DETERMINATION OF KEY PERFORMANCE INDICATORS FOR MEASURING LIBYAN AIRPORTS SUCCESS

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Approval of the Graduate School of Natural and Applied Sciences, Atılım University.

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I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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ABSTRACT

DETERMINATION OF KEY PERFORMANCE INDICATORS FOR MEASURING LIBYAN AIRPORTS SUCCESS

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An airport is one of the most important modes of transportation and they have a large effect on local, regional, and national economies. According to several recent studies, the global air traffic density has registered rapid growth in recent years. Therefore, performance measurements in airport settings have been of paramount importance both in Libya and worldwide. This thesis proposes a framework to help decision makers in the Libyan airport industry with performance upgrades. The goals of this study are twofold: First, to develop a set of essential airport key performance indicators (KPIs) in five aspects of airport performance based on previous studies to help airport authorities in Libya with effective decisions regarding airport performance. Then, the AHP method is applied to determine KPI weights by summarizing the opinions of experts. Second, it provides a performance comparison between the three international airports in Libya (MJI, MRA, and LAQ) based on the comparison judgments of experts by using two different multi-criteria decision-making methods, namely AHP and Grey Theory. The results of this study have identified 17 Key Performance Indicators (KPIs) in five activity areas that, in their view, are the most important airport performance indicators in the present case study. The results also showed that MRA Airport performed better than the other two airports. MJI Airport ranked next followed by LAQ.

Keywords: Airport Key Performance Indicators (KPIs), AHP, Grey System theory, Libyan airports, Airport performance evaluation.

ÖZ

Libya Havalimanı Ana Performans Başarı Ölçümleri Göstergelerinin Belirlenmesi

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Havaalanları, en önemli ulaşım yollarından biridir ve yerel, bölgesel ve ulusal ekonomiler üzerinde büyük etkiye sahiptir. Yakın tarihli birkaç araştırmaya göre, küresel hava trafik yoğunluğu son yıllarda hızlı bir büyüme kaydetmiştir. Bu nedenle, havalimanı düzenlemelerinde performans ölçümü, gerek Libya'da gerekse dünya çapında büyük önem taşımaktadır. Bu tez, performans yükseltimi için Libya havaalanı sektöründeki karar verici şahıslara yardımcı olacak bir çerçeve önermektedir. Bu çalışmanın hedefleri iki yönlüdür: Birincisi, havaalanı performansı ile ilgili etkili kararlar ile Libya'daki havaalanı yetkililerine yardımcı olmak için daha önceki çalışmalara dayanarak havalimanı performansının beş yönü çerçevesinde temel havaalanı anahtar performans göstergelerinin (KPI'lar) bir setini geliştirmek olacaktır. Ardından uzmanların görüşlerini özetleyerek KPI ağırlıklarını belirlemek için AHP yöntemi uygulanacaktır. İkincisi, iki farlı çoklu ölçüte karar verme metotlarını, yani AHP, kullanım ile uzmanların mukayese yargılarına esas olan Libya'daki uluslararası üç havaalanı (MJI, MRA, ve LAQ) ve Grey Teorisi arasında bir performans mukayesesini sağlar. Bu araştırmanın sonuçları; kendi görüşleri olarak, bu durum araştırmasındaki çok önemli havaalanı performans göstergelerinin olduğu beş faaliyet alanında 17 Anahtar Performans Göstergesini (KPI) tanımladı. Sonuçlar keza MRA Havaalanının diğer iki havaalanından daha iyi hizmet verdiğini de gösterdi. MJI Havaalanı LAQ'den sonraki sıraya girdi.

Anahtar Kelimeler: Havaalanı önemli performans göstergeleri (KPI'lar), AHP, Grey Sistem teorisi, Libya havaalanları, Havaalanı performans değerlendirmesi.

To Soul of My Parents

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The airport industry has become a very important sector in the country because it can generate economic and social value. (Fasone, Giuffrè et al. 2012). During the last decades, the air transport industry has changed much and the number of flight movements includes air transport of passengers and cargo vastly increasing worldwide (Zietsman and Vanderschuren 2014) and (Bezerra and Gomes 2016). Airports Council International (ACI) expects that global air traffic will grow by about 5.2% per annum until 2029 (ACI 2016). On the other hand, the competition between airports has been increasing continually, so airports expend greater effort to attract as many airlines and airport users as possible in order to improve profitability. However, ineffective responses to the increasing demands for air travel may create significant congestion and thus affect the performance of an airport.

In this context, due also to increases in the demand for air travel and an increase in competition in the airport industry, airports do not only need to invest a large amount of money in creating changes in the size and capacity to deal with these challenges, they also need to optimize any available resources and develop new strategic plans, in addition to the need to reassess over time airport safety, airport logistics, and security and management. The key factor in achieving these requirements, making the airport reliable and working effectively is performance measurement (Bezerra and Gomes 2016); (Zietsman and Vanderschuren 2014) and (Andersson Granberg and Munoz 2013). Further, performance measurement has become a necessary activity in the airport industry and it has evolved from measuring only financial and operational performance to include several other important aspects such as environmental, safety, social, security, etc. (Fernandes and Pacheco 2007, Skouloudis, Evangelinos et al. 2012, Bezerra and Gomes 2016).

Furthermore, without having enough information about the current state of airport performance, it is not easy to recognize which areas of activity or which specific parts need to be improved. Therefore, Key Performance Indicators (KPIs) are used to evaluate airport performance in different areas of activity. KPIs may be used by airports as a benchmarking tool by comparing their performance against itself or against other airports across different aspects in order to improve overall efficiency and attract more airlines.

1.2 Research Problem Statement

Airports whether public or privately owned, as any other business enterprise, need to monitor their performance continuously to reveal how successful they are in a competitive industry Gillen and Lall (1997). However, many organizations still lack adequate guidelines on how to develop key performance indicators (Chae 2009; Lindberg; Tan et al. 2015). According to the literature review, there is a lack of detailed studies about Libyan airports, and none of the previous studies have investigated the performance of Libyan airports by utilizing KPIs. In order to help airports in Libya to make accurate decisions in their performance management efforts, this study provides a useful set of key performance indicators across five aspects of airport performance.

1.3 Goals of the Study

The main aim of this study is to derive a set of essential airport KPIs in five Key Performance Areas (KPAs) based on previous studies to provide decision makers in the Libyan airport industry a practical framework to measure and monitor the airport performance over time as well as, calculating the importance weight of the KPIs according to the opinions of experts by applying AHP method. The sub-goal of the study is to provide a comparison of the performance of the three international airports in Libya MJI, MRA, and LAQ by summarizing the opinions of experts by using two different multi-criteria decision-making methods, AHP and Grey Theory, to provide a comparison of the performance of the three international airports in Libya MJI, MRA, and LAQ by summarizing the opinions of experts.

1.4 Research Contributions

The research is the first study of its kind that develops KPIs for Libyan airports to assess airport efficiency in different activity areas. Such a contribution enables decision makers in the airport industry to use KPIs as a benchmark tool either for internal or for external benchmarking to identify poorly performing areas so that decision makers can take action for performance upgrades. In addition, this study has applied two methods of Multiple-Criteria Decision-Making (MCDM), AHP and Grey Systems Theory.

1.5 Research Methodology

The research methodology that was employed in order to achieve the stated objectives is illustrated in Figure 1.1. The methodology consists of the following steps:

1. Performing an extensive literature review to identify an initial set of key performance indicators across several aspects of airport performance.
2. Validate and amend the initial KPIs by surveying experts at Misurata International Airport (IATA: MRA) by using purposive sampling technique. According to the results, a list of airport key performance indicators is introduced and a number of indicators from the initial list were ignored due to their lower importance.
3. Applying the AHP method to determine the relative importance of the KPAs and the KPIs, based on the expert’s judgment gathered through the surveys.
4. Apply AHP and Grey System Theory methods to provide a comparison of the three international airports in Libya.

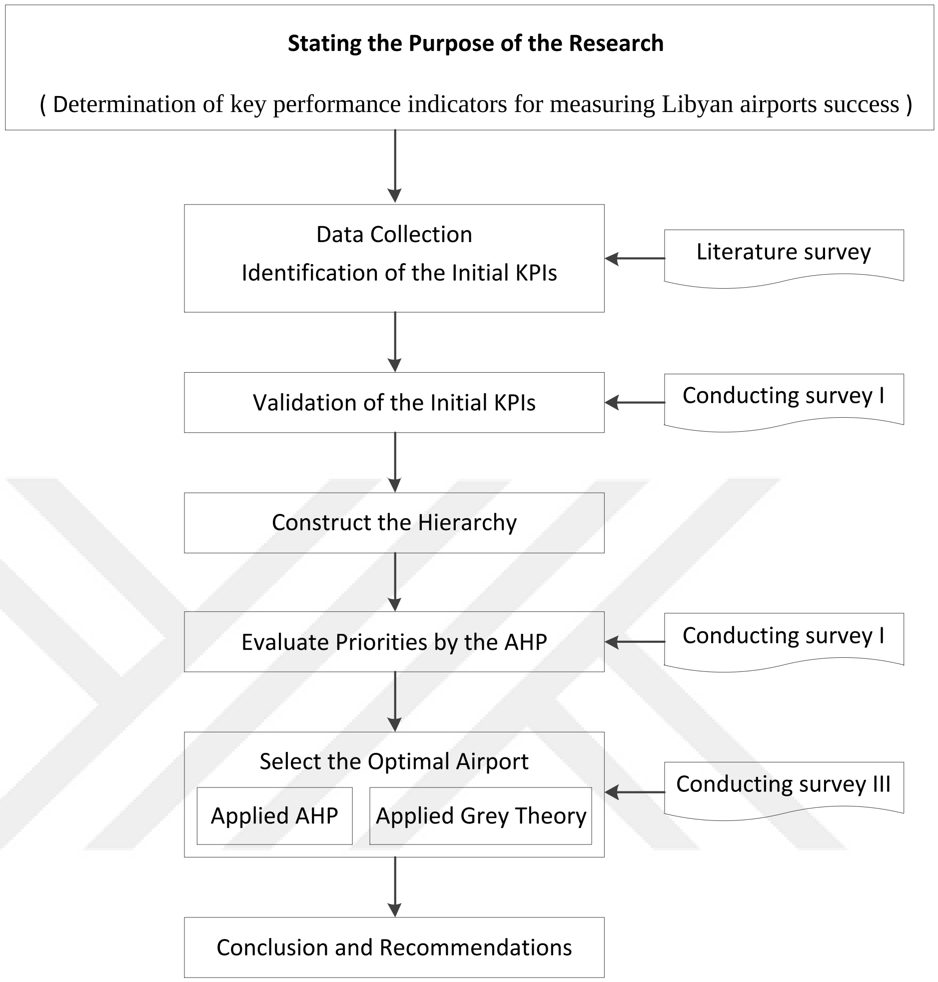

Figure 1.1-Research Methodology

1.6 Limitations of the Study

The limitations of this study that may have a potential impact on the quality of the findings can be described as follows:

- Although the performed questionnaire survey for evaluating the initial KPIs targeted experts who were working in the airlines and airports industry for many years, the survey was limited to Misurata International Airport.
- Another limitation of this study is that the pairwise comparisons were performed by relying only on the judgments of four experts to determine the priority of the indicators. However, to achieve more accurate results, the number of judgments should be increased.

Regardless of these limitations, this study provided a set of useful KPIs that can be used to monitor airport performance and to determine any areas of poor performance.

1.7 Thesis Organization

This thesis is organized into five chapters. Chapter 1 presents a general framework for the research study. Chapter 2 provides a review of the literature related to the research study. Chapter 3 describes AHP and Grey Systems Theory, multi-criteria decision-making methods. Chapter 4 details the methods used in this study, and Chapter 5 presents the conclusion and the recommendations of the research study.

CHAPTER 2

LITERATURE REVIEW

Due to significant growth in passenger traffic during the last few years, many airports have become unable to cope with this growth in an efficient manner. Therefore, airports need to develop a new strategic plan to optimize airport operations and make airports more reliable. Additionally, many airports seek to develop their levels of service and also to expand airport capacity, including the development of terminals, runways, etc., in order to enhance the economic growth of the respective countries and the cities that they serve.

Furthermore, in many cases, the efficiency of airport operations may be improved significantly without investing large amounts of money to build new infrastructure by developing and using a list of measures which focuses on the important aspects of an airport and which are important for the success of an airport. These measures are needed to examine how well each department of the airport is operating and to determine the inefficient components in each department so that management can work to make improvements.

This study proposes a list of airport KPIs as measures for monitoring and evaluating the performance of Libyan airports. However, in order to select the appropriate indicators for a particular organization, it is important to have a clear idea about the strategic objectives of that organization (Parmenter 2015). In this study, however, the author was unable to find real and reliable strategies for an airport to select key performance indicators for airports; therefore, he relied only on previous studies to determine the most suitable KPIs to achieve the study goals. In this chapter, we will explain what KPIs are and the importance of performance measurements to take an airport or an organization from a level of acceptable adequacy to a high level of excellence. Additionally, we will cover what the literature contains about airport KPIs.

2.1 Background to Key Performance Indicators

KPIs are metrics that organizations use in order to assess performance. In other words, KPIs help organizations to determine the extent of their success in achieving their objectives (Gillen and Lall 1997; Lindberg, Tan et al. 2015). The KPIs have been defined thus: "KPIs represent a set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization." (Parmenter 2015).

The airport industry is one industry that has a long history of working to identify the appropriate key performance indicators as a key to its success (Grabowski, Ayyalasomayajula et al. 2007). In the airport industry, key performance indicators are very important tools to manage, monitor and provide indications of the current status of an airport. KPIs help airports to determine which components require more care and continuous monitoring to achieve the values that will satisfy customers.

In general, developing key performance indicators for any organization has always been a daunting task (Lapide 2000; Chae 2009). In this regard, although, many organizations around the world today use key performance indicators to reveal how successful they are, very few organizations use the correct KPIs to appraise their performances (Parmenter 2015). The reason for this is due to a lack of understanding of performance measures by business leaders (Parmenter 2015).

However, the key performance indicators do not provide any analyses or suggestions about how to increase the efficiency of an airport, if in fact they are indeed used as indicators to show which activity area in the airport needs further attention and development to raise the efficiency of the airport. Furthermore, KPIs also aim to improve situational awareness and perception in an airport, which will help airport management to decide correctly in order to achieve objectives (Kosanke and Schultz 2015).

Key performance indicators can be either qualitative or quantitative and they may have different units (Lai, Potter et al. 2015). These indicators usually need to be compared to previously collected data in order to support their interpretation through performing a benchmarking (Francis, Humphreys et al. 2002). Quantitative key performance indicators have a feature such that they can be easily compared to other KPIs from similar organizations (Andersson Granberg and Munoz 2013).

The units of key performance indicators are very important when KPIs are used for benchmarking in order to discern the performance gap between an organization and best practice (Wang, Ho et al. 2004; Lindberg, Tan et al. 2015). However, airport benchmarking to identify poor performing areas can be either internal benchmarking or external benchmarking (Wyman 2012).

Furthermore, airports or any other organization need to work with a few number of key performance indicators to have a good focus and to avoid lack of alignment between KPIs and a balanced scorecard (Chae 2009; Parmenter 2015). Key performance indicators need to be simple and staff need to understand them because if they are too complex, they will not work (Parmenter 2015). In practice, organizations that have worked with a large number of KPIs achieved less than expected (Parmenter 2015).

David Parmenter is a leading expert in the development of key performance indicators. He has emphasized that for a KPI to be a performance measure, it needs to be linked to the critical success factors (CSFs) of the organization, to at least one of the balanced scorecard (BSC) perspectives, and to the strategic objectives of the organization (Parmenter 2015). Figure 2.1 shows the linkage between vision, strategies, BSC perspectives, CSFs and KPIs.

