

University of Bahrain

College of Engineering



Department of
Mechanical Engineering

An investigation into the factors that lead to the efficient use of the New Public Transport System in Riyadh City: A case of Riyadh City in KSA

**A Thesis submitted in partial fulfillment of the requirements for the
degree of science of master's in engineering management**

Submitted by:

Omar Ghalib Abdullah

Academic ID: 20189555

Supervised by:

Prof. Saad Muhammad Suliman (May Allah have mercy on him)

Dr. Venu Parameswaran Pillai

Co-supervisor:

Prof. Abdulaziz El-Tamimi

May 24, 2023May 2021

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May 24, 2023*

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في مدينة الرياض: حالة مدينة الرياض بالمملكة العربية السعودية**

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مقدمة من الطالب:

عمر غالب عبد الله

الرقم الجامعي: 20189555

إشراف:

البروفيسور: سعد محمد سليمان (رحمه الله)

الدكتور: فينو باراميسوارانبيلاي

المشرف المساعد:

البروفيسور: عبد العزيز بن محمد التميمي

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Abstract

This research has provided new insight into the service quality dimensions SERVQUAL model for Riyadh's Public Transport System (RPTS).

The study attempted to solve the problem of the enormous dependency on private cars and road congestion in Riyadh City. Accordingly, it has structured the most important criteria, attributes, and KPIs that will lead Riyadh's citizens and residents to depend heavily on the new public transport system. Additionally, the study has found some of the optimal standards and strategies that lead ridership to use the public transport system effectively and effectively.

The SERVQUAL model has been used in this study to structure the framework of the study, which fits the needs of RPTS's ridership. The method was an integration between Fuzzy Analytical Hierarchy Process (FAHP) method and Quality Function Deployment (QFD) model. Two questionnaire types have been used. The first type was a public questionnaire with a sample size of 385 participants from Riyadh City, distributed using the online platforms such as WhatsApp, Telegram, and Instagram; the responses rate was 97%. SPSS has been used for analyzing the public questionnaire results; then, these results have been converted into fuzzy numbers using the Fuzzy Number Conjoint Model (FNCM) to overcome the uncertainty of the public participants' answers. The second questionnaire type was an experts' questionnaire with a sample size of 20 experts from the Royal Commission of Riyadh City (RCRC), with a responses rate of 77%. FAHP method has been used for prioritizing the results of the experts' questionnaire; then, the weighted results have been exported to the first stage of the QFD model.

The study results found that facility reliability, service reliability, and cultural mobility are critical quality dimensions that lead to the efficient use of RPTS. Additionally, accessibility to the service; time quality; safety & security; and personnel quality are the most critical attributes for achieving the goal of this study.

A new software application has been developed as a decision-making tool that facilitates the calculation of the FAHP method. It can also deal with consensus problems in FAHP. Additionally, the application can deal with the QFD process with the original four phases and customize the phases according to users' needs. Moreover, both FAHP and QFD can be integrated with this application.

Keywords

SERVQUAL model, service quality dimensions, public transportation in Riyadh City, AHP, FAHP, QFD, QFD Stages, HOQ, Consensus in AHP, Aggregate Individual Judgment (AIJ), Collective Judgment Matrix (CJM), ridership, customer requirement, technical requirement, management requirement, standards, and strategies

الملخص

قدم هذا البحث رؤية جديدة في نموذج مقياس جودة الخدمة (SERVQUAL) لنظام النقل العام الجديد في مدينة الرياض. كما حاولت الدراسة حل مشكلة الاعتماد الكبير على السيارات الخاصة. وكذلك ازدحام الطرق في مدينة الرياض، وبناءً على ذلك ، فقد اقترحت الدراسة أهم المعايير والسمات ومؤشرات الأداء الرئيسية التي ستقود المواطنين والمقيمين في مدينة الرياض إلى الاعتماد بشكل كبير على نظام النقل العام الجديد، بالإضافة إلى ذلك فقد اقترحت الدراسة الحلول المثلى التي تقود الركاب استخدام نظام النقل العام بشكل فعال.

تم استخدام نموذج (SERVQUAL) في هذه الدراسة لهيكلة اطار الدراسة، التي بدورها تتناسب مع متطلبات ركاب نظام النقل العام الجديد. الطريقة المستخدمة في هذه الدراسة هي الدمج بين عملية التسلسل الهرمي التحليلي الضبابي (FAHP) مع نموذج نشر وظائف الجودة (QFD). تم استخدام نوعين من الاستبيانات. النوع الأول هو استبيان العامة بحجم عينة 385 مشاركًا ، كما تم استخدام برنامج SPSS لتحليل نتائج استبيانات العامة ، بعد ذلك ، تم تحويل هذه النتائج إلى أرقام ضبابية باستخدام نموذج اقتران الرقم الضبابي (FNCM) للتغلب على مشكلة عدم اليقين الناتجة عن إجابات المشاركين العامة. النوع الثاني من الاستبيان هو استبيان الخبراء بحجم عينة 20 خبيرًا من الهيئة الملكية لمدينة الرياض (RCRC) ، وقد تم استخدام طريقة (FAHP) لتحديد أولويات نتائج استبيان الخبراء. ثم تم تصدير النتائج الموزونة إلى المرحلة الأولى من مراحل QFD.

وجدت نتائج الدراسة أن موثوقية المرافق ، وموثوقية الخدمة ، والحراك الثقافي هي أبعاد مهمة و التي بدورها ستقود النقل العام في مدينة الرياض للعمل بكفاءة وفعالية. بالإضافة إلى ذلك ، تعد سهولة الوصول إلى الخدمة ، وجودة الوقت ، والسلامة والأمن ، وجودة الموظفين من أهم السمات التي يجب توفرها من أجل تحقيق هدف النقل العام.

تم تطوير تطبيق برمجي جديد يقوم بعمل خوارزمية طريقة FAHP ، ويمكنه أيضًا التعامل مع الإجماع في عملية التحليل الهرمي (Consensus in AHP) بالإضافة إلى ذلك ، يحتوي التطبيق على عملية QFD بمراحلها الأربع ، ويمكنه أيضًا تخصيص المراحل حسب احتياجات المستخدمين. علاوة على ذلك ، يمكن دمج كل من FAHP و QFD في هذا التطبيق.

Dedication

Because the essence of this research is about decision-making, I dedicate this research to those **who taught me how decisions are professionally made, my father & mother, Ghaleb and Aida**

إهداء

لأن محور هذا البحث يكمن في طرق اتخاذ القرارات،
أهدي هذا البحث لمن علمني الصواب في اتخاذ القرارات،
أبي وأمي: غaleb وعائدة

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CHAPTER 1

Introduction to The Thesis

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1.1 General Introduction

The civilizational and urban development of cities worldwide has led to many urban problems, including problems of urban transport, mainly represented by congestion of streets, traffic jams, noise, and environmental pollution. Consequently, public transportation systems have become essential for facilitating urban life matters. Having public transportation systems is one of the most critical aspects of achieving stability in developed and developing countries alike, [Othman et al. \(2019\)](#)

The concept of public transportation in Saudi Arabia, specifically in Riyadh City, is a new trend. Although the Kingdom of Saudi Arabia (KSA) is the largest oil exporting county, unfortunately, its old public transportation system needed to be more efficient, [Al Faleh \(2005\)](#). However, nowadays, Saudi Arabia is booming with a vast transportation system, a "[buses] Network that integrated with the Riyadh Metro Network to give the ridership the best public transit mode through many lines that cover main streets, highways, and sub-streets" [riyadhmetro.sa \(2021\)](#).

Riyadh is the capital of the Kingdom of Saudi Arabia, the largest Metro Metropolitan Area in the Kingdom, [Majid Aldalbahi & Guy Walker \(2016\)](#). In 2018 the population of Riyadh was 7.677 million, and it's expected to become 9.5 million by the end of 2025 [GAS \(2017\)](#). This population growth will generate a traffic jam in the city; moreover, the percentage of car ownership is already high in Riyadh as the study showed that by 2019 there were about 2,100,000 cars with a population of 10,100,000 people, [Majid Aldalbahi & Guy Walker \(2016\)](#).

In the first congress of the International Association of Public Transportation (UITP), the issue of public transportation in the Medal East Countries (MECs) was raised as it suggested that MECs should have a long-term strategy to improve their

public transit, [R. Belwal & S. Belwal \(2011\)](#). In this context, Saudi Arabia has implemented a vast transportation plan for its public transportation.

Accordingly, the Saudi Arabian government is investing more than \$22 billion to build a new metro system in Riyadh City, with a total length of 176 km across six lines and 85 stations, [Alshalalfah et al. \(2017\)](#)

1.2 The research problem

The huge dependency on private cars has caused severe congestion problems, which cost Riyadh City about \$21 billion, in addition to another impact on economics, society, and the environment ([Ar Riyadh Development Authority \(ADA\) 2015](#)). Moreover, Riyadh had recorded the most severe fatal car accident in the world at an average of 4.4 deaths/per 1000 persons, with losses of \$3.6 billion each year ([General Department of Traffic 2015; Global Mass Transit Report 2011](#)).

Because of this and to reduce the traffic congestion in Riyadh City, as well as reduce the heavy dependency on private cars, authorities in Saudi Arabia have been provided a new transportation system ([Alotaibi O., & Potoglou D., 2017](#)), as defined earlier in the Introduction.

Moreover, [Alotaibi O. & Potoglou D., 2017](#)) found that the previous policies of the public transport system are conventional and need to be improved; they have suggested a set of policies that can help the new transportation system in Riyadh. Their suggestions are shown in **Chapter 3, Section 3.5, First Paragraph**

Accordingly, a set of criteria and attributes should be considered to encourage the ridership of public transport to change their mode from depending on their private care to public transport services. Hence, the attributes of this research could be classified as follow, **(1) Operation Quality, (2) Time Quality, (3) Personnel**

Quality, (4) Physical Quality of the service, (5) Safety and Security, (6) Local Culture alignment, and (7) Environmental Sustainability. *Accordingly, this study will present the most critical criteria, attributes, and KPIs leading Riyadh's citizens and residents to depend heavily on the new public transport system. Additionally, the study will optimize the best solutions that lead the ridership to use the transportation system effectively and effectively.*

1.3 Research Questions

About the research problem the following questions are raised to help solve the research problem:

- **Q1:** What are the quality dimensions, attributes, and key performance indicators (KPIs) that lead the Riyadh Public Transport system to work efficiently and effectively?
- **Q2:** What are the most critical riders' requirements and the technical requirement for the Riyadh Public Transport system?
- **Q3:** What management roles are required to make those quality dimensions, attributes, and key performance indicators (KPIs) work efficiently and effectively?
- **Q4:** What are the most important standards and strategies that lead ridership to use the system efficiently and effectively?

1.4 Research Objectives

Regarding the research questions, five goals have been achieved as follows:

1. Identifying the most crucial customer requirements that affect the performance of the RPTS through FAHP method

2. Highlighting the most important technical requirements that satisfy the RPTS riders through the 1st stage of the QFD model
3. Highlighting the most critical management requirements that satisfy the technical requirement through the 2nd stage of the QFD model
4. Highlighting the standards and strategies that RPTS management should implement through the 3rd stage of the QFD model
5. Developing an optimization model, which is an integration between FAHP method and QFD model to use RPTS efficiently and effectively

1.5 Significant of the research

The research study is significant and has practical benefits because of the following reasons:

1. It provides new insights into public transportation's service quality dimensions, specifically on its customer and technical requirements.
2. promoting the use of public transit as an alternative to private cars, which achieves environmental sustainability
3. It has modified the original phases of the Quality Function Deployment (QFD) as it proposed only three stages instead of four phases
4. A new software application has devolved as an effective decision-making tool based on the Fuzzy Analytical Hierarchy Process (FAHP) theory. Moreover, the software application can integrate FAHP with QFD
5. The comparative analysis of several AHP applications used in this study will convey valuable information for the future related research

1.6 The study setting

The above objectives will be achieved after analyzing the study framework, shown in **Chapter 4, Section 4.1, Table 4.1**. The study will be done by conducting a public and

expert questionnaire. Then, the Fuzzy Number Conjoint Model (FnCM) was used to analyze the public questionnaire, and the Fuzzy Analytical Hierarchy Process (FAHP) was used to analyze the experts' questionnaire.

This thesis has been done in eight chapters. **Chapter one** presents a general introduction to the research and the research problem, questions, significance, and limitations. **Chapter two** has provided a historical review of public transportation in the Kingdom of Saudi Arabia. **Chapter three** provided the literature review. After reviewing the related studies, **Chapter four** has structured the public transportation dimensions for Riyadh City, which is the study framework. **Chapter five** has explained the methods used in the research; this has been done through a comparative analysis between four applications of the AHP method. After comparing the selected methods, one approach has been chosen for analyzing the expert questionnaire and developing the software application that calculates the AHP result using a fuzzy technique, and this was **Chapter six**. The result of the public questionnaire has been explained in the **Appendices**. **Chapter seven** presents the results of both questionnaires. Finally, **Chapter Eight** has concluded the research and provided some recommendations.

This study has re-structured the service quality dimensions to fit the new transportation system in Riyadh. Then these dimensions have been analyzed through an integrated FAHP and QFD model. Moreover, a new software application has been developed that can quickly perform the AHP, FAHP, QFD, and integrated FAHP-QFD calculations.

1.7 Terminology and Abbreviations

The abbreviations and keywords used in this research are listed in **Table 1.1**

Table (1.1): List of the research abbreviations

Abbreviation	Explanation
KSA	Kingdom of Saudi Arabia
RPTS	Riyadh's Public Transport System
SERVQUAL	Service Quality Dimensions
Effective	Providing a result that is desired
Efficient	Providing the desired results without wasting time, and in an environmentally friendly manner
SQAMPS	Service Quality as a Measure of Passenger Satisfaction
Cr	Criteria
A	Attributes
KPIs	Key Performance Indicators
S-KPIs	Sub Key Performance Indicators
PQ	Public Questionnaire
EQ	Experts' Questionnaire
SPSS	Statistical Package for the Social Sciences
AHP	Analytical Hierarchy Process
FAHP	Fuzzy Analytical Hierarchy Process
FNCM	Fuzzy Number Conjoint Model
CLS	Classical Likert Scale
FLS	Fuzzy Likert Scale
TFN	Triangular Fuzzy Number
PCM	Pairwise Comparison Matrix
FPCM	Fuzzy Pairwise Comparison Matrix
AIJ	Aggregate Individual Judgment
CJM	Collective Judgment Matrix
QFD	Quality Function Deployment
HOQ	House of Quality
Flutter	a software development kit
UX	User Experience Design
UM	User Manual
VSC	Visual Studio Coad
IDE	Integrated Development Environment

1.8 Research limitations

This research was limited to four limitations, namely, Objective, Human, Spatial, and Time limitations

1.8.1 Objective Limitation

The research was limited to building an optimization model for using the new public transportation in Riyadh City effectively and efficiently

1.8.2 Human limitation

The research was limited to the Royal Commission for Riyadh City (RCRC) experts. The experts' selection has been made by recommendations of academic professors and after the thesis supervisors' approval.

Accordingly, the selection of the experts was limited to those with higher qualifications with professional field experience in the same area of the thesis.

1.8.3 Spatial Limitations

The study focused on the city of Riyadh and the neighborhoods where public transport buses and the metro pass. the metro map and buses map are shown in **Figure 1.1** and **Figure 1.2**, respectively.

1.8.4 Time Limitation

The public questionnaires were distributed to the residents of Riyadh City from March 2022 to May 2022. For the expert questionnaires, they were distributed and analyzed from April to June 2022



Fig. 1.2: Riyadh Buses Lines Map

www.riyadh-metro.com

CHAPTER 2

Review of Public Transportation In KSA

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2.1 History of Public Transportation in Saudi Arabia

[Al-Rashid et al. \(2020\)](#) conducted a study in the Dammam Metropolitan Region. They have classified four reasons why the Saudi Public Transportation Company (SAPTCO) needed to be more efficient. (1) "There was a lack of information at the bus stops, i.e., no schedule or route map was available to keep the people informed about accurate timing and travel routes." (2) "The allocated SAPTCO public bus stops were minimal on their route." (3) "the operating hours were also minimal, i.e., the SAPTCO public bus usually operates between 3:00 p.m. and 10:00 p.m., and it has no services for the morning hours". (4) "The intra-city SAPTCO public bus design and supporting infrastructure are not gender-responsive". For instance, the buses were high-floor vehicles, space for baby strollers/wheelchairs in vehicles was absent, and a lack of connecting footpaths for bus stops. Such a lack of focus in providing and improving public transport services increases the mobility constraints for the women population".

They also claimed that in SAPTCO services, "there were no waiting rooms or shaded areas at the bus stops. It is difficult to wait in hot weather for the bus even for 5 min, particularly for kids, women, and senior citizens."

Moreover, their study stated that "women's mobility has been somewhat limited and challenged in spatiotemporal terms, and partly due to socio-cultural barriers." The study aims to support the public transportation infrastructure to be adequate for women's needs. As a result, women in Dammam City are forced to use taxis. The study suggested that "women's travel needs should be associated with the physical environment and social and cultural norms of particular areas." Their study has concluded that the barrier restricting women from using public transportation is that

there are no separate seats for women or labels referring that this seat is reserved for women; ditto for waiting stations.

Regarding the cultural factor, which affects public transportation in Saudi Arabia, one study has found that "even if public transit were provided, wealthier families would still prefer to drive" [Ratrou, N.T. et al. \(2021\)](#). On the other hand, public transportation in Saudi Arabia is meant only for people who cannot own private cars, such as wage workers [Mercier, Jean \(2009\)](#) and [Silva Cruz, I. & Katz-Gerro \(2016\)](#).

[H. Peterson & Z. AL KASSIM \(2020\) \[23\]](#), in their study, suggested that "To avoid these problems, there must be carefully designed transit systems that include development input from all economic levels, genders, and ages."

Islamic culture and privacy conventions have affected the public transportation system development in Riyadh [Aldalbahi \(2016\)](#).

2.2 Excessive Use of Private Cars in Saudi Arabia

As the introduction mentions, the colossal dependency on private cars has caused severe congestion problems. Several reasons lead Saudi families to depend heavily on their private cars, such as high income, modernization, state-sponsored fuel subsidy, rapid urban development, and improved economic factors, [Al Fouzan \(2011\)](#). Also, [Al-Rashid et al. \(2020\)](#) stated that lower fuel price, comfort, and socio-culture are another-factors derived Riyadh citizens to use their private cars.

[Majid Aldalbahi & Guy Walker \(2016\)](#) claimed that by 2021, 90% of the roads would be overloaded and congested. Accordingly, the growing transportation demand in Riyadh City is enough to boost an effective public transportation system.

Petrol support in Saudi Arabia is one of the factors that led to an increase in the number of private cars, which led to the lack of public transportation [Al-Dubikhi](#)

(2007). He also claimed that the economic aspect is essential to why Saudi Arabian people do not depend on public transportation. To illustrate, "upper, middle and even working-class Saudi residents tell visitors that public transport is only for foreign blue-collar workers." Therefore, the cultural factor is also an essential factor to be focused on; moreover, females in Saudi Arabia "Expect a door-to-door service which public transport, generally, is ill-equipped to provide" [Alfozan \(2011\)](#). Riyadh's demographic is another factor that affects its public transportation. According to [ADA \(2004\)](#), "Half of the city's population are under 18 and hence below the legal driving age. very soon they will grow up, which is likely to result in increasing car numbers".

Weather condition is one of the most critical factors that led people in Riyadh City to use their private cars. [Stover et al. \(2012\)](#) claimed that weather conditions are an essential factor that is poorly considered as a barrier in bus ridership.

Riyadh City's desert climate is scorching and dry in summer and cold in winter. Accordingly, weather conditions can negatively affect the use of public transportation. This was studied in Pierce County, Washington, by the same researchers that assured that weather conditions could negatively affect transit ridership. The result of the study was classified as the following "High winds negatively affected ridership in winter, spring, and autumn. Cold temperatures led to decreases in ridership in winter. Rain negatively affected ridership in all four seasons, and snow was associated with lower ridership in autumn and winter". This is significant as another study done by [Guo et al. \(2007\)](#) concluded that ridership in Chicago was "higher in good weather and lowered in bad weather."

In terms of security, [Al-Rashid et al. \(2020\)](#) have shown in their study that "about 88.6% of women were not worried while using a private vehicle. On the contrary, 34.8% of the women were anxious, and 34.3% were concerned while using and

accessing a SAPTCO public bus. The results highlight that the significant reason for making women feel unsafe is poorly maintained buses and bus stops where there are no specific provisions to make them convenient, accessible, and safe." In this context, many studies assured that security and safety factors are essential for public transportation users, especially women; these factors strongly jeopardize women's mobility. For example, "personal security is the foremost concern that limits women's mobility significantly" [Robin \(1999\)](#).

Another study has been done by [Gasmi, K. et al. \(2017\)](#) and [Rushdi, A.I. et al. \(2014\)](#). They conclude that "Tests performed in the Eastern Province in Dhahran and found that traffic contributed 43-78% of the total extractable organic matter (EOM) of emission levels and that elevated levels of NO_x, NO, and NO₂ were significantly linked to times when automobile traffic was at its worst".

2.3 The New Transport System (Riyadh Metro and Buses)

According to [Alshalalfah et al. \(2017\)](#), the government of Saudi Arabia is investing more than \$22 billion to build a metro system in Riyadh, with a total length of 176 km across six lines and 85 stations.

The bus-transport system in Riyadh includes the establishment of buses transport network consisting of 24 tracks, extending for 1230 km to cover the entire city of Riyadh, through 1,000 buses of different sizes and capacities, with a total capacity of 900,000 Passengers per day. The buses are manufactured according to the highest specifications by the central bus manufacturers worldwide. Its network consists of bus lines with dedicated lanes, bus lines, regular bus lines, and feeder bus lines within the neighborhoods, [RCRC \(2021\)](#)

[Engineer Hassan Al-Mousa \(2017\)](#), Director of the Transport Planning Department at the Royal Commission for Riyadh (RCRC), noted that 89 percent of daily trips in

Riyadh amount to 10 million trips made by private cars. [Al-Mousa](#) also indicated that the RCRC had prepared a plan to develop the transportation system within its comprehensive strategic plan of Riyadh City. The plan aims to provide safe and easy transportation by developing a sustainable transportation system that meets the city's existing and expected transportation requirements by 2023. The plan includes six main axes: (1) the future road network development plan; (2) the comprehensive plan for traffic management; (3) the comprehensive plan for public transport; (4) setting standards to achieve integration between the distribution of land uses and various urban activities; (5) studying the economics of transport in Riyadh; (6) developing and activating administrative structures, human cadres and technical capabilities capable of managing the city's transportation system and constantly evaluating its performance. This was significant as some of these strategies have been implemented in different cities worldwide and resulted in outstanding achievements in increasing the amount of ridership. However, great goals would be achieved if more policies were focused on them.

[H. Peterson & Z. AL KASSIM \(2020\)](#), in their study, proved that people who are living in the Eastern Province of Saudi Arabia are willing to use public transport as the survey showed that "public transportation is needed and would be utilized."

