistem performansı üzerindeki sürdürülebilirlik, tedarik zinciri operasyonlarına değerler eklenerek desteklenebilir. Yenilikçi projeler sürdürülebilir tedarik zinciri yönetimini destekleyebilecek katma değerli faaliyetlere destekte bulunur.

Havayolu endüstrisindeki dönüm noktası niteliğinde olan projelerinden biri Kablosuz Uçak İçi Eğlence sistemidir. Proje, Uçak İçi Eğlence sistemlerinin en yenilikçi çeşidi olarak temsil ediliyor. Bu sistem uçuş sırasında yolcuların kendi taşınabilir elektronik cihazları ile internet üzerinden bağlantılarını sağlar. Ayrıca, sistem boyut, ağırlık ve enerji tüketiminde azalma sağlar. Sistem ayrıca havayolları için yolcu memnuniyeti artışı, maliyet tasarrufu, ek gelir ve fonksiyonel verimlilik sunar.

Araştırmanın amacı, Sürdürülebilir Tedarik Zinciri operasyonlarının yönetimi sırasında Kablosuz IFE sistemini ekonomik, müşteri ve çevresel bakış açıları açısından Kablolu IFE sistemi ile karşılaştırarak değerlendirmektir. Tezde çok fazlı değerlendirmeler uygulanmıştır. TBL ve MCDM yaklaşımları aynı araştırmadaki iki farklı sistemi verimli bir şekilde karşılaştırmak için kullanılır. Araştırma, bir bakım, onarım ve revizyon şirketi olan Türk Hava Yolları Teknik A.Ş. de uygulanmıştır.

TBL kapsamındaki araştırmada maliyet fayda analizi, müşteri anket çalışması ve çevresel değerlendirme uygulanmaktadır. İlk olarak, maliyet-fayda analizinde, kablolu ve kablosuz IFE sistemleri ekonomik kriterlere bağlı olarak karşılaştırılmaktadır. Analizin sonucu kablosuz IFE sisteminin uygulanmasının Kablolu IFE sisteminden daha karlı olduğunu göstermektedir. İkinci olarak, müşteri anket çalışmasında müşteri kriterleri için anket soruları üretilir ve potansiyel müşterilerin kablosuz ve kablolu IFE kullanırken memnuniyet seviyelerinin belirlenmeleri amaçlanmaktadır. Anketin sonucu, müşteriler kablosuz IFE kullandığında memnuniyet düzeyinin kablolu IFE kullanmaktan daha yüksek olduğunu göstermektedir. Son olarak, çevresel değerlendirmede çevresel kriterler değerlendirilir ve kablolu - kablosuz IFE sistemlerinin rekabet gücü ölçülür. Değerlendirmenin sonucu, kablosuz IFE sisteminin kullanılmasının, çevrede kablolu IFE kullanmaktan daha olumlu etkiler gösterdiğini göstermektedir.

MCDM yaklaşımı kapsamında ANP ve TOPSIS yöntemleri uygulanmaktadır. İlk olarak, ANP, uzmanlardan ve literatür incelemelerinden veri toplayarak ekonomik, müşteri ve çevresel kriterlerin önem ağırlıklarını değerlendirmek için uygulanır. Çalışma verimli IFE sistemini seçmeyi etkileyen en önemli kriterin müşteri kriteri olduğunu göstermektedir. Ek olarak, tercih edilen IFE sistemi belirlenirken ekipman çeşitliliği en önemli alt kriter olarak ortaya çıkmaktadır. İkinci olarak, çalışmada TOPSIS yöntemi kullanılmıştır. Bu bölümde, alternatifler TBL kriterlerinin analizine göre sıralanmıştır. Kablosuz IFE sıralamada birinci seçilmiştir.

Özet olarak, tüm kriterler ve alternatifler çok fazlı metodolojiler uygulanarak değerlendirilir, böylece kablosuz IFE sisteminin, kablolu IFE sisteminden daha verimli ve karlı olduğuna karar verilir.

1. INTRODUCTION

The world-wide concerns about the environmental protection have been increasing because of the climate change and the rise in global warming. Thanks to the triggers from government regulators, social responsibility organizations, international rules and global competition, industries have been put a commitment on green and sustainability practices.

There is a demand for more sustainable outputs for reducing energy consumption, usage of resource and environmental footprint, as well as enhancing the environmental superiority of companies throughout global market contexts.

The integration of environmental thinking into supply chain management, including product design, procurement and selection of materials, production processes, delivery of the final product to customers, is characterized as a Sustainable Supply Chain Management (SSCM) (Srivastava, 2007). SSCM is an important model for reducing on environmental impacts and increasing satisfaction levels of customers.

In the globalized world, there is a rivalry throughout business industries that affects airline companies in particular because of the industry’s wide-ranging existence. Aircrafts are costly and complex machines requiring thousands of state-of-art components.

With growing attention to sustainable development, airline companies focus on product and process innovation activities to achieve green and sustainable aviation. As a result of adopting innovative practices and continuous improvement in processes systematically, better environmental performance of products and processes can be gained under industrial competitiveness. Therefore, airline companies show their significant movements to bring about sustainable development by addressing the global climate change issue and effective technologies to mitigate the negative effect on the environment.

SSCM requires analysis a three-part framework of environmental, economic, and social aspects. All three main SSCM dimensions discussed in this paper are established on the TBL theory of (Elkington, 1994) that is the most common conception in terms of sustainability. Some companies implemented the TBL model to measure their accomplishment from a wider perspective to increase major business value.

When targeting to a more sustainable universe, aviation industries highly prefer light weight components and solutions. One of the important project for reducing the environmental impacts of airline companies is Wireless In-flight Entertainment (WIFE) systems. WIFE system provide savings in many areas through reduction of size, weight, energy consumption and it is designed to influence the passenger's comfort level in a positive way.

Wireless in-flight entertainment is growing into one of the most advanced areas of the in-flight experience. Besides, WIFE system has been providing in-flight internet connectivity to passengers with the rule of following necessary instructions. Additionally, airlines can allow the use of portable electronic devices (PEDs) during the entire flight following after a safety evaluation process[1].

The aim of the thesis is to evaluate Wireless IFE system in the scope of SSCM by depending on economical, customer and environmental dimensions of systems by doing comparison with Wired IFE system in detail and to apply at Turkish Airlines Technic Inc.

The researched problem is considered as a multi-step study. In the first step, triple bottom line criteria are evaluated by cost benefit analysis, survey assessment and the environmental calculation. In the second step, two-phase MCDM approach is computed.

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[1] https://www.easa.europa.eu/easa-and-you/passengers/portable-electronic-devices-ped-board

In the first step, firstly, economical factors are evaluated by using cost benefit analysis to determine the most effective IFE system. Secondly, customer oriented criteria are taken into consideration to conduct survey assessment. By means of survey, satisfaction level of customers is evaluated for two different IFE systems.

Thirdly, environmental criteria are operated to calculate fuel amount used and CO_2 emission given outside by depending on material amount.

In the second step of the thesis, firstly, ANP examines the triple bottom line aspects acquired from the appropriate experts and literature to assess that factors are more likely to affect the option of the most advantageous IFE system. ANP is chosen in this analysis because there is a relationship of dependence.

Lastly, TOPSIS is employed for ranking and evaluating alternatives with respect to importance weights and results gained from economic, customer and environmental analyses. Criteria values are employed to optimize the profit criteria and to minimize cost criteria to detect the effects of the criteria.

As a result of the literature research, it is seen that many studies have been performed on the SSCM and the triple bottom line concept with the increment of the environmental concerns. Due to the fact that the concept of triple bottom line concept is wide-ranging subject, there is not any work of that on evaluating in-flight entertainment systems. One of the areas where the studies are insufficient is the studies to evaluate the relationship between the triple bottom line concept and sustainability of IFE systems.

This thesis contributes to the literature being the first study that proposes an integrated triple bottom line assessment for sustainable supply chain management with cost benefit, survey, environmental assessment and MCDM methods on a case study to select the most efficient IFE system.

2. LITERATURE REVIEW

2.1. Literature Review on Sustainable Supply Chain Management

Thanks to government regulations, environmental sensitivity and responsibility, focusing on sustainability researches has become very important day by day. Especially, in aviation industry, the studies are increasing rapidly because even a small part of positive effect on the industry can change the direction of all management strategies. In the literature review, it can be seen that SSCM can touch on many different sectors in area of new product designing, green supplier selection, re-manufacturing systems, reverse logistics, sustainable purchasing, eco-conception, waste and transportation management as given in Table 2.1.

Additionally, from the perspective on aviation sector, it can be determined that SSCM mainly focus on reducing CO_2 gas emission, light weight component solution, air traffic management, passenger satisfaction improvement, recycling of retired aircrafts, green activities inside aircraft and in airlines. Moreover, literature review on in-flight entertainment systems shows that researchers generally focus on customer experience, aircraft safety, future of technologies. There is no study focalizes on sustainability and triple bottom line effect of in-flight entertainment systems.

Table 2.1: Literature Review on SSCM

Author, Year	**Objective of the Study**	**Methods Used**	**Topic of the Study**	**Impact Category**
Liu, 2007	Aiming to introduce future in-flight systems guiding	Literature review	In-flight entertainment systems	Customer focused
Srivastava, 2007	Classifying general essential problems on SSC practices.	Literature Review	SSCM	Environmental Economic
Huynh& Bretschneider,2009	Analyzing more technological versions of in-flight entertainment systems	A qualitative analysis	In-flight entertainment	Quality, Reliability, Technology
Daaboul et al.,2013	Designing the reverse supply chain by using light weight resolution technics	Reverse logistics	Sustainable supply chain management	Energy consuming Sustainable light weight solutions
Moreira et al.,2014	Examining benefits of product life cycle and eco-design activities	A qualitative analysis	Product life and eco-design management	Environmental Economic

Author, Year	**Objective of the Study**	**Methods Used**	**Topic of the Study**	**Impact Category**
Tsai et al.,2014	Evaluation of impacts on implementation of green activities in aircraft cabins	Activity-Based Costing, the Theory of Constraints, a mathematical programming model	Sustainable Aviation	Environmental
Keivanpour et al.,2015	Approaching for SSCM by focusing on end-of-life (EOL) aircraft solutions	Literature review	Management of end of life aircrafts	Environmental
Kim et al.,2015	Examining effectivity of in-flight services from the aspect of customer experience	A qualitative analysis	In-flight entertainment	Customer experience
Tognetti et al.,2015	Showing that the emissions can be reduced with zero cost rise by focusing on energy mix	Multi-objective optimization; SCM network optimization	SSCM	Environmental Economic
Watrobski, 2016	Analyzing a set of practical applications.	MCDM Methods	Green logistics	Environmental Economic

Author, Year	**Objective of the Study**	**Methods Used**	**Topic of the Study**	**Impact Category**
Jha, 2016	Examining three-dimensional (3D) printing, autonomous ships, green technologies and their impacts on the ship building industry	Qualitative research method	Green technologies	Economic Technological
Morgado et al.,2016	Introducing an in-flight entertainment model for passengers with disabilities	A qualitative analysis	In-flight entertainment	Passenger focused
Gechevski et al.,2016	Explaining different perspectives of reverse and green logistics.	Qualitative research method	Green logistics	Ecological Environmental Site constraints
Alfalla-Luque et al.,2017	Evaluating integration of supply chain in aircraft sector	A qualitative analysis	Supply chain management	Suppliers Customers
Lam et al., 2017	Analyzing prevention of attacks against aircraft safety	A qualitative analysis	In-flight entertainment	Safety of aviation

Author, Year	**Objective of the Study**	**Methods Used**	**Topic of the Study**	**Impact Category**
Ameli et al.,2017	Analyzing of the balance between economic and environmental effects during new product development phase	Optimization method	New product designing	Economic Environment Product design
Becken &Mackey, 2017	Classification of categories on reducing carbon emission gases in aviation industry	A qualitative analysis	Mitigation of carbon emissions	Green gas emissions Energy
Scur & Barbosa, 2017	Analyzing green practices like reverse logistics, sustainable purchasing.	Qualitative research method	SSCM	Environmental
Toro et al., 2017	Aiming to calculate greenhouse gas emission and minimizing fuel consumption.	Mixed-integer linear programming	Green location routing	Environmental
Nurjanni et al., 2017	Minimizing total cost, negative environmental impacts.	Tchebycheff approach, Weighted sum method	Green supply chain management	Environmental Economic Social

Author, Year	**Objective of the Study**	**Methods Used**	**Topic of the Study**	**Impact Category**
Frehe & Teuteberg, 2017	Proposing software applications used while making strategic decision about freight transport and supply chains.	Literature review	Green logistics	Environmental Economic Social Technological
Keivanpour et al.,2017	Analyzing retired aircrafts in respect of different aspects	Optimization, Lean management	Directing retired aircraft models	Environmental Social Economic
Roehrich et al.,2017	Showing key factors for achieving sustainable supplier selection by using self-determination theory (SDT)	A qualitative analysis	Green supplier selection	SDT mechanisms of autonomy, competence and relatedness
Tolio et al.,2017	Exploring future technological de- and remanufacturing systems	A qualitative analysis	Sustainable de- and remanufacturing systems	Environmental Social Economic
Benitez et al.,2018	Examining advantages of lean and green applications on supply chain	Importance-performance analysis	SSCM	Environmental

Author, Year	**Objective of the Study**	**Methods Used**	**Topic of the Study**	**Impact Category**
Tsai&Lai, 2018	Establishing a model to integrate green activities in production planning and control	A mathematical programming decision model, (ABC), the theory of constraint (TOC)	Management of green production planning and control	Environmental Economic
Guimarans et al,2019	Studying on improvement of air traffic management	Optimization	Sustainable air traffic operations	Air traffic management
Jalalian et al.,2019	Proposing a model to improve the social-environmental balance in the airline sector	Mixed integer non-linear prog. &Multi-objective simulated annealing algorithm	Management of sustainable airline industry	Environment Energy Customer satisfaction

2.2. Literature Review on Sustainable Supply Chain Management and MCDM

Sustainability is a concept that involves economical, social and environmental factors. Those factors can be evaluated with MCDM methods that are used for the purposes of measuring performance. The applications are demonstrated in Table 2.2.