2.1.1 Characteristics of Key Performance Indicators

There are a number of characteristics of the KPIs which can be used as a guide to selecting effective KPIs for an organization. However, the KPIs need not fulfill all of the characteristics below in order to be useful indicators:

- The KPIs should reflect and express the overall objectives of an organization that it is looking to achieve (Meier, Lagemann et al. 2013).
- It must be relevant and meet the objectives, strategy and the vision of the organization (Parmenter 2015).

- It is able to be measured and it could be either a quantitative or qualitative indicator (Chan and Chan 2004).
- It has a significant impact on one or more of the balanced scorecard perspectives (Parmenter 2015).
- The KPIs may have units; therefore, they can be used in comparison with equivalent measures for other organizations (Yoshida 2004).
- Clearly, explain the type of work that is required by staff to rectify or change a particular situation (Parmenter 2015).

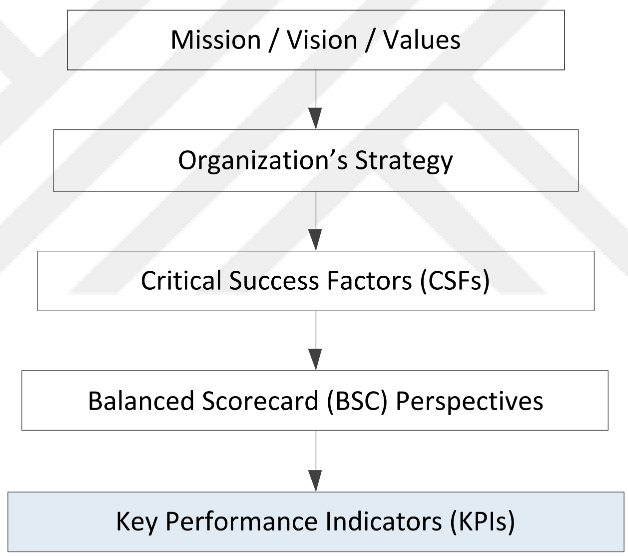

Figure 2.1-Linkage Chart between Mission, Vision, Strategy, CSFs, BSCs and KPIs (Parmenter 2015).

2.2 Importance of Measuring Organization Performance

Performance measurement is a broad topic and it is defined as the process of measuring the efficiency and effectiveness of an action (Neely, Gregory et al. 2005). Organizations need to evaluate their performance and effectiveness periodically to determine whether objectives are being achieved and how their performance compares to similar best practices businesses. According to (Spitzer 2007), measurement is a very important key for any organization to be successful in a competitive market.

However, measurement does not only tell where the organization is now, it can transfer the organization further when it did it correctly (Spitzer 2007). Furthermore, organizations need to conduct a measurement to guide their decisions and to be away from impact by competition; otherwise, they will experience trouble and their finances will be under threat. However, after performing the correct measurements, organizations still need to take action to deal with problems to achieve their objectives.

With regard to the aviation industry, airports are considered complex organizations that have many interacting parts, airlines, passengers, ground handling company, security, fire and police services, etc. (Humphreys and Francis 2002; Diana 2010; Wyman 2012). Therefore, it is not easy to create an appropriate system for measuring airport performance (Humphreys and Francis 2002). However, interest in performance measurements of airports has been increasing in recent years, especially with the changes of airport ownership patterns in many countries around the world to private or partially private ownership (Humphreys and Francis 2002; Müller, Ülkü et al. 2009). The increasing interest in measuring airport performance has led to the introduction of new indicators that reflect the future objectives of airports. The shifting ownership patterns have created more emphasis on commercialization (Humphreys and Francis 2002).

Furthermore, measuring airport performance can be conducted for several purposes, such as to evaluate the efficiency of various aspects of an airport in financial and operational terms, to validate safety and security procedures, and to assess the potential environmental impacts of airport activities (Humphreys and Francis 2002). In general, measuring the performance of an organization helps to improve decision-making processes and it provides an early signal of potential problems; therefore, an organization can take action at the appropriate time (Spitzer 2007). However, for any organization, continual performance improvement depends on continual measuring. In summary, for the correct performance measurement, organizations should select appropriate indicators for measurements to provide proof of how successful they are and to determine which areas that may need stronger focus for improvement.

2.2 Literature on Airport Key Performance Indicators

The literature review on airport KPIs considers two specific subjects, airport performance and the importance of key performance indicators in the airport industry. However, previous studies have addressed several aspects of airport performance, such as efficiency / productivity, service quality, safety, security, economic / financial, and environmental considerations, etc., by adopting different approaches (Bezerra and Gomes 2016). In this context, the airport service quality has received considerable attention in the last decade and the studies in this field have adopted different approaches to examine airport service quality as one of the keys to improving airport performance, e.g. (Fodness and Murray 2007; Pabedinskaitė and Akstinaitė 2014; Brida, Moreno-Izquierdo et al. 2016; Pantouvakis and Renzi 2016), and Bezerra and Gomes (2016) who examined seven factors that can provide a comprehensive approach to measuring the service quality of airport according to the perceptions of passengers. The factors include check-in, security, convenience, ambience, basic facilities, mobility, and price. 23 indicators were included in all these factors; for example, the check-in factor contains four indicators: wait-time at check-in, check-in process efficiency, availability of luggage carts and courtesy and helpfulness of check-in staff.

In another effort, Rhoades, Waguespack Jr et al. (2000) developed a list of quantitative KPIs for US airports that can be used to evaluate the quality of airport facilities and operations based on the perspective of stakeholders (e.g., airlines, cargo operations, tenants, etc.). The study identified twelve indicators including parking, gate boarding areas, baggage claim facilities and information display systems.

Kazda and Caves (2015), in his book “Airport Design and Operation”, pointed out that the quality of an airport according to passenger perception is associated with short waiting times at check-in and security checkpoints, helpfulness of airport staff and the efficiency of the entire process.

Despite the many studies that have been undertaken to understand airport service quality from various perspectives, there is a need for further investigation to examine the validity and reliability of service quality measurement (Bezerra and Gomes 2016).

With regard to safety and security, Enoma and Allen (2007) developed five key performance indicators related to this area: breach of security, evacuation in cases of emergency, hysteria control, attack on airport facilities or installations and criminal behavior directed at cargo on board aircraft. The time required until normal operations are resumed is the success measure of these indicators. The authors argue that safety and security are becoming more important than anything else for airport management after many terrorist attacks against airports around the world. According to Kazda and Caves (2015), security at an airport is a necessary system to stop acts of terrorism and to protect the assets, and information about the airport.

Regarding airside operations, Norin (2008) investigated the logistics at an airport that related to the turn-around process, which are activities that affect an airplane from touch down until take off. The study suggested a group of KPIs to evaluate the performance of those activities using a conceptual model. In addition, Norin, Granberg et al. (2012) have defined the logistics activities at the airport as planning and controlling all resources and information that creates value for customers utilizing the airport, such as passengers, airlines, cargo service consumers, restaurants, and many other agencies operating at the airport. Based on the last definition, airport logistics is a very broad concept and therefore this study considers turn-around activity times as one of the proposed key performance indicators which may include many activities such as loading and unloading baggage, fueling, catering, cleaning, water, sanitation processes and the process of supplying power (Norin 2008).

Moreover, indicators related to the airside area such as the number of runways and runway length are included in some studies, notably those of Fan, Wu et al. (2014); Lai, Potter et al. (2015); Fung, Wan et al. (2008); Gillen and Lall (1997); and Yu, Hsu et al. (2008) to be studied as important indicators in the evaluation of the efficiency of airports. In more recent research, Kosanke and Schultz (2015) proposed a list of KPIs to evaluate airside operation performance.

As regards the financial and environmental key performance indicators, Humphreys and Francis (2002), reported that the increase in air traffic demand and patterns of airport ownership changes have led to the introduction of new financial and environmental measures. The authors provide good discussion about a wide range of past, present, and future of airport key performance indicators. With regard to environmental issues, Morrell and Lu (2000) and Ignaccolo (2000) studied the noise related to airport activities and its impact on communities in the vicinity of airports.

With regard to professional related literature, Airports Council International (ACI) Wyman (2012) published a guide to assist airports worldwide to improve their performance. The Guide provides a very useful set of 42 indicators across six key performance areas with a definition for each indicator. It also determines the types of airports where the indicator is capable of being applied.

Additionally, there is currently an extensive body of literature on airport benchmarking for assessing performance by examining many different factors such as service, safety, environment, cost, and revenue factors, notably those of Schmidberger, Bals et al. (2009); Adler, Liebert et al. (2013); Chung, Ahn et al. (2015); Kılkış and Kılkış (2016) and MacLean, Richman et al. (2016). However, the author reviewed literature that related to airport benchmarking to expand his knowledge and to obtain an accurate general background about the indicators that are used for benchmarking the performance of airports across different aspects.

2.3 Air Transport in Libya

Air transport in Libya is the commercial carriage of passengers, freight, and mail by aircraft, both within Libyan cities and between Libya and many other countries. However, Libya is currently served by three international airports, Mitiga Airport (MJI), Misurata Airport (MRA), and Al Abraq Airport (LAQ). The two largest and busiest airports in Libya, Tripoli International Airport (IATA: TIP) and Benina International Airport (IATA: BEN) have been closed since 2014 due to civil war. Moreover, airports in Libya are publicly owned and operated by the Libyan Civil Aviation Authority (LYCAA) and the Libyan Airports Authority which are state agencies under the Ministry of Transportation.

- Mitiga Airport (IATA: MJI) is the international airport of Tripoli, the capital of Libya, and it is the only airport that serves Tripoli at the present time. MIJ operates 24 hours with two runways. Check-in processes for international and domestic flights occur in the same building.
- Misurata Airport (IATA: MRA), 207 kilometers east of Tripoli, is an international airport in Misurata, Libya which also acts as an air base and training center for the Libyan Air Force. MRA operates 24 hours with two parallel runways. Arrival facilities at MRA for international and domestic flights are in a different building while check-in processes for international and domestic flights occur in the same terminal.
- La Abraq Airport (IATA: LAQ) is an international airport located in eastern Libya, 25 kilometers east of Al Bayda City and 1,243 kilometers east of Tripoli. LAQ operates 24 hours with a single terminal for international and domestic flights.

At the present time, in Libya, there are two state-owned airline companies: Afriqiyah Airways and Libyan Airlines, which operate scheduled domestic and international services to different destinations in Africa, Asia, and Europe. In addition, there are several private airlines of which the most popular are Libyan Wings, Buraq Air, which also operates domestic and international scheduled services. Nevertheless, the air transport sector in Libya faces many problems in the quality of air transport infrastructure and available airline seat km/week. According to the Africa Competitiveness Report in 2013, Libya was classified at a very low ranking, 129th among 144 countries surveyed on the quality of air transport infrastructure (Africa Competitiveness Report 2013).

2.4 Summary

In order to link this study with other related research, Chapter 2 provided a review of three subjects: background to KPIs, the importance of measuring organization performance, and airport KPIs. In addition, the chapter also provided a brief overview of air transport in Libya. However, according to the literature review, the author discerned that the efficiency of airport activities has not been evaluated utilizing a unified framework as was also mentioned by Fung, Wan et al. (2008) and Yoshida (2004). In summary, the reviewed literature helped to develop a theoretical framework for the study concerning the use of KPIs as an effective technique to evaluate airport efficiency.

CHAPTER 3

Multi-Criteria Decision-Making (MCDM) Methods

In this research study, an evaluation approach was required to deal with multiple criteria for the calculation of the relative weights and for the selection process. Multi-criteria decision-making techniques have become widely used by many researchers and authorities to evaluate transportation systems. MCDM techniques are very important tools that can be used in different areas (Mardani, Zavadskas et al. 2016). MCDM includes a diversity of methods for modeling the problems regarding decisions based on combined human judgments. According to Pérez, Carrillo et al. (2015), 58 different multi-criteria decision-making methods were performed from1982 to 2014 to solve various types of problems in urban passenger transport systems. However, in the fields of transportation systems, for modeling and solving multi-choice problems, AHP and Fuzzy-AHP methods are the most used techniques and the airline industry is the most studied transport infrastructure regarding application of MCDM approaches (Mardani, Zavadskas et al. 2016).

In this study, the author used AHP and Grey Theory methods to achieve the stated aim. This chapter provides a brief description of both methods.

3.1 Analytic Hierarchy Process (AHP)

AHP is one of the most used methods in multi-criteria decision-making (MCDM) (Zietsman and Vanderschuren 2014). It was introduced by Thomas L. Saaty in 1977 (Saaty 1980). AHP is defined as a theory of measurement that depends on the judgments of decision makers to determine priority scales by using pairwise comparisons (Saaty 2008). AHP has found widespread attention as a suitable tool for modeling and solving decision problems to make decisions in many fields such as business, healthcare, industry, government, etc. to select the best alternative, to analyze investment risk, for performance evaluation, etc.

With regard to the application of AHP in the airport industry, Zietsman and Vanderschuren (2014) used AHP to evaluate a plan for a multi-airport in Cape Town in South Africa. Yoo and Choi (2006) applied the AHP method to determine the relative weights of criteria that need improvement during the passenger security screening process in order to improve the detection of prohibited items. In another effort, Postorino and Praticò (2012) employed the AHP approach to analyze regional multi-airport systems to identify the importance that customers give to different segments of a passenger terminal at a particular airport.

In this study, the author applied the AHP method to prioritize a list of key performance indicators and to compare the three international airports in Libya based on the opinions of a group of experts. The Analytical Hierarchy Process method is based on four main components (Saaty 2008):

1. Define the problem and determine the type of information that is required present the problem thoroughly.
2. Structure the problem into a hierarchy as a first step to deal with a complex problem effectively in an organized manner and to identify their components. In fact, there is no single general hierarchical form to structure a decision problem; this depends on the type of decision. To create a hierarchy structure in the analytic hierarchy process, we should include adequate relevant details. However, selecting the correct factors is the most important work in making a decision. Further, the selected factors should be arranged in successive levels descending from the overall goal of the study to the criteria and sub-criteria to the alternatives. Every level will describe a different aspect of the problem. Figure 3.1 depicts three levels of hierarchy of the AHP approach.
3. Conduct pairwise comparisons among all activities at every level of the hierarchy. This stage of the analytical hierarchy process can be accomplished by asking the participants associated with the problem to evaluate each group of activities in a pairwise manner with respect to all or some activities at a higher

level. This depends on a hierarchical model of the decision problem. This step constitutes the most important part of analytical hierarchy process because it provides a system for data collection.

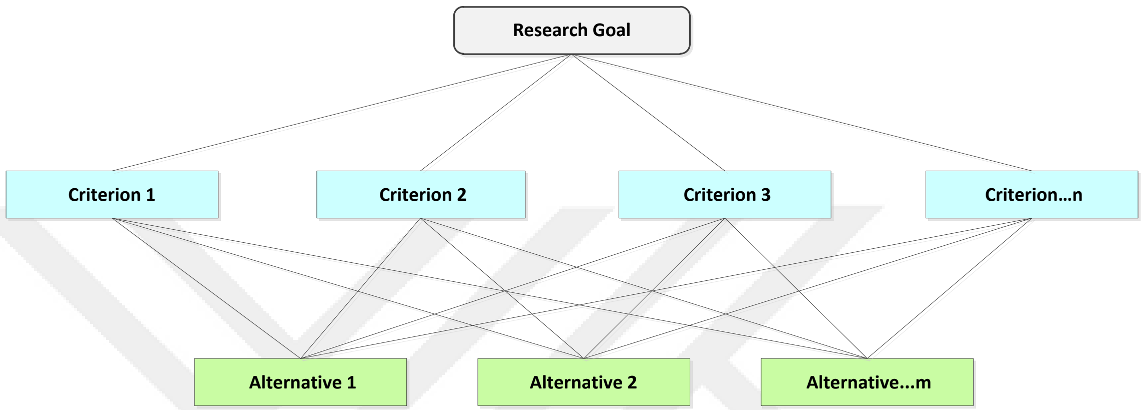

Figure 3.1-Hierarchical Structure of AHP

4. The fourth step is to compute the weights in order to establish the priorities of the hierarchy and to assess the consistency of the subjective judgments in every comparison matrix.