Recently, [Youssef Z., Alshuwaikhat H., & Reza I. \(2021\)](#) studied Riyadh's new public transport system. They considered travel time, fuel cost, Metro fare, and walking time as the main factor in their study to evaluate how these factors can limit Riyadh's citizens from using Metro. The results were as follows: increasing the fuel cost by 10% would increase the metro ridership by 5.3 %, reducing car dependency. Decreasing the walking time to the nearest metro station would increase the metro ridership by 7.2%. If walking time to the nearest metro station were more than 11 minutes, the choice of metro service would reduce to 4.2%.

Regarding the metro fare, if the ticket price increased by 10%, the metro ridership would decrease by 6.9%. On the other hand, the result showed that when charging the parking by SAR 1 per hour, car dependency would drop by 14%. Finally, if car ownership decreased by 1%, the metro ridership would increase by 0.12%

This chapter have presented the history of public transportation in Saudi Arabia. At the beginning of the chapter, a presentation of historical information about the Saudi Arabian Public Transport Company (SAPTCO) and the reasons why the old transportation system wasn't efficient enough. Moreover, it shows how culture significantly affected not using the old transport system. After that, the reasons why Saudi Arabian people depend heavily on their private cars have been presented. Finally, the new transport system in Riyadh has been introduced in the last section of this chapter.

CHAPTER 3

Literature Review

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3.1 Introduction to the Literature review

From reviewing the related literature, numerous studies covered the components of service quality in the public transportation field, such as service quality criteria; attributes; KPIs; technical characteristics; standards; and strategies that enhance transportation systems in various countries and cultures.

The vast increase in private cars worldwide has become a serious issue that must be considered. It's expected that over the next two decades, the number of current vehicles driven, which is one billion, will be doubled, [Sperling and Gordon \(2009\)](#). According to the [World Health Organization \(2004\)](#), the increasing number of car users has caused critical problems, such as pollution; congestion; and road accidents resulting in heavy traffic. Another issue to consider is the increasing rate of deaths caused by car accidents. [Mathers and Loncar \(2006\)](#) claimed, "Deaths caused by traffic accidents would be the second highest cause of death for men by 2030."

3.2 Service Quality Attributes

Under public transportation services, there are a lot of criteria that can enhance the use of public transport efficiently and effectively; however, these criteria can vary from one country to another or from one culture to another.

Service quality in public transportation is a historical research area. [Gronroos \(1982\)](#); [Berry, Zeithaml, & Parasuraman \(1985\)](#); [Parasuraman, Zeithaml, & Berry \(1985\)](#); [Zeithaml, Parasuraman, & Berry \(1985\)](#); [Fick and Ritchie \(1991\)](#); [Brady & Cronin, \(2001\)](#) proposed the SERVQUAL model; then they have applied it in several areas to measure the commuters' perception. The model has five dimensions: Reliability; Assurance; Tangibility; Empathy; and Responsiveness.

Some researchers have modified the SERVQUAL model by replacing or adding one or more dimensions to the model to improve the service quality in public transport

per the given market and region conditions. [Luke and Heyns \(2006\)](#) added comfort, the extent of service, Safety, and affordability as dimensions for improving the service quality in the public transport service. Moreover, [Pakdil and Aydın \(2007\)](#) modified it by adding employees, flight patterns, availability, and image as a new dimension for improving airline service. [Cronin and Taylor \(1992\)](#); [Brady and Cronin \(2001\)](#) also supported the change in the conceptual framework of service quality. [Govender \(2014\)](#) also modified the SERVQUAL model by adding the extent of the service, comfort, Safety, and affordability.

[Randheer K., AL-Motawa A. & Vijay P. \(2011\)](#) studied the commuters' perception of service quality in public transportation in India. The study distributed a questionnaire to 512 public transportation users following the classical SERVQUAL model. Their study modified the model by eliminating the tangibility dimension and adding a "culture" as a new dimension. Although the study is significant, tangibility must be addressed as an essential dimension in Saudi Arabia. They found that aligning with local values, error-free records, neat staff, understanding commuters' specific needs, punctuality, and safe transaction were the high-priority attributes in their study.

[Barabino B. & Francesco M. \(2016\)](#) stated, "the findings of the service quality in the public transportation field are often misleading because the perspectives of transit operators dominate." Accordingly, the passenger perspective must be considered when setting the dimensions of the quality service; thus, their study suggested a framework called TRANSQUA to reduce the gap between Public Transportation companies and users. The attributes in their research have been collected from two perspectives, users and experts. The users' views made a long list of attributes, such as "ease in collecting pre-trip information; ticket purchasing; access to bus stops;

waiting time at a bus stop; and comfort on board." These attributes have been merged into a "User desires List" group.

On the other hand, the experts' perspectives also made a long list of attributes called the "Experts' desires List." Then the two lists merged into one group to generate the attributes of the study. As a result, they found that the most critical attributes are: firstly, waiting time (regularity), as the users don't accept to stay more than twice the scheduled headway; secondly, space on board, as a user cannot board two consecutive buses because of overcrowding, and thirdly, cleanliness, as a user gets stained clothes because of a dirty bus interior.

New research has been conducted on this area, modifying the SERVQUAL dimensions to suit the market and commuters' requirements across nations. In this context, [AL-Motawa, & Vijay, 2011](#); [Manikandan & Vanniarajan, 2016](#); [Ceran and Esen, 2018](#); [Vilakazi and Govender, 2014](#); [Pakdil and Kurtuluşoğlu, 2014](#)) have modified the classical SERVQUAL model to fit their objectives.

The researchers [Valenzo-Jiménez, Lázaro-López, and Martínez-Arroyo, 2019](#) in their study summarized thirty-one (31) studies related to the SERVQUAL model that has been done in Africa, America, Asia, Oceania, and Europe. The summary table was in the area of each study, dimensions of SERVQUAL, Methodology, Objective, and place & sample size.

[Esin C. and Bengü C. \(2018\)](#) listed how researchers have used the classical SERVQUAL model and how some modified it.

[Khattak and de Palma \(1997\)](#) surveyed Brussels residents to examine the relationship between weather conditions and transferring mode choice, "Fifty-four percent of automobile users stated that they changed their mode, departure time, and or route choice because of weather conditions. Twenty-seven percent of those

respondents stated that the influence of weather on travel mode change was either "very important" or "important." Another survey done in Geneva by [de Palma and Rochat \(1998\)](#) found that "fifty-three percent of respondents stated that the influence of weather conditions on mode choice was "very important" or "important."

3.3 Analytical Hierarchy Process (AHP)

[Thomas L. Saaty](#) developed the AHP in 1971- 1975 at the Wharton School (the University of Pennsylvania, Philadelphia, Pa). [M. Bertolini et al. \(2006\)](#) defined the core meaning of this method as follows:

Analytic: "indicates that the problem is broken down into its constitutive elements."

Hierarchy: "indicates that a hierarchy of the constitutive elements is listed with the main goal."

Process: "indicates that data and judgments are processed to reach the final result."

AHP has been utilized in several fields, such as "multi-criteria decision making, planning, resource allocation, conflict resolution" and economic problem-solving [Yang J. & Lee H. \(1997\)](#).

AHP is a Multi-Criteria Decision Making (MCDM) measurement tool. "It used to derive ratio scales from discrete and continuous paired comparisons" [Saaty R. W., \(1987\)](#).

The advantage of this method is that the process of hierarchical analysis combines mathematics and philosophy to compare several options and determine which are the best, [Ishizaka, A., and Labib, A \(2011\)](#). This can be done by a concept called pairwise comparison (PCM). It is the process of comparing two criteria at once instead of comparing many criteria at a time. Thus, the choice is more manageable.

Fountzoula C. and Aravossis K., 2021, in their study, summarized 62 studies from the year 2010 to the year 2020 conducted on AHP techniques. Their summary table consisted of the author(s) name, the year of the publication, the country where the study was implemented, the application used, and the study area.

Abbas Mardani, Edmundas Kazimieras Zavadskas, Zainab Khalifah, Ahmad Jusoh, and Khalil MD Nor. (2016) collected twenty-four (24) articles about AHP and FAHP; their summary table consisted of the author(s) name, the year of the publication, the technique and approach used, the application area and scope, the study purpose, the gap & research problem, and the outcomes of each study.

For our study, several studies have been reviewed to set the high-priority criteria of the study. **Table 3.1** detailed those studies in terms of the author(s) name, year of publication, area of study and region, the objective of the study, and high-priority criteria.

Table (3.1): AHP-related study

SN	Author(s)	Year	Area of the study and region	Objective	Model Developed	High priority criteria
1	Duleba S. et al.	2011	Transportation	Prioritizing the elements of supply quality within three levels to be compared with participants of the public bus system to help the policymakers to synthesize various aspects of public transportation.	AHP	G: Supply Quality L1: Service quality; Tractability; L2: Approachability; Travel time; Directness; L3: Frequency; Need of transfer; Physical comfort; Perspicuity;
2	Dudek M. et al.	2018	Transportation, Poland	It assessed several public transportation solutions in a 15 km. traffic corridor that runs through the center of Wrocław, Poland.	Electre III/IV and AHP	Standard city buses using a separate bus lane and fast tram were essential scenarios from both preferences of passengers and operators. Waiting time, accessibility to the bus stop, and cost of the purchase were the most important criteria to be considered from both preferences of passengers and operator
3	Al-Moherz D. et al.	2016	Transportation, Egypt	Evaluating the factors that impact the mode choice of transportation in Egypt.	AHP	Main criteria: Reliability; Travel time, Travel cost;

SN	Author(s)	Year	Area of the study and region	Objective	Model Developed	High priority criteria
						Comfort Sub-criteria: Humidity; Legroom; Seat width; Temperature; Noise and vibration
4	Mahmoud M., & Abdel-kader M.	2016	Transportation, Assiut, Egypt	Measuring user preferences toward sustainable transport indicators in Assiut City	AHP	Absolute weighing of sustainable transport indicators: Access to public transport; Availability of cycling and walking paths; Quality of public transport; Number of cycling trips
5	Seunglim Kang, and Lee.	2006	Transportation, Jeju, Korea	Providing a new decision-making process that is related to policies on the promotion of public transportation ridership. Implementing the approach to constructing a 'JEJU' public transportation city model to verify the applicability of the AHP method.	AHP	

SN	Author(s)	Year	Area of the study and region	Objective	Model Developed	High priority criteria
6	Alkharabsh eh A. et al.	2021	Transportation, Amman, Jordan	To evaluate and facilitate the public transport system's supply quality evaluation in Amman City, Jordan	MCDM and Grey AHP	The final weight scores for public transport supply quality criteria. L1: Transport quality; Fare; Service quality L2: Safety of travel; Discounted tickets; Mental comfort; Time availability L3: The limited time of use; Frequency of lines; Journey time; Awaiting time; Time to reach stops

SN	Author(s)	Year	Area of the study and region	Objective	Model Developed	High priority criteria
7	Moslem S. & Duleba S.	2018	Transportation, Mersin, Turkey	Getting an overview of passenger demands in Mersin City, Turkey.	AHP	Passengers evaluator group: L1: Service quality; Transport quality Tractability L2: Physical comfort Mental comfort Info. before travel L3: The limited time of use Need of transfer Journey time Distance to stop

SN	Author(s)	Year	Area of the study and region	Objective	Model Developed	High priority criteria
8	Aldas D. et al.	2018	Transportation, Curitiba, Singapore, Santiago de Chile, & Montreal	Analyzing the impacts of transport models and choosing the best alternative, considering four cities with a high urban mobility index and optimal conditions of sustainable development	AHP	The best sustainable transport alternative: Curitiba City 31.8%; Singapore 27.6 %; Santiago de Chile 17.8 %; Montreal 22.9 %

SN	Author(s)	Year	Area of the study and region	Objective	Model Developed	High priority criteria
9	Duleba S. et al.	2021	Transportation	Evaluating Public Transportation Development	Interval-Valued Spherical FAHP	L1: Transport quality; Tractability; Service quality L2: Safety of travel; Information before travel; Physical comfort Mental comfort L3: Fit connection; Safety of stops Time to reach stops
10	Erick P., & Myamba B.	2016	Transportation, Dar Es Salaam City, Tanzania	Prioritizing the Challenges Facing Public Transportation	Vague Analytical Hierarchy Process (VAHP)	Public Transportation Challenge (F_m): Inefficient traffic management system (F ₃); Inadequacy of proper public transit service (F ₂); Inadequacy of road transport infrastructure (F ₁) Sub-Public Transportation Challenge (F_{mn}): Inadequacy of parking lots and terminals Poor management of drivers and pedestrians' indiscipline on roads (F ₃₂); Poor control of vehicle breakdowns and road accidents (F ₃₃);

SN	Author(s)	Year	Area of the study and region	Objective	Model Developed	High priority criteria
						Poor management of traffic lights and other signals (F ₃₁)
11	Salavat A. et al.	2016	Transportation, Isfahan, Iran	Defining appropriate criteria for the systematic approach to evaluate and prioritize multiple candidate corridors for public transport investment simultaneously to serve travel demand	AHP and Clustering Approaches	NOT CLEAR
12	Zhang X. et al.	2020	Transportation, Ningbo, China	Evaluating the passenger satisfaction of urban multimode public transport	Integration of Analytic Hierarchy Process (AHP), Entropy Weight Method (EWM), and Fuzzy Comprehensive Evaluation (FCE)	Criteria: Waiting time; Transfer convenience; Information; Interior sanitation; Service Sub-Criteria: Waiting time; Punctuality of first and last shift; Transfer convenience between buses; Transfer convenience between bus transit and rail transit; Sign the definition of the station; Transfer convenience between bus and bicycle; Interior hygiene; Sanitary facilities in the vehicle;

SN	Author(s)	Year	Area of the study and region	Objective	Model Developed	High priority criteria
						Discounts for seniors, students, and I.C. cards; Station voice announcement in-bus
13	Utama D. et al.	2020	Transportation, Ciputat District, Indonesia	Determining the Quality of service level for two types of public transport	Fuzzy logic and AHP methods	L1: Reliability Responsiveness Empathy Tangible L2: Punctuality; Security; Comfort; Availability of Transportation Services; Responsive Aspiration to the customer; Driver's Attitude; Driver's Care; New Vehicle; Seating Facilities; Cleanliness; Neatness

14	Toni Lupo.	2013	Transportation, Palermo, Italy	Evaluating and prioritizing customer satisfaction for the public urban transit service provided in the city of Palermo, Italy	Fuzzy AHP	Dimension: Route Characteristics; Safety and Security; Information; Personnel; Comfort Service attributes: Path; Distance Between Bus Stops; Number of Bus Stops; Personnel Helpfulness; Availability of Schedule/Maps at Bus Stops; Bus Stops Location; Availability of Shelter and Beaches at Bus Stops; Security Against Crime on Bus
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SN	Author(s)	Year	Area of the study and region	Objective	Model Developed	High priority criteria
15	Moslem S. and Duleba S.	2019	Transportation, Mersin, Turkey	Providing a suitable framework for transport development tenders	Fuzzy AHP	L1: Tractability; Transport Quality; Service Quality L2: Perspicuity; Information during travel; Information before travel; Mental comfort; Physical comfort L3: The limited time of use; Need of transfer; Fit connection; Time to reach stops; Journey time

3.4 Quality Function Deployment (QFD)

This methodology was "originally developed in Japan by Professors [Yoji Akao and Shigeru Mizuno in the late 1960s](#) while working for Mitsubishi's shipyard; QFD was later adopted and widely used by other companies such as Toyota and its suppliers" [A guide to quality function deployment, \(2022\)](#).

It is applied when planning for a new product or service. It also can be used for improving an existing product or service. The core concept of this methodology is to consider the users' requirements; then translate their needs into engineering characteristics. "The methodology was introduced in Japan in the late 60s, and about 15-20 years later entered the USA. It is worth to be mentioned that nowadays, it has been applied in many organizations in Europe" [Tsoukalidis I. et al. \(2009\)](#)

[Rao K. & Thakar G. 2013](#) claimed, "Quality must be designed into the product, not inspected into it, and to build a quality product, customers' requirements must be considered and incorporated into the product. They also stated that "QFD is a tool for bringing the Voice of the customer into the product development process from the conceptual design through the manufacturing process. It begins with a matrix that links customer requirements to technical requirements. Therefore, QFD is an excellent tool for this matter as it integrates the customers' needs (what they want) with a set of technical requirements (how an operator can achieve them). Not only customers and engineers are involved in this method but also experts and officials.

To set the elements of House of Quality (HOQ), a sufficient number of customers' needs and technical characteristics shall be found and analyzed. Many researchers across nations applied the House of Quality technique, the primary step in the QFD. [Jomnonkwao, Champahom, and Vatanavongs \(2020\)](#); [Kurtulmuşoğlu, Pakdil & Atalay \(2016\)](#); [Bajčetić T. et al. \(2016\)](#); [Moubachir and Bouami \(2015\)](#); [Tsoukalidis et al., \(2009\)](#); [Chan C. et al. \(2019\)](#); [Dinulescu et al., \(2020\)](#); [Rao and Thakar, \(2013\)](#);

Pakdil and Kurtulmuşoğlu, (2014); Martinsa et al., (2016); Deveci et al., (2019), investigated into the customers and technical requirements that contributed in the improvement of the Quality of the public transportation services.

Some researcher goes more profound into the Quality of public transportation service. They applied a Multi-Criteria Decision Making (MCDM) approach, such as the Analytical Hierarchy Process (AHP); some researchers have integrated the AHP with the QFD to generate an effective decision on the service quality attributes. Duleba et al., Mishina and Shimazaki (2011); Dudek, Solecka, and Richter (2018); Al-Moherz et al. (2016); Mahmoud and Abdelkader (2015); Seunglim Kang and Lee (2006); Alkharabsheh, Moslem, Oubahman, and Duleba, (2021); Kim Y., (2018); Moslem, and Duleba, (2018); Nosala K., and Solecka K., (2014); Aldas D. et al., (2018); Duleba S., Gündoğdu F., and Moslem S., (2021); Rivero Gutiérrez, L. et al., (2021); Erick P. et al., (2016); Salavat A. et al., (2016); Boujelbene Y., and Derbel A. (2015); Zhang X. et al., (2020); Utama D. et al., (2020); Toni Lupo, (2013); Moslem S. and Duleba S., (2019); and Oğuztimur S., (2011) conducted studies on the integration of AHP with QFD. The outcomes of these studies are shown in **Table 3.2**

Several studies have been reviewed for the current research to set high-priority customer and technical requirements. **Table 3.2** detailed those studies in terms of the author(s) name, year of publication, area of study and region, the objective of the study, and high-priority customer requirements (what) and high-priority technical requirements (how).

Table (3.2): QFD-related studies

SN	Author(s)	Year	Area of the study and region	Objective	Model Developed	Results of the study	
						High priority Commuters' needs (What)	High-priority technical characteristics (How)
1	Jomnonkwao K., et al.	2020	Transportation, Thailand	Propose guidelines for precise service quality (S.Q.) improvements of intercity rail services in Thailand.	Factor analysis (F.A.), cluster analysis (C.A.), and importance-performance analysis (IPA)	Security systems available to prevent crime; Punctuality; Neat and clean train interior; On-time, accurate delivery of advertised services; Crews deliver services politely; Crews understand special passenger requirements; The terminal provides enough trip guidance and information	No technical requirements have been specified since QFD doesn't apply
2	Kurtulmuşoğlu F., et al.	2016	Transportation, Turkey	Improve service quality in the passenger transportation industry.	Fuzzy Quality Function Deployment (FQFD)	The courtesy of employees, The competency of employees; Cleanliness in buses; Accessories such as plug and T.V. availability in a bus; Employees' responsiveness and willingness towards customer needs and expectations during service time; Trustworthy employees 24-hour service availability; Availability of ticket sales on a website	Minimum time on ticketing process; Error-free services; Minimum time waiting in queue for a ticketing process; Employees' empathetic approach toward customers; Well, dressed-up employees; Tangible features of the service area; Competent employees; Error-free records;

SN	Author(s)	Year	Area of the study and region	Objective	Model Developed	Results of the study	
						High priority Commuters' needs (What)	High-priority technical characteristics (How)
							Advanced technical online services;
3	Bajčetić S., et al.	2016	Transportation, Belgrade, Serbia	Identifying urban public transport users' needs and requests and improving service quality in Belgrade public transport	Quality Function Deployment (QFD)	Punctuality & regularity; Accessibility in time; Safety and security; Reliability; Not crowded vehicle	Vehicle equipment; Stop; Stop environment; Transport network density; Pedestrian availability coefficient; Capacity; Assortment of tickets; Traffic Policy; Information; Staff education;
4	Prabowo R., et al.	2018	Transportation, Semarang, Indonesia	Analyzing the priorities for Semarang Corridor II's consumer requirements in six different shelters. As well as reinforcing the assessment from the consumers.	Importance Performance Analysis (IPA) and (OFD)	Punctuality of arrival; Fast transit time when crowded with a passenger; Free of congestion; Ease of accessing information from officers; Accident insurance; The presence of security officers at each bus stop	The process of going up and down passengers from fast vehicles A clean bus stops Safe bus stops Comfortable bus stops
5	Moubachir & Bouami.	2015		Providing a new approach for the transition	Quality Function Deployment (QFD)		

SN	Author(s)	Year	Area of the study and region	Objective	Model Developed	Results of the study	
						High priority Commuters' needs (What)	High-priority technical characteristics (How)
				between QFD phases			
6	Tsoukalidis I. et al.	2009	Athens	Planning of an alternative transportation system (paratransit)	Quality Function Deployment (QFD)	Collect me from the desired point; Collect me at the desired time; Transport me to the desired point; Transport me straight to the desired point; Attractive price; Provide me security for my children (if alone); inner vehicle in good condition;	Ease to enter the car (low profile); Up to 8 passengers per vehicle; Automatic payment system; System conservation cost
7	Chan C., et al.	2019	Transportation, Hong Kong	Understanding the passengers' needs Voice of the customer (VOC) when they situated in the train cars of urban rail	Interpretation type of deployment of quality function deployment (QFD)	Behaved environment; Safe stand Easy to get on and off Pleasant feeling	No technical characteristics were taken since the study focused only on interpreting the VOC inside the train car
8	Dinulescu R. et al.	2020	Transportation, Bucharest	Improving the service quality of public transportation by Establishing innovative strategies	Quality Function Deployment (QFD)	Display the route schedule inside the bus; Display the waiting time for arrival and departure; Punctuality of time scheduling; Maintenance of the bus; Cleanliness;	Time scheduling activities; Maintenance management; Display of arrival and departure time on digital screen; Existence of an information system

SN	Author(s)	Year	Area of the study and region	Objective	Model Developed	Results of the study	
						High priority Commuters' needs (What)	High-priority technical characteristics (How)
						A unique subscription for all public means of transport More busses during the night; Air conditioning is available during the summer; Safe busses	
9	Rao K., & Thakar G.	2013	Transportation, Bangladesh	Discussing "how to gain passenger satisfaction" of the most popular type of public transport system, namely the metropolitan bus service	Quality Function Deployment (QFD)	Punctuality of time scheduling; Reserved seats for ladies & P.H; Economic charges; Waiting time for arrival & departure; Concession passes for daily passengers; Display of arrival & departure timings at bus stops; Availability of more no. of bus stops as per the requirements	Time scheduling activities; No. of buses in demanding routes; No. of bus pass counters; Insurance activities; Feasible rate setting; No. of bus pass counters; No. of buses at demanding Peak timings; Qualified drivers & conductors; Display of arrival and departure timings;
10	Pakdil F., & Kurtulmuşoğlu F.	2014	Transportation, Turkey	Improving the Quality of highway passenger transportation services.	SERVQUAL & (QFD)	Employees' empathetic approach toward customers; Technical specifications of buses; Error-free services; Competent employees	Employee-oriented technical requirements; Technical specifications of buses; Error-free services in highway passenger transportation.
11	Martinsa V. et al.	2016	Transportation, Maraba, Brazil		Quality Function Deployment (QFD)	Vehicle Capacity; Permanence time inside the vehicles;	Implement a public transport network that enables the integration of all its lines with the

SN	Author(s)	Year	Area of the study and region	Objective	Model Developed	Results of the study	
						High priority Commuters' needs (What)	High-priority technical characteristics (How)
						Bus stops adapted for people with special needs - PNEs; Integration Terminal; Bus quantity per fleet; Waiting time at stops; Training and friendliness of the staff; Bus stops	payment of a single tariff in the municipality. (Basic project); Construction at the expense of the winning bid of a connecting station (integration terminal). (Basic project); Fleet expansion initially at 15%. (Basic project); Possibility of future expansion, with the construction of connecting stations and the implementation of new lines (Basic design); Reduction of the current extension average of the lines by using the new system. (Basic project);
12	Deveci M. et al.	2019	Transportation, Turkey	Developing a quantitative assessment framework for public bus operators to translate passenger demands into	Principal Component Analysis (PCA), Quality Functions Deployment (QFD), interval-valued		

SN	Author(s)	Year	Area of the study and region	Objective	Model Developed	Results of the study	
						High priority Commuters' needs (What)	High-priority technical characteristics (How)
				service quality specifications.	intuitionistic fuzzy (IVIF), and Fuzzy-QFD		

3.5 Standard and Strategies for Public Transportation

[Alotaibi O. & Potoglou D. \(2017\)](#) claimed that authorities in Saudi Arabia had provided a new transportation system to reduce the traffic congestion in Riyadh City and the heavy dependency on private cars. The authors' study evaluated whether Riyadh's public transportation policy measures are adequate. Also, the study has introduced relevant measures to facilitate shifting from private cars to public transit usage. They found that a previous policy measure is a conventional approach, increasing the road infrastructure to cope with the growth of personal vehicles. However, new policies have been made to develop the new transportation system (1) "Improving the infrastructure to enhance accessibility to and from public transit stations"; (2) "selecting appropriate Transit-Oriented Development sites"; (3) "parking charges"; and (4) "separate carriages for families"; and (5) "promoting the safety of public transport facilities are perceived as the most effective strategies."