In the literature that comprises of sustainability and MCDM methods in aviation, studies mainly concentrate on green aviation, triple bottom line effect, green aviation fleet management, green supplier selection, green airport evaluation, transportation management. In addition to this, in other industries, reverse logistic and green packaging areas are principally investigated.

Table 2.2: Literature Review on SSCM and MCDM

Author, Year	**Objective of the Study**	**Methods Used**	**Topic of the Study**	**Impact Category**
Vahabzadeh et al, 2015)	Choosing the greenest reverse logistic options.	Fuzzy-Vikor method	Sustainable logistics	Environmental Economic Social
Luthra et al, 2017)	Introducing a supplier preference concept in an automobile industry in India	AHP, VIKOR	Sustainable supplier selection	Environmental Economic Social
Wu et al,2015	Balancing TBL performance by analyzing environmental, social and economical factors.	Dematel Method	SSCM	Environmental Economic Social Operational

Author, Year	**Objective of the Study**	**Methods Used**	**Topic of the Study**	**Impact Category**
Gorener et al.,2017	Aiming to improve effectiveness of sustainable supplier selection in a MRO company	Fuzzy Logic AHP TOPSIS	Supplier Performance Evaluation (SPE)	Economic Social
Lee et al.,2017	Proposing an integrated model to analyze sustainable fleet management	MCDM	Green aviation fleet management	Environmental Economic
Lu et al.,2017	Evaluating a sustainability model to analyze and manage impacts of airports	MCDM	Sustainable airport management	Environmental Social Economic
Rostamzadeh et al., 2015	Proposing to measure the uncertain activities on green studies.	Fuzzy VIKOR	SSCM	Environmental
White et al., 2015	Searching the complexity of decisions made in an automotive component manufacturer.	Fuzzy AHP, Fuzzy TOPSIS	Green packaging design	Customer Regulatory Operational Environmental

Author, Year	Objective of the Study	Methods Used	Topic of the Study	Impact Category
Bai et al, 2015	Developing a holistic concept for sustainable fleet management	VIKOR method	Sustainable transportation assessment	Environmental Economic Social
Lam & Dai, 2015	Selecting suitable logistics service providers and to develop environmental sustainability in GSCM.	ANP-QFD	SSCM	Environmental
Tognetti et al, 2015	Showing that the CO_2 emissions of the supply chain can be reduced with zero cost rise by focusing on energy mix during the production.	Multi-objective optimization; Supply chain network optimization	SSCM	Environmental Economic
Prakash & Barua, 2015	Focusing on overcoming reverse logistics adaption barriers.	AHP and TOPSIS method	Green logistics	Economic Technological Organizational
Wang et al., 2016	Approaching for sustainable supplier preference in film sector	AHP, TOPSIS	Green Supplier Selection	Environmental Economic

Author, Year	Objective of the Study	Methods Used	Topic of the Study	Impact Category
Chinda & Ammarapala, 2016	Managing waste management in a construction industry by means of reverse logistics.	AHP	Sustainable supply chain decision making	Environmental Economic Social
Watrobski, 2016	Analysing a set of practical applications.	MCDM	Green logistics	Environmental Economic
Dweiri et al, 2016	Selecting the best suppliers in automotive industry in Pakistan	AHP	Sustainable supplier selection	Delivery Price Quality
Yu & Hou, 2016	Selecting the greenest supplier in the automobile manufacturing industry.	Modified AHP	Green supplier preference	Environmental Economic Social
Hamdan & Cheaitou, 2017	Solving sustainable supplier selection and assignation	Fuzzy TOPSIS, Branch-cut algorithm.	Green supplier selection	Environmental Economic Social
Tavana et al., 2017	Performing sustainable supplier selection in a dairy factory by means of selected analytics.	ANP, QFD	Sustainable supplier selection	Environmental Social Economic

Author, Year	**Objective of the Study**	**Methods Used**	**Topic of the Study**	**Impact Category**
Qin et al, 2017	Green supplier selection in interval type-2 fuzzy environment	MCMD	Green supplier selection	Environmental Economic Social
Mavi et al., 2017	Selecting sustainable reverse logistic supplier in plastic sector.	Fuzzy SWARA, Fuzzy MOORA	Sustainable reverse logistics	Environmental Economic Social
Yazdani, 2017	Providing methods to reduce operations costs.	DEMATEL QFD	Green Supplier Selection	Environmental Economic
Raj& Srivastava, 2018	Proposing a model to develop performance of sustainability for an aircraft company	Fuzzy Best Worst MCDM	Sustainability of an aircraft manufacturing company	Environmental Social Economic

2.3. Literature Review on Cost-Benefit Analysis

C/B analysis is an important method, particularly make companies determine the advantages and disadvantages of their decisions. Especially in aviation sector, evaluation of cost and benefits in early stages, can make a great contribution to future of the sector. In the literature, it is clearly seen that aviation safety, sustainability, airport safety, green logistics, green aviation, aviation air quality and transportation management are mainly mentioned fields as shown in Table 2.3.

Table 2.3: Literature Review on Cost-Benefit Analysis

Author, Year	**Objective of the Study**	**Topic of the Study**	**Impact Category**
Jorge & Rus, 2004	Aiming to improve airport infrastructure activities by analyzing costs and benefits.	Airport transportation management	Economical
Jacobson et al., 2006	Proposing to assess cost saving evaluation of new technologies	Airport safety management	Economical Social
Dorbian et al., 2011	Aiming to measure changing ratio of air quality by decreasing aviation fuel and emissions.	Aviation air quality	Economical Environmental
Cavka & Cokorilo, 2012	Providing a framework for evaluating the cost of protection in the case of an accident	Aviation safety management	Economical Social
He et al., 2014	Determining the economic effect of aviation noise to determine policy options and guide decision-making.	Sustainable supply chain management	Economical Environmental
Hospodka, 2014	Presenting economic effects of applying electric taxi systems.	Green aviation	Economical Social

Author, Year	**Objective of the Study**	**Topic of the Study**	**Impact Category**
Stewart & Mueller, 2014	Working on profit and expense of safety scope to determine the best security standards to protect airports.	Airport safety management	Economical Social
Gillen & Morrison, 2015	Providing an economic overview of current issues and future prospects for aviation safety	Aviation safety	Economic Social
Araujo et al., 2015	Showing the positive effects of RFID tech. in reverse logistics.	Green logistics	Economical Technological

3. SUPPLY CHAIN MANAGEMENT

SCM is the management of a good or service's entire production process from the raw materials to the final product being shipped to the customers (Gechevski et al, 2016). A business must create a network of distributors to achieve this mission, which will transfer the commodity from the manufacturers of raw materials to the organizations which deal directly with consumers.

The principle of supply chain management is firstly offered by (Oliver, 1982) when the Financial Times interview conducted. In time SCM concept has begun to show up as popular discipline.

The ultimate goal of supply chains is delivering right outputs to the right consumers at the right location and the right period for the lowest total cost. SSCM activities must be planned carefully and managed consistently because it is a key to support sustainability of businesses.

Supply chains are complex systems thus it is separated into processes to be managed effectively. APIC Supply Chain Council promotes a framework called Supply Chain Operations Reference (SCOR) model. The model breaks supply chain processes into six main groups.[2] SCOR model's steps are defined as follows:
-Plan: the processes in which diagraming how everything functions in the supply chain.
-Source: building contacts with suppliers and purchasing materials.
-Make: includes all manufacturing processes.
-Deliver: transmitting products to customer.
-Return: bringing back products from customers.

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[2] http://www.apics.org/apics-for-business

-Enable: involves all the other processes that a supply chain requires to work smoothly.

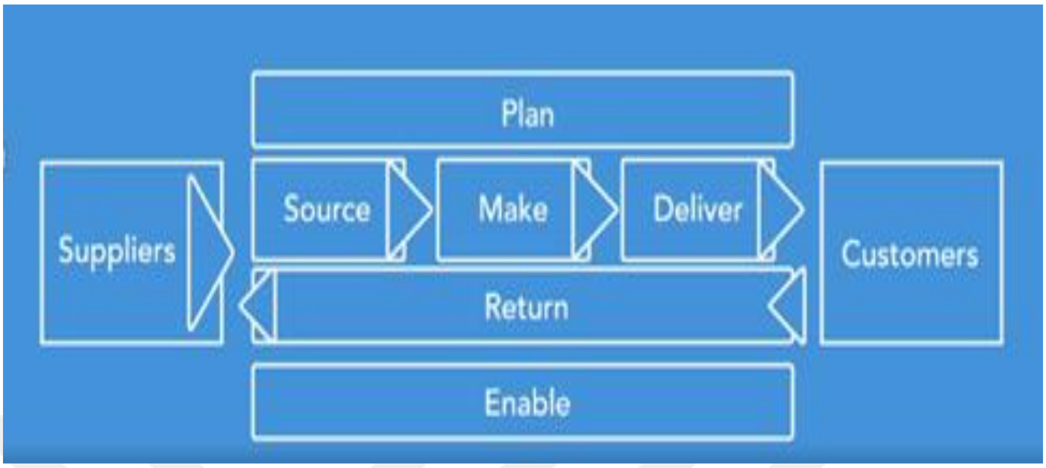

Figure 3.1: SCOR Model Structure

The management of the modern supply chain is much more than just where and when. It affects the quality of products and services, distribution, costs, consumer experience and eventually productivity. Companies can reduce excess costs, waste and reach products on time to customers by managing the supply chains effectively.

SCM isn’t just a mechanism in an enterprise to reduce costs and achieve greater operational efficiencies. While these are important considerations, modern supply chain management requires tactical integration of end-to-end business processes to maximize economic value and competitive advantage. The stronger and more effective the SCM of a company is, the more it preserves its reputation for business and long-term sustainability.

As the global market continues to develop, companies must focus on more efficient supply chains by creating innovative activities and adding values to operations. Innovation can have a vital impact on the performance of the supply chain since innovation and supply chain activities are connected and affect each other mutually.

4. TRIPLE BOTTOM LINE APPROACH IN SUPPLY CHAIN MANAGEMENT

TBL aims to quantify the level of commitment of a corporation to corporate social responsibility over time and its impact on the environment. The prominent British sustainability consultant (Elkington, 1994) promoted the phrase "triple bottom line" as his way to quantify success in America. The idea supports that we could manage a business in a way that not only earns economic gains, but also enhances the lives of people and the planet. TBL is a sustainability metric that involves measures of economic, environmental and financial performance as seen in Figure 4.1. Those aspects intersect and affect each other.