3.1.1 Pair-Wise Comparison

When the hierarchy of the problem is constructed, the next step is to make a series of pairwise comparisons to determine preferences between the criteria to represent weight ratios. However, by using Saaty’s nine-point scale, as demonstrated in Table 4.1, decision makers can construct a relative importance matrix for many different criteria at each level of the hierarchy. A pairwise comparison matrix will indicate that one element is strongly more increasingly important than another one and to what extent. With regard to judgment scales, many authors have started using different numerical scales, such as power scale, root square scale, geometric scale, etc., to estimate the priority in the AHP method (Franek and Kresta 2014).

Table 3.1-The AHP Pairwise Comparison Scale (Saaty 2008)

Intensity of Importance	Definition	Explanation
1	Equal importance	Two elements i and j contribute equally to the objective
3	Moderate importance	Element i is slightly favored than element j
5	Strong importance	Element i is strongly favored than element j
7	Very strong importance	Element i is favored very strongly than element j
9	Extreme importance	Element i is absolutely more important than element j
2,4,6, and 8	To present intermediate values between the two adjacent judgments	

In fact, selecting the appropriate scale for an AHP problem is very difficult because there is no fixed manual to show which scale is suitable to estimate the priority for a certain AHP problem and among all the suggested scales, the Saaty linear scale is the most used scale in a wide variety of applications (Franek and Kresta 2014).

3.1.2 Consistency Verification

Checking the consistency of judgments is an important step to implement the analytic hierarchy process approach and maintain coherence among the judgments. The consistency is correct if all the relations between judgments occur in a perfect manner and without fault. For instance, in a pairwise comparison matrix A, if someone prefers x_1 three times more to x_2 (a_{12} = 3) and he prefers x_2 two times more to x_3 (a_{23} = 2), then the preference of x_1 to x_3 should be 6 (a_{13} = 6) and not any other number. In this case, the consistency ratio is equal to zero (CR = 0%) and any increase in deviation from number 6 will increase the inconsistency (Saaty 1990).

$$A = \begin{pmatrix} 1 & 3 & 6 \\ 1/3 & 1 & 2 \\ 1/6 & 1/2 & 1 \end{pmatrix}$$

However, sometimes it is not possible to have perfect consistency; therefore, a consistency ratio of up to 10% is considered acceptable. However, if the consistency exceeds 10% ($C.R > 0.10$), the decision maker needs to revise his judgments until the value of the consistency ratio becomes approximately 10% or less (Saaty and Vargas 2012, Brunelli 2014). In this paper, the author has checked that every relation produces perfect consistency.

The consistency of pair-wise comparison matrix A can be assessed by calculating the consistency index (CI) and consistency ratio $(C.R)$.

$$\text{CI} = (\lambda_{\max} - n) / (n - 1) \tag{3.1}$$

λ_{max} is the principal eigenvalue of the matrix A, and n is the number of criteria.
Matrix A is consistent if and only if the largest eigenvalue λ_{max} is equal to n (Saaty 1990).

After obtaining the consistency index value (CI), we can compute the consistency ratio $(C.R)$ by dividing the consistency index (CI) by the random index (RI).

$$C.R = CI/RI \tag{3.2}$$

Table 4.1 exhibits the corresponding value of the random consistency index which was developed by Thomas L. Saaty.

Table 3.2-Values of Random Index (RI) (Saaty and Vargas 2012)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

The AHP process requires the inclusion of sufficient relevant details of the problem in the hierarchic structure. In this paper, the author works not to overlook issues related to the problem so as to reach a successful decision. The methodology of the analytical hierarchy process (AHP) is illustrated in Figure 3.2.

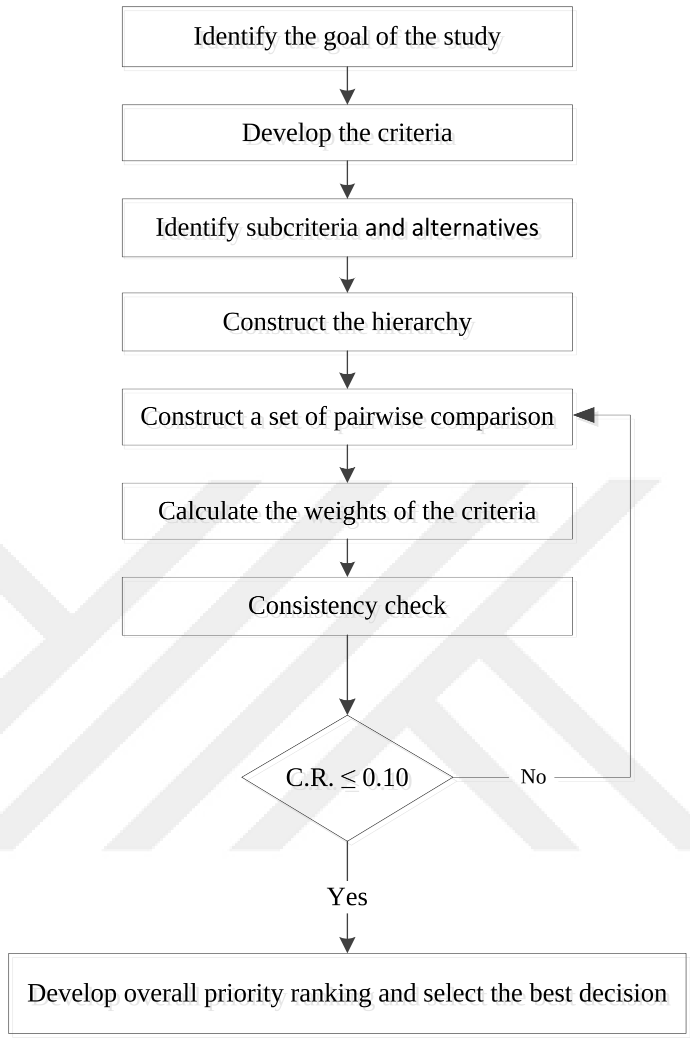

Figure 3.2-The AHP Methodology

3.1.3 Advantages of the AHP method

1. One of the most important advantages of the analytical hierarchy process (AHP) is that it can be used to evaluate quantitative and qualitative criteria on the same judgment scale in a systematic manner (Franek and Kresta 2014).

2. The AHP method is easy to understand and easy to apply when analyzing different types of complex decisions (Guh, Po et al. 2009).

3. A hierarchical structure of the criteria is another feature of AHP. It enables decision makers to enhance their understanding of complex decisions by focusing on specific criteria, alternative criteria, and sub-criteria when determining weights (Saaty 2000).

4. Almost anyone can use the AHP method because the judgment process is flexible and simple for a wide range of unstructured problems; moreover, it does not need advanced technical knowledge (Saaty 1990).

5. In the AHP method, a decision maker can deal with tangible properties as well as intangible ones, where there is no standard scale of measurement to measure the importance and value of intangible criteria such as losing investor confidence and capital fleeing (Saaty 1990, Saaty and Vargas 2012).

3.1.4 Applications of the AHP

Since its introduction, AHP has been applied by individuals, companies, and governments to different types of decision problems, in economic, industrial, political, social, technological, and other fields (Saaty 2008).

Oil companies use the AHP method to select the best type of platform to build offshore in order to drill for oil and gas. Automotive companies, for example, the Ford Motor Company has used AHP to improve customer satisfaction by establishing priorities for criteria (Saaty 2008). In politics, the AHP method is used in such areas as conflict resolution and security assessments. Moreover, in social concerns, AHP is performed in education, such as to improve industrial engineering quality, as well as in environmental issues, in medicine for therapy selection and also in the public sector for market selection (Saaty and Vargas 2012). A number of companies use AHP to select the best contractor and to select warehouse sites (Vaidya and Kumar 2006). summary, AHP is the most popular example of MCDM that has been used in many different applications for decision making.

3.2 Grey System Theory

Grey System Theory was initiated by Julong Deng in 1982 as a method to solve problems involving small samples in addition to poor, uncertain and incomplete information (Ju-Long 1982; Julong 1989). The Grey decision-making method deals with uncertain systems with incomplete and inadequate information that is not easy for fuzzy methods to handle by creating useful information from the available data (Liu and Forrest 2010). Grey Theory, fuzzy and rough systems are the most used methods to study uncertain systems (Liu and Forrest 2010). However, in many cases, the problems of selection have many uncertainties because human judgments are usually uncertain and cannot be represented by an accurate numeric value (Li, Yamaguchi et al. 2007; Kose, Kabak et al. 2013). Therefore, the Grey Theory is a suitable method to deal with this type of issue involving uncertain information as the uncertainty can be expressed by a grey number and grey variables.

In the Grey Theory approach, based on the availability of information, the system is called black if the system information is unknown. If the system information is completely known, the system is named white. However, if the system contains both known and unknown information (uncertain information), the system is named a grey system (Ju-Long 1982; Li, Yamaguchi et al. 2007; Liu and Forrest 2010; Liu, Fang et al. 2012). Furthermore, uncertain information in a grey system can be expressed in a grey number and in grey variables as techniques for analyzing complex systems (Li, Yamaguchi et al. 2007).

In this study, the author used the Grey Theory method to represent decision makers' judgments to compare the three international airports in Libya. The decision makers' judgments are expressed in grey numbers to state the preferences in the comparison process.

3.2.1 Grey Number

A grey number is a real number with uncertain information whose value is unknown; however, the range where the value is located is known (Li, Yamaguchi et al. 2007; Li 2009; Liu and Forrest 2010). Generally, the symbol "$\otimes G$" is used to denote the grey number (Kose, Kabak et al. 2013). The following section discusses the types and operation of the grey number.

If we Let X be the universal set, then a Grey set G of X is defined by its two mappings: $\overline{\mu}_G(x)$ and $\underline{\mu}_G(x)$.

$$\begin{cases} \overline{\mu}_G(x):\ x \longrightarrow [0,1] \\ \underline{\mu}_G(x):\ x \longrightarrow [0,1] \end{cases} \tag{3.3}$$

$\overline{\mu}_G(x) \geq \underline{\mu}_G(x), \quad x \in X$

$\overline{\mu}_G(x)$ and $\underline{\mu}_G(x)$ are the upper and lower limit of the Grey set G respectively.

IF $\overline{\mu}_G(x) = \underline{\mu}_G(x)$, the Grey set G becomes a fuzzy set.

The following are the classifications of Grey numbers (Liu and Forrest 2010, Kose, Kabak et al. 2013):

- Grey numbers with only a lower limit: This type of grey number is denoted as $\otimes G \in [\underline{G}, \infty)$, where $\underline{G}$ represents the lower limit of the Grey number $\otimes G$.
- Grey numbers with only an upper limit: This type of Grey number is denoted as $\otimes G \in [\overline{G}, \infty)$, where $\overline{G}$ represents the upper limit of the Grey number $\otimes G$.
- Interval Grey numbers: These numbers have both a lower $\underline{G}$ and an upper limit $\overline{G}$, written as $\otimes G \in [\underline{G}, \overline{G}\ )$.
- Black and white numbers: When $\otimes G\ \in (-\infty, +\infty)$ and if the grey number $\otimes$ G has neither an upper nor lower limit, then $\otimes$ G is defined as a black Grey number. When Grey number $\otimes G\ \in (\underline{G}, \overline{\mathrm{G}})$, and $\underline{\mathrm{G}} = \overline{\mathrm{G}}$, $\otimes$ G is denoted as a white number.

With respect to the Grey number operations, it is an operation on sets of intervals (Li, Yamaguchi et al. 2007). The operation rules of interval Grey numbers can be defined as follows: We assume that we have Grey numbers $\otimes G_1\ \in [\ \underline{G}_1, \overline{G}_1]$, $\underline{G}_1 < \overline{G}_1$, and $\otimes$ $G_2\ \in [\underline{G}_2, \overline{G}_2]$, $\underline{G}_2\ <\ \overline{G}_2$, then the operations between grey numbers (Li, Yamaguchi et al. 2007):

The addition operation is given by:

$$\otimes G_1 + \otimes G_2 = \left[\underline{G}_1 + \underline{G}_2, \overline{G}_1 + \overline{G}_2\right]. \tag{3.4}$$

The subtraction operation is given by:

$$\otimes G_1 - \otimes G_2 = \left[\underline{G}_1 - \overline{G}_2, \overline{G}_1 - \underline{G}_2\right]. \tag{3.5}$$

The multiplication of $\otimes G_1$ and $\otimes G_2$ is given as:

$$\otimes G_1 . \otimes G_2 = \left[min\left(\underline{G}_1\underline{G}_2, \underline{G}_1\overline{G}_2, \overline{G}_1\underline{G}_2, \overline{G}_1\,\overline{G}_2\right), max\left(\underline{G}_1\underline{G}_2, \underline{G}_1\overline{G}_2, \overline{G}_1\underline{G}_2, \overline{G}_1\,\overline{G}_2\right)\right]. \tag{3.6}$$

The division of $\otimes \mathrm{G}_1$ and $\otimes \mathrm{G}_2$ is defined as follows:

$$\otimes G_1 \div \otimes G_2 = \left[\underline{G}_1, \overline{G}_1\right] \times \left[\frac{1}{\underline{G}_2}, \frac{1}{\overline{G}_2}\right]. \tag{3.7}$$

The length of Grey number $\otimes G$is given as follows:

$$L(\otimes G) = \left[\overline{G} - \underline{G}\right]. \tag{3.8}$$

Comparison of two Grey numbers $\otimes G_1$ and $\otimes G_2$: the possibility degree of the two Grey numbers $\otimes G_1 \leq \otimes G_2$ can be shown as follows (Shi, Liu et al. 2005):

$$P\{\otimes G_1 \leq \otimes G_2\} = \frac{max\left(0, L^* - max\left(0, \overline{G}_1 - \underline{G}_2\right)\right)}{L^*} \tag{3.9}$$

where $L^* = L(\otimes G_1) + L(\otimes G_2)$.

The relationship between two Grey numbers $\otimes G_1$ and $\otimes G_2$ can be determined as follows (Li, Yamaguchi et al. 2007; Kose, Kabak et al. 2013):

- If $\underline{G}_1 = \underline{G}_2$ and $\overline{G}_1 = \overline{G}_2$, we say that $\otimes G_1$is equal to $\otimes G_2$, written as $\otimes G_1 = \otimes G_2$. Then $P\{\otimes G_1 \leq \otimes G_2\} = 0.5$.
- If $\underline{G}_2 > \overline{G}_1$, we say that $\otimes G_2$ is larger than $\otimes G_1$, written as $\otimes G_2 > \otimes G_1$. Then $P\{\otimes G_1 \leq \otimes G_2\} = 1$
- If $\overline{G}_2 < \underline{G}_1$, we say that $\otimes G_2$ is smaller than $\otimes G_1$, written as $\otimes G_2 < \otimes G_1$. Then $P\{\otimes G_1 \leq \otimes G_2\} = 0$

- If there is an intercrossing part in them, when $P\{\otimes G_1 \leq \otimes G_2\} > 0.5$, we say that $\otimes G_2$ is larger than $\otimes G_1$, written as $\otimes G_2 > \otimes G_1$. When $P\{\otimes G_1 \leq \otimes G_2\} < 0.5$, we say that $\otimes G_2$ is smaller than $\otimes G_1$, written as $\otimes G_2 < \otimes G_1$.

3.2.2 Grey Model Process

The Grey Theory model is performed out by following several steps (Li, Yamaguchi et al. 2007; Kose, Kabak et al. 2013). To explain the steps of the Grey Theory model to solve decision-making problems, we assume that $A = \{A_1, A_2 \dots \dots A_n\}$ is a set of n decision criteria for $B = \{B_1, B_2 \dots \dots B_n\}$ which is a discrete set of m possible alternatives and a decision group consisting of K persons.