[Belwal R. and Belwal S. \(2010\)](#) stated that "personal convenience, comfort, and flexibility, ease of use and quick maneuverability, privacy & safety, availability of public transportation, and cultural" are the high-priority reasons that lead people in Oman to depend on their private cars and avoid using the public transportation

In another study, [Alhedr T. \(2016\)](#) aimed to support the strategies to utilize Riyadh's new public transportation system successfully. He focused on the following factors: High operating costs, poor locations of stations and lines, a general preference for private vehicles, the scorching weather in most months of the year, and the remarkable traditions and cultural norms. Hence, from these factors, we found that time-saving, the need for reliable buses, accessibility, privacy, security & Safety should be considered in Riyadh's public transportation system. **Table 3.3** concludes the Incentives & Strategies that have been applied internationally to increase the number of public transport ridership.

Table (3.3): Real-world practices for shifting travel mode to public transit *Alhedr T. (2016) [30]*

S.N .	City	Incentives & Strategies applied to increase the number of public ridership	Percentage of increase in public ridership	Competitive advantage	Reference
1	Champaign-Urbana metro area 1991 - 1993	Parking management at the University of Illinois, which is the center of the metro area The construction of park-and-ride facilities Introducing the university pass program Marketing campaign directed at university students and employees	21.8 %	University-dominated cities.	Stanley (1995), for The Transit Cooperative Research Program (TCRP)
2	Blacksburg, Virginia 1991 – 1993	Same strategies of the Champaign-Urbana metro area	17.3%		Stanley (1995),
3	Orlando, Florida 1994 – 1996	Aggressive marketing & public relations program Business partnerships and collaborations Emphasis on customer service/amenities	38%	Rapid regional growth in the area during 1994 - 1996	Stanley (1998),
4	Tallahassee, Florida 1994 – 1996	Partnerships with universities (special passes) State government partnership and passes Service refinements Marketing (dependent populations).	11.7%		

S.N .	City	Incentives & Strategies applied to increase the number of public ridership	Percentage of increase in public ridership	Competitive advantage	Reference
5	Salt Lake City 2000 – 2002	Promotional free-pass offer Increased emphasis on Quality of Service Development of a region-wide Transportation Demand Management (TDM) program Re-organization of the Utah Transit Authority.	13.9%		Stanley and Hyman (2005)
6	Gainesville, Florida 2000 – 2002	Access agreement for the University of Florida students; Downtown area land use policy directing developer support for pedestrians and public transportation.	37%	Expand the service to serve the University of Florida	Stanley and Hyman (2005)
7	Portland, Oregon 1990 – 2000	(a) Adopt and implement ordinances and plans for street connectivity; (b) adopt maximum parking ratios and implement specific parking requirements; (c) create transportation management associations (TMAs); (d) adopt free-zone transit policies in regional centers; and (e) Implement other transit strategies such as the development of a transit system map which met Metro requirements; placing and designing buildings in such a way to encourage transit use; and supporting transit use	11.6%		Ellis et al.'s (2005)

S.N .	City	Incentives & Strategies applied to increase the number of public ridership	Percentage of increase in public ridership	Competitive advantage	Reference
		through improving pedestrian facilities and infrastructure.			
8	Calgary, Canada 1996 -2013	(a) heavy investment in transit infrastructure; (b) strict parking policies, especially in downtown; (c) minimizing private vehicle access to downtown (no freeways leading to downtown); (d) park-and-ride facilities providing sufficient parking spaces; and (e) managing urban form through comprehensive policies.	90%		Freemark (2014) and the Victoria Transport Policy Institute (2015a)
9	Vancouver, Canada 2002 – 2004	(a) adding more TOD development; (b) policies to make driving more expensive; and (c) parking management and pricing.	24.6%		TransLink (Metro Vancouver's regional transportation authority) (2013)
10	Freiburg, Germany 1982 – 2007	(a) integrate land use and transportation planning (mix land uses development along transit corridors); (b) policies to limit car access (car-free zones in selected parts of downtown and other areas, and traffic-calmed neighborhood regulations); and (c) parking	18%		Buehler and Pucher (2011)

S.N .	City	Incentives & Strategies applied to increase the number of public ridership	Percentage of increase in public ridership	Competitive advantage	Reference
		management policies (waive the minimum parking requirement, parking cash-out, reserve parking in neighborhoods for residents, and limited in duration and highly-priced on-street parking). Moving			
11	Perth, Australia 2000 – 2012	(a) policies prioritizing public transportation (bus priority system and reducing automobile lanes in favor of transit); (b) a marketing program focusing on behavioral changes; (c) building more park-and-ride facilities; and (d) applying parking policies (control parking in the CBD, identify other parking management areas to control parking within them, apply maximum parking regulations, and regulations to impose parking licenses with fees for all non-residential motorists).	39%		Richardson and Burgess (2005) & TravelSmart Workplace Program (2013)

This chapter have presented the previous studies applied to public transportation services. At the beginning of the chapter, we introduced the dimensions of the original model of service quality (SERVQUAL). Then, we presented how researchers used this model in the public transportation field. Additionally, we have reviewed the studies which modified this model. After that, we introduced the concept of the AHP method and how researchers used it to prioritize their studies' criteria in importance. After that, the QFD model and how researchers have integrated this model with the AHP method have been introduced. Additionally, we have highlighted the most important customer and technical requirements for public transport services. Finally, a list of standards and strategies from the best international practices has been extracted.

CHAPTER 4

Structuring The Dimensions of RPTS

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4.1 Structuring The Dimensions of RPTS

The data used for structuring the dimensions of this study have been collected from the related studies with the help of experts from the Royal Commission for Riyadh City (RCRC). As explained in the literature review, the core data, such as customer requirements, technical requirements, management requirements, and standards & strategies, have been collected from previous studies. Moreover, the experts have added value to the collected data as they crystallized our literature data to achieve the goal of this study.

It is clear from the literature review that the researchers found many criteria and attributes of the quality of the public transport services; then, they categorized them into several classifications according to their characteristics. Accordingly, with the help of previous literature and RCRC experts, this study has restructured the public transportation service quality in a "Service Quality model as a Measure of Passenger Satisfaction (SQAMPS)." This model has classified the research dimensions into 3-main **Criteria (Cr_n)**, namely, **(Cr₁) service reliability**, which combines the reliability, responsiveness, and assurance dimensions, **(Cr₂) Facilities' reliability**, which is considered tangibility dimension; and **(Cr₃) culture mobility**, which considered empathy dimension. Consequently, these criteria have been sub-divided into seven attributes **(A_n)**, namely **(A₁) operation quality**, **(A₂) time quality**, **(A₃) personnel quality**, **(A₄) physical quality of the service**, **(A₅) safety & security**, **(A₆) local culture values**, and **(A₇) environmental sustainability**. Likewise, each attribute is subdivided into Key Performance Indicators (P_n), and some KPIs have sub-KPIs (SP_n). Consequently, after gathering the required data, the criteria, attributes, KPIs, and sub-KPIs have been structured with respect to the AHP method, as shown in **Figure 4.1 and Table 4.1**

As mentioned earlier, the method used for analyzing and prioritizing the above criteria, attributes, KPIs, and S-KPIs is AHP. Therefore, to avoid the difficulties of AHP applications and according to [Duleba S. et al. \(2011\)](#), "we used a simplified Saaty-scale for scoring so that the missing data of the matrices could be calculated by an algorithm as well. That is to reveal a priority ranking of the elements of service quality within each level. This may help the policymakers and experts to synthesize various aspects of public transportation."

Therefore, with respect to the AHP structure, shown in **Figure 4.1**, and using the simplified Saaty's scale to evaluate the criteria, attributes, KPIs, and sub-KPIs mentioned in **Table 4.1**, 19 PCMs with different sizes will be applied, illustrated in **Table 4.2**. As a result, there will be three matrices of size 5×5 , four matrices of size 4×4 , six matrices of size 3×3 , and six matrices of size 2×2

These matrices will be used for designing the Experts' Questionnaire (EQ). The design procedure has been explained in [Appendix A, Section A5.1.2](#). Moreover, a copy of the expert questionnaire was attached in the same appendix after explaining the design procedure.

From these PCMs, we will perform the prioritization analysis to obtain the global weight of the QSAMPS dimensions. Then the global weight will be calculated from the obtained local weights. The investigation has been explained in **Chapter 7, Section 7.2.2**

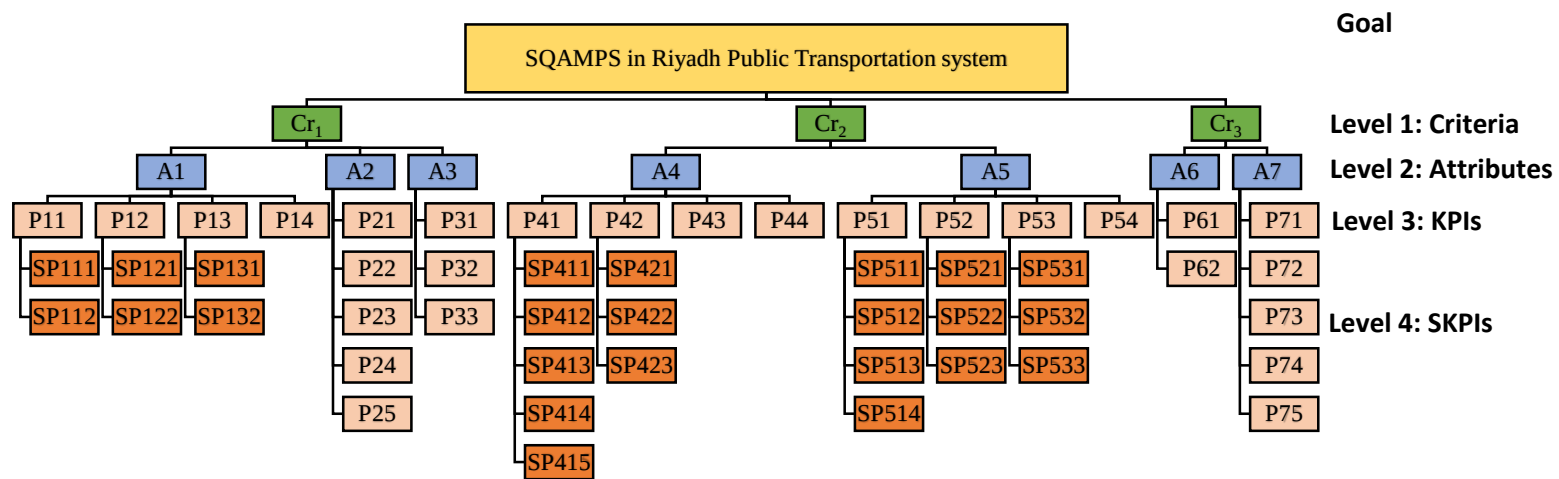


Figure 4.1: AHP structure

Table 4.1. Service quality Criteria, attributes, KPIs, and S-KPIs, (SQAMPS)

Identified by the literature review

Cr _n	A _n	Attribute	P _{ni}	Key Performance Indicators	SP _{nij}	Sub-Key Performance Indicators
Cr₁: Service Reliability	A₁	Operation Quality	P₁₁	Service Information: Providing sufficient and precise information about the provided service	SP₁₁₁	Displaying clear information on waiting time, routes, & schedules, emergencies, delay, or cancellation of service before and during a journey
					SP₁₁₂	The ease to submit complaints, requests, and opinions on regular days or holidays with quick responding
			P₁₂	Ticketing process: Providing an easy ticketing process	SP₁₂₁	Online ticket reservation and payment via mobile App.
					SP₁₂₂	Manual ticket reservation & payment via prepaid cards
			P₁₃	Affordability: Economical fare price	SP₁₃₁	Economical fare price
					SP₁₃₂	Economical means to reach the service
	A₂	Time Quality	P₁₄	Availability and continuity of the service all the time		
			P₂₁	A fixed and definite schedule of arrival & departure		
			P₂₂	Optimal waiting time at a stop		
			P₂₃	Fast transit time when crowded with passenger		
			P₂₄	Transport passengers straight to the desired point		
			P₂₅	Optimal walking time to reach a stop		
	A₃	Personnel Quality	P₃₁	Employees' knowledge, coordination, motivation, and handling medical emergencies (Competency)		
			P₃₂	Driver professionalism		
			P₃₃	Providing exceptional services for the disabled, females, elderly, and children at bus and station		
Cr₂: Facilities Reliability	A₄	Physical quality of the service	P₄₁	Passenger Physical Comfort	SP₄₁₁	Easy to get on and off (height of vehicle step)
					SP₄₁₂	Enough seats
					SP₄₁₃	Modern-looking vehicle and station
					SP₄₁₄	Enough spacing between seats and legroom
					SP₄₁₅	Comfort seat
			P₄₂	Passenger Mental Comfort	SP₄₂₁	Cleanness (interior and exterior hygiene & sanitary)
					SP₄₂₂	No engine noise disturbance when inside the vehicle
					SP₄₂₃	Perfect air quality and temperature inside the vehicle and stations
			P₄₃	Availability of car parking at a stop		
			P₄₄	Availability of special facilities for serving disorders		

Cr_n	A_n	Attribute	P_{ni}	Key Performance Indicators	SP_{nij}	Sub-Key Performance Indicators
	A₅	Physical Safety and secure	P₅₁	Assuring safe travel conditions during the journey	SP₅₁₁	No traffic accidents
					SP₅₁₂	No broken-down of vehicle
					SP₅₁₃	Seat belts and Airbags
					SP₅₁₄	Safe stand when inside the vehicle
			P₅₂	Availability of emergency equipment	SP₅₂₁	Easy escaping out of the vehicle in emergency cases
					SP₅₂₂	Availability and ease of using emergency equipment, such as first aid, phone, etc.
					SP₅₂₃	Firefighting systems inside vehicles and stations
			P₅₃	passenger security & privacy	SP₅₃₁	Safety from theft, robbery, and pickpocketing at auto stops and inside the vehicle
					SP₅₃₂	Privacy inside the vehicle and station
					SP₅₃₃	Availability of Anti-virus partitions between seats, such as COVID-19 shields
			P₅₄	Safe stop at stations		
C₃: Culture Mobility	A₆	Social mobility	P₆₁	Providing free services such as water and Arabic coffee		
			P₆₂	Aligning with the local cultural values		
	A₇	Environmental Sustainability	P₇₁	Level of emission, noise pollution, and sight pollution caused by public transportation means		
			P₇₂	Availability of technology inside the fleet and stations		
			P₇₃	Level of congestion impact or disruption caused by the public transportation means		
			P₇₄	Level of road deterioration caused by public transportation means		
			P₇₅	The economic impact of energy on the environment		

Table (4.2): AHP Pairwise Comparison Matrices (PCMs) used in the study

Level No.	Matrix size	Pairwise comparison matrix design
GOAL		Service Quality as a Measure of Passenger Satisfaction (SQAMPS) in Riyadh Public Transportation system
L1	3×3	The Criteria (Cr ₁ , Cr ₂ , Cr ₃) with respect to the goal (PSMSQ)
L2	3×3 2×2 2×2	Attributes (A ₁ , A ₂ , A ₃) with respect to Cr ₁ Attributes (A ₄ , A ₅) with respect to Cr ₂ Attributes (A ₆ , A ₇) with respect to Cr ₃
L3	4×4 5×5 3×3 4×4 4×4 2×2 5×5	KPIs (P ₁₁ , P ₁₂ , P ₁₃ , P ₁₄) with respect to A ₁ KPIs (P ₂₁ , P ₂₂ , P ₂₃ , P ₂₄ , P ₂₅) with respect to A ₂ KPIs (P ₃₁ , P ₃₂ , P ₃₃) with respect to A ₃ KPIs (P ₄₁ , P ₄₂ , P ₄₃ , P ₄₄) with respect to A ₄ KPIs (P ₅₁ , P ₅₂ , P ₅₃ , P ₅₄) with respect to A ₅ KPIs (P ₆₁ , P ₆₂) with respect to A ₆ KPIs (P ₇₁ , P ₇₂ , P ₇₃ , P ₇₄ , P ₇₅) with respect to A ₇
L4	2×2 2×2 2×2 5×5 3×3 4×4 3×3 3×3	Sub-KPIs (SP ₁₁₁ , SP ₁₁₂) with respect to P ₁₁ Sub-KPIs (SP ₁₂₁ , SP ₁₂₂) with respect to P ₁₂ Sub-KPIs (SP ₁₃₁ , SP ₁₃₂) with respect to P ₁₃ Sub-KPIs (SP ₄₁₁ , SP ₄₁₂ , SP ₄₁₃ , SP ₄₁₄ , SP ₄₁₅) with respect to P ₄₁ Sub-KPIs (SP ₄₂₁ , SP ₄₂₂ , SP ₄₂₃) with respect to P ₄₂ Sub-KPIs (SP ₅₁₁ , SP ₅₁₂ , SP ₅₁₃ , SP ₅₁₄) with respect to P ₅₁ Sub-KPIs (SP ₅₂₁ , SP ₅₂₂ , SP ₅₂₃) with respect to P ₅₂ Sub-KPIs (SP ₅₃₁ , SP ₅₃₂ , SP ₅₃₃) with respect to P ₅₃
	19	Pairwise Comparison Matrices (PCMs)

This chapter have presented the dimensions used in the study and showed how we have re-structured the service quality dimensions to fit the new transportation system in Riyadh City. Moreover, it showed the AHP structure with its level; after that, the pairwise comparison matrices PCMs have been set with respect to the AHP structure.

CHAPTER 5

Research Methodology

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5.1 Methodology Framework

This section explained the general framework of the research methodology. It will also present how the FAHP method has been integrated with the QFD model. Hence. This research methodology has been done through four phases, as shown in **Figure 5.1** and explained in the following subsections.

5.1.1 Phase 1

The first phase in the research methodology was reviewing the related studies to extract the data used in the current study. The next step in phase 1 was classifying this information per the study method, which integrates the FAHP method and QFD model. For the FAHP, to build the hierarchy of the AHP, we've extracted the most important **customer requirements** of public transportation from the best international practices. These requirements have divided into four levels: criteria (L_1), attributes (L_2), KPIs (L_3), and S-KPIs (L_4), as shown in **Figure 4.1**

On the other hand, the literature on the best international practices has been reviewed to extract the most important **technical requirements, standards & strategies** for building the QFD stages. Moreover, we've interviewed public transportation experts to evaluate these selections; as well as, and they have recommended some **management requirements** for satisfying the selected technical requirements in the QFD model.

5.1.2 Phase 2

The second phase of the methodology was prioritizing the above factors in terms of importance. Where the customer requirements have been prioritized through the FAHP method, the technical requirements and, standards & strategies have been

selected from the best international practices; then, the management requirement has been chosen through transportation experts.

5.1.3 Phase 3

The third phase was integrating the FAHP results with the QFD model. We correlated the relationship between the prioritized results of customer requirements (what) with the prioritized technical requirements (how) to satisfy the customer requirements. Then, the relationship between the technical requirement (what) and management departments (how) have been correlated to satisfy the selected technical requirements. Finally, we correlated the relationship between the management roles (what) and standards & strategies (how) to satisfy the management roles.

5.1.4 Phase 4

Finally, the fourth phase ranked the technical requirement, management requirement, standards & strategies in importance and provided some recommendations.