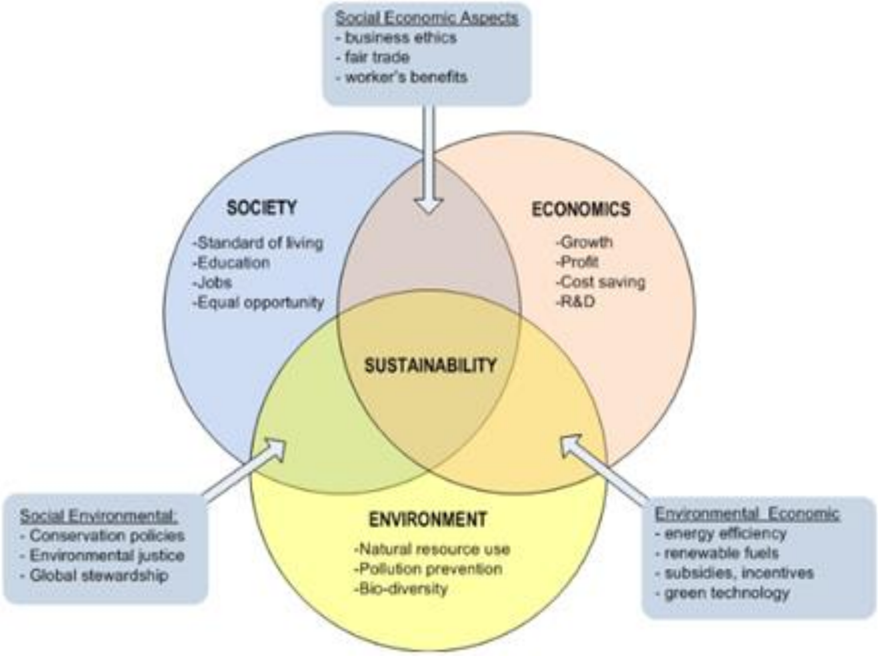

Figure 4.1: Three Pillars of Sustainability (Rodriguez et al.,2002)

Sustainability enables societies more equal and provides a more compromising world to generations (Dyllick & Hockerts, 2002). The sustainability conception which is described by the United Nations (March 20, 1987) as following: "Sustainable development addresses current requirements without jeopardizing future generations' ability to fulfill their own requirements." [3]

TBL is a common approach used to assess the sustainability which can be implemented through the application of supply chain operations. Triple bottom line sustainability is defined with other words as people, planet and profit that are the substantial supply chain evaluation. People and the planet are the resources and users of manufactured outputs. In SCM terms, manufacturing and consumption outcome in goods and services which ensure profitability and prosperity. The supply chain and its management of the operations are therefore converging with triple bottom line standards.

Supply chain management provides system efficiency, speed of service and cost efficiency. Those keywords can be implemented and succeeded effectively by managing SSC operations. Those operations are becoming more important because of innovation, researching new technologies and creative proceedings.

Supply chain structures are designed to target at rising profits and decreasing customer expenditures, as representing higher living standards and lower environmental costs. To be successful at proving those standards at the same time needs expertise in efficiency of the sustainability and operations management.

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[3] http://www.un-documents.net/ocf-02.htm

5. SUSTAINABLE SUPPLY CHAIN MANAGEMENT

Supply chains are critical links which connect the inputs of an organization to its outputs. Conventional challenges include reducing costs, maintaining just-in-time delivery, and reducing travel times so that market problems could be better addressed. Nevertheless, the growing environmental costs of these networks and increasing market demand for environmentally friendly goods have led many companies to look at sustainability in the supply chain as a new measure of efficient operations management. The change represents awareness that sustainable supply chains also imply competitive supply chains.

Most companies are restricted to assessing the viability of their own business operations, and are unable to expand this measurement to their suppliers and clients. This situation makes it highly difficult to assess their true environmental costs, and their ability to eliminate waste from supply chains. Sustainable process' can be achieved by implementing metrics as shown in Figure 5.1.

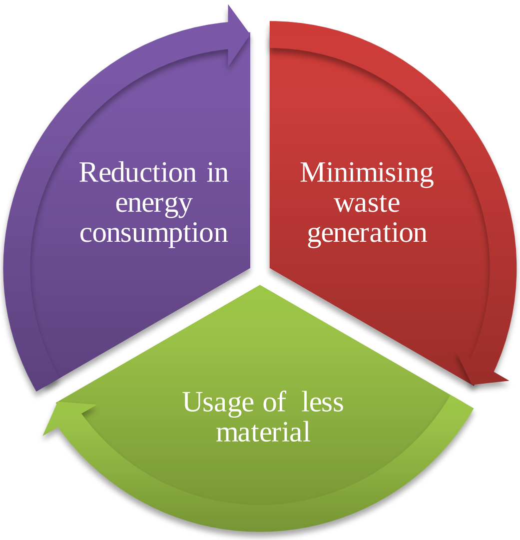

Figure 5.1: Sustainable Process Metrics

Powered by regulations and increased awareness of the environment, sustainability has become an important consideration for leading national and international associations and research institutions. Sustainability problems within companies contribute to strategic level decision-making on corporate social responsibility and have serious consequences for the management of the supply chain.

Supply chain sustainability is a business issue impacting the supply chain or logistics network of an enterprise in view of drivers as demonstrated in Figure 5.2. Sustainability in the supply chain is progressively perceived necessary to deliver productivity among executives, and has substituted monetary cost, value, and speed as the primary subject of discussion among supply professionals. A sustainable supply chain seizes incentives for creating value and provides substantial competitive advantages for process technologists.

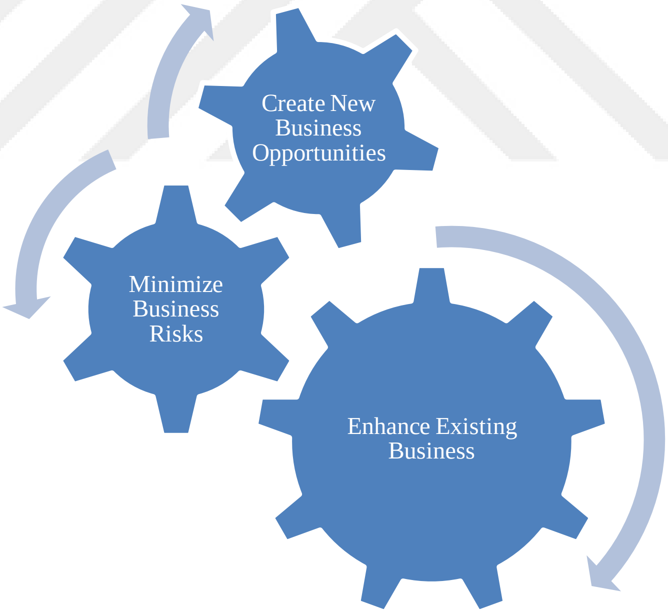

Figure 5.2: Business Drivers for Supply Chain Sustainability

Sustainable supply chain management constitutes integrating environmentally and financially viable methods into the entire supply chain lifecycle, from product design and development to material selection (including processing of raw materials or agricultural production), manufacturing, packaging, transport, warehousing, distribution, consumption, return and disposal (Chen et al, 2016).

Management of the environmentally sustainable supply chain and practices can help organizations not only reduce their total carbon footprint, but also optimize their end-to-end operations, environmental stewardship, resource management and social responsibility to bring greater cost savings and profitability. In order to succeed, supply chain sustainability activities must offer improved environmental efficiency within a feasible operating system.

For most businesses, the supply chains have far better environmental effects than any other aspect of their operations. While most commercial and public attention has been on a product's environmental profile includes its source and whether it is recyclable, it is important to illustrate the sustainability issues associated with the transport and distribution of those goods.

Sustainability programs also seek to promote equity and positive benefits for manufacturers, staff, consumers, end-users and other stakeholders. Sustainability gives businesses a chance to establish new business relationships and build stronger core competencies. Furthermore, sustainable practices can optimize business protection by assuring supply chains are resilient and shock-proof against unexpected price, availability, and quality changes. (Shou et al, 2019)

6. IN-FLIGHT ENTERTAINMENT SYSTEM

All airlines are concerned about customer satisfaction and keeping up with competitors. Therefore paying a particular attention to in-flight systems is considered as one of the main aspires. Airlines are perpetually seeking new and innovative ways to boost the in-flight expertise because advanced, user friendly in-flight amusement technologies can invariably be in demand.

The first purpose of the IFE is to provide passengers relief with food and beverages, especially when they see nothing else than the sky. The aircraft's enclosed atmosphere can cause passengers inconvenience (Liu, 2007). The second purpose of IFE is to reduce stress level of passengers intelligently and effectively, and to make them enjoy their flight to the last.

With the increasing demands of the passengers, the competition of airlines and the advancement of technology, the airline companies started to offer more sophisticated services in where electronic devices played a major role. This has led to the in-flight entertainment system being a multi-purpose system, with the exception of catering and physical comfort. Moreover, in-flight entertainment systems provide passengers with the opportunity to follow their work throughout the flight, watching movies, listening to music, and playing games.

The demand for passenger travel is expected to increase by 5 percent per year over the next 20 years, and by 2040, a total of 56,000 new aircraft will be needed to meet the expected demand [4]. Therefore the use of the in-flight entertainment will be one of the most requested factors of attracting customers for aviation companies in the coming years.

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[4] https://www.icao.int/Pages/default.aspx

There are two types of in-flight entertainment systems that are classified as wireless and wired IFE.

6.1. Wireless In-Flight System

Technology is ever-changing so with the rise in laptops, smartphones, tablets e-readers and MP3 players, airline companies have initiated to provide in-flight entertainment that can stream content to passengers' own devices.

In this system, customers can access to the published movies, music, reading and various entertainment content by a web page for computers and by a developed application for smartphones and tablets. After the application is installed, the in-flight entertainment system will be used. Moreover, airlines are willing to present on board Wi-Fi connectivity that gives chances for passengers to encounter an even more personalized system. This type of new innovative project is called wireless in-flight system.

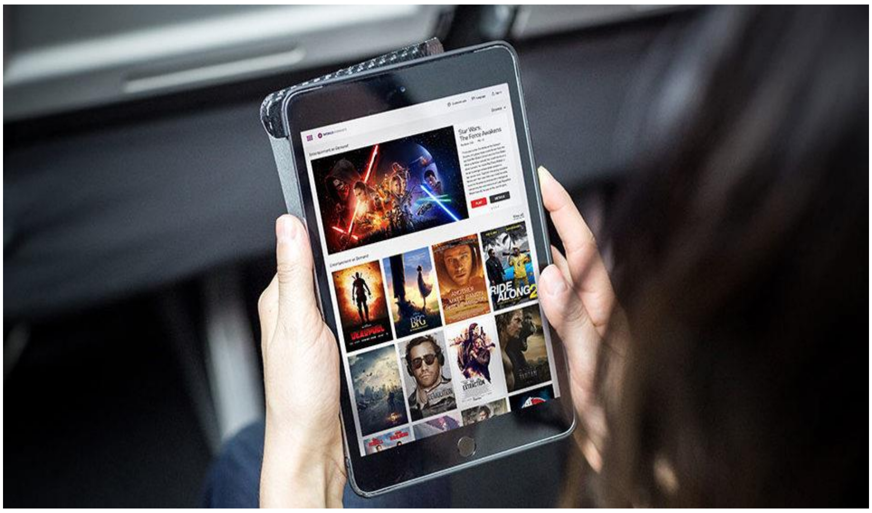


Figure 6.2: Wireless In-Flight Entertainment System

According to understanding obtained from Turkish Airlines Technic Inc., the two systems are compared in terms of customer pleasure, cost, maintenance and weight.

It can be said that the wireless in-flight entertainment system has many advantages over wired in-flight entertainment system. These are as follows:
Passenger satisfaction: Passengers can have access to many kinds of films, music and games streamed to their portable electronic devices (PEDs).

Lighter aircraft with reduced fuel burn: The biggest difference between the wired and the wireless in-air entertainment system is on the seat side. Many seat side components are not used therefore it presents a lighter aircraft and thanks to the decrease in aircraft, fuel burn is reduced.

A very short installation time: No installation is required on the seat side. This can absolutely shorten the delivery time of the system.

A much lower initial investment costs: No exterior hardware and special demand are needed. It enables the system to be initiated easily with a low cost.

Less maintenance costs: Since the wireless system will not be a seat side or will consist of only a power unit, it will generate less maintenance costs than the wired system.

Being passenger oriented: In wired systems, the devices are manufactured according to the firms' rules so it can be hard to understand all the critical details of the systems. In addition to this, the response time of the systems is very slow. Otherwise, in the wireless IFE system, the passengers can use their own devices to enjoy the entertainment system by easily connecting to the system.

Ancillary revenues for airlines: Airlines can obtain ancillary revenues by enabling additional services such as advertising and online shopping.

Operational efficiencies for airlines: Contents can be updated more frequently and content integration lead times and costs are eliminated.

6.2. Wired In-Flight System

Today, modern in-flight entertainment systems present astonishing number of films, television series, songs, games and moving-maps. They are considered with embedded hardware (touch screens, seat remote controls, earphones).

Figure 6.3: Wired In-Flight Entertainment System

With the helping of analysis based on related information on Turkish Airlines Technic Inc., it is seen that there are some limitations of wired in-flight systems as below:

Setting up of the System: Installation of of the system is a laborious and long-term process. Also, the existing systems are difficult and costly to install, and to maintain is a disadvantage in terms of capturing and developing technology.