- Step 1: Determine the criteria weights $\otimes W_j \ (j = 1, 2, \dots \dots, n)$ by using the following equation:

$$\otimes W_j = \frac{1}{K}\left[\otimes W_j^1 + \otimes W_j^2 + \cdots + \otimes W_j^K\right] \tag{3.10}$$

The decision-makers will use the linguistic variables depicted in Table 3.3 to express their preferences, and then the linguistic variables can be expressed in Grey numbers to determine the weights. The weight of a criterion of the Kth decision maker can be expressed by Grey number $\otimes \mathrm{W}_j^K = \left[\underline{\mathrm{W}}_j^K, \overline{\mathrm{G}}_j^K\right]$.

Table 3.3-The Importance of Grey Number for the Weights

Importance	Abbreviation	Scale of grey number $\otimes W$
Very Low	VL	[0.0, 0.1]
Low	L	[0.1, 0.3]
Medium Low	ML	[0.3, 0.4]
Medium	M	[0.4, 0.5]
Medium High	MH	[0.5, 0.6]
High	H	[0.6, 0.9]
Very High	VH	[0.9, 1.0]

- Step 2: We use the linguistic variables as shown in Table 3.4 to evaluate the alternatives.

Table 3.4-Linguistic assessment and the associated grey values

Performance	Abbreviation	Scale of grey number $\otimes W$
Very Poor	VP	[0.0, 1.0]
Poor	P	[1.0, 3.0]
Medium Poor	MP	[3.0, 4.0]
Fair	F	[4.0, 5.0]
Medium Good	MG	[5.0, 6.0]
Good	G	[6.0, 9.0]
Very Good	VG	[9.0, 10.]

Then we can calculate the rating value as:

$$\otimes G_{ij} = \frac{1}{K}\left[\otimes G_{ij}^{1} + \otimes G_{ij}^{2} + \cdots + \otimes G_{ij}^{K}\right] \quad (3.11)$$

where $\otimes G_{ij}^{K}, (i = 1,2, \dots, m; j = 1,2, \dots, n)$ is the criteria value given by the Kth decision maker and can be presented by the Grey number $\otimes G_{ij}^{K} = \left[\underline{G}_{ij}^{K}, \overline{G}_{ij}^{K}\right]$.

- Step 3: Construction of Grey Decision Matrix: The rating value of each alternative to each criterion can be presented by the Grey number shown below.

$$D = \begin{bmatrix} \otimes G_{11} & \otimes G_{12} & \cdots & \cdots & \otimes G_{1n} \\ \otimes G_{21} & \otimes G_{22} & \cdots & \cdots & \otimes G_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \\ \otimes G_{m1} & \otimes G_{m2} & \cdots & \cdots & \otimes G_{mn} \end{bmatrix} \quad (3.12)$$

- Step 4: The normalization of the Decision Matrix:

$$D^{*} = \begin{bmatrix} \otimes G_{11}^{*} & \otimes G_{12}^{*} & \cdots & \cdots & \otimes G_{1n}^{*} \\ \otimes G_{21}^{*} & \otimes G_{22}^{*} & \cdots & \cdots & \otimes G_{2n}^{*} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \\ \otimes G_{m1}^{*} & \otimes G_{m2}^{*} & \cdots & \cdots & \otimes G_{mn}^{*} \end{bmatrix} \quad (3.13)$$

For a benefit criterion, $\otimes G_{ij}^{*}$ is expressed as

$$\otimes G_{ij}^{*} = \left[\frac{\underline{G}_{ij}}{G_j^{max}}, \frac{\overline{G}_{ij}}{G_j^{max}}\right]. \tag{3.14}$$

where $G_j^{max} = max_{1 \le i \le m}\{\overline{G}_{ij}\}$

For a cost criterion, $\otimes G_{ij}^{*}$ is expressed as

$$\otimes G_{ij}^{*} = \left[\frac{G_j^{min}}{\overline{G}_{ij}}, \frac{G_j^{min}}{\underline{G}_{ij}}\right]. \tag{3.15}$$

where $G_j^{min} = min_{1 \le i \le m}\{\underline{G}_{ij}\}$.

- Step 5: Establish the weighted normalized Grey decision matrix D_W^{*} as presented below:

$$D_W^{*} = \begin{bmatrix} \otimes V_{11} & \otimes V_{12} & \cdots & \cdots & \otimes V_{1n} \\ \otimes V_{21} & \otimes V_{22} & \cdots & \cdots & \otimes V_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \\ \otimes V_{m1} & \otimes V_{m2} & \cdots & \cdots & \otimes V_{mn} \end{bmatrix} \tag{3.16}$$

where $\otimes V_{ij} = \otimes G_{ij}^{*} X \otimes W_j$

- Step 6: Make the ideal alternative as a referential alternative. For a set of m possible alternatives $A = \{A_1, A_2, A_3, \ldots\ldots, A_m\}$, the ideal alternative $A^{max} = \{\otimes G_1^{max}, \otimes G_2^{max}, \ldots, \otimes G_n^{max}\}$ can be determined by:

$$A^{max} = \left\{\left[\max_{1 \le i \le m} \underline{V}_{i1}, \max_{1 \le i \le m} \overline{V}_{i1}\right], \left[\max_{1 \le i \le m} \underline{V}_{i2}, \max_{1 \le i \le m} \overline{V}_{i2}\right], \ldots, \left[\max_{1 \le i \le m} \underline{V}_{in}, \max_{1 \le i \le m} \overline{V}_{in}\right]\right\} \tag{3.17}$$

- Step 7: Compute the Grey possibility degree between the compared alternatives set $A = \{A_1, A_2, A_3, \ldots, A_m\}$ and the ideal referential alternative A^{max}.

$$P\{A_i \le A^{max}\} = \frac{1}{n}\sum_{J=1}^{n} P\{\otimes V_{ij} \le \otimes G_j^{max}\} \tag{3.18}$$

- Step 8: Rank the alternatives. According to the results from the comparison between the alternatives set and the ideal referential alternative A^{max} in the 7th step, the ranking order of all alternatives can be determined. However, the alternative A_i has a better ranking order when $P\{A_i \le A^{max}\}$ is smaller.

CHAPTER 4

METHODS AND PROCEDURES

This study attempts to offer a set of essential airport KPIs to provide decision makers in the Libyan airport industry with a practical framework to measure and monitor airport performance over time. It also helps airports to identify potential problems in different areas for improvement. In other words, the results of this study are expected to be used as a guide by decision makers in the aviation industry to upgrade airport performance and to meet customer requirements, of course, within the budget and operational constraints of the airports.

However, in order to achieve the objectives of this research and to identify a suitable set of KPIs across several aspects of airport performance, the author has conducted a comprehensive literature review and was briefed on many previous studies related to the subject. Furthermore, for a good airport performance evaluation, it is important to study the entire airport system and not only some activity areas because the focus on some airport activity areas may lead to sub-optimization as well as to failure to determine the problems in the aspects that have not been studied (Oum and Yu 2004).

The methods and procedures that were performed in order to achieve the stated aim of this research have a number of steps:

4.1 Selection of Initial KPIs

This study started with the determination of the key performance areas for categorizing the indicators. The term ‘key performance areas’ is also used by Airports Council International (ACI) and the International Civil Aviation Organization (ICAO) (Wyman 2012). However, based on the literature review (some of which is discussed in the introduction), there is a variety of approaches to categorize airport indicators, depending on the study objectives and the authors’ background (Bezerra and Gomes 2016b). Some studies categorize indicators into two or three KPAs, as the case of Anne (2008), where three categories were used. Andersson Granberg and Munoz (2013) categorized the indicators into five activity areas to develop a list of indicators by surveying managers of several airports in Sweden and Spain. Airports Council International (ACI), in its guide to airport performance measures, categorizes the indicators into six KPAs. In some other studies, the indicators were categorized into more than six KPAs (Wyman 2012). In this study, the author categorized the indicators into five KPAs believed to cover the most important aspects of airport performance. The five Key Performance Areas (KPAs) are:

- Passenger service: This dimension covers a wide range of subjects that focus on passenger satisfaction. In general, airports give passenger satisfaction high priority to achieve a strong relationship with passengers in an increasingly competitive environment.
- Airside Area: Airside area is an area of aircraft movement containing runways, taxiways and apron areas where various logistical operations are performed (Wyman, 2012). The airside area dimension includes a number of key performance indicators related to aircraft movements and logistical operations. Many different logistical operations are performed from the moment an airplane touches down to while it is on the ground, and until it takes off again. These activities are defined as a turn-around process (Norin, 2008).
- Financial Perspective: The financial dimension includes a wide range of indicators relating to revenue, costs, and profit. These indicators are used to produce an overall picture of the airport's financial performance so that the strengths and weaknesses in the financial aspect can be identified by applying a benchmarking technique.
- Safety and Security: The area of safety and security is one of the most important responsibilities of the airport. The indicators within this aspect pertain to safety and security issues in different parts of the airport, including airside areas, terminals, and landside areas. These indicators are used to track accidents and also threats originating from people such as from terrorism acts and crimes.
- Environmental: This dimension has received strong focus in recent years from many airport managements to minimize negative environmental effects (Wyman,

2012). Environmental key performance indicators, consist of many different subjects, including energy consumption, contamination events, recycled waste, noise pollution, etc.

In the next step, five of the initial airport KPIs were identified for each key performance area based on previous relevant literature. Table 4.1 presents a range of initial KPIs and the sources of the collected indicators.

Airports operate under completely different environments regarding airport activities, ownership patterns, financial, site conditions, etc. Therefore, the appropriate KPIs for each airport will differ from one airport to another (Wyman 2012). For example, larger airports will probably concentrate more on various KPIs than will smaller airports (Wyman 2012). In addition, partially or fully privatized airports are more likely to concentrate on different KPIs than non-privatized airports (Wyman 2012). Even in the case of airports operating in similar environments, managers will have diverse perspectives regarding which KPIs are more important than others. The list of KPIs of most importance to a particular airport will change over time as operating conditions change and new issues arise (Wyman 2012). These points were considered while the author was selecting the initial set of KPIs.

Table 4.1-Initial KPIs for Airports

KPAs	KPIs	Source
Passenger service	Check-in waiting times	Bezerra and Gomes (2016)
	Baggage delivery time	Humphreys and Francis (2002)
	Waiting time at security control	Bezerra and Gomes (2016)
	Number of boarding gates	Lozano, Gutiérrez et al. (2013)
	Number of baggage collection belts	Lozano and Gutiérrez (2011)
Airside Area	Turn-around process time	Andersson Granberg and Munoz (2013)
	Number of runways	Yu, Hsu et al. (2008)
	Number of delayed flights in a day	Lozano, Gutiérrez et al. (2013)
	Length of Runway	Fan, Wu et al. (2014)
	Taxi departure delay	Wyman (2012)
Financial Perspective	Expenditure per passenger	Humphreys and Francis (2002)
	Income per passenger	Humphreys and Francis (2002)
	Non-aeronautical income per passenger	Humphreys and Francis (2002)
	Revenue per $m^2$of floor space	Humphreys and Francis (2002)
	Total Cost per work load unit (WLU)	Humphreys and Francis (2002)
Safety and Security	Number of incidents at security checkpoints in a year	Andersson Granberg and Munoz (2013)
	Number of aircraft accidents in a year	Wyman (2012)
	Time between shutdown and reopening in case of breach of airport's security	Enoma and Allen (2007)
	Time taken to begin the operations again in case of evacuation	Enoma and Allen (2007)
	Time taken to resume normal service after an attack on airport facilities	Enoma and Allen (2007)
Environmental	Energy consumption (Kwh/m^2)	Kılkış and Kılkış (2016)
	Number of contamination events measured per year	Humphreys and Francis (2002)
	Percentage of recycled waste measured per year	Kılkış and Kılkış (2016)
	Area affected by noise in the airport vicinity	Humphreys and Francis (2002)
	Number of complaints about airport activity measured per year	Humphreys and Francis (2002)

4.2 Conducting a Questionnaire Survey

A questionnaire survey was conducted in order to validate the initial KPIs and to confirm how important they are as measures of airport performance. The survey was distributed to professionals and expert employees at Misurata International Airport (IATA: MRA, ICAO: HLMS).

A purposive sampling technique was employed to select knowledgeable informants to participate in the survey. The purposive sampling is a non-probability sampling and it is a very useful technique when the specific type of information or knowledge required is held by only specific members of an organization (Tongco 2007). The purposive sampling technique is the deliberate choice of an informant based on the characteristics of the informant and it does not need a specific number of informants (Tongco 2007). In this study, the authors decided to use purposive sampling because the information required to achieve the research objectives regarding the importance of airport KPIs is held by only a certain group of employees at the airport.

In order to select the most reliable and the most qualified informants, managers and supervisors of the MRA airport, airlines, and ground handling companies, were met in person and asked to participate in the survey. Additionally, they were asked to name the most appropriate informants to participate in this survey. Finally, forty experts were selected using the purposive sampling technique. Participants were selected from three airlines (Turkish Airlines, Afriqiyah Airways, and Libyan Airlines), from three ground handling companies (Libyan Ground Services, Asfar Avia and Gulf Handling Services), and from various departments of MRA Airport (including operational, planning, safety and security, ATC, and firefighting departments, etc.).

This study utilized a questionnaire survey (as seen in Appendix A) that includes questions to rank the KPIs within each key performance area. The questionnaire survey consists of three parts:

- The first part of the survey contains an introduction to give a brief summary of the purpose of the questionnaire survey.
- The second part of the survey includes some questions to elicit general information on the informants being surveyed. The data required in this section includes company name, workplace (optional), the respondent's name, the respondent's title, and the respondent's work experience.
- The third part of the survey is used to determine the most important KPIs in each key performance area. The participants were asked to rank the importance of each indicator by using a scale ranging from 1 (not important) to 5 (most

important). The final ranking of the key performance indicators is based on how important they are as measures of airport performance.

4.2.1 Characteristics of Questionnaire Survey Respondents

The results of the questionnaire survey were collected and organized in an Excel file and then imported into SPSS software to perform a number of statistical analyses. As illustrated in Table 4.2, the participants in this study comprised 40 employees. The participants from Misurata airport management consists of 22.5% of the sample size, in addition to participants from Afriqiyah Airways; 20% of the sample were working at the Libyan Ground Services company, 15% of the sample size from Libyan Airlines; 7.5% were working at Turkish Airlines, also the same percentage as the Asfar Avia company, while respondents from the Gulf Handling Services company comprised 5% of the sample size.

Table 4.2-Respondent's distribution according to the workplace

Workplace	Observations	Percentage
Misurata Airport Departments	9	22.5%
Afriqiyah Airways	9	22.5%
Libyan Ground Services	8	20%
Libyan Airlines	6	15%
Turkish Airlines	3	7.5%
Asfar Avia	3	7.5%
Gulf Handling Services	2	5%
Total	40	100%

Figure 4.1 shows the respondents' work experience in the airport industry. 7 percent of the respondents had less than five years' work experience; 35 percent of the respondents had from 5 to 9 years' experience, while 58 percent had worked in the airport industry for more than 10 years.