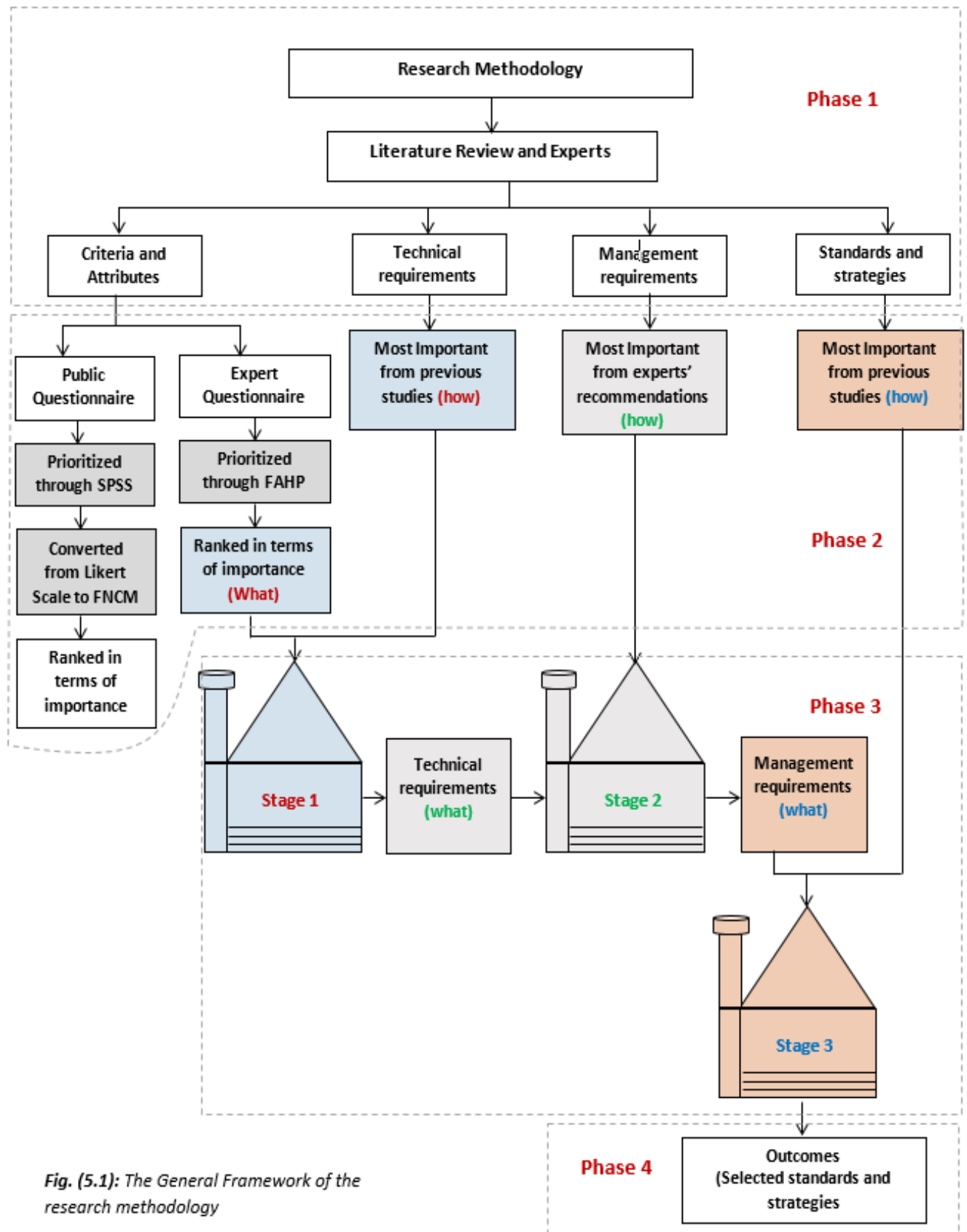


Fig. (5.1): The General Framework of the research methodology

5.2 The Questionnaire Types Used and Samples Sizes

Two questionnaire types have been applied to surveying the importance of the customer requirements of the RPTS.

The reasons why we have conducted two types of questionnaires can be explained as follow:

1. Since one of the objectives of this study is to recommend standards and strategies for public transportation, we can rely not only on the public users' views but also on experts' opinions as they have a critical perspective on this matter.
2. To avoid any biases from the public participants, experts can answer objectively and without bias
3. In the QFD model, there are a lot of technical decisions that should be made; therefore, experts were critical in this part of the study
4. We wanted to know what the public users think regarding the public questionnaire; and their requirements.

Regarding the public questionnaire, it targeted the population of Riyadh City with a sample size of 385. They distrucbuted using the online platforms such as WhatsAPP, Telegram, and Instagram with a responses rate was 97%. The population of Riyadh City in 2018 was 7.677 Million [GAS \(2017\)](#). Accordingly, the sample size of the public questionnaire can be calculated using the flowing equation,

$$n^* = \frac{N \left(\frac{Z\alpha}{2} \right)^2}{\left(\frac{Z\alpha}{2} \right)^2 + 4 N e^2} \dots\dots\dots \text{Equation 5.1}$$

Where:

n^* : sample size

N: Population size

$Z_{\frac{\alpha}{2}}$: Z-score when $\alpha = 5\%$ under two tail test

e: margin of error

Hence, the sample size can be calculated as follow:

$$n = \frac{7,677,000 (1.96)^2}{(1.96)^2 + 4 (7,677,000) 0.05^2} = 385$$

Moving to the expert questionnaire, which targeted the Royal Commission of Riyadh City (RCRC) experts. The sample size used is 100% of all available experts in the RCRC. The total number of participants in the expert questionnaire was 19; only 15 experts were valid to be analyzed because some were not available to revise the questionnaire when a high consistency ratio had been observed. This gives a response rate of 77%. **Figure 5.2** shows the sample size for each questionnaire.

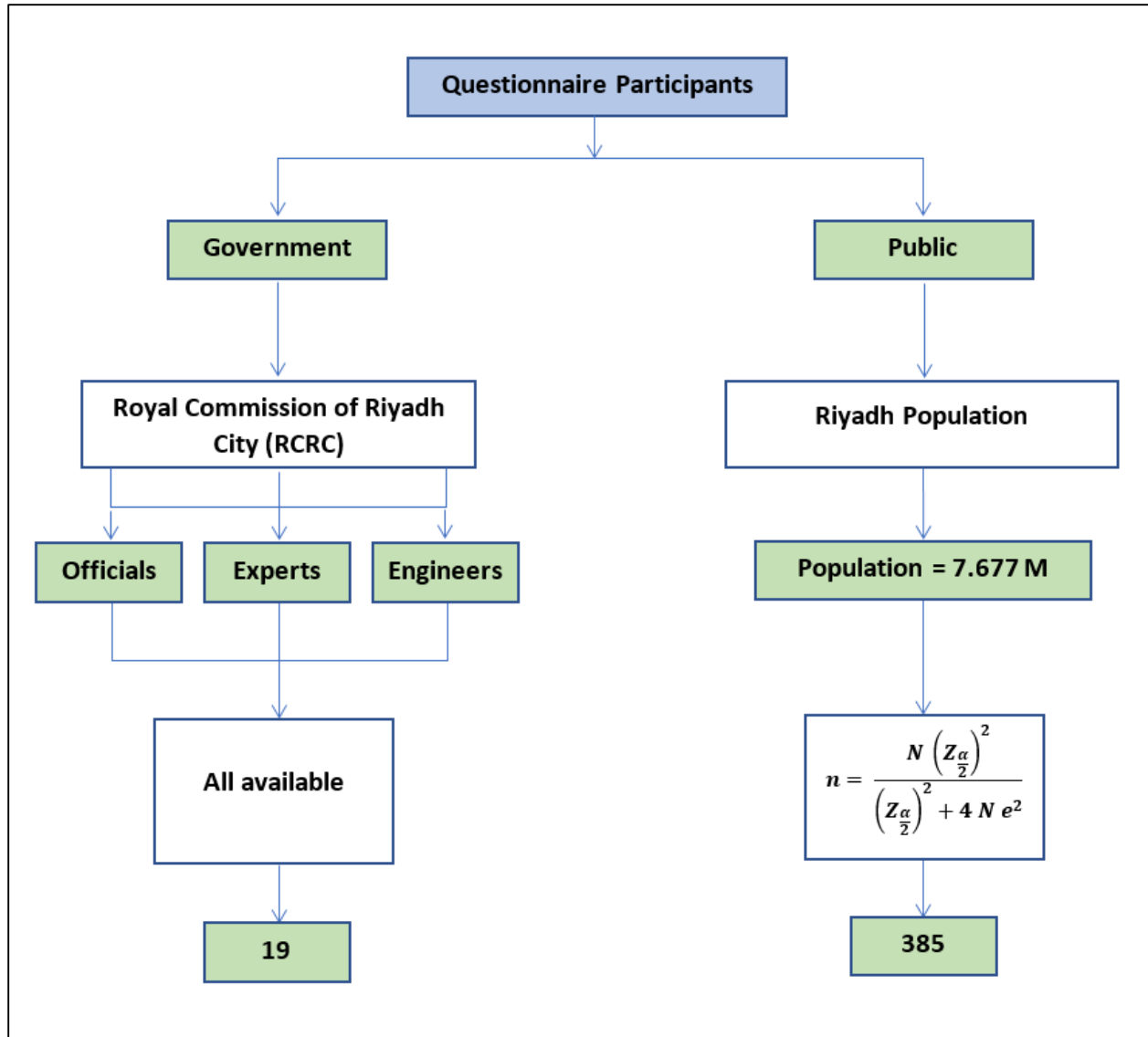


Fig. (5.2): Questionnaire participants and sample size

5.2.1 Design of public and Experts Questionnaires

Both questionnaires' designs are detailed in [Appendix A, Section A5.1.1](#), and [Section A5.1.2](#). Also, a copy of the public and expert questionnaires has been attached.

5.3 Methods of Solution, using AHP and FAHP for The Expert Questionnaire

In order to select the most appropriate method for solving the research problem, we've reviewed the related literature on AHP and FAHP applications. From the revision, we observed several methods for using AHP and FAHP applications. As a result, we nominated three approaches that had been widely used for solving AHP and FAHP problems: **(1)** The Eigen Value Method (EVM), proposed by [Saaty \(1980\)](#). **(2)** The Row Geometric Mean Method (RGMM), proposed by [Buckley \(1985\)](#). **(3)** The Extent Analysis Method (EAM), proposed by [Chang \(1996\)](#). **Figure 5.3** illustrates all the methods used in this study under the expert questionnaire. Moreover, **Figure 5.3** also shows the approaches used for measuring the consistency idiocies (CI)

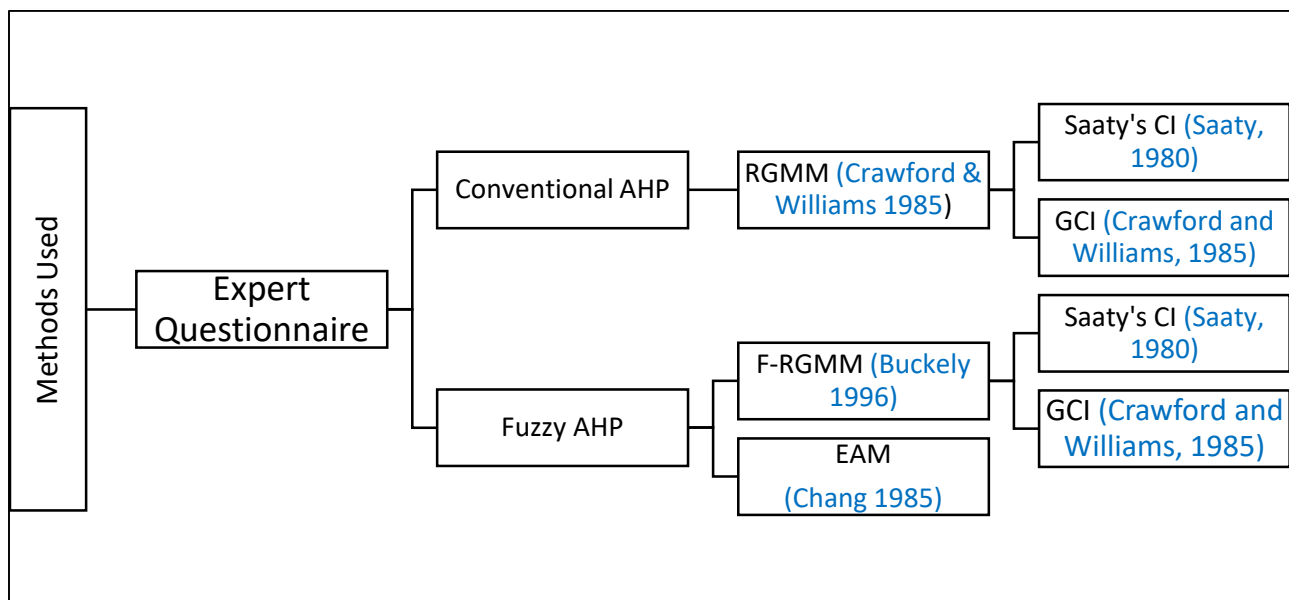


Fig. (5.3): Methods used for the experts' questionnaire analysis

The reason behind using several applications in solving the research problem can be explained as follows:

1. We have fuzzified the classical AHP results. From the literature, we found that researchers used two methods for converting the classical AHP into Fuzzy AHP, namely, Fuzzy-RGMM and EAM. Accordingly, we applied both of them on a simplified numerical example to compare their differences. Hence, we select one method for solving this research problem and use it for the software application we developed, explained in **Chapter 6**.
2. We observed that sometimes the Consistency Ration (CR) gives high or negative values; hence, we wanted to ensure that the selected method could accurately measure and improve the CR values.
3. We have developed a software application that integrated a FAHP method with a QFD model; accordingly, we wanted to make sure that the selected method has no defects or consistency errors
4. We have used a consensus AHP model, which is group decision-making, and we wanted to ensure that the selected method is appropriate for developing the consensus model.

*Therefore, the following sections will first present the generalized form for using the AHP method in this study. Then they will show the steps and equations for all methods mentioned in **Figure 5.3**. After that, a comparison between AHP and FAHP has been explained in [Appendix A, Section A5.2.3](#)*

5.3.1 General form of using AHP and FAHP in this research

This section will explain the general structure of AHP and FAHP. Also, the flowcharting of the algorithm for solving this research problem, shown in **Figure 5.2**

5.3.1.1 Algorithm of AHP

The AHP uses linear algebra to evaluate the results of each pairwise comparison. Each criterion takes on a certain amount of importance, which is the weight of each criterion. The higher the amount, the more critical the criterion is for the entire decision, [Ho, W., and Ma, X. \(2018\)](#).

To illustrate the solution for the AHP technique, imagine you need to buy a new bike, knowing that product A is cheaper than product B and product B has more features than A. Which product will you choose? Will you consider the cost or the features? Sometimes, decisions are made based on our instincts or past experiences. [Prof. Thomas L. Saaty \(1980\)](#) contributed to the Multi-Criteria Decision-Making (MCDM) field by developing a way to help a decision-maker proceeding all the information about the decision, which is called Analytic Hierarchy Process (AHP) that determines the best alternative. Accordingly, products A and B are going to be compared with each other based on their criteria through a Pairwise Comparison Matrix (PCM)

Because the use of the AHP in this study followed a consensus approach and integrated with a QFD model, the solution steps have been generalized in an algorithm. This algorithm has divided into 4-phases, and each phase consists of several, as follows:

Phase 1: From step 1 to step 4, establishing the expert questionnaire with respect to the AHP technique,

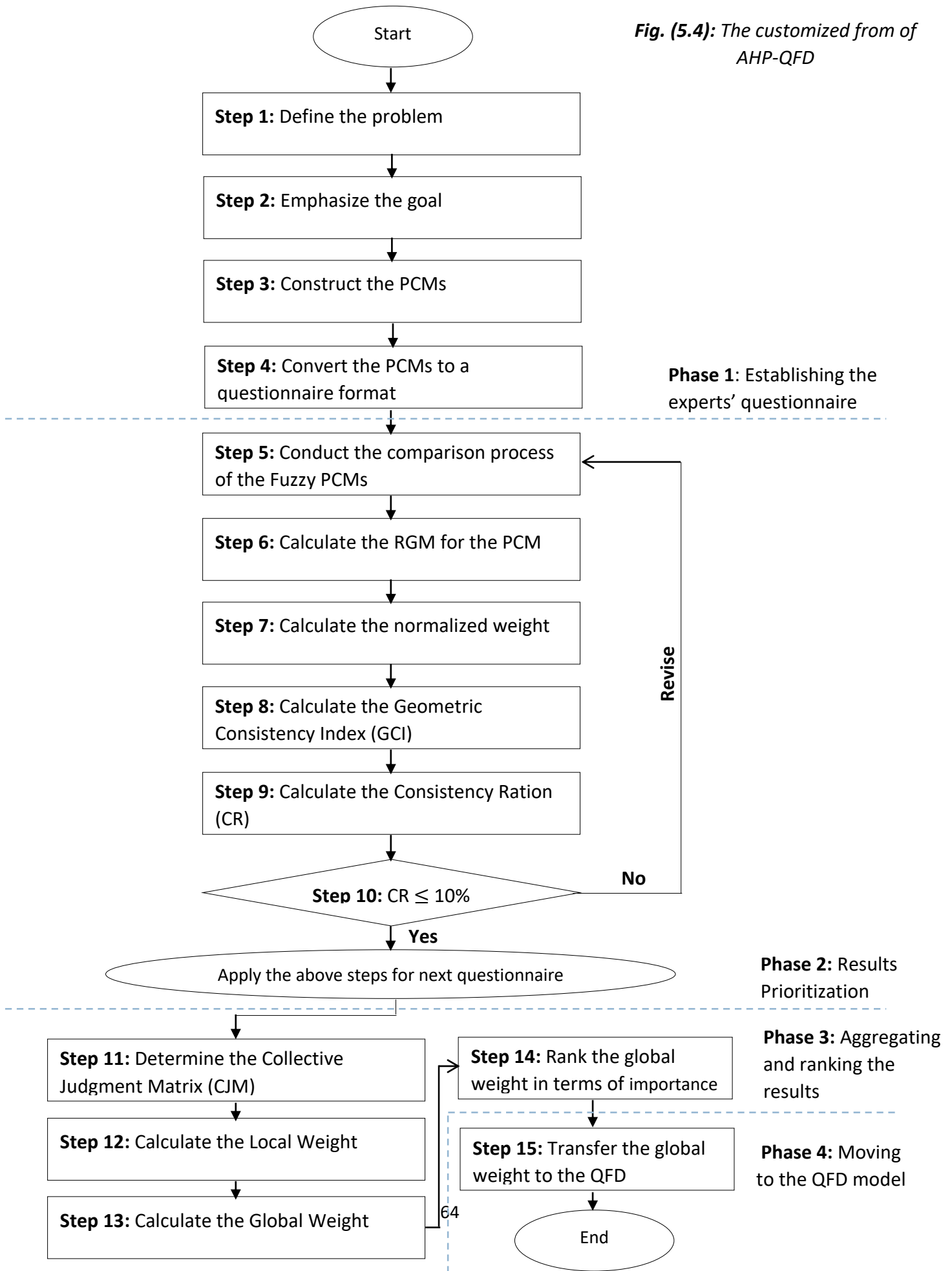
Phase 2: From step 5 to step 10, prioritizing the results

Phase 3: From step 11 to step 14, aggregating all the participants' respondents in a Collective Judgment Matrix (**CJM**)

Phase 4: Step 15, transferring the prioritized results (global weight) to the first stage of the QFD.

The above phases have been graphically flowcharted in **Figure 5.4**

Fig. (5.4): The customized from of AHP-QFD



5.3.1.2 Algorithm of FAHP

The FAHP method's objective is the same as the classical AHP method. However, [Buckley \(1985\)](#) and [Chang \(1996\)](#) have integrated the fuzzy concept into the classical AHP to solve the uncertainty of the classical AHP. That is by using fuzzy numbers instead of crisp numbers. Therefore, the same algorithm followed in the classical AHP will be followed here, considering the vague concept. As explained earlier, two methods were widely used for solving the FAHP problem. The first method is the F-RGMM, proposed by [Buckley \(1985\)](#), and the second is the EAM, proposed by [Chang \(1996\)](#).

Appendix A, Section A5.2 explains the fuzzy theory in general and an explanation of the Fuzzy-AHP and the Triangular Fuzzy Number (TFN), which is the approach used for converting crisp numbers into fuzzy numbers. Accordingly, reading that section before the following equations is strongly recommended.

5.3.2 Classical AHP Steps and Equations, using RGMM

The following procedure is the steps for using the RGMM in solving the AHP problem:

Step 1: Define the problem

Step 2: Emphasizes the goal of the study and set up the levels of the AHP structure by constructing a decision hierarchy structure as shown in **Figure 4.1**

Step 3: Construct a set of Pairwise Comparison Matrices (PCMs) per the hierarchy structure, shown in **Table 4.2**. Then, fill in the participants' responses using Saaty's relative scale measurement in the PCM, as shown in **Table 5.1**. The general form of the PCM is expressed in **Matrix 5.1**

Table (5.1): Saaty's scale*Saaty T. (1980)*

AHP Saaty (1980)	Explanation
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extremely Importance
2	Equally to Moderately
4	Moderately to Strongly
6	Strongly to very strong
8	Very strong to extremely
1/3	Values for inverse comparisons
1/5	
1/7	
1/9	
1/2	The inverse of intermediate values between the two adjacent judgments
1/4	
1/6	
1/8	

Matrix 5.1: The general form of the PCM

Goal	C ₁	C ₂	....	C _n
C ₁	1	a_{ij}	....	a_{in}
C ₂	$\frac{1}{a_{ij}}$	1	....	a_{jn}
⋮	....	....	1	....
C _n	$\frac{1}{a_{in}}$	$\frac{1}{a_{jn}}$	....	1

Step 4: Convert the PCMs into a questionnaire format, as detailed in **Appendix A, Section A5.1.2**

Step 5: Conduct the comparing process of the PCM elements by using the expert questionnaire form, as shown in **Appendix A, Section A5.1.2**

Step 6: Calculate the Row Geometric Mean for the PCM element using **Equation (5.2)**

$$RGMi = \sqrt[n]{\prod_{j=1}^n a_{ij}} \dots\dots (5.2)$$

Where,

a: element (criteria) of the matrix

i: Rows

j: Columns

n: Matrix size

Step 7: Calculate the normalized weight for the elements using the following equation:

$$Wi = \frac{\sqrt[n]{\prod_{j=1}^n a_{ij}}}{\sum_{j=1}^n (\sqrt[n]{\prod_{j=1}^n a_{ij}})} \dots\dots (5.3)$$

Step 8: After filling all the PCMs, the Consistency Index (CI) is determined using two approaches. One proposed by Saaty uses the maximum eigenvalue of the matrix, called λ_{max} , and can be expressed as follow:

$$CI = \frac{\lambda_{max} - n}{(n-1)} \dots\dots\dots (5.4)$$

The second approach has proposed by [Juan Aguaron et al. \(2003\)](#), which suggested that "if the prioritization procedure is not the EVM, it is not recommended to use the Saaty approach to evaluate the CI." Therefore, because the approach used in this study is the RGM, the Geometric Consistency Index (GCI) proposed by [Crawford and Williams, 1985](#); [Harker, 1987](#); [Golden and Wang, 1989](#); [Wedley, 1991](#); [Takeda](#)

and Yu, 1995; Monsuur, 1996; Escobar and Moreno Jimenez, 1997; Aguaron, 1998; Aguarón and Moreno-Jiménez 2003) will be used. It can be expressed as follow:

$$GCI = \frac{2 \sum_{i < j \geq 1}^n (\ln(aij) - \ln(\frac{w_i}{w_j}))^2}{(n-1)(n-2)} \dots\dots\dots (5.5)$$

Step 9: Calculate the Consistency Ration (CR) for the whole PCM using the following equation in case the Saaty approach is used:

$$CR = \frac{CI}{RI} \dots\dots\dots (5.6)$$

Where RI is the random index proposed by Saaty, shown in **Table 5.2**

Table 5.2: values of RI for $n = 3, \dots, 15$ Saaty T. (1980)

n	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

If the method is the GCI, the following equation will be used with the help of the approximated thresholds (K_n) of the random index proposed by Juan Aguaron et al. (2003). **Table 5.3** shows the threshold values.

$$CR = \frac{GCI}{k(n)} \dots\dots\dots (5.7)$$

Table 5.3 values of $k(n)$ for $n = 3, \dots, 16$ Juan Aguaron, et al. (2003)

n	3	4	5	6	7	8	9	10	11	12	13
K(n)	3.147	3.526	3.717	3.755	3.755	3.744	3.733	3.709	3.698	3.685	3.674
	14	15	16								
	3.663	3.646	3.646								

Because our software application can have a matrix size bigger than 16×16 , we have developed Random Index values corresponding with $K(n)$ values up to a matrix size of 100×100 . The explanation of this has been done in **Appendix C, Section C6.4**

Step 10: Check the CR values.