Expense: The installation of an IFE is expensive. In addition, the weight of aircraft components also has a large impact on cost. The difference between the wired IFE and the wireless IFE system is evident on the seat side. In the wireless IFE, all the components of the seat side are reduced to the passenger's own device.

Serviceability: The use of wired systems for passengers is not very useful due to sensitivity of the screens. Passengers can be more comfortable while using their own devices.

7. PROPOSED METHODOLOGY

In this study, triple bottom line approach that affects sustainability of IFE systems by focusing on supply chain management is researched. In the thesis, three phase triple bottom line approach and two phase MCDM analysis are conducted.

Triple bottom line factors are categorized as economical, customer and environmental. As a first step, three phase triple bottom line approach is implemented for three criteria separately. Firstly, for economical assessment, cost benefit analysis is carried out on economical criteria. Secondly, for customer assessment, survey analysis is performed by depending on customer criteria. Lastly, for environmental assessment, environmental analysis is conducted. As a result, triple bottom line approach is completed and those analysis outcomes are taken into consideration when calculating MCDM analysis.

As a second step, two phase MCDM analysis is performed. MCDM criteria data are formed by triple bottom line analysis. Firstly, ANP method is carried out to evaluate weight and rank of criteria by studying on expert opinions. Secondly, TOPSIS method is implemented by using results of TBL and ANP analyses to rank alternatives.

In conclusion, by implementing TBL and MCDM approaches, the most preferable alternative is determined.

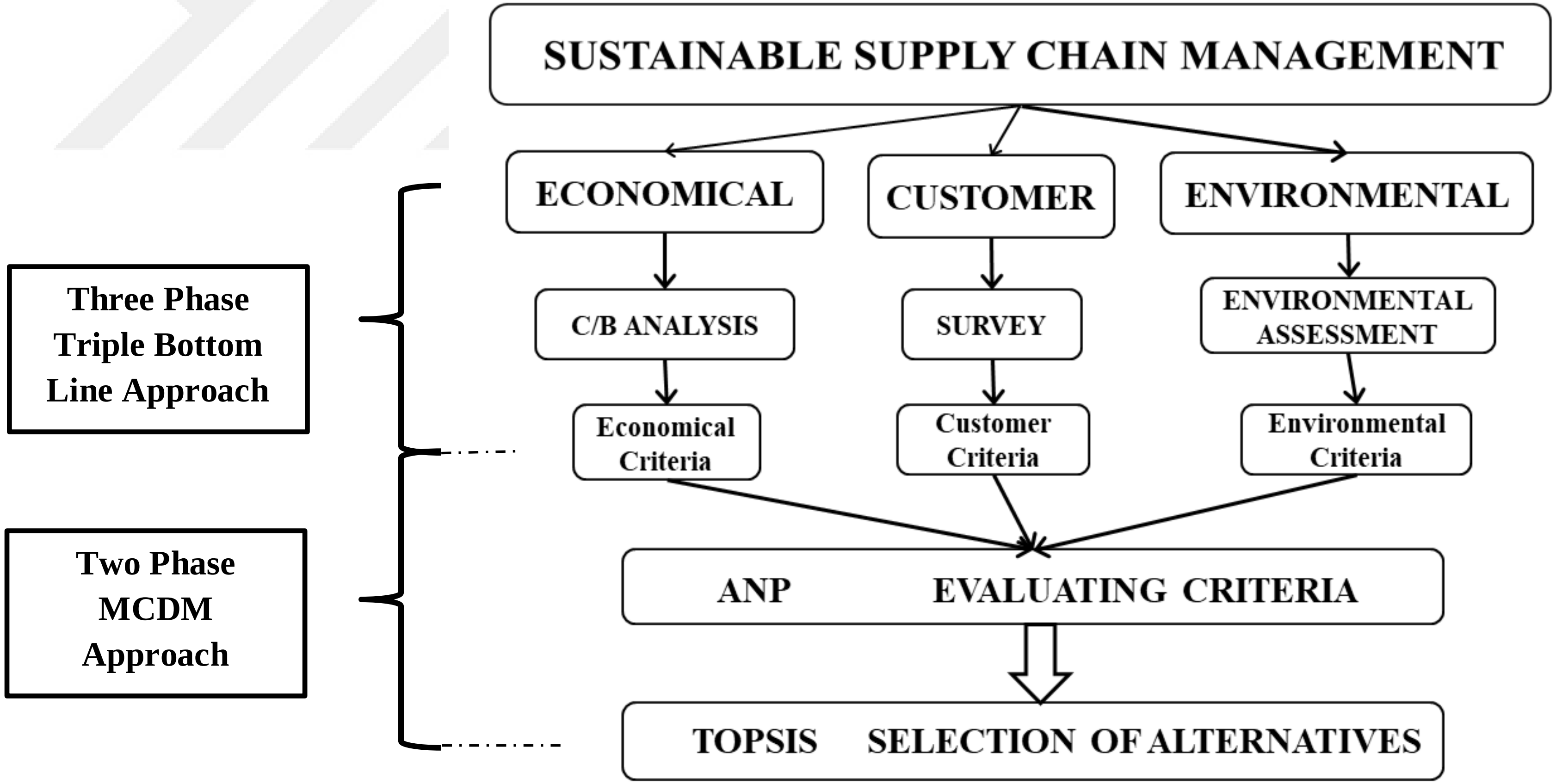


Figure 7.1: Conceptual Model of the Study

7.1. Cost-Benefit Analysis to Evaluate Economical Criteria

Cost-Benefit Analysis (CBA) is a comprehensive methodology for evaluating investment alternatives with respect to costs and benefits such as continuing cost and labor savings (David et al, 2013). CBA is the most substantially used project evaluation methodology to compare projects by observing their benefits and costs in order to make decision on an investment plan. If the comparison is made among several projects, the project which is the most beneficiary is chosen. Otherwise, if the decision is made for a project, the project that has net benefits more than the net costs is resolved as profitable.

The purpose of using CBA is choosing the right project that brings maximum profit. While managing the CBA for any project, all costs and benefits should be converted to a common monetary units to advance the basis for comparison.

Steps of cost-benefit analysis can be outlined as below:

Step 1: Evaluation of the economical factors:
In this step, costs and benefits under economical factors effecting to choose more beneficial system are identified and classified.

Step 2: Measurement for expected costs and benefit:
For planned years, costs and benefits are computed by depending on general factors.

Step 3: Monetizing costs and benefits:
All costs and benefits must be placed with the same currency.

Step 4: Discount costs and benefits to achieve current values:
This shows that future costs and benefits are converted into present value. Each organization assumes to own a particular rate of discount.

The equation used in monetary terms for estimating the PV of future cost or profit is:

$$PV = \frac{F}{(1+i)^n} \tag{1}$$

Step 5: Calculate net current values:
This is achieved by removing profits from expenses. If a positive result is obtained, the investment plan is considered effective. There are other considerations to be taken into account, however.

Step 6: Calculating the ratio of PV of costs and benefits:
In the step, according to the comparison of ratios, more beneficial system is chosen. The calculation is shown in the formula as below:

$$C/B = \frac{\sum PV\ of\ total\ future\ costs}{\sum PV\ of\ total\ future\ benefits} \tag{2}$$

$$\mathrm{C/B} = \frac{\sum_{t=0}^{n} \frac{C_t}{(1+i)^n}}{\sum_{t=0}^{n} \frac{B_t}{(1+i)^n}} \tag{3}$$

where C is cost, B is benefits, n is year, and i is the discount rate.

According to the result of C/B analysis, below steps are followed:

If C/B<1, Benefits are greater than costs. The plan should be allowed to continue.
If C/B>1, Costs are greater than benefits. The plan shouldn’t be allowed to continue.
If C/B=1, Costs are equal to the benefits which means the plan should be permitted to continue.

7.2. Environmental Assessment to Evaluate Environmental Criteria

In this part, there is no a specific method that was used. The calculations to analyze environmental criteria are generated and the results are evaluated with verbal explanation.

7.3. Survey Analysis to Evaluate Customer Criteria

Survey analysis is implemented in this part of the thesis. In the survey analysis, prepared questions are directed to potential passengers. The purpose of the customer survey is to evaluate the level of customer satisfaction for some specific customer criteria.

7.4. ANP Method to Evaluate Weights of Criteria

ANP is a generalized form of the Analytic Hierarchical Process (AHP) that is developed by (Saaty, 1980). The AHP solves decision problems with a finite range of options and evaluates the criteria and alternatives affecting the decision in a hierarchical order. Problems are not always expressed in a hierarchical structure. Analytical Network Process is a technique that can be used in such problems.

ANP evaluates the criteria and alternatives affecting the decision and eliminates the necessity of modeling in a single direction. The method enables all interactions, dependence and feedback in the decision-making system to be included in the model and systematic evaluation of all relationships. In the ANP method, the study is modeled by employing structure of the network as shown in Figure 7.2, while the dependencies between the sub-criteria and the internal dependencies of the sub-criteria are considered.

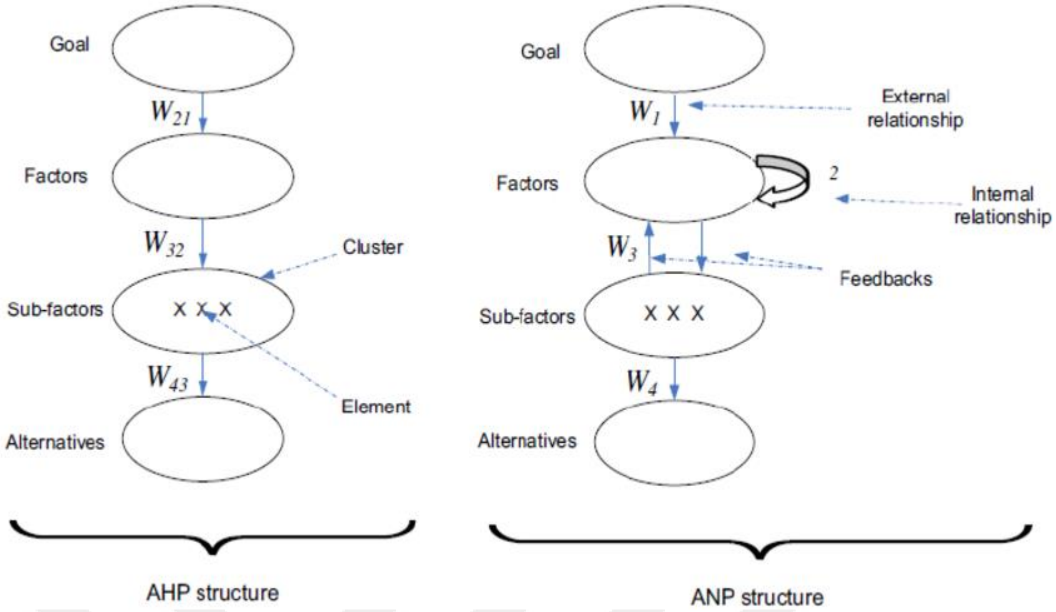


Figure 7.2: AHP and ANP Structure (Saaty & Vargas, 2006)

There is a goal at the top of the structure and below, there are criteria, sub-criteria and alternatives, respectively. In the structure, the same level of criteria are independent of each other, but in real life, the most accurate decision can be made by considering the relationships between the criteria of the decision problem.

The relationship between the criteria within a set of criteria is called internal dependency, while the relationships between criteria in different criteria sets are called external dependency.

The implementation the path of the ANP process can be summarized as below:

Step 1. Identifying the problem and building the form:
In the first stage, the problem is identified and the objective, main criteria, sub-criteria, alternatives are classified.

Step 2. Determining the relationships between criteria:
This specifies relations between criteria and sub-criteria and establishes internal, external dependencies.

Step 3. Performing binary comparisons between criteria and alternatives:
Binary comparisons are made by decision-makers using the defined measure values.

Step 4. Conduct consistency analysis of the matrix comparison:
To assess the accuracy of the comparisons, the consistency ratio (CR) must be computed for every matrix after the comparison matrices have been constructed. If the CR value is less than 0.10, binary comparisons can be stated to be consistent. There is an inconsistency if the values are larger than 0.10 and the decision makers should review the paired comparisons.