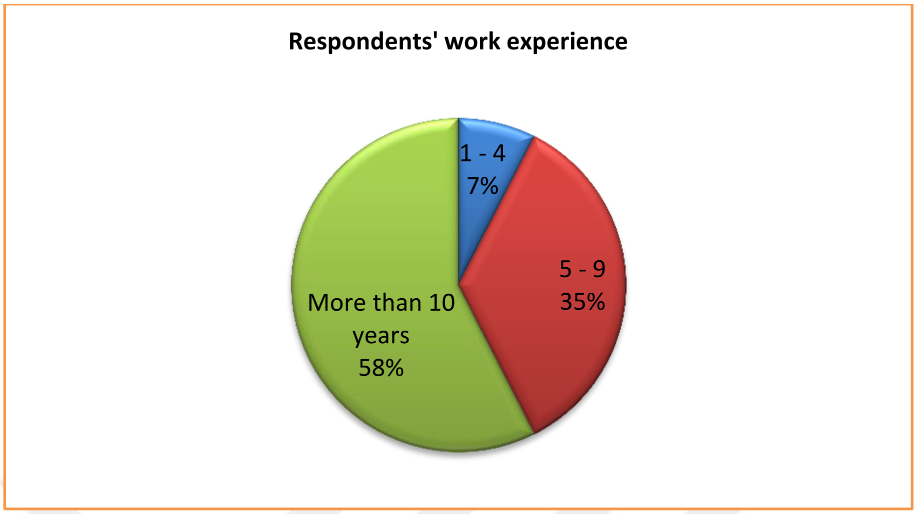

Figure 4.1-Respondents' work experience in years on the airport industry

According to the survey results presented in Table 4.3, each of the individual key performance indicators was ranked under its group. The final key performance indicators were selected with the aim of drawing a small number of KPIs across different components of the airport so that they can be easily understood and successfully managed (Chae, 2009, Parmenter, 2015). However, the initial KPIs were modified such that eight indicators which received less than 60% importance were omitted from the initial group. The results indicated that the number of baggage collection belts is regarded as a less important KPI in the passenger service group with a mean importance value of 1.95 representing 39% importance. Taxi departure delay and length of runway are regarded as less important KPIs in the airside area group with 48% and 47% importance, respectively. In the financial perspective dimension, revenue per m^2 of floor-space (terminal rentals paid by airlines for space utilization) and expenditure per passenger with less than 60% importance were removed from the initial KPIs due to less importance. With regard to the safety and security dimension, the time taken to resume normal service after an attack on airport facilities scoring 57% importance and number of aircraft accidents scoring 49% importance were considered less important KPIs and were thus omitted. As regards the environment dimension, the percentage of recycled waste with a mean value of 2.3 representing 46% importance was removed from the group due to the lower importance percentage. Finally, seventeen indicators across five performance areas of the airport were proposed as measures for airport performance.

Table 4.3-Descriptive statistics for the KPIs

KPAs and observed KPIs	Average	Freq. (%)	SD	∝	Ranking
A: Passenger Service				0.86	
A1: Check-in waiting times	3.58	72%	1.42		1
A2: Waiting time at security control	3.38	68%	1.48		2
A3: Number of boarding gates	3.08	62%	1.18		3
A4: Baggage delivery time	3.03	61%	1.32		4
A5: Number of baggage collection belts	1.95	39%	1.07		5
B: Airside Area				0.88	
B1: Turn-around process time	3.88	78%	1.32		1
B2: Number of delayed flights in a day	3.33	67%	1.37		2
B3: Number of runways	3.03	61%	1.40		3
B4: Taxi departure delay	2.4	48%	1.23		4
B5: Length of Runway	2.33	47%	1.23		5
C: Financial Perspective				0.85	
C1: Total Cost per work load unit (WLU)	3.58	72%	1.38		1
C2: Non-aeronautical revenue per passenger	3.43	69%	1.41		2
C3: Income per passenger	3.3	66%	1.26		3
C4: Revenue per m^2 of floor-space (Terminal rentals paid by airlines for space utilization)	2.38	48%	1.27		4
C5: Expenditure per passenger	2.33	47%	1.29		5
D: Safety and Security				0.63	
D1: Number of incidents at security checkpoints in a year	3.48	70%	1.39		1
D2: Time taken to begin the operations again in case of evacuation	3.25	65%	1.28		2
D3: Time between shutdown and reopening in case of breach of airport's security	3.05	61%	1.37		3
D4: Time taken to resume normal service after an attack on airport facilities	2.83	57%	1.52		4
D5: Number of aircraft accidents in a year	2.43	49%	1.44		5
E: Environmental				0.68	
E1: Energy consumption (Kwh/m^2)	3.45	69%	1.45		1
E2: Area affected by noise in the airport vicinity	3.20	64%	1.45		2
E3: Number of contamination events	3.05	61%	1.29		3
E4: Number of complaints about airport activity	2.98	60%	1.39		4
E5: Percentage of recycled waste	2.30	46%	1.30		5

Notes: SD - Standard deviation; ∝ – Cronbach's Alpha.

In addition, Cronbach's alpha (α) is computed to estimate the internal consistency of reliability associated with the scores that are derived from the five-point scale. Cronbach's alpha (α) values for each key performance area are presented in Table 4.3. The Cronbach's alpha values ranged from 0.63 to 0.88, which are still above the lower acceptable limits of 0.50-0.60 (Kaplan and Saccuzzo, Stewart and Mohamed 2003), indicating acceptable consistency. Table 4.4 demonstrates the final set of the KPIs with explanations and importance of each KPI.

Table 4.4-Explanations and Importance of the KPIs

KPAs	Key Performance Indicators (KPIs) definitions
A	**A1:** This KPI measures the average time that passengers spend on completing the check-in process. Shorter times will help provide more space in a terminal. This indicator is useful for internal benchmarking (Wyman 2012).
	A2: This KPI measures the average time that passengers spend at security control from entering a queue until to completing the process. This indicator is useful for internal and external benchmarking (Wyman 2012).
	A3: This indicator measures the number of boarding gates available at an airport. Increasing the number of boarding gates has a positive effect on airside efficiency (Gillen and Lall 1997).
	A4: This is one of the most used indicators by airports (Humphreys and Francis 2002). This indicator measures the average time of baggage delivery. The time is measured from delivery of the first bag until the last bag. This indicator can be used for internal and external benchmarking (Wyman 2012).
B	**B1:** This indicator measures the average turn-around activity times from the moment that a plane touches down, continues while the plane is on the ground and until it takes off.
	B2: This indicator measures the number of delayed flights per day. According to the Federal Aviation Administration (FAA), 15 minutes deviation from an airport flight schedule is considered delayed (Pathomsiri, Haghani et al. 2008).
	B3: This indicator measures the number of runways. In order to avoid delays and also to control airport noise, airports would need to supply sufficient runways (Gillen and Lall 1997, Humphreys and Francis 2002).

Table 4.4 (continued)

KPAs	Key Performance Indicators (KPIs) definitions
C	**C1:** Total costs (operating costs + non-operating costs) divided by Work Load Units (WLU), measured per year. WLU is defined as one passenger processed (departing or arriving) or 100 kg of freight handled (inbound or outbound) (Wyman 2012).
	C2. Non-aeronautical revenue (e.g., retail concessions, car parking, rent, food and beverage, advertising, etc.) divided by the number of passengers, measured over one year. Around 40% of total airport income is derived from the non-aeronautical sector (ACI 2015).
	C3: Total airport income divided by number of passengers departing and arriving, measured over one year.
D	**D1:** This indicator measures the number of incidents at security checkpoints over the course of a year.
	D2: This indicator measures the length of time it takes to restart operations in cases of evacuation (e.g., fire, bomb threat, terrorism, etc.). Airports need to resume normal operations quickly to avoid large losses in revenue.
	D3: This indicator measures the time between shutdown and reopening the airport in the event of a breach of security (Enoma and Allen 2007). The speed of dealing with a person in security breach is very important to begin operations again after an incident.
E	**E1:** This indicator measures the energy used per square meter in kilowatt hours. The indicator is widely used and can be used for internal and external benchmarking (Wyman 2012).
	E2: This indicator measures the area around the airport that may be affected by aircraft noise (area within 60 dB noise contour - km^2). Airports need to take some environmental measures prior to obtaining permission to expand. For example, airports need to maintain noise levels in the area surrounding the airport at or below 60 dB (Humphreys and Francis 2002, Kılkış and Kılkış 2016).
	E3: This indicator measures the number of contamination events in a year, e.g., fuel leaks from tanks or pipes on the ground or leakage of de-icing chemicals. Airports need to follow the correct procedures for storage and handling to prevent or minimize spill accidents (Kazda and Caves 2015).
	E4: This indicator measures the number of complaints from the community around an airport regarding airport activity over a one-year period. Aircraft noise is one of the main reasons for complaints.

4.3 Implementation of the AHP Method

As the KPAs and the indicators within them have been identified in the previous stage, the following steps are taken in order to apply the AHP method:

4.3.1 Construct the Decision Problem into a Hierarchy

When using the AHP method, in order to determine the weights of the KPIs as the main goal of this study, the hierarchy structure was constructed to represent relations within the structure and to perform pairwise comparisons at each level of the hierarchy. The hierarchy consists of four levels as shown in Figure 4.3. The top level, determination of key performance indicators for measuring Libyan airports success is set to be the goal of the study. The second level consists of five KPAs, namely passenger service, airside area, financial perspective, safety and security, and environmental. The third level consists of the key performance indicators within each key performance area, and the fourth level comprises the three candidate airports which need to be evaluated as sub-goals of the present study.

4.3.2 Pairwise Comparison Matrices and Weighting

After the problem is structured hierarchically, the next step is the elicitation of the pairwise comparison judgments of experts. In total, six pairwise comparison matrices were constructed. A pairwise comparison matrix for the KPAs in level 2 is constructed by using the concept of a reciprocal matrix, which is explained in Chapter 3. Similarly, five pairwise comparison matrices are then generated for the KPIs in level 2.

The surveys were distributed to seven senior supervisors and managers at MRA Airport who were selected using the purposive sampling technique. The participants used the survey to give their preferences on the KPAs, indicators and for comparisons between the three airports at the next stage. (For the pairwise comparison tables, see Appendix (B).)

The author gathered four responses, two from MRA airport departments, one from airlines, and one from ground handling companies. Three responses were removed from the AHP analysis due to incomplete data and the consistency ratio (CR>10%).

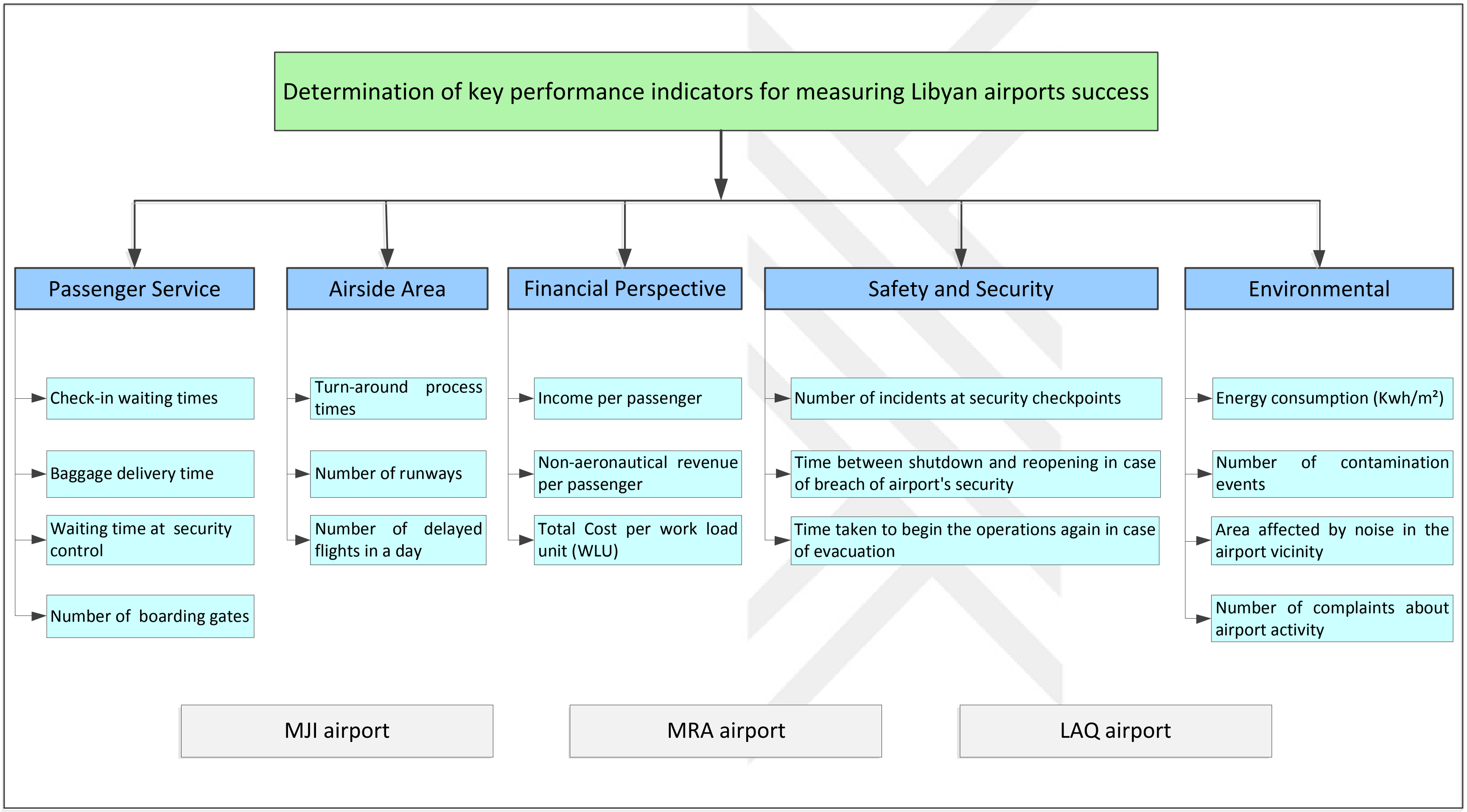

Figure 4.2 - The Hierarchy Structure of Key Performance Indicators

Furthermore, to avoid inconsistent answers from the participants in the pairwise comparison matrices, the author was working with the participants on the BPMSG free online software (BPMSG website), so the participants were able to revise their judgments until the results were acceptably consistent. This software is a decision-making support tool. It is used for the calculation of priorities and the evaluation of alternatives (Goepel 2013). Furthermore, before calculating the weights of all the key performance indicators, the geometric mean method was used to combine the judgment of the participants for each matrix to obtain a single judgment for each pairwise comparison matrix.

Additionally, the Expert Choice software will be used in the remaining steps of the AHP method to determine the global weights of the indicators. The Expert Choice software was designed to simplify the implementation of the analytical hierarchy process steps. The software was developed by Expert Choice, Inc. and it is available commercially (Expert Choice 2017).

To determine the weights as seen in the following section, the judgments of the decision-makers (experts) were entered into the Expert Choice application followed by the software automatically calculating the weights of each criterion and the consistency ratio for the pairwise comparison matrices.

4.3.2.1 Pairwise Comparison for the KPAs

Table 4.5 presents the priorities (importance weights) of the key performance areas. The priorities show the importance value of one criterion over another criterion. In general, there are significant differences in percentages among the five key performance areas. The passenger services (A) and safety and security (B) dimensions have the highest priority with respect to the goal of the study with a percentage of 33.7% and 30.8%, respectively. These percentages reflect the importance of these activity areas for monitoring and managing Libyan airports. The airside area (C) is ranked the third most important KPA with a percentage of 20.4%. The financial perspective (D) is fourth in priority with a relatively small percentage of 9.1%. Finally, the environmental perspective (E) is ranked the least important key performance area in priority with a percentage of 5.9%.

The results also show that the value of the consistency ratio (CR) 1.8% is far less than 10%, which means that the pairwise comparison evaluation is consistent and acceptable based on AHP theory (Saaty 1990).

Table 4.5-Results of KPAs Pairwise Comparisons

Key Performance Areas (KPAs)		Priority	Rank
A	Passenger services	0.337	1
B	Safety and Security	0.308	2
C	Airside Area	0.204	3
D	Financial Perspective	0.091	4
E	Environmental	0.059	5
Consistency Ratio (CR) = 1.8%			

With regard to the priorities of the KPIs, the experts' judgments of the indicators under each KPA, which were entered into the Expert Choice software, resulted in the priorities of each key performance indicator with respect to the goal of the study, as presented in the following sections.