If the consistency ratio was greater than 10 %, the values in the PCM should be adjusted to get a CR value less than or equal to 10%. The adjustment of the CR can be done by returning the questionnaire to participants (experts) and asking them to revise the answers until reaching the acceptable CR. The flowchart shown in **Figure 5.5** illustrates the procedure of CR adjustment.

The adjusted CRs values in this study have been practically shown in **Chapter 7, Section 7.2.2, Table 7.11**

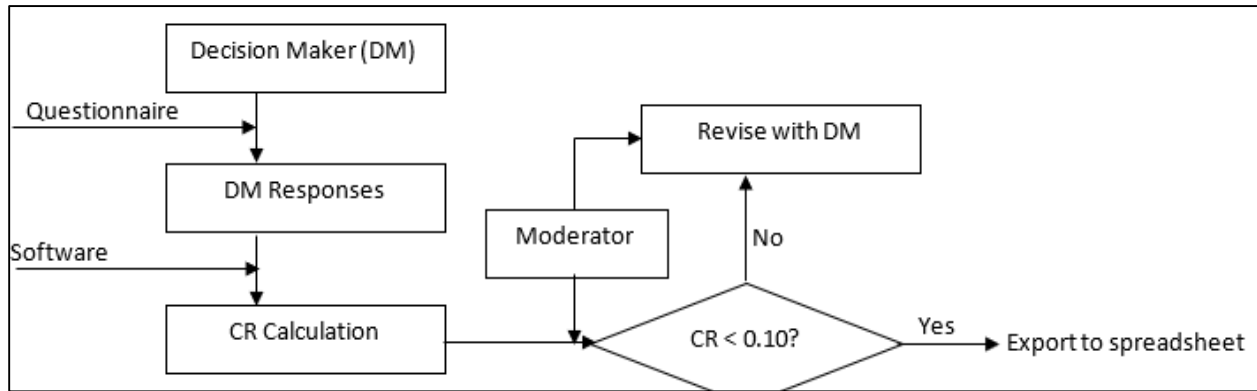


Fig. (5.5): CR Adjustment

Source: Zhibin Wu & Jiuping Xu (2012)

Before going to step 11 and for a better understanding of this step, it is strongly recommended to go through **Appendix 5, Section A5.3**, and read what is meant by a consensus model in AHP. Also, the Aggregate Individual Judgment (AIJ) and the Collective Judgment Matrix (CJM) are explained there.

Step 11: Having done filling all the PCMs for all participants, the Collective Judgment Matrix (CJM) is determined using the equation of Aggregate Individual Judgment (AIJ) as expressed below:

$$AIJ = aij^{(c)} = \prod_{p=1}^S (aij^k)^{\Delta P} \dots\dots (5.8)$$

Where,

(*c*): the collective judgment matrix

P: number of participated experts in the questionnaire

S Number of the approved questionnaires

K Number of matrix criteria

Δ weight of each expert. In this study, the weights are assumed to be equal

Step 12: Set the priority lists by calculating the local weight using **Equation 2** of each element from the CJM.

Step 13: To get the overall prioritization of all criteria, the global weights of these elements must be calculated by multiplying the local weights of each level by the priority of each previous level. The calculation and equation of the global weight have been detailed by the following researchers, [Duleba S. et al. \(2018\)](#); [Duleba S. et al. \(2011\)](#); [Al-Moherz D. et al. \(2016\)](#); and [Mahmoud M. & Abdel- Kader M., \(2016\)](#).

Step 14: Ranking the global weights in terms of importance

Step 15: Because the AHP method has been integrated with the QFD model, this step will take place in this analysis where the global weight of the criteria is going to be exported to the first stage of the QFD, which is generally called the House of Quality (HOQ); however, in our study, it has been named the characteristic service deployment.

5.3.3 Fuzzy AHP Steps and Equations, Using F-RGMM

The following are the steps for using the F-RGMM in solving the FAHP problem:

Step 1: Define the problem

Step 2: Emphasizes the goal of the study and set up the levels of the AHP structure by constructing the decision hierarchy structure as shown in **Figure 4.1**

Step 3: Construct a set of Fuzzy Pairwise Comparison Matrices (FPCMs), shown in **Matrix 5.2**, to all criteria and fill in the participants' responses using [Buckley's \(1985\)](#) relative scale measurement, shown in **Table 5.4**. This fuzzy scale has also been used by [Soberi, M. S. F., & Ahmad, R. \(2016\)](#); [Dayanandan, U., & Kalimuthu, V. \(2018\)](#); [Franek, J., & Kresta, A. \(2014\)](#); [El-Din, H. K., Abd El Munim, H. E., & Mahdi, H. \(2019\)](#); and [Ayhan, M. B. \(2013\)](#)

Matrix 5.2 Fuzzy Pairwise Comparison Matrix

Goal	C ₁	C ₂	....	C _n
C ₁	(1,1,1)	$(a_{ij})l, (a_{ij})m, (a_{ij})u$	....	$(a_{in})l, (a_{in})m, (a_{in})u,$
C ₂	$\left(\frac{1}{a_{ij}}\right)u, \left(\frac{1}{a_{ij}}\right)m, \left(\frac{1}{a_{ij}}\right)l$	(1,1,1)	....	$(a_{jn})l, (a_{jn})m, (a_{jn})u$
⋮	....	....	(1,1,1)	....
C _n	$\left(\frac{1}{a_{in}}\right)u, \left(\frac{1}{a_{in}}\right)m, \left(\frac{1}{a_{in}}\right)l$	$\left(\frac{1}{a_{jn}}\right)u, \left(\frac{1}{a_{jn}}\right)m, \left(\frac{1}{a_{jn}}\right)l$	....	(1,1,1)

Table (5.4): Fuzzy Scale

AHP, Saaty (1980) (Crisp number)	FAHP, (Buckley, 1985) (Fuzzy number)	Explanation
1	(1,1,1)	Equal Importance
3	(2,3,4)	Moderate Importance
5	(4,5,6)	Strong Importance
7	(6,7,8)	Very Strong Importance
9	(9,9,9)	Extremely Importance
2	(1,2,3)	Equally to Moderately
4	(3,4,5)	Moderately to Strongly
6	(5,6,7)	Strongly to very strong
8	(7,8,9)	Very strong to extremely
1/3	$(\frac{1}{2}, \frac{1}{3}, \frac{1}{4})$	Values for inverse comparisons
1/5	$(\frac{1}{4}, \frac{1}{5}, \frac{1}{6})$	
1/7	$(\frac{1}{6}, \frac{1}{7}, \frac{1}{8})$	
1/9	$(\frac{1}{9}, \frac{1}{9}, \frac{1}{9})$	
$\frac{1}{2}$	$(\frac{1}{1}, \frac{1}{2}, \frac{1}{3})$	The inverse of intermediate values between the two adjacent judgments
$\frac{1}{4}$	$(\frac{1}{3}, \frac{1}{4}, \frac{1}{5})$	
1/6	$(\frac{1}{5}, \frac{1}{6}, \frac{1}{7})$	
1/8	$(\frac{1}{7}, \frac{1}{8}, \frac{1}{9})$	

Step 4: Convert the FPCMs into a questionnaire format, as detailed in [Appendix A, Section A5.1.2](#), taking into account that to convert the FPCM into a questionnaire format, it shall be defuzzified into classical AHP by taking the middle value of the fuzzy number.

Step 5: Conduct the comparing process of the FPCM elements by asking the participants, as shown in [Appendix A, Section A5.1.2](#)

Then, the participant's answers will be converted to a fuzzy number using the scale shown in **Table 5.4**

Step 6: Calculate the Fuzzy Row Geometric Mean for the FPCM element using the following equation:

$$FRGMI = \left(\sqrt[n]{\prod_{j=1}^n (a_{ij})l_{ij}} ; \sqrt[n]{\prod_{j=1}^n (a_{ij})m_{ij}} ; \sqrt[n]{\prod_{j=1}^n (a_{ij})u_{ij}} \right) \dots\dots (5.9)$$

Step 7: Calculate the fuzzy weight for the elements using the following equation:

$$FWi = \left(\frac{\sqrt[n]{\prod_{j=1}^n (a_{ij})l_{ij}}}{\sum_{j=1}^n (\sqrt[n]{\prod_{j=1}^n (a_{ij})u_{ij}})} ; \frac{\sqrt[n]{\prod_{j=1}^n (a_{ij})m_{ij}}}{\sum_{j=1}^n (\sqrt[n]{\prod_{j=1}^n (a_{ij})m_{ij}})} ; \frac{\sqrt[n]{\prod_{j=1}^n (a_{ij})u_{ij}}}{\sum_{j=1}^n (\sqrt[n]{\prod_{j=1}^n (a_{ij})l_{ij}})} \right) \dots (5.10)$$

Step 8: Calculate the crisp weight:

$$CWi = \left(\frac{FWi}{3} \right) \dots\dots\dots (5.11)$$

Step 9: Calculate the normalized fuzzy weight for the elements using the following equation:

$$NFWi = \left(\frac{CWi}{\sum_{j=1}^n (CWi_j)} \right) \dots\dots\dots (5.12)$$

Step 10: Calculate the crisp values for the lower, middle, and upper of FPCM using:

$$Ca_{ij} = \left(\frac{\sum_{i=1}^n (a_{ij})l}{3} ; \frac{\sum_{i=1}^n (a_{ij})m}{3} ; \frac{\sum_{i=1}^n (a_{ij})u}{3} \right) \dots\dots\dots (5.13)$$

Step 11: Calculate the Consistency Index for the whole FPCM using GCI. The original FPCM shall be defuzzied, and then calculate the *GCI* using **Equation 5.5**. Alternatively, the middle values of the FPCM are selected to calculate the GCI. The equation of it has been expressed as follows:

$$GCI = \frac{2 \sum_{i < j \leq n} (\ln(a_{ij})m - \ln(\frac{NCWi}{NCWj}))^2}{(n-1)(n-2)} \dots\dots\dots (5.14)$$

Worthy mentioned that using Saaty's approach to evaluate the CI when using RGMM is not recommended as it gives high CR values greater than the acceptable ratio of 10%. This was proven when the problem was solved in both approaches. As shown in **Table 5.5**

Step 12: Calculate the Consistency Ration (CR) for the whole FPCM using Equation 5.6

Step 13: Check the CR values. The same checking procedure followed in the classical AHP will be applied here, explained in **Figure 5.5**

Before going to step 14 and for a better understanding of this step, it is strongly recommended to go through **Appendix 5, Section A5.3**, and read what is meant by a consensus model in AHP. Also, the Aggregate Individual Judgment (AIJ) and the Collective Judgment Matrix (CJM) are explained there.

Also, the concept of the aggregate individual judgment (AIJ) and the collective judgment matrix (CJM) are explained in this appendix.

Step 14: Calculate the Fuzzy Aggregate Individual Judgment (FAIJ) to obtain the Collective Judgment Matrix (FCJM) using

$$FAIJ = aij^{(c)} = \prod_{P=1}^S (aij^k)^{\Delta P} \dots \dots \dots (5.15)$$

Where:

(c): the collective judgment matrix

P: number of participated experts in the questionnaire

S Number of the approved questionnaires

K Number of matrix criteria

Δ weight of each expert; in this study, the weight was assumed to be equal

Step 15: Convert the aggregate fuzzy weight to crisp weight using the following:

$$ACW_i = \frac{aij^{(c)}}{3} \dots \dots \dots (5.16)$$

Step 16: Setting up the local weight using **Equation (5.3)**

Step 17: calculate the global weight using the same approach as the classical AHP

Step 18: Rank the global weights in terms of importance

Step 19: Because the AHP method has been integrated with the QFD model, this step will take place in this analysis where the global weight of the criteria is going to be exported to the first stage of the QFD, which is generally called the House of Quality (HOQ); however, in our study, it has been named the characteristic service deployment.

5.3.4 Fuzzy AHP Equations, Using EAM

The following are the steps for using the EAM in solving the FAHP problem:

Step 1: Define the problem

Step 2: Emphasizes the goal of the study and set up the levels of the AHP structure by constructing the decision hierarchy structure as shown in **Figure 4.1**

Step 3: Construct the set of the Fuzzy Pairwise Comparison Matrices (FPCMs), shown in **Matrix 5.2**, to all criteria and fill in the participants' responses using the [Buckley \(1985\)](#) relative scale measurement, shown in **Table 5.1**.

Step 4: Convert the FPCMs into a questionnaire format, as detailed in [Appendix A, Section A5.1.2](#), taking into account that to convert the FPCM into a questionnaire format, it shall be defuzzified into classical AHP by taking the middle value of the fuzzy number.

Step 5: Calculate the fuzzy synthetic extent for the PCM element, that is, priority weight:

$$S_i = \sum_{j=1}^n a_{ij} \left[\sum_{i=1}^n \sum_{j=1}^n a_{ij} \right]^{-1} \dots\dots\dots (5.17)$$

Step 6: Determine the number of DoP to be calculated for each FPCM through the following equation:

$$n(n-1) \dots \dots \dots (5.18)$$

For example, if the matrix size is 3×3 , then we have to calculate 6 DoP

Step 7: Calculate each convex fuzzy number's degree of possibility (DoP). Two fuzzy numbers are compared to get the DoP of one fuzzy number greater than another.

Assume the DoP of $A_2 = (l_2, m_2, u_2) \geq A_1 (l_1, m_1, u_1)$ that is

$$V(A_2 \geq A_1) = hgt (A_1 \cap A_2) = \mu_{A_2}(d) = D \dots \dots \dots (5.19)$$

$$= \begin{cases} 1 & \text{if } m_1 \geq m_2 \\ 0 & \text{if } l_2 \geq u_1 \\ \frac{l_2 - u_1}{(m_1 - u_1) - (m_2 - l_2)}, & \text{otherwise} \end{cases} \dots \dots \dots (5.20)$$

Where:

hgt: the highest intersection point

D: its value

d: it's ordinate as shown in **Figure 5.6**

Accordingly, D is given by:

$$D = V(A_2 \geq A_1) = \frac{u_2 - l_1}{(u_2 - m_2) - (m_1 - l_1)} \dots \dots \dots (5.21), \text{ Illustrated in } \mathbf{Figure 5.6}$$

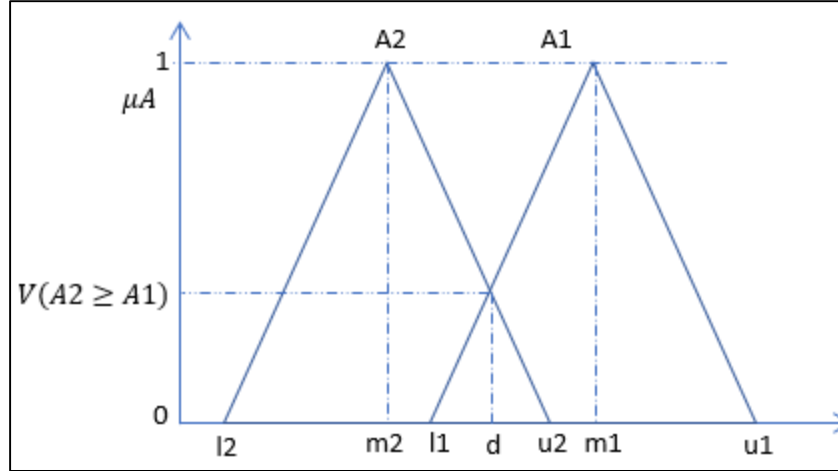


Fig. (5.6): DoP graph

Step 8: obtaining the DoP values of a convex fuzzy number to be greater than k (number of criteria in each FPCM) convex number A_i ($i = 1, 2, \dots, k$) can be calculated by:

$$V(A \geq A_1, A_2, \dots, A_k) = \min V(A_i \geq A_k), (k = 1, 2, \dots, n); (i = 1, 2, \dots, n) \dots (5.22)$$

Step 9: calculate the weight vector:

Assume that:

$$d'(A_i) = \min V(S_i \geq S_k)$$

for $k = 1, 2, \dots, n; k \neq i$

Then, the Weight Vector is given by:

$$w' = (d'(A_1), d'(A_2), \dots, d'(A_n))^T \dots \dots \dots (5.23)$$

Where A_i ($i = 1, 2, \dots, n$) are n element

Step 10: Calculate the normalized weight vector:

$$w = (d(A_1), d(A_2), \dots, d(A_n))^T \dots \dots \dots (5.24)$$

Before going to step 14 and for a better understanding of this step, it is strongly recommended to go through **Appendix 5, Section A5.3**, and read what is meant by a consensus model in AHP. Also, the Aggregate Individual Judgment (AIJ) and the Collective Judgment Matrix (CJM) are explained there.

Step 11: Calculating the Fuzzy Aggregate Individual Judgment (FAIJ) to obtain the Collective Judgment Matrix (FCJM) using **Equation (5.15)**

Step 12: Convert the aggregate fuzzy weight to crisp weight using **Equation (15)**

Step 13: Setting up the local weight using **Equation (5.3)**

Step 14: calculate the global weight using the same approach as the classical AHP

Step 15: Rank the global weights in terms of importance

Step 16: Because the AHP method has been integrated with the QFD model, this step will take place in this analysis where the global weight of the criteria is going to be exported to the first stage of the QFD, which is generally called the House of Quality (HOQ); however, in our study, it has been named the service characteristic.

*Accordingly, before selecting the method of solution. An illustrative numerical example has been solved using all the above techniques to compare the results with each other and decide which method will be selected for prioritizing the study criteria, attributes, KPIs, and sub-KPIs, shown in **Table 4.1**. Additionally, to set the method for developing the software application, shown in **Chapter 6***

5.3.5 Comparison Between AHP & FAHP Methods

The comparison between AHP and FAHP methods has been explained in [Appendix A, Section A5.2.3](#)

5.4 The selected method

As mentioned earlier, a simple illustrative numerical example has been used to apply all the above methods to select the appropriate method for this study. It is worth noting that this numerical example has been used in several studies, and each study has its objective. **(1)** [Z. Xu \(2000\)](#), in his study, developed this numerical example to illustrate the weighted geometric mean method (WGMM) in AHP when a consensus model is used. He used Saaty's CI to evaluate the consistency index. **(2)** [Escobar M. T. et al. \(2004\)](#) used the same example to illustrate the procedure of RGMM in a consensus model and apply the concept of GCI when a consensus model is applied. **(3)** [Dong et al. \(2008\)](#); have also resolved the same example to support the concept of Aggregate Individual judgment (AIJ) and using GCI as a consistency measure instead of Saaty's CI.

Accordingly, we've used this example in all of the above methods to be compared with each other, then deciding the most appropriate method. Additionally, to be selected for developing the software application, which integrated a consensus AHP method with a QFD model.

Excel spreadsheets have been used to solve this numerical example with all methods. The detailed solutions of this numerical example are explained in [Appendix A, Section A5.4](#)

After solving the numerical example with all methods, we observed that some CR values were negative when using the classical AHP using the RGMM with Saaty's

CI, as shown in **Table 5.5**. [Aguaron J. et al. \(2003\)](#) discussed the reason behind these negative values. They claimed that when the prioritization method is the RGM, using Saaty's CI for evaluating the consistency index is not recommended.

On the other hand, when GCI was used to evaluate the consistency, no negative values were found, and all CRs were less than 10%. Moreover, the CR values in GCI have been improved from Saaty's CI approach. Illustrated in **Table 5.5**

Regarding the F-RGMM, when Saaty's CI approach was used to evaluate the consistency, some CRs were greater than 10%, which is not acceptable by the theory. It is worth mentioning that the increase in these CRs can be classified as a mathematical problem, not a consistency issue. Because the original experts' answers were consistent and acceptable when compared with the other papers' results of the same example. Therefore, to solve this problem, the GCI approach is suggested to be applied to evaluate the consistency index; this has been used and showed a significant improvement in the CR values, as shown in **Table 5.5**

Table (5.5): CR Comparisons

Method Used	CR - E1	CR - E2	CR - E3	CR - E4	CR - E5	CR – CJM
RGMM – Saaty CI	1.14 %	6.83 %	0.74 %	– 0.82 %	– 0.57 %	0.57 %
RGMM – GCI	3.83 %	6.69 %	3.39 %	4.70 %	6.26 %	2.05 %
FRGMM – Saaty CI	7.93 %	11.42 %	5.86 %	8.93 %	13.57 %	5.89 %
FRGMM – GCI	3.91 %	6.73 %	1.30 %	4.83 %	6.47 %	1.82 %
EAM	-	-	-	-	-	-

Regarding the EAM, we don't need to calculate the CR because the degree of possibility is used to select the most appropriate values.

In terms of priority, by looking at the CJMs of each method, shown in [Appendix A, Section A5.4](#), The following priority results were found and presented graphically in **Figure 5.5**

RGMM-Saaty CI: (53.11%, 26.40%, 13.40%, 7.08%)^T

RGMM-GCI: (53.11 %, 26.40 %, 13.41 %, 7.03 %)^T

F-RGMM-Saaty CI: (51.55 %, 27.61 %, 13.46 %, 7.38 %)^T

F-RGMM-GCI: (51.55 %, 27.61 %, 13.46 %, 7.38 %)^T

EAM: (48.18 %, 29.83 %, 14.87 %, 7.12 %)^T

To sum up, Saaty's CI approach to evaluate the consistency in the RGMM and the FRGMM is neglected due to negative and high CR values. On the other hand, the GCI approach on the RGMM and the FRGMM is the acceptable and approved method because it improved the CR values, and all results were less than 10%, as shown in **Table 5.5**. No issues were found when the EAM was used. Therefore, RGMM with GCI, FRGMM with GCI, and EAM are accepted, giving relatively similar priorities for the given criteria. **Figure 5.5** has graphically presented a comparative chart between all the above methods.