Step 5. Generation of weighted super matrix and limit super matrix:
Super matrix is a fragmented matrix, where each matrix segment represents the relation between two parameters within a model. The long-term relative impacts of the parameters are calculated by the super matrix power. To ensure that the importance weights are equalized at some point, power of (2n + 1) to the super matrix is taken where n is a randomly selected large number and the resulting new matrix is named as the limit super matrix.

$$W = \begin{array}{cc} & \\ & \\ C_1 & \begin{matrix} e_{11} \\ e_{12} \\ \vdots \\ e_{1n_1} \end{matrix} \\ C_2 & \begin{matrix} e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \end{matrix} \\ \vdots & \vdots \\ C_m & \begin{matrix} e_{m1} \\ e_{m2} \\ \vdots \\ e_{mn_m} \end{matrix} \end{array} \begin{array}{cccc} C_1 & C_2 & \cdots & C_m \\ e_{11} \cdots e_{1n_1} & e_{21} \cdots e_{2n_2} & \cdots & e_{m1} \cdots e_{mn_m} \\ \end{array}$$

$$\begin{array}{cc|cccc} & & C_1 & C_2 & \cdots & C_m \\ & & e_{11}\cdots e_{1n_1} & e_{21}\cdots e_{2n_2} & \cdots & e_{m1}\cdots e_{mn_m} \\ \hline C_1 & \begin{matrix} e_{11} \\ e_{12} \\ \vdots \\ e_{1n_1} \end{matrix} & W_{11} & W_{12} & \cdots & W_{1m} \\ W = C_2 & \begin{matrix} e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \end{matrix} & W_{21} & W_{22} & \cdots & W_{2m} \\ \vdots & \vdots & \vdots & \vdots & \vdots\vdots\vdots & \vdots \\ C_m & \begin{matrix} e_{m1} \\ e_{m2} \\ \vdots \\ e_{mn_m} \end{matrix} & W_{m1} & W_{m2} & \cdots & W_{mm} \end{array}$$

Figure 7.3: Limit Super Matrix General Form (Saaty & Vargas, 2006)

Step 6. Choosing the best alternative:

The associated limit super matrix defines the options and criteria's weights of significance. The alternative with the highest weight is defined as the best alternative in the problem of preference, and the alternative with the highest weight is specified as the most important criterion in the problem of weighting.

Table 7.1: Saaty’s Fundamental Scale (Saaty,1980)

Numerical Scale	Verbal Scale
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values

The criteria must be compared in pairs as stated in Step 3 to assess the effects of the criteria on the model in the ANP method. Scale 1-9 developed by Saaty (1980) is used in these paired comparisons shown in Table 7.1.

The pair comparison matrices A=(aij) are constructed using the ratings given in Table 7.1 as shown below to compute the priorities of the components generating those matrices in next actions:

$$\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{21} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \text{ where } a_{11} = \frac{1}{aij} \forall i,j = 1,\dots, a_{ii} = 1 \forall i = 1,\dots,n \qquad (4)$$

If the decisions are compatible, then:

$$a_{kj}a_{11kj} = a_{ij} \quad \forall i,j,k = 1,\dots.,n \qquad (5)$$

The following could be expressed for all the elements in this matrix:

$$a_{ij} = {}^{w_i}/_{w_j} \forall i,j = 1,\dots,n \qquad (6)$$

And this lead to the following equation:

$$\begin{bmatrix} {}^{w_1}/_{w_1} & {}^{w_1}/_{w_2} & \cdots & {}^{w_1}/_{w_n} \\ {}^{w_2}/_{w_1} & {}^{w_2}/_{w_2} & \cdots & {}^{w_2}/_{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ {}^{w_n}/_{w_1} & {}^{w_n}/_{w_2} & \cdots & {}^{w_n}/_{w_n} \end{bmatrix} \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} = n \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} \qquad (7)$$

An easy way to get a priority vector approximation is to employ a matrix A column normalization and then take the rows ' arithmetic mean. Accordingly:

$$W_i = \sum_{k=1}^{n} \left[{}^{a_{ij}} \Big/ {}_{\sum_{k=1}^{n} a_{ij}} \right] / n \qquad (8)$$

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{\sum_{j=1}^{n} a_{ij} . w_j}{w_i} \qquad (9)$$

A matrix's CI is demonstrated by:

$$CI = \frac{\lambda_{\max} - \mathrm{n}}{\mathrm{n} - 1} \qquad (10)$$

And by comparing the CI values shown in Table 7.2, the CR is obtained. The CI and CR were discovered with λ max value.

$$CR = CI/CR \qquad (11)$$

$$\lim_{n \to \infty} (W)^{2k+1} \qquad (12)$$

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

Table 7.2: Saaty’s CI Values

7.5. TOPSIS Method to Evaluate Alternatives

TOPSIS is a decision-making method which is employed with multiple criteria. According to (Hwang &Yoon, 1981) that developed the TOPSIS methodology, the fundamental logic of TOPSIS is to describe the positive and the negative ideal solution. The positive optimal solution offers a consequence that enhances the benefit criteria and reduces the cost criteria while the negative optimal solution enhances the cost criteria and reduces profit criteria. The optimum alternative presents the one, which has the shortest distance to the optimal solution and has the ultimate distance to the negative optimal solution. The method goes to the solution by implementing six main steps.

The implementation stages of the TOPSIS method can be summarized as follows: (Prakash & Barua, 2015).

Step 1: Generation of Decision Matrix (A)

In the decision matrix, there are decision points whose superiorities are listed and in the columns, assessment criteria are used in decision-making. Matrix A is the decision-maker's first matrix. The matrix of the decision shows as below:

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{21} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \tag{13}$$

In matrix A_{ij}, m presents number of points of judgment and n presents number of variable of assessment.

Step 2: Generating a Normalized Decision Matrix (R):

The matrix is normalized by dividing the square root of the sum of the squares of the values in the column with each value in the matrix of decision. Below formula is employed for normalization:

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \tag{14}$$

The standard decision matrix indicated by R is expressed as follows:

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{15}$$

Step 3: Creation of Weighted Normalized Decision Matrix (V):

The weight values (w_i) of the parameters for the assessment are described. The sum of the weight values of the criteria is equal to 1. ($\sum_{i=1}^{n} w_i = 1$)

Later, multiply the elements in each column of the R matrix by the value to produce the V matrix. The V matrix is demonstrated as following:

$$V_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_n r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_n r_{mn} \end{bmatrix} \tag{16}$$

Step 4: Developing Ideal (A^*) and Negative Optimal (A^-) Solutions:

The TOPSIS model implies that there is a monotonous rising or declining trend in each evaluation variable.

In order to construct the optimal solution collection, the largest of the weighted evaluation variables in the V matrix, in the column values (if the corresponding evaluation factor is minimized, the smallest) is selected. The optimal solution collection is demonstrated in the below formula:

$$A^* = \{(\max v_{ij} |\ j \in J), (\min v_{ij} |\ j \in J')\} \qquad (17)$$

The result that is calculated by equation (14) is shown as below:

$$A^* = \{v_1^*, v_{2,}^* \ldots, v_n^*\} \qquad (18)$$

The set of negative ideal solutions is formed by selecting the smallest of the weighted evaluation variables in the V matrix, in the column values (if the corresponding evaluation variable is maximized, the largest). The negative optimal solution collection is presented in the following formula.

$$A^- = \{(\min v_{ij} |\ j \in J), (\max v_{ij} |\ j \in J')\} \qquad (19)$$

The result that is calculated by equation (16) is shown as below:

$$A^- = \{v_1^-, v_{2,}^- \ldots, v_n^-\} \qquad (20)$$

Both formulas show the profit (maximization) and the expense (minimization).

The ideal and negative optimal solution set comprises evaluation factors, namely m elements.

Step 5: Calculating the separation distance from the ideal and negative ideal solution for each alternative:

Evaluating the deviations of the assessment variable value from the ideal and negative ideal solution collection for each decision point, Euclidean Distance Method is introduced. The values of deviation on the decision points generated are called ideal separation (S_i^*) and negative optimal separation (S_i^-) measure. The calculation of the optimal separation (S_i^*) measure is shown in the formula (21) and the calculation of the negative ideal separation (S_i^-) measure is shown in the equation (22).

$$S_1^* = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^*)^2} \tag{21}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2} \tag{22}$$

The count of S_i^* and S_i^- are naturally as many as the number of decision points.

Step 6: Calculation of relative proximity to ideal solution:
The positive and negative ideal separation measures are employed to determine each decision's distance to the ideal solution. (P_i^*). The computation of the propinquity to the ideal solution is demonstrated in below equation:

$$P_i^* = \frac{S_i^-}{S_i^- + S_i^*} \tag{23}$$

The result of P_i^* gets a value within the range of $0 \ll P_i^* \ll 1$ and $P_i^* = 1$ indicates the absolute proximity of the respective decision point to the ideal solution and $P_i^* = 0$ shows absolute proximity of the corresponding decision point to the negative ideal solution.

8. APPLICATION

8.1. Background

The assessment of the TBL effect on in-flight entertainment systems in area of SSCM is considered in a multiple-step methodology.

-For economical perspective, a cost-benefit analysis is done.
-For customer perspective, a survey analysis is conducted.
-For environmental perspective, an environmental analysis is completed.

Finally, to select between the two in-flight entertainment systems, a MCDM problem with two phases is implemented.

-For evaluating weights of criteria, ANP is implemented.
-For ranking alternatives, TOPSIS method is computed.

As a first step, a cost-benefit analysis is implemented to examine two different IFE systems' efficacy by comparing economic criteria. As a second step, survey is applied to potential passengers to determine the level of pleasure on two IFE systems separately by depending customer criteria. As a third step, a calculation assessment is applied in order to evaluate impacts of environmental criteria with two different IFE systems.

As a final step, ANP and TOPSIS are employed as two phase decision making problem. ANP is used to assess the ranking of the parameters by measuring their weights on the basis of data gathering from experts. TOPSIS is applied for evaluating the criteria and to rank the alternatives as a decision support model.

Although decision making can be done by ANP itself, but MCDM process can be improved if it is integrated with many other decision support tools. The main goal of implementing TOPSIS additionally instead of continuing with ANP is gaining more particular and comprehensive results by integrating outcomes of ANP and TBL evaluations in TOPSIS methodology to finalize the general application.

In the thesis, the opinions of three experts were used for the whole model. Additionally, literature reviews on sustainability, SCM, TBL effect in aviation and in-flight entertainment systems were considered as main resources.

The experts work as experienced chief engineers at Turkish Airlines Technic Inc. that is producing and selling IFE systems with the aim of localization of aircraft components in Turkey. During the study, decision-makers worked together to make common decisions in various MCDM models.

Data collection from experts to calculate the weights of criteria is an important process to gain more accurate results so experts must be compatible with each other. In the thesis, experts were chosen from the team that is realizing comprehensive IFE projects inside the aircrafts.

The experts are working at the departments of mechanical design, avionics design and system design as chief engineers for more than five years in the project team. The experts dominate related design, calculation and certification steps with making consensus about related subjects by depending on general aviation rules. Also, the experts studied at the departments of mechanical engineering, electrical engineering and aircraft engineering therefore they have general technical background to implement related projects correctly. Two of our experts have degree of Master Science at the mentioned departments.

According to the information about the experts, it seen that the experts and their educational and professional background are compatible to implement the projects inside the aircrafts and to collect the data to conduct ANP analysis for the thesis.

Turkish Airlines Technic Inc. is part of the brand community of Turkish Airlines and established in 2006. The brand, which is one of the leading aviation service suppliers in the world, provides its customers with its expert team; offers high quality and comprehensive maintenance, repair, modification and reconfiguration services. The company operates in two locations in Istanbul, at Istanbul Airport and at Sabiha Gökçen Airport. In addition to engineering and maintenance activities, the company provides services in many areas of component maintenance and replacement support, design, certification and production. The company is certified through European Aviation Safety Agency (EASA), Federal Aviation Agency (FAA) and Turkish Directorate General of Civil Aviation (DGCA) for executing the performance of maintenance services. Moreover, it also has the distinction of being a “Maintenance Training and Examination Organization” within the scope of EASA Part-147 and SHY-147.

Our aim for the research is choosing the most advantageous IFE system by depending on the conception of SSCM. There are two possible alternatives which support sustainability of the company and IFE industry: Wireless IFE system (A1) and Wired IFE system (A2).

In the general methodology, the company makes a decision depending on the following three main criteria and fourteen sub-criteria. The main criteria are classified as economical (C1), customer (C2), environmental (C3). The sub-criteria are fuel cost (C11), indirect cost (C12), labor cost (C13), maintenance cost (C14), material cost (C15), benefit (C16), equipment variety (C21), flight safety (C22), preparation time (C23), CO_2 gas emission (C31), fuel amount (C32), material amount (C33), noise effect (C34), electromagnetic interference effect (C35). The two alternatives Ai (i = 1, 2) are analyzed by employing the ANP and TOPSIS methods.

Detailed information about those variables will be given in the sections below.