4.3.2.2 Passenger Services KPIs Pairwise Comparisons

As can be seen from Table 4.6, check-in waiting times (indicator A1) is the most important indicator with a value of 0.363 over the others. Indicator A2, the number of boarding gates (0.326) records the second highest weight. Baggage delivery time (indicator A3) is ranked the third most important indicator with a value of 0.163. Waiting time at security control (indicator A4) is regarded the least important as an indicator for the passenger services dimension with a value of (0.148).

The consistency ratio (CR) in this pairwise comparison was 0.8%. This percentage does not exceed the percentage allowed according to the theory of the AHP, which is 10%.

Table 4.6- Results of Passenger Services KPIs Pairwise Comparisons

Passenger Services Indicators		**Priority**	**Rank**
A1	Check-in waiting times	0.363	1
A2	Number of boarding gates	0.326	2
A3	Baggage delivery time	0.163	3
A4	Waiting time at security control	0.148	4
Consistency Ratio (CR) = 0.8%			

4.3.2.3 Safety and Security KPIs Pairwise Comparisons

Table 4.7 shows the results of safety and security KPIs pairwise comparisons. The time between shutdown and reopening in case of breach of airport's security (Indicator B1) with a value of (0.550) is considered a far more important indicator than the remaining indicators in this dimension. The number of incidents at security checkpoints (Indicator B2) ranks second in priority with a value of 0.240, while the time taken to begin the operations again in case of evacuation (Indicator B3) is the least important indicator with a value of 0.210. In addition, a consistency ratio (CR) of 1.9% was achieved in this pairwise comparison.

Table 4.7-Results of Safety and Security KPIs Pairwise Comparisons

Safety and Security indicators		**Priority**	**Rank**
B1	Time between shutdown and reopening in case of breach of airport's security	0.550	1
B2	Number of incidents at security checkpoints	0.240	2
B3	Time taken to begin the operations again in case of evacuation	0.210	3
Consistency Ratio (CR) = 1.9%			

4.3.2.4 Airside Area KPIs Pairwise Comparisons

Table 4.8 summarizes the results of the pairwise comparison matrices for the airside area KPIs. The turn-around process time (Indicator C1) is considered the most important indicator in this dimension with a weight value of 0.667. Number of delayed flights in a day (Indicator C2) is the second important indicator, and Number of runways (Indicator C3) is viewed as the least important indicator for the airside area dimension with a low weight value of 0.111. The pairwise comparison matrix is consistent with a consistency ratio (CR) value 0% and the largest eigenvalue $\lambda_{max} = 3$. However, this confirms what has been discussed in Chapter 3 (the matrix is constant if $\lambda_{max} \geq n$).

Table 4.8-Results of Airside Area KPIs Pairwise Comparisons

Airside Area indicators		**Priority**	**Rank**
C1	Turn-around process time	0.667	1
C2	Number of delayed flights in a day	0.222	2
C3	Number of runways	0.111	3
Consistency Ratio (CR) = 0.0%			

4.3.2.5 Financial Perspective KPIs Pairwise Comparisons

Table 4.9 presents the weights of the financial perspective KPIs. Non-aeronautical revenue per passenger (Indicator D1) is the most important indicator with a value of 0.644 which is the highest value. Income per passenger (Indicator D1) is considered the 2nd most important indicator as it constitutes a weight of 0.271, followed by Indicator D3, The total cost per work load unit (WLU), which was recorded as having the lowest weight score with a value of 0.085. A consistency ratio (CR) of 5.6% was achieved in this pairwise comparison.

Table 4.9-Results of Financial Perspective KPIs Pairwise Comparisons

Financial Perspective indicators		Priority	Rank
D1	Non-aeronautical revenue per passenger	0.644	1
D2	Income per passenger	0.271	2
D3	Total Cost per work load unit (WLU)	0.085	3
Consistency Ratio (CR) = 5.6%			

4.3.2.6 Environmental KPIs Pairwise Comparisons

Table 4.10 presents a summary of the results of environmental KPIs pairwise comparisons. Energy consumption (Indicator E1) scored the highest weight with a value of 0.430, followed by Area affected by noise in the airport vicinity (Indicator E2) with a value of 0.328. Number of complaints about airport activity (Indicator E3) and Number of contamination events (Indicator E4) are the least important indicators with a value of 0.157 and 0.085 respectively. The results also show that the consistency ratio (CR) of 1.7% was achieved.

Table 4.10-Results of Environmental KPIs Pairwise Comparisons

Environmental indicators		Priority	Rank
E1	Energy consumption (Kwh/m²)	0.430	1
E2	Area affected by noise in the airport vicinity	0.328	2
E3	Number of complaints about airport activity	0.157	3
E4	Number of contamination events	0.085	4
Consistency Ratio (CR) = 1.7%			

4.3.2.7 Determining the Global Weights of the KPIs

To arrive at the overall weights for the KPIs, the local weight for each indicator is multiplied by its parent key performance area weight. Table 4.11 presents the calculation results and the rankings of the KPIs based on their level of importance as measures of airport performance.

As seen from Table 4.11, Time between shutdown and reopening in cases of breach of airport security (Indicator B1) is the highest weight with a value of (0.1694), which shows the importance of this indicator in relation to the other remaining indicators for Libyan airports. Turn-around process time (Indicator C1) with a value of (0.1360) is regarded as the second most important indicator followed closely by check-in waiting times (Indicator A1) with a value of (0.1223). Number of boarding gates (Indicator A2) scored fourth in the rankings with a value of (0.1099).

On the other hand, Number of contamination events (Indicator E4) with a value of (0.0050), total cost per work load unit (Indicator D3) with a value of (0.0077), and Number of complaints about airport activity (Indicator E3) with a value of (0.0093) were recorded as the least important KPIs. In general, indicators relating to the environmental and financial perspective aspects recorded the lowest overall weights, while indicators relating to safety and security, passenger services and airside area aspects scored the highest weights.

According to the opinions of experts, the AHP method derives the importance weight for all KPIs. However, at this point, the main objective of the study has been achieved. In the following sections, the two multiple criteria decision-making methods, AHP and the Grey system will be applied to compare the three international airports in Libya.

Table 4.11-The Global Weights and the Rank of the KPIs

KPAs	Global Weights	KPIs	Local eights	Global Weights	Ranking
A	0.337	A1	0.363	0.1223	3
		A2	0.326	0.1099	4
		A3	0.163	0.0549	8
		A4	0.148	0.0499	9
B	0.308	B1	0.550	0.1694	1
		B2	0.240	0.0739	5
		B3	0.210	0.0647	6
C	0.204	C1	0.667	0.1360	2
		C2	0.222	0.0453	10
		C3	0.111	0.0226	13
D	0.091	D1	0.644	0.0586	7
		D2	0.271	0.0247	12
		D3	0.085	0.0077	16
E	0.059	E1	0.430	0.0254	11
		E2	0.328	0.0194	14
		E3	0.157	0.0093	15
		E4	0.085	0.0050	17

4.3.2.8 Using AHP to Compare Airports

This study focuses on three airports MJI, MRA, and LAQ, to compare their performance. Seventeen pairwise comparisons matrices were constructed between three international Libyan airports (MJI, MRA, and LAQ) with respect to each indicator. The same four experts were asked again to use Saaty's nine-point scale as found in Appendix (B) to give their preferences on the airports based on the values of the indicators for each airport.

To determine the weights for each airport, answers to each question in the seventeen pairwise comparisons matrices were geometrically averaged. Then the judgments were entered into the Expert Choice software, which automatically calculates the importance weight of each airport and the consistency ratio for the pairwise comparison matrices. In addition, consistency ratios (CR) of 0.2 to 7.3 percent were achieved for the seventeen comparisons.

As presented in Table 4.12, MRA airport ranked first with an importance weight value of 0.417. MJI ranked next with a value of 0.339, followed by LAQ with the value of 0.244. In addition, consistency ratios (CR) of 0.2 to 7.3 percent were achieved for the seventeen comparisons.

Table 4.12-AHP Results for Airport Selection

Airport	IATA Code	Location	Statues	Ranking	Ranking
Mitiga Airport	MJI	Tripoli	Publicly owned	0.339	2
Misurata Airport	MRA	Misurata	Publicly owned	0.417	1
Al Abraq Airport	LAQ	Al Bayda	Publicly owned	0.244	3

Figure 4.4 presents the performance of the three airports in the five key performance areas. The chart highlight areas where the performance could improve. MRA airport has good performance in passenger services, safety and security, and airside area relative to other indicators. MJI airport showed good performance in safety and security. LAQ airport needs to improve its overall performance. In general, the three airports need to improve their performance of the financial perspective and environmental areas.

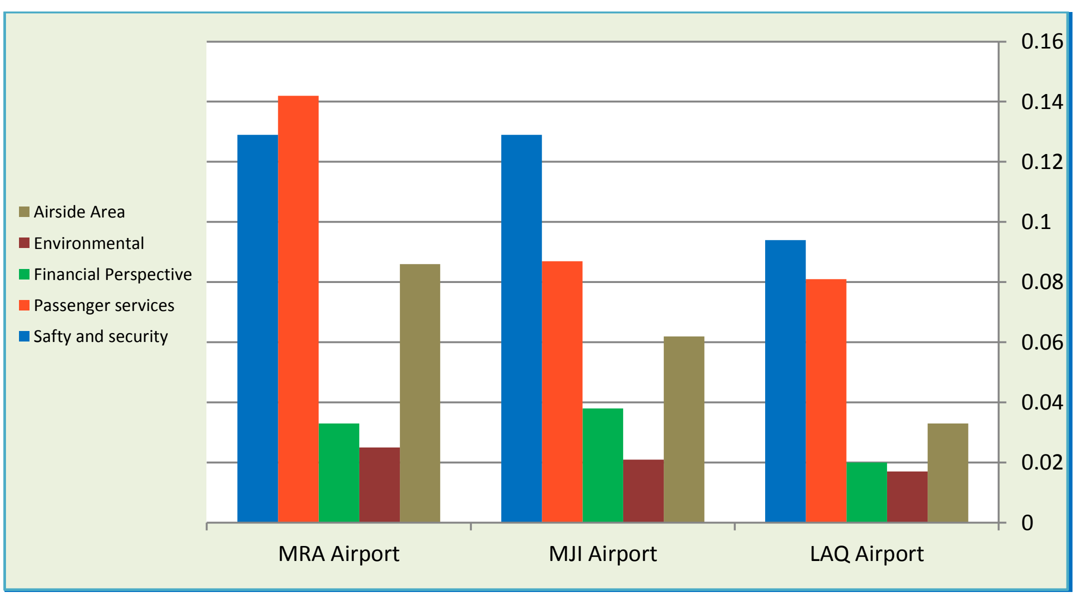

Figure 4.3-Airports Performance Chart

When these key performance indicators are employed, they can help airports to benchmark their respective performance against others based on the values of the indicators. Moreover, they can enable an airport to perform internal benchmarking by comparing its performance with itself in different aspects during a period of time.

4.4 Implementation of Grey System Theory

This study applied the Grey System Theory to compare the performances of the three international airports in Libya (MJI, MRA, and LAQ) across multiple aspects of airport performance. The method will use the KPAs identified earlier in this chapter as evaluation criteria. Figure 2.9 shows the selection structure for the Grey System theory.

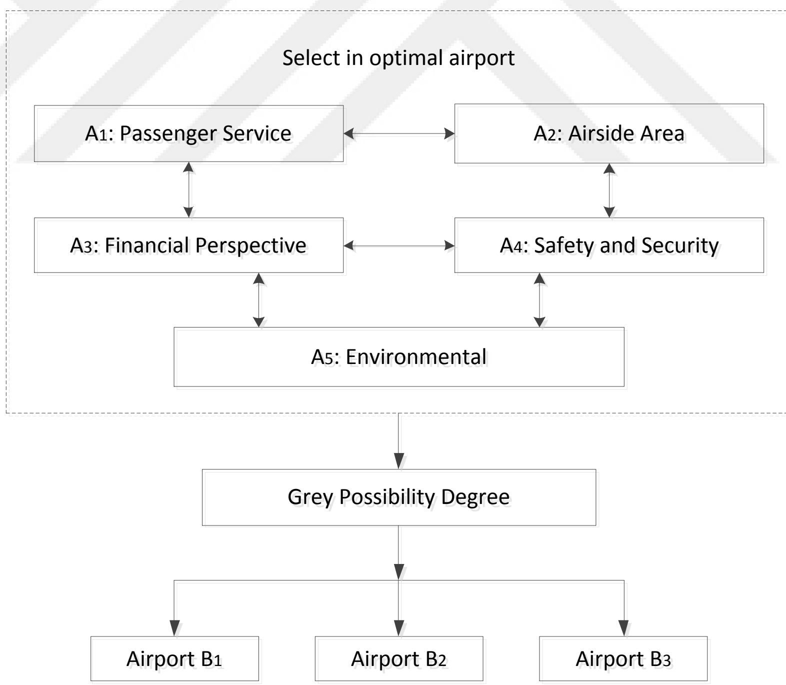

Figure 4.4-Selection Structure of Airports

The study focuses on three major airports $\mathrm{B}_i = (i = 1, 2, 3)$ as alternatives against five attributes $A_j = (j = 1, 2, 3, 4, 5)$ which are named KPAs in Table 4.13. The three attributes A_1, A_2, and A_3 are benefit attributes, while the A_4 and A_5 attributes are cost attributes. The greater values are better for benefit attributes and the smaller values are better for cost attributes. The calculation procedures as explained in Chapter 3 were carried out using macros in MS Excel as follows:

Table 4.13-Criteria for Airports Selection

KPAs	KPIs	Status
A_1: Passenger Service	- Check-in waiting times - Waiting time at security control - Number of boarding gates - Baggage delivery time	Benefit
A_2: Airside Area	- Turn-around process time - Number of delayed flights in a day - Number of runways	Benefit
A_3: Financial Perspective	- Total Cost per work load unit (WLU) - Non-aeronautical revenue per passenger in a year - Income per passenger in a year	Benefit
A_4: Safety and Security	- Number of incidents at security checkpoints in a year - Time taken to begin the operations again in case of evacuation - Time between shutdown and reopening in case of breach of airport's security	Cost
A_5: Environmental	- Energy consumption (Kwh/m²) - Area affected by noise in the airport vicinity - Number of contamination events in a year - Number of complaints about airport activity in a year	Cost

Step 1: Determine the attributes $(A_1, A_2, A_{3,} A_4, \textit{and } A_5)$ weights. A total of four aviation experts from government agencies and airline companies were carefully selected based on their experience in the airport industry to participate in the questionnaire survey (see Appendix C). The surveyed experts were firstly asked to determine the importance of the attributes for airport evaluation by using linguistic variables that can be expressed in Grey numbers (as shown earlier in Table 3.3). The evaluations of the attributes were then collected and the weights were determined using Equation 3.10. The results are given in Table 4.14.

Table 4.13-The Linguistic Assessment of the Attributes

A_i	Expert #1	Expert #2	Expert #3	Expert #4	$\otimes W$		Whitening degree
A_1	H	H	VH	VH	0.75	0.95	0.85
A_2	MH	H	M	H	0.53	0.73	0.63
A_3	ML	M	ML	ML	0.33	0.43	0.38
A_4	VH	VH	MH	VH	0.80	0.90	0.85
A_5	L	M	VL	VL	0.13	0.25	0.19

Step 2: Calculating the attribute rating values for the three airports. In the second step of the survey, the experts were asked to evaluate the airports with respect to individual attributes by using linguistic variables (as shown in Table 3.4). Then the rating values are calculated based on Equation 3.11. The results are given in Table 4.15.