Based on that, ***F-RGMM with GCI approach as a consistency evaluation approach will be used for this study because they give an optimal CR compared to the other papers' results of the same example. Additionally, the reason behind selecting the GCI as a consistency measure is that Aguarón, J., & Moreno-Jiménez, J. M. (2003) claimed that "If the prioritization procedure is not the EVM, the Saaty approach to evaluate the consistency is not appropriate, by construction, and new consistency measures, related to the prioritization procedure, are required."***

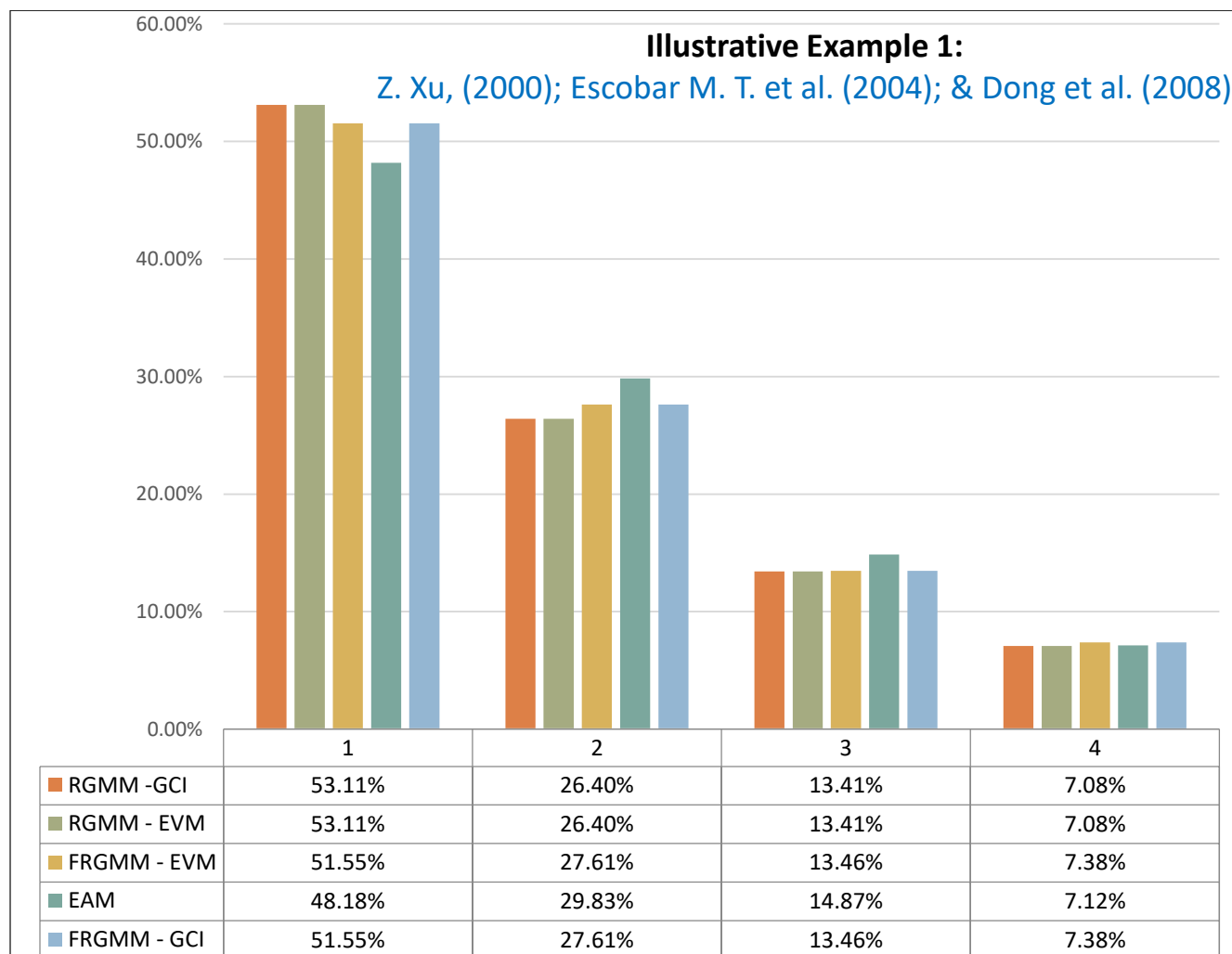


Fig. (5.7): A comparison chart of all methods

5.5 Public Questionnaire Methodology

Two methods have been followed to analyze the public questionnaire results. *The first method* is finding the descriptive statistics of the public answers using (SPSS). The results have been detailed in [Appendix B, Section B7.2](#)

The second method was fuzzing the results obtained from the first method by converting the Classical Likert Scale (CLS) on 1-9 into Fuzzy Likert Scale (FLS). The fuzzy Number Conjoint Model (FnCM) has been used for converting the results. The details of this method have been explained in [Chapter 7, Section 7.1.1](#)

We will adopt the results obtained from the second method as it overcomes the problem of uncertainty resulting from public questionnaires

5.6 Quality Function Deployment (QFD) Methodology

Quality Function Deployment (QFD) mainly depends on customer perspectives or requirements. It uses a series of matrices diagrams that resemble connected houses. The original form of the QFD consisted of four stages, **(1)** House of Quality (HOQ), **(2)** Parts Deployment, **(3)** Process Planning, and **(4)** Production Planning, as shown in **Figure 5.8**

The use of the QFD in this study is based on the prioritized results (global weight) obtained from the FAHP analysis, shown in **Chapter 7, Section 7.2.2, Table 7.16**

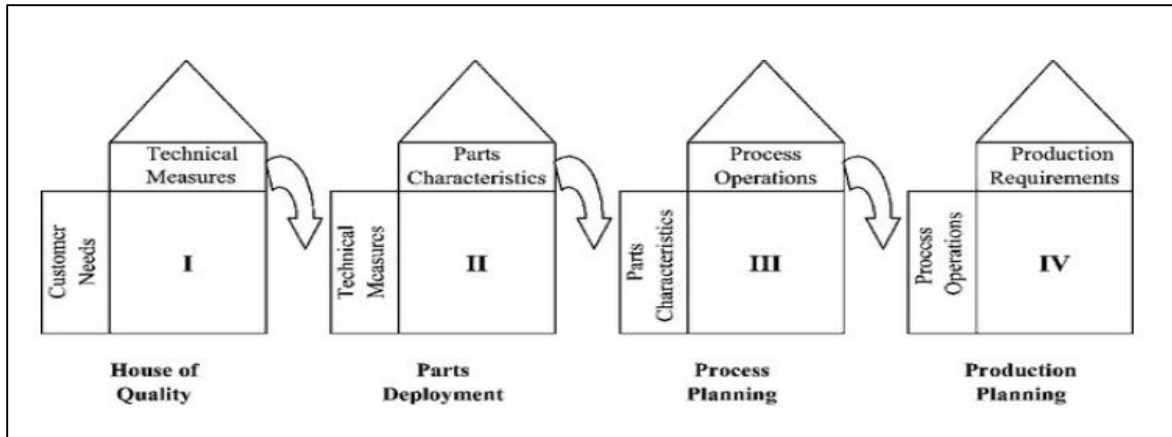


Fig. (5.8): The four stages model of QFD Source: [Chan L. & Wu. M. \(2022\)](#)

The QFD model aims to identify the customer requirements for a provided product or a service. Then it translates those requirements into a product or service design characteristic, which will help determine how the customer will be satisfied and where the quality function should be deployed.

A House of Quality (HOQ) diagram is used as a **first stage** in the (QFD). It aims to determine the relationship between the customer and the technical requirements of a provided product or service. **The second stage**, the parts deployment, aims to determine how these technical requirements will be satisfied by correlating their relationships with the parts' characteristics. After that, **the third stage** takes place by correlating the relationships of the parts' characteristics with the process operation. Finally, the relationships between process operation and production requirements are determined in the **fourth stage**. Hence, the aim of using this method can be explained as follow:

1. Understand and accurately define users' requirements
2. Determine how these requirements are associated with the technical characteristics to attain users satisfactions

3. Try to improve the service quality by converting the Voice of Customers (VOCs) into technical characteristics and then determining the technical priorities.

5.6.1 The Component of the House of Quality (HoQ)

According to [Russell and Tayler, p.175-178, \(2011\)](#), the house of quality consists of six sections, as follows: **(1)** customer requirements, **(2)** a competitive assessment, **(3)** technical characteristics, **(4)** a relationship matrix, **(5)** a tradeoff matrix, and **(6)** a target values section. Shown in **Figure 5.9**

The details of these sections are explained in [Appendix 5, Section 5.5](#)

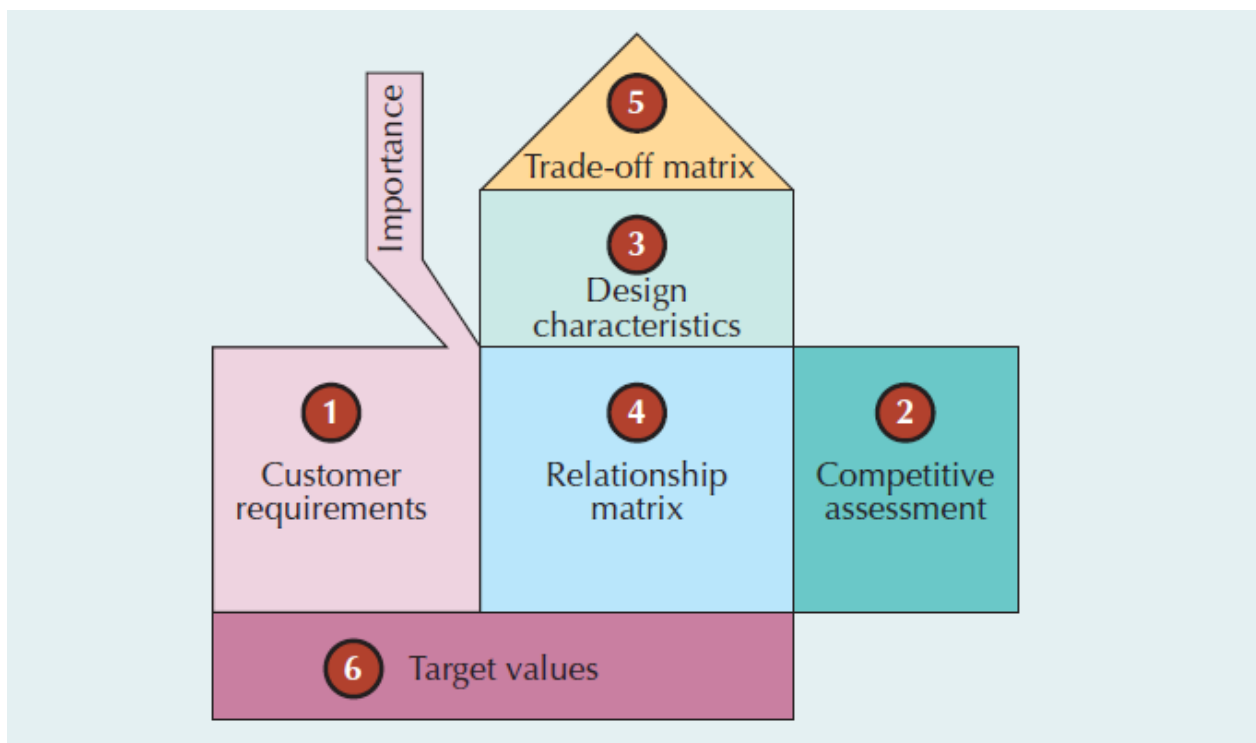


Fig. (5.9): The House of Quality Sections [Russell and Tayler, \(2011\)](#).

5.6.2 The Stages and sections of the QFD Model for This Study

The stages used in this study differ from the original stages explained above. Only three stages have been developed as a QFD model, shown in **Figure 5.10**. *The first stage* aims to identify the most important technical requirements. *The second stage* seeks to identify the most important management requirements. *The third stage* aims to identify the most important management requirements, standards & strategies that contribute to using RPTS effectively and efficiently.

Regarding the HOQ sections in this study, only four sections have been utilized, as follows: **(1)** a customer requirements section, **(2)** a technical characteristic section, **(3)** a relationship matrix, **(5)** and **(6)** an importance section. As shown in **Figure 5.11**

The reason why we have not implemented the two residual sections, namely, "a tradeoff matrix" and "a competitor assessment," is that we wanted to observe the priority of the technical requirements, management requirements, and the standards & strategies for Riyadh Public Transportation Service

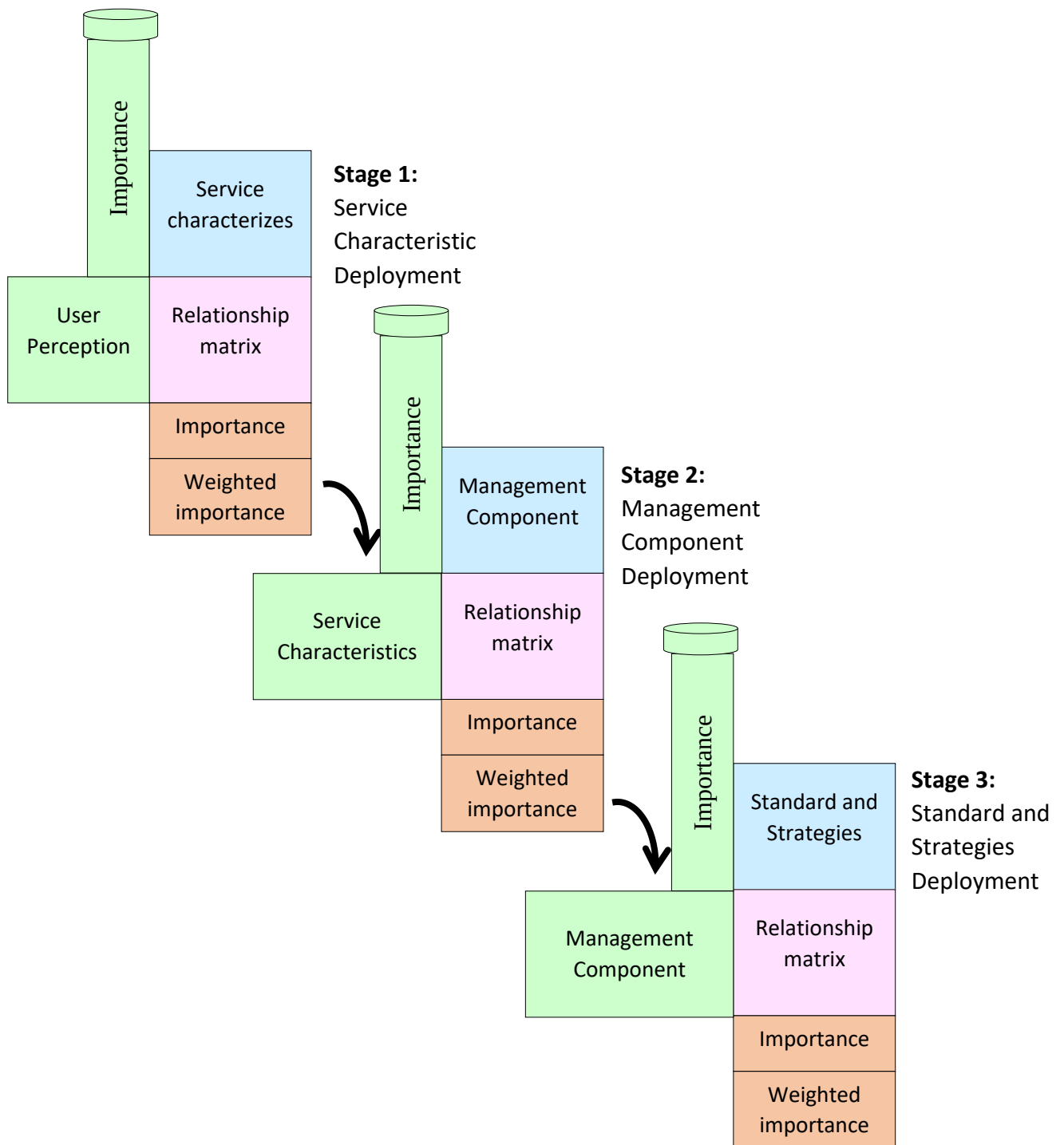
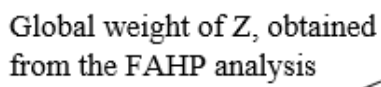


Fig. (5.10): QFD stages of this study



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5.6.3 The Equations of The QFD Model

By looking at **Figure 5.11**:

- Let Z be the customer requirement in **section (1)**, and each customer requirement's importance is expressed as $B = (b_i)_{z \times 1}$, in which b_i represents the judgment on the importance of i^{th} customer requirement.
- Let Y be the technical requirement in **section (2)**, and the importance of each technical requirement is expressed as $T = (t_j)_{y \times 1}$
- Let R be the relationship matrix in **section (3)** and expressed as $R = [r_{ij}]_{z \times y}$, "in which r_{ij} represents the contribution and influence on the i^{th} customer requirement and j^{th} technical requirement, that is, the correlation degree between i and j ," [LI Na, et al. \(2012\)](#). In other words, the equation of the relationship matrix can be calculated by using **Equation 5.25**

$$R = [r_{ij}]_{z \times y} \dots\dots\dots (5.25)$$

- Let I be the relative weight of each technical requirement in **section (4)** and can be expressed as shown in **Equation 5.26**

$$I_j = \sum_{i=1} b_i \times r_{ij} \dots\dots\dots (5.26)$$

- Let W be the normalized weight in **section (5)**, which is the weight of each j^{th} technical requirement and can be expressed as shown in **Equation 5.27**

$$W_j = \frac{I_j}{\sum_{j=1} I_j} = \frac{\sum_{i=1} b_i \times r_{ij}}{\sum_{j=1} \sum_{i=1} b_i \times r_{ij}} \dots\dots\dots (5.27)$$

This chapter have presented the methodology used in this research. At the beginning of the chapter, the general framework of the research methodology has been developed. Then, the two types of questionnaires used have been explained: the public and expert questionnaires. The design of the pubic questionnaire has been designed concerning the SPSS software application, and the expert questionnaire design has been designed with respect to a Consensus Fuzzy Analytical Hierarchy Process FAHP model. After that, the steps and equations (Methods) of solution using AHP and FAHP have been explained. A simple illustrative numerical example has been used to apply the solution methods to select the most appropriate method for solving this research problem. Based on that, the chosen method was Fuzzy Row Geometric Mean Method (FGRMM) under the FAHP method. After that, the methodology of analyzing the public questionnaire has been explained. Finally, the Quality Function Deployment (QFD) technique has detailed in this chapter's last section.

CHAPTER 6

A Developed Software Application as a Decision-Making and Quality Improvement Tool

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6.1 Introduction to the Application

Before considering this program, we used MS Excel to analyze the research questionnaires and the collected data. However, the number of matrices we have are huge as we were required to make 285 pairwise comparison matrices, each with a different size. Therefore, we programmed these matrices using a programming language to avoid the complexity of making these matrices and formulating the equations of AHP and QFD, as shown in **Chapter 5**.

An online AHP calculator developed by [Klaus D. Goepel](#) encouraged us to build our program. However, our application differs from his application as it uses a fuzzy theory in the AHP calculations; it handles the QFD model calculation and integrates these two methods, FAHP & QFD.

In terms of usefulness, it's a valuable tool in the Multi-Criteria Decision Making (MCDM) field because it follows the Analytical Hierarchy Process (AHP) for prioritizing the users' criteria or alternatives. Among the MCDM methods, the AHP method, proposed by [Thomas L. Saaty \(1980\)](#) considered the best one because it combines psychology with mathematics to make a decision. The concept of the AHP method has been explained in **Chapter 5, Section 5.3.1**. Moreover, **Figure 5.4 (Phase 1 to Phase 3)** presents the algorithmic flowchart of using this Method. Additionally, the application has contributed to the service quality field because it can solve QFD problems. *Accordingly, we have developed this tool to contribute to the decision-making field and help people quickly make decisions. However, programming the AHP approach was complex and relatively expensive.*

6.2 What is the App.?

The application is a calculator that performs the Fuzzy Analytical Hierarchy Process (FAHP) and prioritizes the user's criteria or alternatives. It can also perform the calculations of the Quality Function Deployment (QFD) model. Moreover, it can easily integrate both methods (FAHP-QFD) by transporting the result obtained from the AHP to the first stage of the QFD.

6.3 Why this App.?

This application aims to facilitate the complexity of the manual calculation of both methods (FAHP & QFD). Because in this application, all you need is to read the user manual, shown below in **Section 6.8**, then, filling your data to get your calculations.

6.4 Application Features

1. Easy to use. As explained above, all you need is to fill in the data you need to prioritize. Then, the application will do the math.
2. Deal with a bigger size of PCM. Comparing one-hundred criteria with each other at a time is intricate. However, this application can solve this type of AHP problem quickly.
3. Customization. Where users can customize their AHP Pairwise Comparison Matrices (PCMs) with different sizes and goals. Also, customization for the QFD is available in this application.
4. Consensus in AHP. A user can fill a set of PCMs that a group of experts had filled; then, a collective judgment matrix (CJM) can calculate the experts' results in one matrix.

5. Fuzzification. After filling the PCMs on [Saaty's scale](#), your entries will be converted into fuzzy numbers to avoid uncertainty generated by the evaluators and produce more accurate results.
6. Multi options. Where the calculations can be done for FAHP in case of only one expert; FAHP for a group of experts (Censuses model); QFD; and integration between AHP-QFD.

6.5 Coding and Programming Language used

First of all, we should differentiate between coding and programming. Coding is writing instructions in the computer language, digital binary numbers. While programming is the process of converting these instructions into a usable program. In our application, we started with the User Experience Design (UX) to construct the easiest way for a user to use the application. **Section 5.6 explains** The UX details. The main reason to understand UX is to ensure our idea is programmable. After that, we started writing the required codes for performing the application, such as tables, equations, and conditions. [Appendix C, Section C6.2](#), lists the essential codes used in this application.

Regarding the programming process, Flutter Software has been used to develop these codes as an application. Flutter is a software development kit developed by Google using the Dart programming language. Dart programming is a language developed by Google and made for client use, such as mobile or web-based applications. Moreover, Dart can also be used to develop desktop applications and servers.

Microsoft created the source-code editor Visual Studio Code (VSC), generally known as Microsoft VSC, for Windows, Linux, and macOS using the Electron Framework. Debugging support, syntax highlighting, intelligent code completion,

snippets, code refactoring, and embedded Git are among the features. VSC was used as the Integrated Development Environment (IDE) where the coding for the website was written. By combining features like software editing, testing, building and packing, and aging in a user-friendly program, Integrated Development Environment (IDE) boosts developer productivity.

5.6 User Experience Design (UX)

The benefit of this design is to simulate how users will use the application and then provide optimal use. The design of the user experience is shown in [Appendix C, Section C6.1](#)

6.7 The Mathematical Equations used in the application

Chapter 5, Figure 5.4 illustrates the algorithm of the application, and **Section 5.3** shows the mathematical equations used

6.7.1 AHP Equations

[Chapter 5, Section 5.3.2](#) shows the mathematical equations for the AHP

6.7.2 FAHP Equations

[Chapter 5, Section 5.3.3T](#) shows the mathematical equations for the FAHP

6.7.3 QFD Equations

[Chapter 5, Section 5.6.3](#) shows the mathematical equations are the QFD

6.8 User Manual (UM)

This User Manual (UM) provides the information and steps for effectively using this application. [Appendix C, Section C6.3](#) provides the user manual in detail.