8.2. Evaluation of Criteria by Triple Bottom Line Approach

8.2.1. Assessment Criteria and Alternatives for the Proposed Methodology

There are three main criteria as economical, customer and environmental that are taken into consideration to evaluate SSCM in aviation sector. The goal of the assessment is to determine the best IFE system in terms of the three pillars of sustainability. The alternatives and the three criteria are demonstrated in figure 8.1.

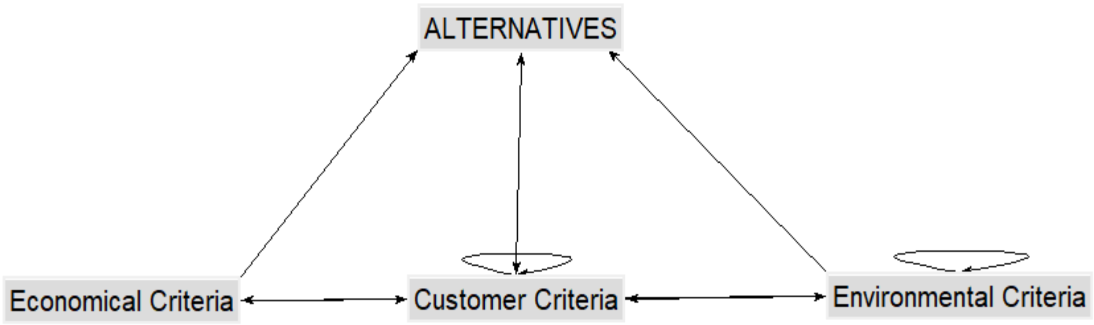


Figure 8.1: Thesis Modelling Structure

- Criteria 1 - Economical:

Material Cost: From an economic perspective, the highest cost comes from material purchases. Airplanes that increase their weight with the use of materials cause more money to be spent economically, so airline companies always try to increase passenger satisfaction with lighter systems and lower costs. Some of the materials used to build systems: Visual display unit (VDU), Remote control device (RCD), noise canceling headphone, seat electronic box (SEB).

Labor Cost: This defines total man/hour cost of employee’s that work on projects until IFE systems being integrated to the aircraft and delivered to the customers.

Fuel Cost: Since the increase in the aircraft weight increases the amount of fuel usage, the cost of fuel increases. Airlines are making innovative efforts to reduce fuel costs. This provides companies productive development advantages for the future.

Maintenance Cost: Systems include the cost of maintenance works to solve problems in a short time that may arise when used in airplanes and to check the systems in general at certain time intervals.

Indirect Cost: This covers the costs of electricity, water, natural gas and training of employees that may arise during the process until the systems are produced and their integration into aircraft is completed.

- Criteria 2 - Environmental:

Material Amount: Any system to be integrated in aircraft increases the aircraft weight directly. This situation indirectly affects the environment negatively.

Fuel Amount: As the amount of material used and the aircraft weight increase, the fuel amount used increases. In this case, the use of fuel increases the negative impact on the environment.

CO_2 Gas Emission: Increased use of fuel increases the amount of CO_2 gas released into the environment. This situation causes great harm to the environment.
Noise Effect: This defines a damaging effect produced by any aircraft or its components during the diverse periods of a flight. Aircraft manufacturers try to find noise reduction techniques by using different kind of materials.

**Electromagnetic Interference Effect:* The effect of electromagnetic interference differs by depending on impact of the materials inside the aircraft.

- Criteria 3 - Customer:

**Entertainment Variety:* Airline companies prefer to increase the variety of entertainment they offer to customers in order to increase customer satisfaction.

Equipment Variety: Rising customer satisfaction can be provided by increasing in the number of equipment in which passengers can use and enjoy during the flight.

Preparation Time: The ease of use, speed and convenience of the systems used in the aircraft increases the customer satisfaction.

Flight Safety: Flight safety is a crucial factor for airline companies and passengers. Many international rules have been established to ensure safety. Based on these rules, the systems are integrated into the aircraft. Ensuring flight safety and reflecting them to customers is the first step to satisfy customers.

- Alternative 1 – *Wired* IFE *System*: That is a traditional and well-known kind of IFE system. The system is composed of embedded hardware thus it demonstrates expensive and heavy results in aircraft industry.

- Alternative 2 – *Wireless IFE System*: That is a newly discovered kind of IFE system. The system provides passengers to use PED's during the flight so it is much inexpensive and lighter than other IFE types.

8.2.2. Evaluating the IFE System Alternatives with Cost-Benefit Analysis

C/B Step 1 - Economical inputs, outputs and network structures for two systems are given in Figure 8.1. In this part, economical and some of environmental criteria are used. The related criteria are defined in Chapter 8.2.

C/B Step 2 – For two systems, envisaged cost and benefit are calculated.

As a common calculation for wireless and wired IFE systems, material amounts are evaluated by assuming that the systems are implemented in a narrow body aircraft. Secondly, fuel costs that are occurred in a year for using the two systems separately in the aircraft are calculated by accepting the fuel cost $108 for a kg of weight. The details are demonstrated in Table 8.1.

Table 8.1: Material Amount - Fuel Cost Calculation

	A1	**A2**
Material Amount (C33)	45 kg	750 kg
Fuel Cost (C15)	$4.860	$81.000

It is assumed that the two different systems have the same amount of sales in five years as seen in Table 8.2.

Table 8.2: Sales Amounts Per Year

Years	2018	2019	2020	2021	2022
Sales Amount	1	3	5	7	9

Accordingly, for five years, costs and benefits that can occur for wired and wireless systems are presented in Table 8.3. Below cost distribution values are generated by hypothesis based on some real values taken from the company.

As a result, in below section, Table 8.3 and 8.4 are demonstrated.

Table 8.3: Cost Distribution Assessment

Years	2018		2019		2020		2021		2022	
	A1	**A2**	**A1**	**A2**	**A1**	**A2**	**A1**	**A2**	**A1**	**A2**
C11	$4.860	$81.000	$14.580	$243.000	$24.300	$405.000	$34.020	$567.000	$43.740	$729.000
C12	$1.000.000	$3.000.000	$1.500.000	$3.500.000	$1.500.000	$3.500.000	$1.500.000	$3.000.000	$1.500.000	$3.000.000
C13	$400.000	$1.000.000	$800.000	$1.500.000	$1.000.000	$2.000.000	$1.500.000	$2.500.000	$2.000.000	$3.000.000
C15	$400.000	$1.000.000	$1.200.000	$3.000.000	$2.000.000	$5.000.000	$2.500.000	$7.000.000	$3.000.000	$9.000.000
C16	$1.000.000	$2.000.000	$3.000.000	$6.000.000	$5.000.000	$10.000.000	$7.000.000	$14.000.000	$9.000.000	$18.000.000

Table 8.4: Estimation of Cumulative Benefits and Costs

Years	2018		2019		2020		2021		2022	
	A1	**A2**	**A1**	**A2**	**A1**	**A2**	**A1**	**A2**	**A1**	**A2**
PV of Costs	$1.752.291	$5.233.430	$3.414.580	$8.243.000	$4.877.961	$10.587.379	$5.687.642	$12.316.901	$6.446.019	$14.394.263
PV of Benefits	$1.030.000	$2.060.000	$3.000.000	$6.000.000	$4.900.000	$9.708.738	$6.598.171	$13.196.343	$8.236.274	$16.472.550
Cumulative PV of Costs	$1.752.291	$5.233.430	$5.166.871	$13.476.430	$10.044.832	$24.063.809	$15.732.474	$36.380.709	$22.178.493	$50.774.973
Cumulative PV of Benefits	$1.030.000	$2.060.000	$4.030.000	$8.060.000	$8.930.000	$17.768.738	$15.528.171	$30.965.081	$23.764.445	$47.437.630
Net Benefits	-$722.291	-$3.173.430	-$414.580	-$2.243.000	$22.039	-$878.641	$910.529	$879.442	$1.790.255	$2.078.287
Net Cumulative Benefits	-$722.291	-$3.173.430	-$1.136.871	-$5.416.430	-$1.114.832	-$6.295.071	-$204.303	-$5.415.629	$1.585.952	-$3.337.342

C/B Step 3-4-5: Present value of costs and benefit are calculated for two systems for each five year. After that, net benefits and net cumulative benefits are calculated as shown in Table 8.4.

For A1 alternative, Table 8.4 shows that in 2020 the system will start to make net profits progressively and in 2022 according to the net cumulative benefit, the system will continue to bring increasing benefits. Below, the Figure 8.2 shows that in year three, PV value of benefits and costs are balanced almost equally.

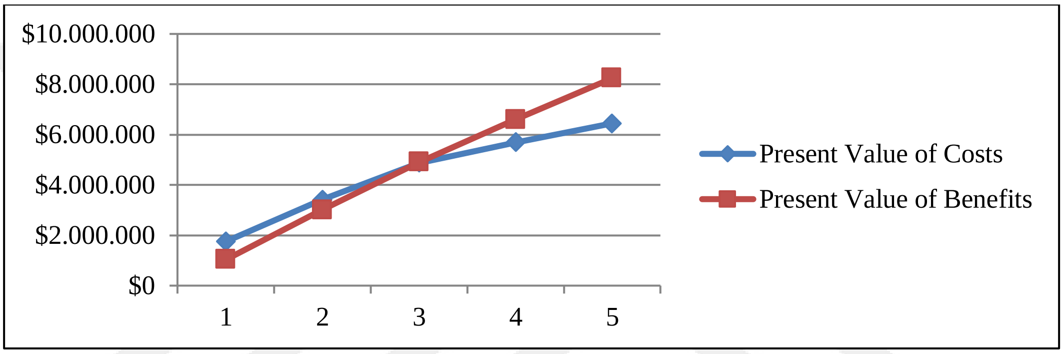


Figure 8.2: Comparison of Cost and Benefit for Wireless IFE

For A2 alternative, Table 8.4 shows that in 2021, the net benefit will begin to progress positively. Otherwise, in respect of the net cumulative benefits, it can be said that the system will not totally bring net benefits until the end of the year 2022. Below, the Figure 8.3 shows that in year 4, PV value of benefits and costs are estimated approximately.

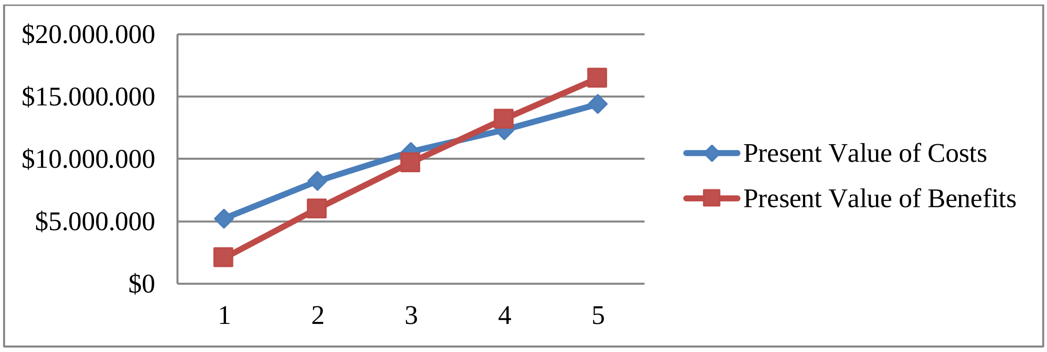


Figure 8.3: Comparison of Cost and Benefit for Wired IFE

C/B Step 6: As a result, ratio of cost and benefit for two IFE systems is demonstrated as below in Table 8.5.

For A1 alternative, the ratio is calculated as less than one that means the system is profitable and is bringing benefit in years.
For A2 alternative, the ratio is calculated as more than one that shows the system is not beneficial and is not providing profits in five years.

Table 8.5: Calculation of Ratio of Cost and Benefit

	A1	**A2**
Total PV of Costs	$22.178.493	$50.774.973
Total PV of Benefits	$23.764.445	$47.437.630
Ratio of Cost and Benefit (C/B)	0,93	1,07

Consequently, firstly, C/B analysis demonstrated that wireless IFE system (A1) is found more beneficial than wired IFE system (A2). Secondly, wireless IFE system (A1) brings net profit earlier than wired IFE system (A2) does and will contribute to the company much positively in the long term.

8.2.3. Evaluating the IFE System Alternatives with Environmental Analysis

E/A Step 1 - Environmental criteria are defined in Chapter 8.2 for two systems.

E/A Step 2 - Material amount generated two kind of IFE systems is calculated. For systems, components, equipments,seats and cabling factors are taken into consideration. Those factors’ real values are obtained from company documents.

E/A Step 3 - Fuel amount that can be expended in a narrow body aircraft for a flight when using wired IFE or wireless IFE is estimated. While doing calculation, it is assumed that unit fuel cost is $759/ton. Accordingly, it is determined that 142 kg fuel amount used while carrying a kg weight for a year. The assumptions of data are originated by company insights.