Table 4.15-Experts Views on Airports Selection Attribute

Aj	Airports (B_i)	Expert #1	Expert #2	Expert #3	Expert #4	$\otimes Gij$
A_1	B_1	F	G	MG	MG	[5.00 6.50]
	B_2	MG	VG	G	F	[6.00 7.50]
	B_3	F	G	F	MP	[4.25 5.75]
A_2	B_1	MP	G	MP	MG	[4.25 5.75]
	B_2	F	VG	G	MG	[6.00 7.50]
	B_3	MP	MG	F	MP	[3.75 4.75]
A_3	B_1	MG	G	F	MG	[5.00 6.50]
	B_2	MG	F	F	F	[4.25 5.25]
	B_3	F	F	MP	MP	[3.50 4.50]
A_4	B_1	MG	VP	MG	MG	[3.75 4.75]
	B_2	MG	VP	MG	P	[2.75 4.00]
	B_3	G	VP	MG	VG	[5.00 6.50]
A_5	B_1	G	VG	MP	MG	[5.75 7.25]
	B_2	G	G	F	MP	[4.75 6.75]
	B_3	VG	G	MP	G	[6.00 8.00]

Step 3: Create the Grey decision matrix D. Based on Equation 3.12, the Grey decision matrix of the three airports can be obtained.

$$D = \begin{bmatrix} [5.00 & 6.50] & [4.25 & 5.75] & [5.00 & 6.50] & [3.75 & 4.75] & [5.75 & 7.25] \\ [6.00 & 7.50] & [6.00 & 7.50] & [4.25 & 5.25] & [2.75 & 4.00] & [4.75 & 6.75] \\ [4.25 & 5.75] & [3.75 & 4.75] & [3.50 & 4.50] & [5.00 & 6.50] & [6.00 & 8.00] \end{bmatrix}$$

Step 4: According to Equation 3.13, the normalized Grey decision matrix D* is established by making the Grey elements lie between 0 and 1.

$$D^* = \begin{bmatrix} [0.67 & 0.87] & [0.57 & 0.77] & [0.77 & 1.00] & [0.58 & 0.73] & [0.66 & 0.83] \\ [0.80 & 1.00] & [0.80 & 1.00] & [0.65 & 0.80] & [0.69 & 1.00] & [0.70 & 1.00] \\ [0.57 & 0.77] & [0.50 & 0.63] & [0.54 & 0.69] & [0.42 & 0.55] & [0.59 & 0.79] \end{bmatrix}$$

Step 5: Calculate the weights of the attributes using Equation 3.16 by Grey multiplication of the weights assigned to the attributes with the corresponding elements of the normalized Grey decision matrix.

$$D_W^* = \begin{bmatrix} [0.50 & 0.82] & [0.30 & 0.56] & [0.25 & 0.43] & [0.46 & 0.66] & [0.08 & 0.21] \\ [0.60 & 0.95] & [0.42 & 0.73] & [0.21 & 0.34] & [0.55 & 0.90] & [0.09 & 0.25] \\ [0.43 & 0.73] & [0.26 & 0.46] & [0.18 & 0.29] & [0.34 & 0.50] & [0.07 & 0.20] \end{bmatrix}$$

Step 6: Determine the ideal airport $S^{\max}$ referential alternative. Based on Equation 3.17, the ideal airport S^{max} is obtained as shown below:

$$S^{max} = \{[0.60 \quad 0.95], [0.42 \quad 0.73], [0.25 \quad 0.43], [0.55 \quad 0.90], [0.09 \quad 0.25]\}$$

Step 7: Calculate the Grey possibility degree between the three compared airports $B_1, B_1,$ and B_1. Every airport is compared with S^{max} to determine the Grey possibility degree. Based on Equation 3.18, the results of the Grey possibility degree of three airports, MJI, MRA, and LAQ, respectively, are shown as follows:

$P\{\text{MJI} \leq S^{max}\}$= 0.51 $P\{\text{MRA} \leq S^{max}\}$=0.49 $P\{\text{LAQ} \leq S^{max}\}$=0.59

Step 8: Rank the three airports based on Grey possibility degree values. The ranking of the three airports is:

$$\text{MRA airport} > \text{MJI airport} > \text{LAQ airport}$$

From the results, it can be stated that MRA is the best airport out of the three because $P\{\text{MRA} \leq S^{max}\}$ is the smaller value. MRA Airport should be an important alternative for both the airlines and passengers. The next important airport is MJI followed by LAQ

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Airports are an essential part of the mass transport infrastructure and they have a significant impact on regional and national economies. To improve airport performance, governments and airport authorities devote considerable resources to developing strategies and implementing measures to develop various aspects of airport performance.

In order to assist airport authorities in Libya to upgrade the performance of the country's airports, this thesis provides a framework for measuring performance. It focuses mainly on developing a list of airport KPIs that can be used to monitor and manage airports. A secondary aim of this study was to select the best practice international airport by using two different multiple criteria decision-making methods. However, in Libya, the detection of airport KPIs is yet to be formulated and documented for assessing airport performance across different aspects.

A literature review was performed to acquire a comprehensive view of airport performance measurements. The literature review focused mainly on three topics, namely how to develop and use KPIs for organizations, airport KPIs, and the importance of measuring performance. The literature review confirmed that no research has been published in the literature about the use of KPIs for the assessment of Libyan airports.

To establish a framework for measuring several aspects of airport performance, a total of 25 indicators under five activity areas were initially identified based on the previous literature review. Then, in order to validate the initial key performance indicators (KPIs), a questionnaire survey was structured and distributed among professionals from Misurata International Airport (IATA: MRA). The significance of airport key performance indicators was determined using the SPSS software. Finally, five KPAs with a total of seventeen key performance indicators have been proposed as the KPIs for airport evaluation.

The Analytical Hierarchy Process (AHP) method was then used as an evaluation model to calculate key performance indicator weights by summarizing the opinions of experts in the airport industry. The results reveal that there are significant differences in the rankings of the KPIs. In terms of KPAs, the dimension of passenger services received the highest weight with a value of 0.337, which as closely followed by safety and security with a value of 0.308. The third most important area is the airside area with a value of 0.204. The financial perspective and environmental were the least important weights receiving values of 0.091 and 0.059, respectively.

In terms of KPIs, check-in waiting times (0.1223) is regarded to be the highest important indicator for the passenger services dimension. With regard to the airside area dimension, the turn-around process time was the most important indicator with a value of 0.1360 over other indicators. For the financial perspective dimension, non-aeronautical revenue per passenger (0.0586) is the most important indicator. Time between shutdown and reopening in case of breach of airport's security (0.1694) is the single most important indicator in terms of safety and security. Energy consumption (Kwh/m^2), with a value of 0.0250, is considered a far more important indicator than the others in term of environmental dimension.

In order to achieve the sub-goals of this research, two case studies were conducted to provide a comparison between three international airports in Libya. The results of these studies can provide direction for airports to take the appropriate action to improve overall performance.

In the first case study, an evaluation model was developed using the AHP method to provide a performance comparison between the three international airports (MJI, MRA, and LAQ) based on the value of the KPIs with respect to the airports. The results indicated that there existed an important difference in the weights between the three airports. MRA airport ranked first with a weight of 0.417, followed by MJI airport with a value of 0.339, and LAQ airport third with the value of 0.244.

In the second case study, the Grey Theory method was used to compare between the three international airports in Libya (MJI, MRA, and LAQ) based on the value of the KPAs by summarizing the judgments of experts in the aviation industry. This case study takes into account that the preferences of the experts often include some uncertainty in estimating an airport's performance. However, the experts were consulted to identify the importance of the five KPAs and then compared the airports with respect to the values of the KPAs by using linguistic variables. Furthermore, unlike the results of the AHP method, the results from the Grey Theory method shows that the airports are close to each other in terms of efficiency and performance.

In conclusion, the results can help Libyan airports to improve their efficiency across different aspects by benchmarking their performance with other airports of similar size and operating in similar circumstances.

In general, this research brings greater insight into the Libyan airport industry to evaluate the level of improvement required in different airport aspects and also to obtain a solid reference to prioritize potential upgrades.

5.2 RECOMMENDATION

The following summary of recommendations is based on the findings and conclusions of the research.

- In order to develop a correct set of key performance indicators more in-depth studies need to be carried out with a larger representation in a survey by including more international and domestic airports.
- The developed KPIs have not been tested operationally yet, so the next step should thus be to implement and test the KPIs for several airports so that benchmarking can be performed as a method for a performance upgrade.

- In this study, the comparison of the three airports using in the two methods was theoretical, because it depended on the opinions of experts. To select the best practice airport in various aspects, it is preferable that a number of airports implement identical KPIs. Then, airport performance can be compared according to the value of each indicator.

REFERENCES

ACI (2015). ACI Airport Economics Report, http://www.aci.aero/Publications/Full-Publications-Listing/2015-ACI-Airport-Economics-Report.

ACI (2016). ACI Annual World Airport Traffic Dataset. http://www.aci.aero/Publications/New-Releases/ACI-World-Airport-Traffic-Forecasts-20162040.

Adler, N., V. Liebert and E. Yazhemsky (2013). "Benchmarking airports from a managerial perspective." Omega **41**(2): 442-458.

Africa Competitiveness Report (2013). the fourth Report, https://www.weforum.org/reports/africa-competitiveness-report-2013.

Andersson Granberg, T. and A. O. Munoz (2013). Developing key performance indicators for airports. 3rd ENRI International Workshop on ATM/CNS, February 19, Singapore.

Bezerra, G. C. and C. F. Gomes (2016). "Performance measurement in airport settings: a systematic literature review." Benchmarking: An International Journal **23**(4): 1027-1050.

Bezerra, G. C. L. and C. F. Gomes (2016). "Measuring airport service quality: A multidimensional approach." Journal of Air Transport Management **53**: 85-93.

BPMSG (website). "Business Performance Management Singapore, http://bpmsg.com/academic/ahp_calc.php.".

Brida, J. G., L. Moreno-Izquierdo and S. Zapata-Aguirre (2016). "Customer perception of service quality: The role of Information and Communication Technologies (ICTs) at airport functional areas." Tourism Management Perspectives **20**: 209-216.

Brunelli, M. (2014). Introduction to the Analytic Hierarchy Process, Springer.

Chae, B. (2009). "Developing key performance indicators for supply chain: an industry perspective." Supply Chain Management: An International Journal **14**(6): 422-428.

Chan, A. P. and A. P. Chan (2004). "Key performance indicators for measuring construction success." Benchmarking: an international journal **11**(2): 203-221.

Chung, T.-w., W.-c. Ahn, S.-m. Jeon and V. Van THAI (2015). "A benchmarking of operational efficiency in Asia Pacific international cargo airports." The Asian Journal of Shipping and Logistics **31**(1): 85-108.

Diana, T. (2010). "Can we explain airport performance? A case study of selected New York airports using a stochastic frontier model." Journal of Air Transport Management **16**(6): 310-314.

Enoma, A. and S. Allen (2007). "Developing key performance indicators for airport safety and security." Facilities **25**(7/8): 296-315.

Fan, L., F. Wu and P. Zhou (2014). "Efficiency measurement of Chinese airports with flight delays by directional distance function." Journal of Air Transport Management **34**: 140-145.

Fasone, V., T. Giuffrè and P. Maggiore (2012). "Multi-airport system as a way of sustainability for airport development: evidence from an Italian case study." Procedia-Social and Behavioral Sciences **53**: 96-105.

Fernandes, E. and R. R. Pacheco (2007). "Airport management: a strategic approach." Transportation **34**(1): 129-142.
Fodness, D. and B. Murray (2007). "Passengers' expectations of airport service quality." Journal of Services Marketing **21**(7): 492-506.
Francis, G., I. Humphreys and J. Fry (2002). "The benchmarking of airport performance." Journal of Air Transport Management **8**(4): 239-247.
Franek, J. and A. Kresta (2014). "Judgment scales and consistency measure in AHP." Procedia Economics and Finance **12**: 164-173.
Fung, M. K. Y., K. K. H. Wan, Y. Van Hui and J. S. Law (2008). "Productivity changes in Chinese airports 1995–2004." Transportation Research Part E: Logistics and Transportation Review **44**(3): 521-542.
Gillen, D. and A. Lall (1997). "Developing measures of airport productivity and performance: an application of data envelopment analysis." Transportation Research Part E: Logistics and Transportation Review **33**(4): 261-273.
Goepel, K. D. (2013). "BPMSG AHP Excel template with multiple inputs." Retrieved June **28**: 2015.
Grabowski, M., P. Ayyalasomayajula, J. Merrick, J. R. Harrald and K. Roberts (2007). "Leading indicators of safety in virtual organizations." Safety Science **45**(10): 1013-1043.
Guh, Y.-Y., R.-W. Po and K.-R. Lou (2009). "An additive scale model for the analytic hierarchy process." International journal of information and management sciences **20**(1): 71-88.
Humphreys, I. and G. Francis (2002). "Performance measurement: a review of airports." International Journal of Transport Management **1**(2): 79-85.
Ignaccolo, M. (2000). "Environmental capacity: noise pollution at Catania-Fontanarossa international airport." Journal of Air Transport Management **6**(4): 191-199.
Ju-Long, D. (1982). "Control problems of grey systems." Systems & Control Letters **1**(5): 288-294.
Julong, D. (1989). "Introduction to grey system theory." The Journal of grey system **1**(1): 1-24.
Kaplan, R. and D. Saccuzzo "Psychological Testing: Principles, Applications and Issues, Brooks/Cole, California, 1993."
Kazda, A. and R. E. Caves (2015). Airport design and operation, Emerald Group Publishing.
Kılkış, Ş. and Ş. Kılkış (2016). "Benchmarking airports based on a sustainability ranking index." Journal of Cleaner Production **130**: 248-259.
Kosanke, L. and M. Schultz (2015). "Key Performance Indicators for Performance-Based Airport Management from the perspective of airport operations."
Kose, E., M. Kabak and H. Aplak (2013). "Grey theory based MCDM procedure for sniper selection problem." Grey Systems: Theory and Application **3**(1): 35-45.
Lai, P. L., A. Potter, M. Beynon and A. Beresford (2015). "Evaluating the efficiency performance of airports using an integrated AHP/DEA-AR technique." Transport Policy **42**: 75-85.
Lapide, L. (2000). "What about measuring supply chain performance." Achieving Supply Chain Excellence Through Technology **2**(2): 287-297.

Li, G.-D., D. Yamaguchi and M. Nagai (2007). "A grey-based decision-making approach to the supplier selection problem." Mathematical and computer modelling **46**(3): 573-581.
Li, Q.-X. (2009). "Grey dynamic input–output analysis." Journal of Mathematical Analysis and Applications **359**(2): 514-526.
Lindberg, C.-F., S. Tan, J. Yan and F. Starfelt (2015). "Key performance indicators improve industrial performance." Energy Procedia **75**: 1785-1790.
Liu, S., Z. Fang, Y. Yang and J. Forrest (2012). "General grey numbers and their operations." Grey Systems: Theory and Application **2**(3): 341-349.
Liu, S. and J. Y. L. Forrest (2010). Grey systems: theory and applications, Springer.
Lozano, S. and E. Gutiérrez (2011). "Slacks-based measure of efficiency of airports with airplanes delays as undesirable outputs." Computers & Operations Research **38**(1): 131-139.
Lozano, S., E. Gutiérrez and P. Moreno (2013). "Network DEA approach to airports performance assessment considering undesirable outputs." Applied Mathematical Modelling **37**(4): 1665-1676.
MacLean, L., A. Richman and S. MacLean (2016). "Benchmarking airports with specific safety performance measures." Transportation Research Part A: Policy and Practice **92**: 349-364.
Mardani, A., E. K. Zavadskas, Z. Khalifah, A. Jusoh and K. M. Nor (2016). "Multiple criteria decision-making techniques in transportation systems: a systematic review of the state of the art literature." Transport **31**(3): 359-385.
Meier, H., H. Lagemann, F. Morlock and C. Rathmann (2013). "Key performance indicators for assessing the planning and delivery of industrial services." Procedia Cirp **11**: 99-104.
Morrell, P. and C. H.-Y. Lu (2000). "Aircraft noise social cost and charge mechanisms–a case study of Amsterdam Airport Schiphol." Transportation Research Part D: Transport and Environment **5**(4): 305-320.
Müller, J., T. Ülkü and J. Zivanovic (2009). "Privatization, restructuring and its effects on performance: A comparison between German and British airports." Unpublished German Airport Performance project working paper.
Neely, A., M. Gregory and K. Platts (2005). "Performance measurement system design: A literature review and research agenda." International journal of operations & production management **25**(12): 1228-1263.
Norin, A. (2008). "Airport Logistics: Modeling and Optimizing the Turn-Around Process."
Norin, A., T. A. Granberg, D. Yuan and P. Värbrand (2012). "Airport logistics–A case study of the turn-around process." Journal of Air Transport Management **20**: 31-34.
Oum, T. H. and C. Yu (2004). "Measuring airports' operating efficiency: a summary of the 2003 ATRS global airport benchmarking report." Transportation Research Part E: Logistics and Transportation Review **40**(6): 515-532.
Pabedinskaitė, A. and V. Akstinaitė (2014). "Evaluation of the airport service quality." Procedia-Social and Behavioral Sciences **110**: 398-409.
Pantouvakis, A. and M. F. Renzi (2016). "Exploring different nationality perceptions of airport service quality." Journal of Air Transport Management **52**: 90-98.