6.9 Challenges we faced

As a civil engineer, using a programming language is difficult to build a complete software application. However, I used what I learned in my Bachelor's Degree with enormous support from software programmers to build this application. Therefore, using a programming language was the major challenge while developing this application.

The second challenge was the integration process between the AHP results and the QFD stages. The prioritized results obtained from the Collective Judgment Matrix were challenging to export to the first stage of the QFD model.

Another challenge we faced was transferring the crisp value of the AHP into fuzzy values. Additionally, calculating the fuzzy weight was challenging as we tried to divide each lower value on the summation of the upper values and vice versa.

CHAPTER 7

Data Analysis

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7.1 Public Questionnaire Analysis

The number of questions in the public questionnaire was 43, and its internal consistency was acceptable and statically reliable as Cronbach's Alpha was 90.3%, as shown in Table 7.1 using the SPSS.

Table 7.1 Internal consistency and the number of questions in the public questionnaire

Cronbach's Alpha	Number of questions
0.903	43

Appendix B, Sections B7.1 and B7.2., explained the result and analysis of the public questionnaire using SPSS. They also presented the public participants' information.

On the other hand, the result and analysis of the public questionnaire using FnCM have been explained in the following section.

7.1.1 Public Questionnaire Results using FnCM

The FnCM technique is used to convert the Crips results into Fuzzy results. Accordingly, we used the frequencies generated from SPSS to convert the C.L.S. into F.L.S. The frequency in this method is how many participants agreed on a specific importance, i.e., respondents' preferences.

Therefore, a conjoint technique has been applied to fuzzing the public questionnaire results. This technique was first developed by [Luce and Tukey \(1964\)](#). This technique aims to measure preferences or relative importance given to various attributes of a product [or a service] [Wen, T. B., Ho, T. C., Kelana, B. W. Y., Othman, R., & Syed, O. R. \(2019\)](#). Moreover, to precisely measure human judgment where their opinions are subjective, vague, and imprecise. In other words, human decisions are based on their feeling. Accordingly, a Fuzzy Number

Conjoint Model (FnCM) proposed by [Turksen and Willson \(1994\)](#) will be applied in our study to convert the public questionnaire results generated via SPSS into fuzzy numbers, detailed in the following section

7.1.1.1 The procedure of FnCM

The purpose of converting the classical scale into a fuzzy scale is to determine the range of the participant's response. If, for example, the participant judged that attribute X has a "*strong importance*," which is "5" on the Saaty scale, shown in Table 5.1, their answer may fluctuate from 4 to 6. Therefore, converting the respondents' results from crisp numbers into fuzzy numbers will help decision-makers to deal precisely with the questionnaire results.

The following steps have been applied to convert the C.L.S., shown in **Table 7.2**, into Triangular Fuzzy Numbers (T.F.Ns.). The same T.F.N. concept explained in **Chapter 5** will be used here to convert the C.L.S. into Fuzzy Likert Scale F.L.S.

Table (7.2): Classical Likert Scale and linguistic rating

Linguistic Rating	Crisp Value
Strongly Unimportant	1
Very Unimportant	2
Moderately unimportant	3
Fairly unimportant	4
Neutral	5
Fairly important	6
Moderately important	7
Very important	8
Strongly important	9

The following are the steps to convert the classical results into Fuzzy results.

Appendix B, Section B7.3 shows the solution of this method using M.S. Excel

Spreadsheet

Step 1: From the SPSS results, extract the frequencies (F_{ij}) of respondents' preferences from the public questionnaire based on nine linguistic values, as shown in **Table 7.2**. The results of this step are shown in **Table 7.3**

Table (7.3): Public questionnaire respondents' frequencies

	Count	Count	Count	Count	Count	Count	Count	Count	Count	Total respondent
	1	2	3	4	5	6	7	8	9	
F1	0	0	0	0	0	0	28	43	304	375
F2	0	0	0	14	102	58	101	15	85	375
F3	0	0	0	0	14	28	28	73	232	375
F4	0	0	0	15	28	30	88	115	99	375
F5	0	0	0	0	0	14	30	14	317	375
F6	0	0	0	0	0	0	14	57	304	375
F7	0	0	0	0	0	0	14	87	274	375
F8	0	0	0	0	0	0	14	42	319	375
F9	0	0	0	0	0	0	15	56	304	375
F10	0	0	0	0	0	0	43	71	261	375
F11	0	0	0	0	0	0	14	57	304	375
F12	0	0	0	0	0	14	28	29	304	375
F13	0	0	0	0	0	14	132	42	187	375
F14	0	0	0	0	0	14	15	14	332	375
F15	0	0	0	0	0	29	0	15	331	375
F16	0	0	0	15	0	73	57	57	173	375
F17	0	0	0	0	0	60	86	57	172	375
F18	0	0	0	15	0	86	87	72	115	375
F19	0	0	0	44	30	15	130	71	85	375
F20	0	0	0	0	0	29	87	100	159	375
F21	0	0	0	0	0	0	29	129	217	375
F22	0	0	0	0	0	58	117	56	144	375
F23	0	0	0	0	0	15	14	73	273	375
F24	0	14	43	29	72	28	29	60	100	375
F25	0	0	0	0	15	15	0	100	245	375
F26	0	0	0	0	0	0	14	15	346	375
F27	0	0	0	0	0	0	0	29	346	375
F28	0	0	14	15	30	127	59	28	102	375
F29	0	0	0	0	14	15	28	57	261	375
F30	0	0	0	0	0	14	29	72	260	375

	Count	Count	Count	Count	Count	Count	Count	Count	Count	Total respondent
	1	2	3	4	5	6	7	8	9	
F31	0	0	0	0	14	43	103	56	159	375
F32	0	0	0	0	0	14	29	72	260	375
F33	0	0	0	0	0	15	0	72	288	375
F34	0	0	0	0	43	28	58	87	159	375
F35	0	0	0	0	43	57	71	74	130	375
F36	0	0	0	0	0	15	0	101	259	375
F37	59	0	73	29	99	57	29	0	29	375
F38	0	0	15	0	30	0	73	112	145	375
F39	0	0	0	0	28	14	58	116	159	375
F40	0	0	0	0	14	28	58	144	131	375
F41	0	0	0	0	28	0	86	115	146	375
F42	0	0	0	0	28	0	72	114	161	375
F43	0	0	0	0	28	0	71	145	131	375

Step 2: Construct the T.F.N. for the linguistic rating (L_j), as shown in **Table 7.4**.

Appendix A, Section A5.2, explains the T.F.N. concept

Table (7.4): TFN for the linguistic rating

Notation (L_j)	Linguistic Rating	T.F.N.
L_1	Strongly Unimportant	1,1,1
L_2	Very Unimportant	1,2,3
L_3	Moderately unimportant	2,3,4
L_4	Fairly unimportant	3,4,5
L_5	Neutral	4,5,6
L_6	Fairly important	5,6,7
L_7	Moderately important	6,7,8
L_8	Very important	7,8,9
L_9	Strongly important	9,9,9

Step 3: Calculate the Weight (W_{ij}) of the public questionnaire factors with respect to linguistic rating L_j using the following equation:

$$W_{ij} = \frac{F_{ij}}{p} \dots\dots\dots \text{Equation 7.1}$$

Where:

F_{ij} is the frequency of respondents' preferences

P is the total number of all participants

Step 4: Calculate the overall membership function, which is the aggregated linguistic rating ($\tilde{T}_i$), using the following equation:

$$\tilde{T}_i = \sum_{j=1}^{L_j} F_{ij} * (L_{ij}, M_{ij}, U_{ij}) \dots\dots\dots \text{Equation 7.2}$$

Where:

L_{ij} = lower value of TFN

M_{ij} = middel value of TFN

U_{ij} = upper value of TFN

Step 5: Calculate the Degree of Similarity between the Aggregated Linguistic Rating $\tilde{T}_j = (t^i_1 + t^i_2 + t^i_3)$ and Linguistic Rating $L_j (l^j_1 + l^j_2 + l^j_3)$ using the following equation:

$$S_{ij}(\tilde{T}_i, L_j) = \frac{1}{1+d(F(\tilde{T}_i)-F(L_j))}, i = 1, 2, 3, \dots, n \text{ and } j = 1, 2, 3, \dots, m.. \text{Equation 7.3}$$

Where:

$$F(\tilde{T}_i) = \frac{(t^i_1 + t^i_2 + t^i_3)}{6} \text{ and } F(L_j) = \frac{(l^j_1 + l^j_2 + l^j_3)}{6}$$

Step 6: Identify the highest membership degree of Similarity observed from **Step 5**. The results of this step are shown in **Table 7.5**

Step 7: Rank the factors based on the highest degree of Similarity

Table 7.5 Highest membership degree of Similarity

	1	2	3	4	5	6	7	8	9
F1	0.114	0.129	0.148	0.174	0.211	0.268	0.365	0.576	0.791

	1	2	3	4	5	6	7	8	9
F2	0.150	0.176	0.214	0.272	0.373	0.594	0.759	0.432	0.301
F3	0.121	0.137	0.159	0.189	0.233	0.305	0.438	0.780	0.582
F4	0.134	0.154	0.182	0.223	0.287	0.402	0.673	0.660	0.398
F5	0.115	0.130	0.149	0.176	0.213	0.271	0.372	0.591	0.764
F6	0.114	0.129	0.148	0.173	0.209	0.265	0.361	0.564	0.815
F7	0.115	0.130	0.149	0.176	0.213	0.271	0.371	0.591	0.765
F8	0.113	0.128	0.147	0.172	0.208	0.262	0.355	0.551	0.843
F9	0.114	0.129	0.148	0.173	0.210	0.265	0.361	0.565	0.813
F10	0.117	0.132	0.152	0.179	0.218	0.279	0.387	0.632	0.705
F11	0.114	0.129	0.148	0.173	0.209	0.265	0.361	0.564	0.815
F12	0.115	0.131	0.150	0.177	0.215	0.273	0.376	0.602	0.747
F13	0.124	0.141	0.165	0.197	0.246	0.326	0.483	0.933	0.519
F14	0.114	0.129	0.148	0.173	0.210	0.265	0.361	0.565	0.813
F15	0.115	0.129	0.149	0.175	0.212	0.268	0.367	0.579	0.786
F16	0.129	0.148	0.174	0.210	0.266	0.362	0.568	0.806	0.446
F17	0.126	0.145	0.169	0.204	0.256	0.344	0.524	0.917	0.478
F18	0.134	0.155	0.183	0.224	0.289	0.407	0.687	0.648	0.393
F19	0.141	0.164	0.196	0.244	0.324	0.478	0.917	0.524	0.344
F20	0.124	0.142	0.166	0.199	0.248	0.329	0.491	0.964	0.510
F21	0.118	0.133	0.154	0.182	0.222	0.286	0.400	0.666	0.667
F22	0.129	0.148	0.174	0.210	0.266	0.362	0.567	0.808	0.447
F23	0.116	0.131	0.151	0.178	0.217	0.277	0.383	0.621	0.720
F24	0.157	0.187	0.229	0.298	0.424	0.737	0.609	0.378	0.275
F25	0.118	0.134	0.155	0.183	0.225	0.290	0.408	0.688	0.647
F26	0.113	0.127	0.145	0.170	0.205	0.257	0.347	0.530	0.897
F27	0.112	0.126	0.144	0.169	0.203	0.255	0.342	0.520	0.928
F28	0.146	0.171	0.206	0.260	0.351	0.540	0.870	0.465	0.318
F29	0.119	0.135	0.156	0.184	0.226	0.292	0.412	0.700	0.637
F30	0.117	0.133	0.153	0.180	0.220	0.282	0.393	0.649	0.686

	1	2	3	4	5	6	7	8	9
F31	0.128	0.147	0.172	0.208	0.263	0.356	0.553	0.839	0.456
F32	0.117	0.133	0.153	0.180	0.220	0.282	0.393	0.649	0.686
F33	0.115	0.130	0.150	0.176	0.213	0.271	0.372	0.592	0.762
F34	0.129	0.148	0.173	0.209	0.265	0.360	0.563	0.817	0.450
F35	0.133	0.154	0.182	0.222	0.285	0.399	0.663	0.671	0.401
F36	0.116	0.131	0.151	0.178	0.217	0.277	0.383	0.621	0.720
F37	0.221	0.284	0.397	0.658	0.676	0.403	0.287	0.223	0.182
F38	0.129	0.148	0.174	0.210	0.267	0.363	0.571	0.801	0.445
F39	0.125	0.143	0.167	0.201	0.252	0.337	0.507	0.972	0.493
F40	0.126	0.144	0.169	0.203	0.254	0.341	0.517	0.938	0.484
F41	0.126	0.144	0.168	0.203	0.254	0.341	0.517	0.940	0.484
F42	0.125	0.143	0.166	0.199	0.249	0.332	0.497	0.987	0.503
F43	0.126	0.144	0.168	0.203	0.254	0.341	0.517	0.940	0.484

7.1.1.2 Public Questionnaire Results

After applying the above steps and identifying the highest membership Degree of Similarity, the importance of the public questionnaire can be ranked as shown in **Figure 7.1.** and **Table 7.6**

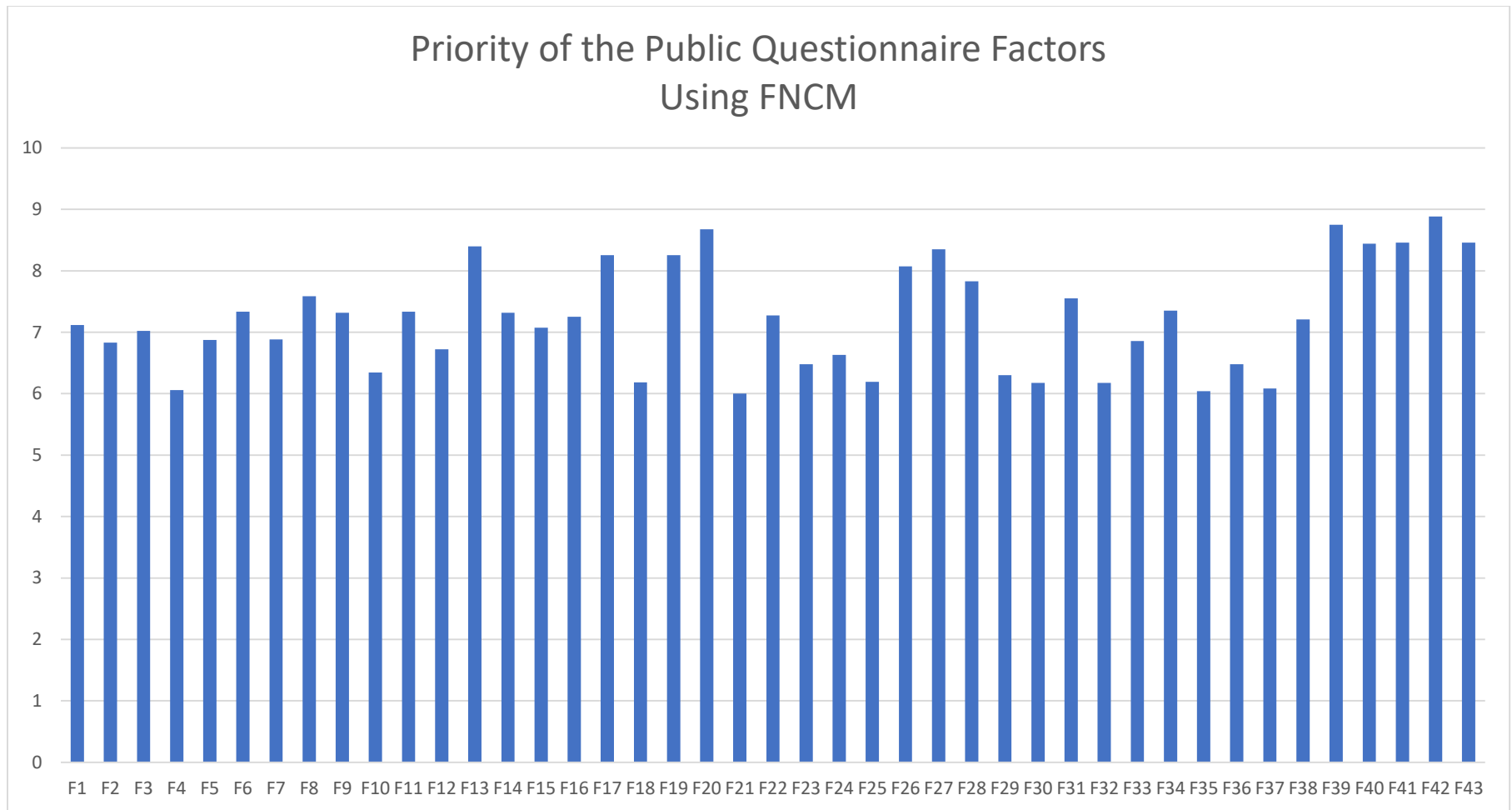


Fig. (7.1): Priority of the public questionnaire factors, using FNCM

Table (7.6): Priority of the public questionnaire factors, using FNCM

Class	Factor No.	Mean	Rank	Class	Factor No.	Mean	Rank
Extremely Important	F42	0.987	1	Strongly Important	F1	0.791	23
	F39	0.972	2		F15	0.786	24
	F20	0.964	3		F3	0.780	25
	F41	0.940	4		F7	0.765	26
	F43	0.940	4		F5	0.764	27
	F40	0.938	6		F33	0.762	28
	F13	0.933	7		F2	0.759	29
	F27	0.928	8		F12	0.747	30
	F17	0.917	9		F24	0.737	31
	F19	0.917	9		F23	0.720	32
Very Strong Importance	F26	0.897	11	Importance	F36	0.720	32
	F28	0.870	12		F10	0.705	34
	F8	0.843	13		F29	0.700	35
	F31	0.839	14		F25	0.688	36
	F34	0.817	15		F18	0.687	37
	F6	0.815	16		F30	0.686	38
	F11	0.815	16		F32	0.686	38
	F9	0.813	18		F37	0.676	40
	F14	0.813	18		F4	0.673	41
	F22	0.808	20		F35	0.671	42
	F16	0.806	21		F21	0.667	43
	F38	0.801	22				

From the analysis of the public questionnaire using FnCM, we found that all the study factors are essential, according to the public users' perspective. However, the importance of these factors has been classified into four classes, namely, **(1)** extremely important; **(2)** very strong important; **(3)** strong important; and **(4)** important.

- **Extremely Important**

Accordingly, *the extremely important* factors are Level of road deterioration caused by public Transport mean (F₄₂), Level of emission, noise pollution, and sight pollution (F₃₉), Comfort seat (F₂₀), level of congestion impact or disruption caused by this mode (F₄₁), Economic impact of energy on the environment (F₄₃), Technology inside the fleet and station (F₄₀), Employees knowledge, coordination, motivation, and handling medical emergency (Competency) (F₁₃), No broken-down of vehicle (F₂₇), Seat capacity (F₁₇), Enough spacing between seats and legroom (F₁₉).

Most of the *extremely important factors* are classified under environmental sustainability. Our research defined environmental sustainability as "the quality of providing a sustainable service considering pollution aspects, road deterioration, congestion, energy, and technology." [Sharmaa D. et al. \(2019\)](#) conducted a study in India to determine the service quality attributes of public transport services. Their research aimed to prioritize factors related to public transportation services. Worthy of mentioning that their characteristics were similar to our research factors and that environmental sustainability got the fourth most important factor among the thirteen factors.

Regarding personnel quality, which is defined in our research as "the quality of being efficient, skilled, and elegant." From the public user perspective, employee competency is considered an extremely important factor. [Kurtulmuşoğlu F. et al. \(2016\)](#), [Pakdil F., & Kurtulmuşoğlu F., Toni Lupo, and Utama D. et al.](#) found in their related studies that crew competency is the priority factor for the public transportation service.

On the other hand, this study defines a safe and secure environment as "the quality of providing a service with safe travel conditions during the journeys, as well as sufficient emergency equipment, security, and privacy for the passenger." The public participants have evaluated this factor as extremely important. This was significant because [Jomnonkwao K. et al.](#); [Bajčetić S. et al.](#); [Tsoukalidis I. et al.](#); [Dinulescu R. et al.](#); [Alkharabsheh A. et al.](#); [Duleba S. et al.](#); [Toni Lupo](#), in their studies have classified safety and security in public transportation services as extremely important factors.

Seat capacity, enough spacing between seats and legroom, and the other related factors mentioned in **Chapter 4, Table 4.1** are classified under physical quality, defined as "the quality of providing a physical and mental comfort for the passengers." [K. et al.](#); [Tsoukalidis I. et al.](#); [Dinulescu R. et al.](#); [Duleba S. et al.](#); [Al-Moherz D. et al.](#); [Zhang X. et al.](#); [Utama D. et al.](#); [Sharmaa D. et al.](#), (2019); [Moslem S. & Duleba S.](#); [Martina V. et al.](#), (2016); [Chan C. et al.](#), (2019), in their studies have also considered these factor as an essential factor for efficient use of the public transportation.

- **Very Strong Importance**

Moving to the next level, the public participants have evaluated the following factors as Very Strong Important: Economic means to reach the service, Fixed and definite schedule of arrival & departure, Optimal waiting time at a stop, Transport of passengers straight to the desired point, Driver professionalism, Easy to get on and off (height of vehicle step), No engine noise disturbance when inside the vehicle, no traffic accidents, Seat belt, and Airbags, Availability and ease to use emergency equipment, e.g., first aid, phone, etc., Privacy inside the vehicle and station, Aligning with the local cultural values. [Ayanda Vilakazi A. \(2014\)](#); [Tsoukalidis I. et al.](#);

Dinulescu R. et al.; Rao K. & Thakar G.; Dudek M. et al.; Al-Moherz D. et al.; Alkharabsheh A. et al., in their studies found that is one of the most critical factors that lead the public users to depend heavily on using buses other than transportation means. This was significant since the economic price of public transportation in our study was a very strong important factor.

In the current study, the time factor in public transportation is defined as “the quality of being punctual and regular.” public participants classified the time factor as a very strong important factor. Moreover, Jomnonkwao K. et al.; Kurtuluşoğlu F. et al.; Bajčetić S. et al.; Prabowo R. et al.; Tsoukalidis I. et al.; Dinulescu R. et al.; Rao K., & Thakar G.; Duleba S. et al.; Dudek M. et al.; Al-Moherz D. et al.; Mahmoud M., & Abdelkader M.; Alkharabsheh A. et al.; Moslem S. & Duleba S.; Duleba S. et al.; Zhang X. et al.; Utama D. et al.; Toni Lupo; Moslem S. and Duleba S.; Sharmaa D. et al., (2019); Martinsa V. et al., (2016); Alkharabsheh A. et al., (2021); Bhattacharya A. et al., (2005); and Tsoukalidis I., (2009), have classified the time factor (punctuality and regularity) as a priority factor for the public transportation.