E/A Step 4 -The amount of CO_2 emission is calculated by depending on the results of step 2 and 3 and shown. In calculation, it is assumed by depending on company insights that thanks to each kg of fuel saved, 3,16 kg/km of CO_2 emissions are prevented.

E/A Step 5 - Lastly, electromagnetic interference effect and noise effect values are compared for two IFE systems according to experts' knowledge and approach at company.

Consequently, the result of the calculations is as given below in Table 8.6.

Table 8.6: Environmental Criteria Evaluation

	A1	**A2**
CO2 Gase Emission (C31)	20.192 kg/km	336.540 kg/km
Fuel Amount (C32)	6.390 kg	106.500 kg
Material Amount (C33)	45 kg	750 kg
Electormagnetic Interferance Effect (C34)	1	7
Noise Effect (C35)	3,4 dB	2,2 dB

According to the environmental analysis, it is seen that wireless IFE (A1) is more sustainable in terms of environmental criteria than wired IFE (A2). The evaluation of criteria indicate that when using wireless IFE, material amount in the aircraft occurs much lighter than using wired IFE. Material amount criteria (C33) stimulates fuel amount and CO_2 gas emission criteria in direct proportion.

Thanks to lighter material usage in wireless IFE system, used fuel amount is as well generated much less when using wireless IFE than using wired IFE. Additionally, with lighter material usage and less fuel amount used, the wireless IFE system gives less CO_2

into the atmosphere. Those criteria support each other in positive way in environmental aspects.

Electromagnetic interference effect (C34) demonstrates radioactive effect sent out of used materials during the flight. Using wireless IFE spreads less negative electromagnetic interference impact inside the aircraft than using wired IFE. The comparison of two systems is made by gathering data from the company.

Noise effect of implementing two systems is determined while gathering related data from experts. According to data, installing complex cabling systems conduce more noise spreading. Wireless IFE has less complex machinery, thus using wireless IFE system cause less noise inside and outside of an aircraft than using wired IFE.

As a consequence, by evaluating environmental criteria, the analysis demonstrates that wireless IFE system is more preferable and environmentalist than wired IFE system. By focusing on decreasing material amount, thanks to impulse between criteria, more sustainable products can be produced and those products can provide ecology more positive impacts.

8.2.4. Evaluating the IFE System Alternatives with Survey Analysis

S/A Step 1 – Customer criteria are defined in Chapter 8.2 for two systems.

S/A Step 2 – To evaluate two systems, survey questions are prepared by depending on related customer criteria. Questions are applied to potential customers in different occupational groups with age range of 20-70 for two systems separately. The scope based on customer criteria is demonstrated as below in Table 8.7. Also, survey questions can be found in Figure A.1.1, in the Appendix.

Table 8.7: Scope of Survey Analysis

Pleasure in using PEDs or seat back screen during the flight
Satisfaction with equipment variety for systems
Reliance in the use of systems during flight
Satisfaction with the ease of use of the entertainment systems

S/A Step 3 – Survey results are compared for two systems on the basis of each customer criteria.

S/A Step 4 – The analysis results of each customer criteria are approximately finalized with “out of 10” version. The result of the survey evaluation is as given in Table 8.8.

Table 8.8: Survey Evaluation Results

	A1	**A2**
Equipment Variety (C21)	9 out of 10	6 out of 10
Flight Safety (C22)	5 out of 10	7 out of 10
Preparation Time (C23)	4 out of 10	8 out of 10

The aim of the customer survey is to determine satisfaction level of potential passengers when they use wireless and wired IFE systems. In aspect of equipment variety criteria (C21), wireless IFE system present more pleasure than wired IFE system. Otherwise, in aspect of flight safety (C22) and preparation time (C23) criteria, wired IFE system takes more attention from customers than wireless IFE.

According to survey results, from equipment variety aspect, using wireless IFE system is seen more attractive than wired IFE system. Customers use their smart devices constantly, thus they prefer to use PEDs during the flights as well. Potential customers substantially prefer watching movie, listening to music, gaming and reading newspapers on their PEDs more than seat back screens.

In prospect of flight safety criteria, with the view of passengers, it is determined that using wired IFE is perceived safer than wireless IFE. Taking PEDs into aircrafts comes interesting but they do not provide much reliance to customers during the flight.

From view of preparation time, it is understood that for customers, using wired IFE system is easier than wired IFE. Wireless IFE is a new system and requires to download an application before the flight because of those reasons, this system makes customers less comfortable than wired IFE. Satisfaction level with the ease of using wired IFE is much more than using wireless IFE.

In conclusion, wireless IFE system is taking much attention from customers thanks to being a technological invention. Otherwise, there some concerns about using wireless IFE but in time, by the supports of airline companies, recognition, reliance and convenience level of the system can be enhanced more and more.

8.3. Evaluation of Criteria Weights and Alternatives by MCDM Approach

8.3.1. Weighting the Criteria with ANP Method

ANP- Step 1. Assessment criteria, explications and network structures are presented in Figure 7.2.

ANP- Step 2. Experts agree that the parameters supporting the ANP methodology must be compared in binary. For the implementation of ANP, a binary matrix for comparison has been established. The priority score is acquired by the decision makers using the essential 1–9 scale described by Saaty’s. The final consensus results of experts are given in Appendix tables from A.2.1 to A.2.2.

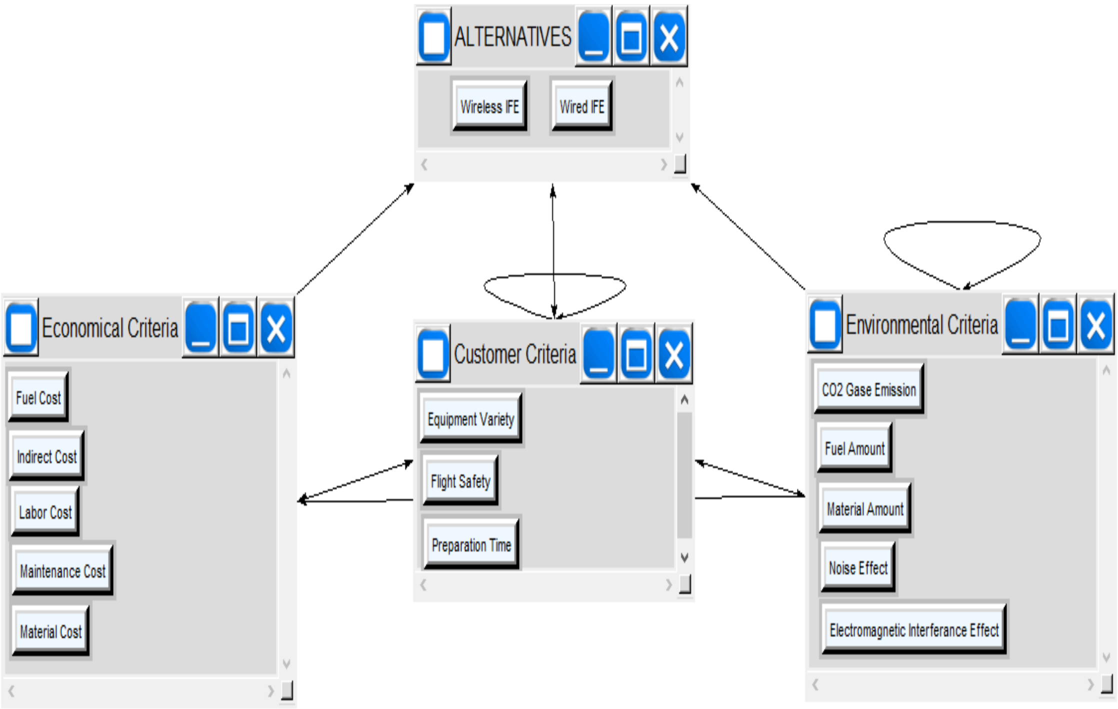


Figure 8.4: ANP Network Structures

The network given above contains dependent variables from each different node. The dependence relationship between criteria is demonstrated in table 8.9 as below with sections of influenced and influencing criteria.

Table 8.9: Dependent Criteria Assessment

Influenced Criteria	**Influencing Criteria**
fuel cost (C11)	equipment variety (C21) and fuel amount (C32)
indirect cost (C12)	equipment variety (C21) and material amount (C33)
labor cost (C13)	equipment variety (C21)
maintenance cost (C14)	equipment variety (C21)
material cost (C15)	equipment variety (C21) and material amount (C33)
equipment variety (C21)	wireless ife (A1) and wired ife (A2).
flight safety (C22)	equipment variety (C21),noise effect (C34),radiation effect (C35) and maintenance cost (C14)
preperation time (C23)	equipment variety (C21)
CO2 gase emission (C31)	fuel amount (C32) and material amount (C33)
fuel amount (C32)	material amount (C33) and equipment variety (C21)
material amount (C33)	equipment variety (C21)
noise effect (C34)	material amount (C33)
radiation effect (C35)	equipment variety (C21)

In ANP methodology, as shown in the application, the decision making problem is based on a network structure. Dependencies between factors and internal dependencies within the factors are also examined in the modelling stage.

For the calculation of ANP, the Super Decision tool that is AHP and ANP based software for decision making is employed.

Comparison of supremacy is made on the basis of all alternatives in the calculation of the ANP system between main criteria and subcriteria. The weighted super matrix is created after all benchmarks are evaluated. Weights are determined for all subcriteria as a result of all processes. Comparison results of main criteria and limit super-matrix are as given below in Table 8.10 and 8.11.

Table 8.10: The Comparison Results of Main Criteria

	Weights
Economical (C1)	0.254
Customer (C2)	0.490
Environmental (C3)	0.256

Table 8.11: The Limit Super-Matrix

	A1	A2	C11	C12	C13	C14	C15	C21	C22	C23	C31	C32	C33	C34	C35
A1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.24776	0.24776	0.00000	0.00000	0.00000	0.00000	0.24776	0.00000	0.00000
A2	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.37885	0.37885	0.00000	0.00000	0.00000	0.00000	0.37885	0.00000	0.00000
C11	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.02129	0.02129	0.00000	0.00000	0.00000	0.00000	0.02129	0.00000	0.00000
C12	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00083	0.00083	0.00000	0.00000	0.00000	0.00000	0.00083	0.00000	0.00000
C13	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00139	0.00139	0.00000	0.00000	0.00000	0.00000	0.00139	0.00000	0.00000
C14	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.01107	0.01107	0.00000	0.00000	0.00000	0.00000	0.01107	0.00000	0.00000
C15	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.06047	0.06047	0.00000	0.00000	0.00000	0.00000	0.06047	0.00000	0.00000
C21	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.08097	0.08097	0.00000	0.00000	0.00000	0.00000	0.08097	0.00000	0.00000
C22	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.04813	0.04813	0.00000	0.00000	0.00000	0.00000	0.04813	0.00000	0.00000
C23	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.05421	0.05421	0.00000	0.00000	0.00000	0.00000	0.05421	0.00000	0.00000
C31	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.02249	0.02249	0.00000	0.00000	0.00000	0.00000	0.02249	0.00000	0.00000
C32	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.01834	0.01834	0.00000	0.00000	0.00000	0.00000	0.01834	0.00000	0.00000
C33	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.03653	0.03653	0.00000	0.00000	0.00000	0.00000	0.03653	0.00000	0.00000
C34	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00546	0.00546	0.00000	0.00000	0.00000	0.00000	0.00546	0.00000	0.00000
C35	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.01223	0.01223	0.00000	0.00000	0.00000	0.00000	0.01223	0.00000	0.00000

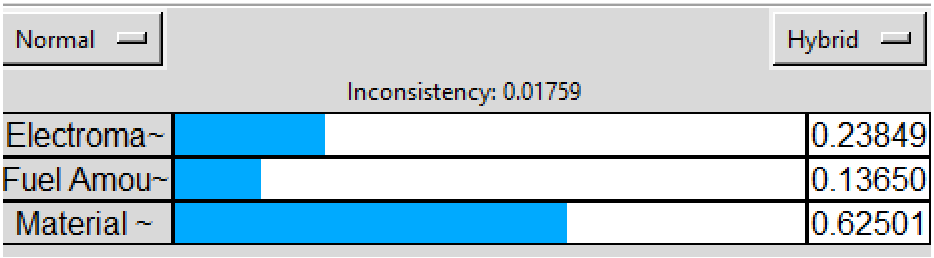
ANP-Step 3. The ANP approach has been applied to the mathematical model. The result from the experts ' common opinion and the weights of the parameters have been determined as in Table 8.12.