Parmenter, D. (2015). Key performance indicators: developing, implementing, and using winning KPIs, John Wiley & Sons.
Pathomsiri, S., A. Haghani, M. Dresner and R. J. Windle (2008). "Impact of undesirable outputs on the productivity of US airports." Transportation Research Part E: Logistics and Transportation Review **44**(2): 235-259.
Pérez, J. C., M. H. Carrillo and J. R. Montoya-Torres (2015). "Multi-criteria approaches for urban passenger transport systems: A literature review." Annals of Operations Research **226**(1): 69-87.
Postorino, M. N. and F. G. Praticò (2012). "An application of the Multi-Criteria Decision-Making analysis to a regional multi-airport system." Research in Transportation Business & Management **4**: 44-52.
Spitzer, D. (2007). "TRANSFORMING Performance Measurement Rethinking the Way We Measure and Drive Organizational Success."
Rhoades, D. L., B. Waguespack Jr and S. Young (2000). "Developing a quality index for US airports." Managing Service Quality: An International Journal **10**(4): 257-262.
Saaty, T. L. (1980). "The Analytic Hierarchy Process, New York: McGrew Hill." International, Translated to Russian, Portuguesses and Chinese, Revised edition, Paperback (1996, 2000), Pittsburgh: RWS Publications.
Saaty, T. L. (1990). Decision making for leaders: the analytic hierarchy process for decisions in a complex world, RWS publications.
Saaty, T. L. (1990). "How to make a decision: the analytic hierarchy process." European journal of operational research **48**(1): 9-26.
Saaty, T. L. (2000). Fundamentals of decision making and priority theory with the analytic hierarchy process, Rws Publications.
Saaty, T. L. (2008). "Decision making with the analytic hierarchy process." International journal of services sciences **1**(1): 83-98.
Saaty, T. L. and L. G. Vargas (2012). Models, methods, concepts & applications of the analytic hierarchy process, Springer Science & Business Media.
Schmidberger, S., L. Bals, E. Hartmann and C. Jahns (2009). "Ground handling services at European hub airports: development of a performance measurement system for benchmarking." International Journal of Production Economics **117**(1): 104-116.
Shi, J., S. Liu and W. Xiong (2005). "A new solution for interval number linear programming." Systems Engineering-theory & Practice **2**: 016.
Skouloudis, A., K. Evangelinos and S. Moraitis (2012). "Accountability and stakeholder engagement in the airport industry: An assessment of airports' CSR reports." Journal of Air Transport Management **18**(1): 16-20.
Stewart, R. A. and S. Mohamed (2003). "Evaluating the value IT adds to the process of project information management in construction." Automation in Construction **12**(4): 407-417.
Vaidya, O. S. and S. Kumar (2006). "Analytic hierarchy process: An overview of applications." European Journal of operational research **169**(1): 1-29.
Wang, R.-T., C.-T. Ho, C.-M. Feng and Y.-K. Yang (2004). "A comparative analysis of the operational performance of Taiwan's major airports." Journal of Air Transport Management **10**(5): 353-360.

Wyman, O. (2012). "Guide to airport performance measures." Airports Council international, ACI.

Yoo, K. E. and Y. C. Choi (2006). "Analytic hierarchy process approach for identifying relative importance of factors to improve passenger security checks at airports." Journal of Air Transport Management **12**(3): 135-142.

Yoshida, Y. (2004). "Endogenous-weight TFP measurement: methodology and its application to Japanese-airport benchmarking." Transportation Research Part E: Logistics and Transportation Review **40**(2): 151-182.

Yu, M.-M., S.-H. Hsu, C.-C. Chang and D.-H. Lee (2008). "Productivity growth of Taiwan's major domestic airports in the presence of aircraft noise." Transportation Research Part E: Logistics and Transportation Review **44**(3): 543-554.

Zietsman, D. and M. Vanderschuren (2014). "Analytic Hierarchy Process assessment for potential multi-airport systems–The case of Cape Town." Journal of Air Transport Management **36**: 41-49.

Appendix A

Introduction

Dear Sir/Madam,

This questionnaire survey is being conducted as part of a Master thesis project currently being conducted at Atilim University with the aim to develop a useful list of key performance indicators (KPIs) in five key performance areas (KPAs). This research will provide decision makers in the Libyan aviation industry with a practical framework that will help to take action for performance upgrades. We therefore request the following information.

Thank you

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Part 1

General Information

Respondent's name	Company name	Workplace
Title	**Work experience**	**Telephone**

Part 2

Validation of the initial KPIs

Please rank the KPIs within each key performance area by using a scale ranging from 1 (not important) to 5 (most important).

Table 1
Ranking of the KPIs

KPAs	KPIs	Ranking From 1 to 5
Passenger Service	Check-in waiting times	
	Baggage delivery time	
	Waiting time at security control	
	Number of boarding gates	
	Number of baggage collection belts	
Airside Area	Turn-around process times	
	Number of runways	
	Number of delayed flights in a day	
	Length of Runway	
	Taxi departure delay	
Financial Perspective	Expenditure per passenger	
	Income per passenger	
	Non-aeronautical income per passenger	
	Revenue per m^2 of floor space	
	Total Cost per work load unit (WLU)	
Safety and Security	Number of incidents at security checkpoints	
	Number of aircraft accidents	
	Time between shutdown and reopening in case of breach of airport's security	
	Time taken to begin the operations again in case of evacuation	
	Time taken to resume normal service after an attack on airport facilities	
Environmental	Energy consumption (Kwh/m^2)	
	Number of contamination events	
	Percentage of recycled waste	
	Area affected by noise in the airport vicinity	
	Number of complaints about airport activity	

Appendix B

Determining the weights of the criteria

1. Introduction

Dear Sir/Madam,

This survey is being conducted as part 2 of the Master thesis project currently being conducted at Atilim University under the title of "determination of key performance indicators for measuring Libyan airports success." The objective of this survey is to determine the weights of main criteria and sub-criteria (KPAs and KPIs) by using the scale of the analytical hierarchy process (AHP), method as shown in Table 1. Then with respect to each indicator, we determine the weights of three Libyan international airports (MJI, MRA, and LAQ) with the aim to compare between the three airports.

To meet this objective, we request that you please kindly provide us with the following information in Parts 1, 2 and 3.

Your feedback will be greatly appreciated.

Thank you

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Part 1

General Information

Respondent's name	Company name	Workplace

Title	Work experience	Telephone

Part 2

Determining the Weights of the KPAs and KPIs

Please use numbers from 1 to 9 as presented in Table 2 to show preference in the following comparison matrices with consideration that the judgments should be consistent.

Table 2-The AHP pairwise comparison scale

Intensity of Importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	To present intermediate values between the two adjacent judgments

Example:

As shown in the matrices below (Table 3), when we compare the importance of ‘economic’ with ‘safety,’ we note that ‘safety’ is more important (5 times) then ‘economic.’ Therefore, 1/5 needs to be entered in the (1,2) position. Then, automatically the value of 5 is entered in position (2,1) for (safety, economic).

Table 3-pairwise comparison example

Criteria	Economic	Safety	Environmental
Economic	**1** (1,1)	**1/5** (1,2)	**3** (1,3)
Safety	**5** (2,1)	**1** (2,2)	**7** (2,3)
Environmental	**1/3** (3,1)	**1/7** (3,2)	**1** (3,3)

As another illustration, the economic criterion is judged to be more important than the environmental criterion and the value of 3 is entered in the (1, 3) followed by the value of l/3 needing to be entered in the (3, 1) position (Environmental, Economic).

The hierarchy structure as demonstrated in Figure (1) represents the relations within the structure. Accordingly we created the pairwise comparison matrices.

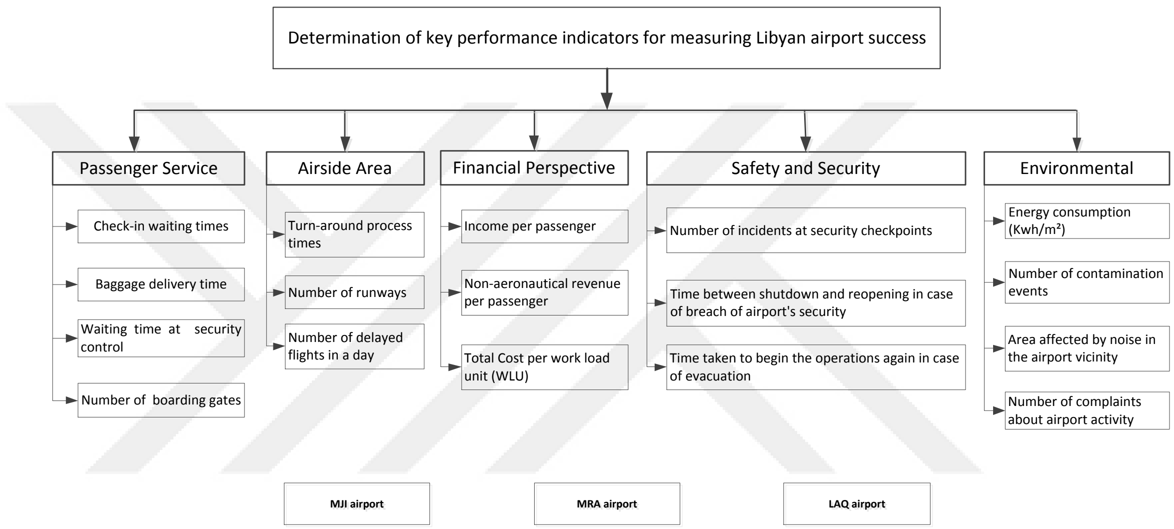

Figure 1-The hierarchy structure of airport key performance indicators

1. Pairwise Comparison

We request that you please provide us with the following information.

1.1 Pairwise Comparison Matrix for Key performance areas (KPAs)

KPAs	Passenger service	Airside area	Financial perspective	Safety and Security	Environmental
Passenger services	1				
Airside area		1			
Financial perspective			1		
Safety and Security				1	
Environmental					1

2. Pairwise Comparison Matrix for key performance indicators (KPIs)

2.1 Pairwise comparisons for Passenger services indicators

Passenger services	Check-in waiting times	Baggage delivery time	Waiting time at security control	Number of boarding gates
Check-in waiting times	1			
Baggage delivery time		1		
Waiting time at security control			1	
Number of boarding gates				1

2.2 Pairwise comparisons for Airside area indicators

Airside Efficiency	Turn-around process times	Number of runways	Number of delayed flights in a day
Turn-around process times	1		
Number of runways		1	
Number of delayed flights in a day			1

2.3 Pairwise comparisons for Financial Perspective indicators

Financial Perspective	Income per passenger	Non-aeronautical revenue per passenger	Total Cost per work load unit (WLU)
Income per passenger	1		
Non-aeronautical revenue per passenger		1	
Total Cost per work load unit (WLU)			1

2.4 Pairwise comparisons for Safety and Security indicators

Safety and security	Number of incidents at security checkpoints	Time between shutdown and reopening in case of breach of airport's security	Time taken to begin the operations again in case of evacuation
Number of incidents at security checkpoints	1		
Time between shutdown and reopening in case of breach of airport's security		1	
Time taken to begin the operations again in case of evacuation			1

2.5 Pairwise comparisons for Environmental indicators

Environmental	Energy consumption (Kwh/m²)	Number of contamination events	Area affected by noise in the airport vicinity	Number of complaints about airport activity
Energy consumption (Kwh/m²)	1			
Number of contamination events		1		
Area affected by noise in the airport vicinity			1	
Number of complaints about airport activity				1

Part 3

Determining the weights of the Airports

The objective of this part of the survey is to provide a performance comparison between the three international airports in Libya based on the values of the KPIs at each airport.

We request that you please use the numbers from 1 to 9 as presented in Table 1 to show the preference in the following comparison matrices with the consideration that the judgments should be consistent.

Check-in waiting times	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Waiting time at security control	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Number of boarding gates	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Baggage delivery time	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Turn-around process times	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Number of delayed flights in a day	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Number of runways	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Total Cost per work load unit (WLU)	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Non-aeronautical revenue per passenger	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Income per passenger	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Number of incidents at security checkpoints	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Time taken to begin the operations again in case of evacuation	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Time elapsed between shutdown and reopening in case of breach of airport's security	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Energy consumption (Kwh/m²)	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Area affected by noise in the airport vicinity	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Number of contamination events	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Number of complaints about airport activity	MJI	MRA	LAQ
MJI	1		
MRA		1	
LAQ			1

Appendix C

Introduction

Dear Sir / Madam

I am presently conducting a study to compare the three international airports in Libya by applying the Grey Theory Method. This research project is part of my thesis studies at the Faculty of Graduate Studies under the guidance of the Department of Industrial Engineering at Atilim University.

Applying the best practice technique helps airports to learn from other successful airports by highlighting areas that need further improvement. We therefore kindly request the following information from you.

Thank you

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Part 1

General Information

Respondent's name	Company name	Workplace
Title	**Work experience**	**Telephone**

Part 2

Determining the importance of each attribute

Please provide your preferences to determine the importance of each attribute in Table 1 for the evaluation of the airport by using the linguistic variables scale given in Table 2.

Table 1-Attributes for airports selection

Attributes	Status	Evaluation
A_1: Passenger Service	Benefit	
A_2: Airside Area	Benefit	
A_3: Financial Perspective	Benefit	
A_4: Safety and Security	Cost	
A_5: Environmental	Cost	

Table 2- The scale of attribute weights

Importance	Abbreviation	Scale of grey number $\otimes W$
Very Low	VL	[0.0, 0.1]
Low	L	[0.1, 0.3]
Medium Low	ML	[0.3, 0.4]
Medium	M	[0.4, 0.5]
Medium High	MH	[0.5, 0.6]
High	H	[0.6, 0.9]
Very High	VH	[0.9, 1.0]

Part 3

Airports Evaluation

Please provide your preferences on the three airports shown in Table 3 using the linguistic variables scale given in Table 4.

Table 3- Experts views on airports selection attribute

Attributes	Status	Airports	Evaluation
A_1: Passenger Service	Benefit	MJI	
		MRA	
		LAQ	
A_2: Airside Area	Benefit	MJI	
		MRA	
		LAQ	
A_3: Financial Perspective	Benefit	MJI	
		MRA	
		LAQ	
A_4: Safety and Security	Cost	MJI	
		MRA	
		LAQ	
A_5: Environmental	Cost	MJI	
		MRA	
		LAQ	

Table 4-The scale for airport's performance

Performance	Abbreviation	Scale of grey number $\otimes W$
Very Poor	VP	[0.0, 1.0]
Poor	P	[1.0, 3.0]
Medium Poor	MP	[3.0, 4.0]
Fair	F	[4.0, 5.0]
Medium Good	MG	[5.0, 6.0]
Good	G	[6.0, 9.0]
Very Good	VG	[9.0, 10.]