Table 8.12: The Standardized Matrix

Criteria	Normalized by Cluster	ANP Weights
C11	0.22399	0.05701
C12	0.00868	0.00220
C13	0.01466	0.00373
C14	0.11647	0.02964
C15	0.63621	0.16193
C21	0.44169	0.21684
C22	0.26259	0.12891
C23	0.29573	0.14518
C31	0.23662	0.06042
C32	0.19299	0.04912
C33	0.38434	0.09782
C34	0.05741	0.01461
C35	0.12864	0.03274

ANP-Step 4. The inconsistency ratio is computed at this implementation level.
Some discrepancies in the final matrix of judgments can not be avoided because numerical values are derived from individuals ' subjective preferences. The question is how acceptable is the amount of inconsistency. ANP is calculating a consistency ratio (CR) for this purpose.

From the analysis in super-decision tool, an example of inconsistency value shown in figure 8.5. Inconsistency value is less than 0.1 which means appropriate to continue the ANP research.



Normal

Hybrid

Inconsistency: 0.01759

Electroma~ 0.23849

Fuel Amou~ 0.13650

Material ~ 0.62501

Figure 8.5: Inconsistency Ratio Evaluation

7.3.2. Evaluating the IFE System Alternatives with TOPSIS Method

Two alternative IFE systems are reviewed and ranked according to the TOPSIS model by using the parameters weights observed with ANP.

TOPSIS- Step 1. The decision matrix is set as given in Appendix table A.3.1.

TOPSIS-Step 2-3. The weighted standardized alternative decision matrix is calculated by multiplying the standardized decision matrix and the weights as shown in Table 8.13. The standardized weighted decision matrix is computed.

Table 8.13: The Weighted Normalized Matrix

	A1	**A2**
C11	0.0034	0.0037
C12	0.0009	0.0034
C13	0.0018	0.0032
C14	0.0072	0.0036
C15	0.0554	0.0035
C21	0.2057	0.0012
C22	0.0749	0.0030
C23	0.0844	0.0030
C31	0.0036	0.0037
C32	0.0028	0.0037
C33	0.0059	0.0037
C34	0.0021	0.0037
C35	0.0275	0.0020

TOPSIS-Step 4-5-6. The values of Si+, Si-, Pi are calculated by employing equations (21), (22) and, (23) by TOPSIS method. Table 8.14 indicates the final solutions as below. In the model, each criteria are evaluated to determine their maximizing or minimizing effects on ranking of alternatives.

Table 8.14: The Final Results of TOPSIS

	Si+	Si-	Pi	Rank
A1	0.058	0.231	0.799	1
A2	0.058	0.011	0.169	2

In conclusion, Wireless IFE system (A1) outcomes the most sustainable alternative among two alternatives with 0.799, whereas wired in flight system (A2) is ranked as second one with 0.169 as the final performance value.

8.4. Results and Discussion

In this research, evaluation of SSCM in aviation sector using multi-phased methodologies is implemented in five steps for a case study in the fields of sustainability and TBL effect of the in-flight entertainment systems.

In the study, economical, customer and environmental prospects are set by literature review and experts’ opinions. In the first phase, according to cost-benefit analysis, the ratio of C/B of wireless IFE (A1) and wired IFE (A2) result as 0.93 and 1,07 respectively. The results imply that alternative (A1) is more beneficial and sustainable than alternative (A2). Additionally, total PV of benefits of alternative (A2) result almost double of alternative (A1) and total PV of costs of alternative (A2) result approximately double of alternative (A1).

In the second phase, according to survey analysis, it is determined that the satisfaction from Equipment Variety (C21) is higher when customers use wireless IFE system (A1), trust in Flight Safety (C22) is more when customers use wired IFE system (A2) and satisfaction with the ease of using wired IFE system (A2) is greater than wireless IFE system (A1).

In the third phase, with environmental analysis, it is shown that when integrating wired IFE system (A2) in airplanes, CO_2 gas emission (C31), fuel amount (C32), material amount (C33) and electromagnetic interference effect (C34) values outcomes much over than integrating wireless IFE system (A1). Otherwise, the value of noise effect (C35) results less while using wired IFE system (A2).

In the fourth phase, economical (C1), customer (C2) and environmental (C3) criteria weights are evaluated by ANP method as 0.254, 0.49 and 0.256 respectively. The weight of customer criteria results much greater than others. This result means that customer criteria (C3) influences as the most important criteria to determine what the best IFE system is. In addition to this, through sub-criteria, the ANP weights of equipment variety (C21), material cost (C15), preparation time (C23) and flight safety (C22) are resulted as much higher than other sub-criteria as 0.21684, 0.16193, 0.14518 and 0.12891 separately. Lastly, it means that equipment variety (C21) effects to choose the most preferable IFE system as the first important sub-criteria.

In the fifth phase, TOPSIS method is implemented to rank alternatives by using ANP weights and criteria evaluation results gained from cost-benefit, survey and environmental analysis. As a result of final evaluation results of TOPSIS, wireless IFE system (A1) ranks as the most sustainable and preferable one with performance value of 0.799. Wired IFE system (A2) is ranked as second alternative with performance value of 0.169.

Limitation in the study is that some data in the thesis are generated with assumptions but some data are taken from experts inside the company.

9. CONCLUSION

Sustainable supply chain management is a significant subject. Accordingly, innovational improvements are getting attention day by day to enhance triple bottom line sustainability and maintain sustainable products, especially, in aviation sector. To deal with SSCM, many researches have been conducted in the recent years.

In this thesis, an integrated triple bottom line approach and MCDM assessment have been studied for evaluation of sustainable in-flight entertainment systems in Turkey.

Sustainable supply chain management is fundamentally examined in aspect of TBL approach. The structural model of the study is generated on the criteria and the alternatives for analyzing sustainability of the systems. Cost benefit, surveying, economical analysis, ANP and TOPSIS methods are applied. The criteria and alternative IFE systems are evaluated by depending on triple bottom line sustainability. The most sustainable alternative is found as wireless IFE system.

As a result, the study presented multi-phase methodologies to analyze sustainability of IFE systems and to determine the preferable system by depending on criteria. The main contributions of the study are performing economical, customer experience and environmental analyses on basis of IFE systems; evaluating importance weights of criteria by implementing ANP method and lastly, by integrating results, proposing TOPSIS methodology for ranking alternatives.

The main limitation of this thesis is that, due to the lack of data, the actual data of the proposed system could not be used in every parts of the model. This limitation is aimed to be ineffective by proposing thesis model structure that focuses on multi areas and integrates different kind of methodologies.

The main contribution of this thesis is that currently there is not any study in the literature that integrates triple bottom line approach and MCDM analyses in area of sustainable supply chain management of in-flight entertainment systems. Integrated MCDM and triple bottom line evaluations in aviation sector have been advanced as presented in literature review section but for assessment of IFE systems has not been developed. With the contribution, a systematic approach have been constructed to determine and to maintain a more sustainable in-flight entertainment systems in aviation industry.

The subject of sustainable supply chain management in aviation sector by depending on triple bottom line approach can be enhanced in future researches by rising the number of criteria affecting the IFE systems, proposing different types of decision making methodologies and comparing international companies that produce IFE systems in aspect of sustainability of their products.

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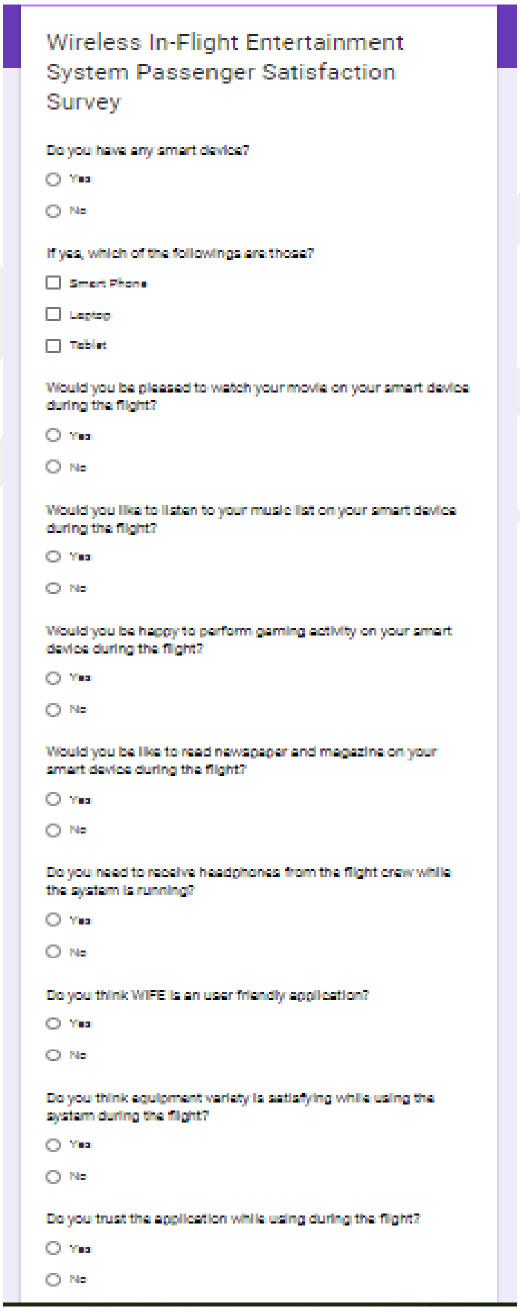
APPENDICE

Appendix A.



Wireless In-Flight Entertainment System Passenger Satisfaction Survey

Do you have any smart device?

○ Yes

○ No

If yes, which of the followings are those?

☐ Smart Phone

☐ Laptop

☐ Tablet

Would you be pleased to watch your movie on your smart device during the flight?

○ Yes

○ No

Would you like to listen to your music list on your smart device during the flight?

○ Yes

○ No

Would you be happy to perform gaming activity on your smart device during the flight?

○ Yes

○ No

Would you be like to read newspaper and magazine on your smart device during the flight?

○ Yes

○ No

Do you need to receive headphones from the flight crew while the system is running?

○ Yes

○ No

Do you think WIFE is an user friendly application?

○ Yes

○ No

Do you think equipment variety is satisfying while using the system during the flight?

○ Yes

○ No

Do you trust the application while using during the flight?

○ Yes

○ No

Figure A.1.1: Customer Survey Questions for WIFE System

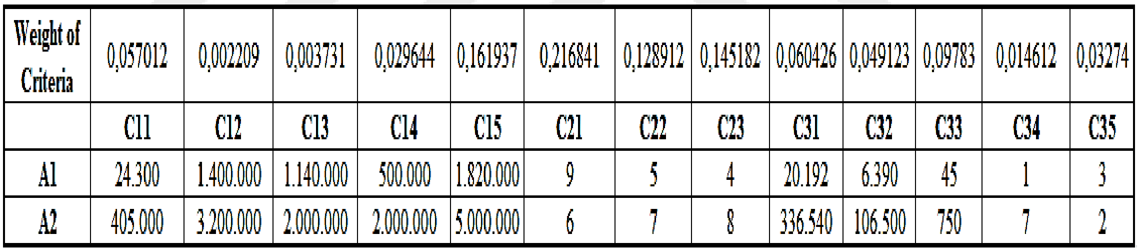
Table A.2.1: ANP Pairwise Comparisons Matrix (Main Criteria)

	Economical	Customer	Environmental
Economical	1,00	0,33	3,00
Customer	3,00	1,00	4,00
Environmental	0,33	0,25	1,00

Table A.2.2: ANP Pairwise Comparisons Matrix (Economical sub-criteria)

	Labor Cost	Material Cost	Indirect Cost	Fuel Cost	Maintenance Cost
Labor Cost	1,00	0,25	3,00	0,25	0,25
Material Cost	4,00	1,00	6,00	3,00	2,00
Indirect Cost	0,33	0,16	1,00	0,25	0,20
Fuel Cost	4,00	0,33	4,00	1,00	0,33
Maintenance Cost	4,00	0,50	5,00	3,00	1,00

Table A.3.1: TOPSIS Evaluation Matrix



Weight of Criteria	0,057012	0,002209	0,003731	0,029644	0,161937	0,216841	0,128912	0,145182	0,060426	0,049123	0,09783	0,014612	0,03274
	C11	C12	C13	C14	C15	C21	C22	C23	C31	C32	C33	C34	C35
A1	24.300	1.400.000	1.140.000	500.000	1.820.000	9	5	4	20.192	6.390	45	1	3
A2	405.000	3.200.000	2.000.000	2.000.000	5.000.000	6	7	8	336.540	106.500	750	7	2

BIOGRAPHICAL SKETCH

Elif Altın educated at Istanbul Okan University in the department of Industrial Engineering and at Universidade do Minho as an Erasmus Student. Currently, she is studying master's degree in Industrial Engineering at Galatasaray University and working at Turkish Airlines Technic Inc.

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