- **Strong Important**

From the public point of view, the following factors are evaluated as strongly important for the efficient use of the public transport system: Displaying clear information on waiting time, routes, & schedules before and during the journey; The Ease of submitting complaints, requests, and opinions on regular days or holidays with quick responding; Ticket reservation & payment via mobile App.; Economical fare price; Availability and continuity of the service; Fast transit time when crowded with passengers; Optimal walking time to reach a stop; Providing special services for disabled female elderly, and children at bus and station; Air quality and temperature inside the vehicle and stations; Car parking at a stop; Safe stand when inside the vehicle; Safety from theft, robbery, pickpocketing at auto stop and inside

the car; Safe stop at a station; and The information on trips. This was supported by [Al-Rashid M. \(2020\)](#); [Sharmaa D. et al. \(2019\)](#); [Rao K. & Thakar G.](#); [Prabowo R. et al.](#); [Dinulescu R. et al.](#); [Moslem S. & Duleba S.](#); [Duleba S. et al.](#); [Moslem S. and Duleba S.](#); [Martina V. et al., \(2016\)](#), as they considered these factor as a priority in a public transportation system.

- **Important**

Public participants have evaluated the following factors as important in the public transport service: Ticket reservation & payment via prepaid cards, Modern looking vehicle, and stations, Cleanness (interior and exterior hygiene & sanitary), Availability of special facilities for serving disorders, ease escaping out of the vehicle in emergency cases, Firefighting system inside vehicle and stations, Anti-virus partitions between seats, such as COVID-19 shield, Providing free services, such as water and Arabic coffee

7.2 Expert Questionnaire Results:

The following sections will present the analysis of the expert questionnaire. It will mainly present the two subsections: the information of the expert participants and the analysis and results of the expert questionnaire using the FAHP method.

7.2.1 Participants' Information of the E.Q.

This section will present the general information of the expert questionnaire participants with their gender, ages, profession, years of experience, and education.

7.2.1.1 Gender of Experts' participants

Nineteen experts participated in this questionnaire, and only 15 male experts were analyzed because four were unavailable to revise their consistency ratio (C.R.).

7.2.1.2 Ages of Experts' participants

About 54% of the experts were between 30-39 years, while the ages of 20 and 29 constituted only 2% of the participants. Three experts were between 60-69 years, and only one expert was above 70 years, as shown in **Table 7.7**

Table (7.7): Age of the expert participants

		Frequency	Percent
Valid	15-19 Years	0	0%
	20-29 Years	2	13.3%
	30-39 Years	8	53.3%
	40-49 Years	1	6.7%
	50-59 Years	0	0%
	60-69 Years	3	20%
	Above 70 Years	1	6.7%
	Total	15	100%

7.2.1.3 Professions of Experts participants

As shown in **Table 7.8**, civil and industrial engineers form the highest percentage of participants, constituting about 55% of total exports. Project managers constituted around 30% of the participants.

Table (7.8): Professions of the expert participants

		Frequency	Percent
Valid	Industrial Engineer	3	20.0%
	Civil Engineer	5	33.3%
	Mechanical Engineer	1	6.7%
	Urban Engineer	1	6.7%
	Project Managers	4	26.7%
	Project Engineer	1	6.7%
	Total	15	100.0

7.2.1.4 Experience of Experts participants

47% of the experts had above 11 years of work experience, while experts with an experience between 6-10 years constituted 40% of the total experts' participants. Only three experts had five years of experience, as shown in **Table 7.9**

Table (7.9): Years of experience of the participants

		Frequency	Percent
Valid	From 1-5 Years	3	20.0%
	From 6-10 Years	5	40.0%
	Above 11 Years	7	46.7%
	Total	15	100.0

7.2.1.5 Education of Experts participants

73.3% of the experts hold a bachelor's degree, while holders of a master's and Ph.D. degrees constituted 26.7% of the total experts' participants, as shown in **Table 7.10**

Table (7.10): Education of the participants

		Frequency	Percent
Valid	Less than high school	0	0%
	High School	0	0%
	Diploma	0	0%
	Bachelor degree	11	73.3%
	Master degree	3	20.0%
	PhD	1	6.7%
	Total	15	100.0

7.2.2 Expert Questionnaire Results:

The number of questions in the expert questionnaire was 19, designed with respect to the A.H.P. method. The design procedure has been explained in detail in **Appendix A, Section A5.1.2**

The consistency ratios (C.R.s) for all matrices and in the C.J.M. were less than 10%, which is acceptable for completing the A.H.P. method. However, some of the C.R. values were greater than 10%. They have been adjusted by returning the questionnaire to the expert to revise his answers to fit the acceptable percentage. The adjusted C.R. values are shown in **Table 7.11**. The algorithm for adjusting the C.R. has been explained in **Chapter 5, Section 5.3.2, Step 10**

Table (7.11): Adjusted Consistency Ratios

Q. No.	Adj.	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
Q#1	CR*	3%	1%	0%	5%	1%	0%	5%	0%	3%	3%	0%	2%	2%	3%	1%
	C.R.							52%								
Q#2	CR*	5%	5%	0%	5%	5%	0%	0%	0%	5%	5%	0%	0%	5%	5%	0%
	C.R.				75%				23%		14%					30%
Q#3	CR*	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	CR															
Q#4	CR*	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	CR															
Q#5	CR*	0%	7%	8%	6%	4%	4%	2%	4%	0%	0%	4%	6%	6%	0%	8%
	C.R.				19%						13%		15%			
Q#6	CR*	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	CR															
Q#7	CR*	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	CR															
Q#8	CR*	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	CR															
Q#9	CR*	2%	8%	7%	8%	6%	2%	0%	8%	1%	6%	7%	0%	4%	2%	7%
	C.R.			19%		26%			35%	16%	15%	15%	40%		22%	
Q#10	CR*	0%	5%	5%	3%	5%	0%	0%	1%	0%	5%	0%	0%	1%	0%	5%
	C.R.				27%	31%					31%			15%		
Q#11	CR*	0%	7%	4%	2%	0%	0%	2%	1%	0%	0%	6%	5%	3%	0%	7%
	C.R.		30%					21%	12%			13%	14%			14%

Q. No.	Adj.	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
Q#12	CR*	5%	6%	5%	3%	7%	3%	0%	7%	4%	4%	4%	3%	6%	5%	8%
	C.R.		34%		22%	10%				17%	15%		14%			
Q#13	CR*	0%	5%	0%	5%	0%	5%	0%	5%	0%	0%	0%	5%	5%	0%	0%
	C.R.		14%		14%								31%			
Q#14	CR*	0%	4%	2%	4%	2%	2%	0%	7%	0%	1%	0%	3%	0%	0%	8%
	C.R.		58%		27%				16%				18%		12%	
Q#15	CR*	5%	6%	0%	1%	4%	2%	0%	8%	5%	5%	2%	0%	1%	5%	9%
	C.R.	17%	60%			12%				17%	17%		70%		18%	
Q#16	CR*	0%	5%	0%	5%	5%	5%	0%	5%	5%	5%	0%	5%	5%	0%	5%
	C.R.	31%	14%			14%			38%	31%	31%		31%		30%	
Q#17	CR*	6%	1%	5%	5%	0%	5%	5%	5%	1%	1%	0%	0%	1%	6%	1%
	C.R.	19%			23%		23%	52%		25%	24%				20%	
Q#18	CR*	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	CR															
Q#19	CR*	0%	8%	4%	7%	1%	7%	0%	5%	0%	2%	0%	4%	6%	0%	8%
	C.R.		20%		17%				13%				11%	25%	30%	12%

M.S. Excel spreadsheet has been used for analyzing the expert questionnaire results using the FAHP method. The excel solution is attached in [Appendix 7, Section 7.4](#). The following tables show the priority of the study framework shown in **Table 4.1**; moreover, they have been prioritized per the levels of the A.H.P. structure, shown in **Figure 4.1**

The priority has considered the local Weight of each criterion, attribute, KPI, and Sub-KPI. After prioritizing the levels of the A.H.P. structure, the global weights have been determined.

The definition of criteria, attributes, KPIs, and S-KPIs have been defined in **Table 4.1**

Table (7.12): Local Weight of Level 1

Criteria	Code	Local Weight	Rank
Service Reliability	Cr ₁	0.278	2
Facility Reliability	Cr ₂	0.558	1
Culture Mobility	Cr ₃	0.164	3

Table (7.13): Local Weight of Level 2

Attribute	Code	Local Weight	Rank
Operation Quality	A1	0.245	6
Time Quality	A2	0.462	3
Personnel Quality	A3	0.293	5
Physical Quality	A4	0.217	7
Safety and Security	A5	0.783	1
Local Culture Alignment	A6	0.623	2
Environmental Sustainability	A7	0.377	4

Table (7.14): Local Weight of Level 3

Key Performance Indicator	Code	Local Weight	Rank
Service Information	P11	0.247	14
Ticketing process	P12	0.199	19
Affordability	P13	0.411	2
Availability and continuity of the service all the time	P14	0.142	25
A fixed and definite schedule of arrival & departure	P21	0.210	18
Optimal waiting time at a stop	P22	0.166	22
Fast transit time when crowded with passenger	P23	0.277	9
Transport passengers straight to the desired point	P24	0.159	23
Optimal walking time to reach a stop	P25	0.189	21
Employees' knowledge, coordination, motivation, and handling medical emergencies (Competency)	P31	0.320	6

Key Performance Indicator	Code	Local Weight	Rank
Driver professionalism	P32	0.281	8
Providing exceptional services for disabled females, the elderly, and children at bus and station	P33	0.399	3
Passenger Physical Comfort	P41	0.255	11
Passenger Mental Comfort	P42	0.249	12
Availability of car parking at the stop	P43	0.157	24
Availability of special facilities for serving disorders	P44	0.338	5
Assuring safe travel conditions during the journey	P51	0.356	4
Availability of emergency equipment	P52	0.259	10
passenger security & Privacy	P53	0.137	26
Safe stop at stations	P54	0.248	13
Providing free services such as water and Arabic coffee	P61	0.299	7
Aligning with the local cultural values	P62	0.701	1
Level of emission, noise pollution, and sight pollution caused by public transportation means	P71	0.217	17
Availability of Technology inside the fleet and stations	P72	0.127	27
Level of congestion impact or disruption caused by the public transportation means	P73	0.240	15
Level of road deterioration caused by public transportation means	P74	0.219	16
The economic impact of energy on the environment	P75	0.197	20

Table (7.15): Local Weight of Level 4

Sub-Key Performance Indicator	Code	Local Weight	Rank
Displaying clear information on waiting time, routes, & schedules, emergencies, delay, or cancellation of service before and during a journey	SP111	0.744	1

Sub-Key Performance Indicator	Code	Local Weight	Rank
The ease to submit complaints, requests, and opinions on normal days or holidays with quick responding	SP112	0.256	14
Online ticket reservation & payment via mobile App.	SP121	0.642	2
Manual ticket reservation & payment via prepaid cards	SP122	0.358	9
Economical fare price	SP131	0.524	4
Economical means to reach the service	SP132	0.476	5
Easy to get on and off (height of vehicle step)	SP411	0.338	12
Enough seats	SP412	0.249	15
Modern-looking vehicle and station	SP413	0.086	24
Enough spacing between seats and legroom	SP414	0.176	20
Comfort seat	SP415	0.152	21
Cleanness (interior and exterior hygiene & sanitary)	SP421	0.399	6
No engine noise disturbance when inside the vehicle	SP422	0.207	19
Perfect air quality and temperature inside the vehicle and stations	SP423	0.394	7
No traffic accidents	SP511	0.379	8
No broken-down of vehicle	SP512	0.146	23
Seat belts and Airbags	SP513	0.226	17
Safe stand when inside the vehicle	SP514	0.248	16
Easy escaping out of the vehicle in emergency cases	SP521	0.347	11
Availability and ease of using emergency equipment, e.g., first aid, phone, etc.	SP522	0.297	13
Firefighting systems inside vehicle and stations	SP523	0.356	10
Safety from theft, robbery, and pickpocketing at auto stops and inside the vehicle	SP531	0.633	3
Privacy inside the vehicle and station	SP532	0.220	18
Availability of Anti-virus partitions between seats, such as COVID-19 shields	SP533	0.148	22

In level 1, from the analysis of the expert questionnaire, the evaluation of the Riyadh public transportation criteria has been ranked as follows: facility reliability (Cr_2) is the first essential criterion that must be considered for the efficient use of the Riyadh public transportation system. Then the second important criterion was service reliability (Cr_1), followed by culture mobility (Cr_3) as the third important criterion, as shown in **Table 7.12**

In level 2, the experts have evaluated the safety and security attribute (A_5) as the first vital attribute for the efficient use of public transportation. The second important attribute was respecting the local culture alignment (A_6), followed by time quality (A_2) as the third important attribute. Then, environmental sustainability (A_7) ranked as the fourth important attribute. The fifth important attribute was personnel quality (A_3), and the sixth and seven attributes were operation quality (A_1) and physical quality (A_4), respectively. Shown in **Table 7.13**

For Level 3, there were twenty-seven KPIs, shown in **Table 7.14**. The most critical ten KPIs have been evaluated in the following order: Aligning with the local culture value (P_{62}), Affordability (P_{13}), Providing special services for disabled females, elderly, and children at bus and stations (P_{33}), Assuring safe travel conditions during the journey (P_{51}), Availability of special facilities for serving handicapped (P_{44}), Employees knowledge, coordination, motivation, and handling medical emergency (Competency) (P_{31}), Providing free services such as water and Arabic coffee (P_{61}), Driver professionalism (P_{32}), Fast transit time when crowded with passengers (P_{23}), and Availability of emergency equipment (P_{52}). The other KPIs were also essential in efficiently operating the RPTS.

In level 4, which is the sub-KPIs, there were twenty-four S-KPIs, shown in **Table 7.15**. From the expert questionnaire analysis, we found that all the S-KPIs were essential, and each has a unique role in achieving optimal usage of the public transport service. However, the most important ten S-KPIs have been evaluated as per the following order: Displaying clear information on trips' schedule, routes, waiting time, emergency cases, delay, or cancellation of service before and during a journey (SP₁₁₁), Online ticket reservation & payment via mobile App. (SP₁₂₁), Safety from theft, robbery, and pickpocketing at auto stop and inside the vehicle (SP₅₃₁), Economical fare price (SP₁₃₁), Economic means to reach the service (SP₁₃₂), Easy to get on and off (height of vehicle step) (SP₄₂₁), Modern looking of vehicle and station (SP₄₂₃), No traffic accidents (SP₅₁₁), Manual ticket reservation & payment via prepaid cards (SP₁₂₂), and Firefighting system inside vehicle and stations (SP₅₂₃).

The above results presented the local Weight of each Level of the study framework, shown in Figure 4.1. However, when calculating the **global Weight** using the method explained in Chapter 5, Section 5.3.2, Step 13, we will reach ***the same factors used for the public questionnaire***, which are forty-three factors. To clarify, we used the global weight equation to rank these factors under the FAHP results, and they have been ranked as shown in **Table 7.16**

After calculating the global Weight of the criteria, attributes, KPIs, and S-KPIs, the following is the ranking of the factors: Safe stop at the station (F₃₆); Aligning with the local culture values (F₃₈); No traffic accidents (F₂₆); Availability of exceptional facilities for serving disorders (F₂₅); Firefighting system inside vehicle and stations (F₃₂); Easy escaping out of the vehicle in emergency cases (F₃₀); Safe stand when inside the vehicle (F₂₉); safety from theft, robbery, pickpocketing at auto stop and inside the vehicle (F₃₃); Fast transit time when crowded with passengers (F₁₀); No

engine noise disturbance when inside the vehicle (F_{22}). The global weights of all factors are presented in **Figure 7.2**

Table (7.16): Global Weight of the factors using FAHP

SN	Factor	Coad	Global Weight	Rank
1	Displaying clear information on waiting time, routes, & schedules before and during a journey	F1	0.0125	29
2	The ease to submit complaints, requests, and opinions on regular days or holidays with quick responding	F2	0.0043	42
3	Ticket reservation & payment via mobile App.	F3	0.0087	35
4	Ticket reservation & payment via prepaid cards	F4	0.0048	40
5	Economical fare price	F5	0.0147	24
6	Economical means to reach the service	F6	0.0133	27
7	Availability and continuity of the service	F7	0.0183	22
8	A fixed and definite schedule of arrival & departure	F8	0.0269	14
9	Optimal waiting time to the stop	F9	0.0213	19
10	Fast transit time when crowded with passenger	F10	0.0355	9
11	Transport passengers straight to the desired point	F11	0.0204	20
12	Optimal walking time to reach a stop	F12	0.0243	16
13	Employees' knowledge, coordination, motivation, and handling medical emergencies (Competency)	F13	0.0261	15
14	Driver professionalism	F14	0.0229	17
15	Providing exceptional services for disabled females, elderly, and children at bus and station	F15	0.0325	12
16	Easy to get on and off (height of vehicle step)	F16	0.0104	33
17	Seat capacity	F17	0.0077	37
18	Modern-looking vehicle and station	F18	0.0027	43
19	Enough spacing between seats and legroom	F19	0.0054	39

SN	Factor	Coad	Global Weight	Rank
20	Comfort seat	F20	0.0047	41
21	Cleanness (interior and exterior hygiene & sanitary)	F21	0.0121	31
22	No engine noise disturbance when inside the vehicle	F22	0.0062	38
23	Air quality and temperature inside the vehicle and stations	F23	0.0119	32
24	Car parking at a stop	F24	0.0190	21
25	Availability of special facilities for serving disorders	F25	0.0410	4
26	No traffic accidents	F26	0.0591	3
27	No broken-down of vehicle	F27	0.0228	18
28	Seat belts and Airbags	F28	0.0352	10
29	Safe stand when inside the vehicle	F29	0.0387	7
30	Easy escaping out of the vehicle in emergency cases	F30	0.0393	6
31	Availability and ease of using emergency equipment, e.g., first aid, phone, etc.	F31	0.0337	11
32	Firefighting systems inside vehicle and stations	F32	0.0404	5
33	Safety from theft, robbery, and pickpocketing at auto stops and inside the vehicle	F33	0.0379	8
34	Privacy inside the vehicle and station	F34	0.0132	28
35	Anti-virus partitions between seats, such as COVID-19 shield	F35	0.0089	34
36	Safe stop at a station	F36	0.1083	1
37	Providing free services such as water and Arabic coffee	F37	0.0306	13
38	Aligning with the local cultural values	F38	0.0715	2
39	Level of emission, noise pollution, and sight pollution	F39	0.0134	26
40	The Technology inside the fleet and station	F40	0.0078	36
41	Level of congestion impact or disruption caused by this mode	F41	0.0148	23
42	Level of road deterioration caused by public transport mode	F42	0.0135	25
43	The economic impact of energy on the environment	F43	0.0122	30

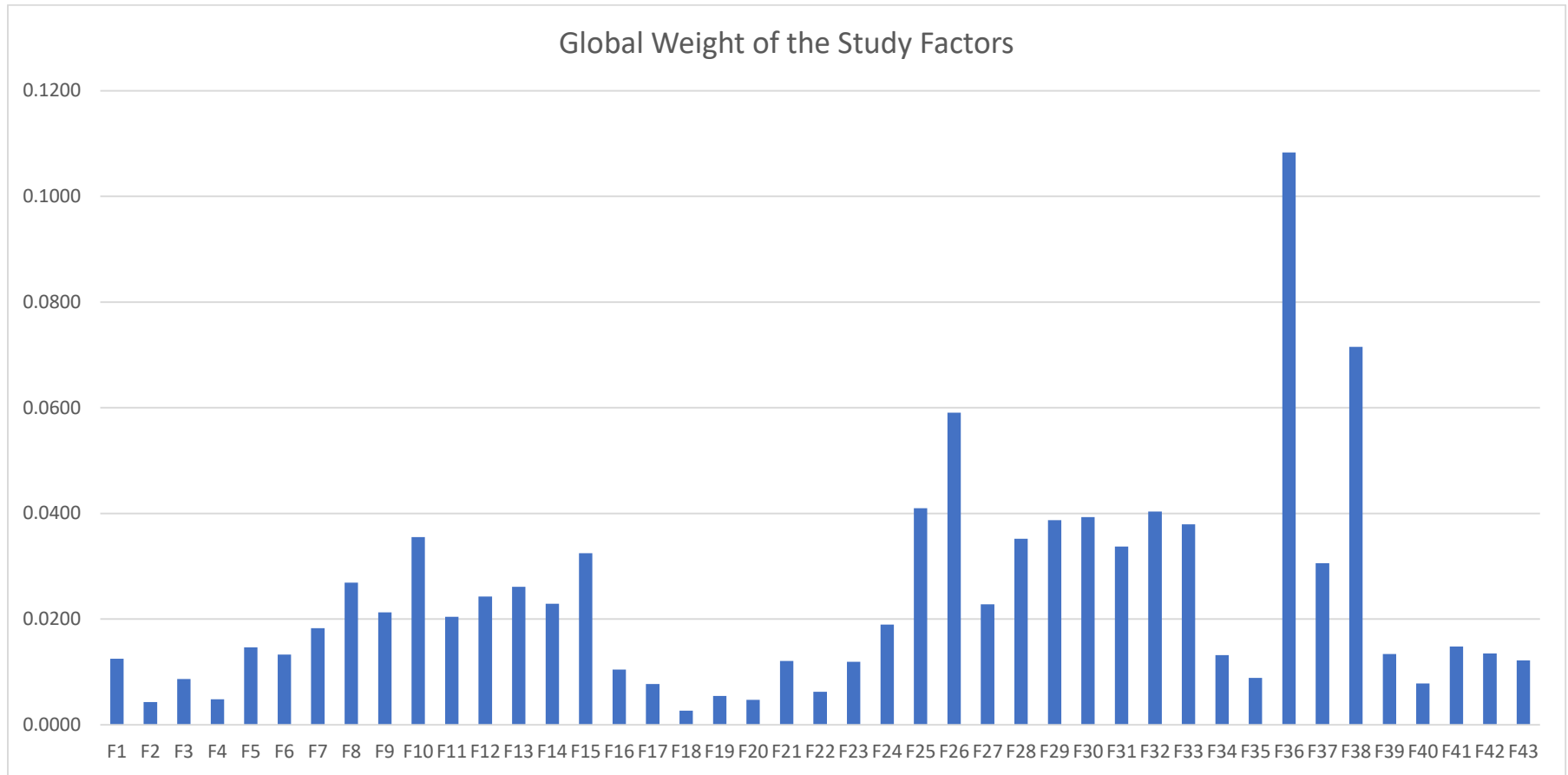


Fig. (7.2): Global Weight of the study factors, from experts' perspective

7.3 Quality Function Deployment Results:

After understanding the concept of the Quality Function Deployment in **Chapter 5, Section 5.6**, the results of each stage of the Q.F.D. are presented in the following sub-sections.

7.3.1 Stage 1: Service Characteristics Deployment S.C.D.

By analyzing the first stage of the Q.F.D., which is the service characteristic deployment, we observed that the following five technical characteristics are the most critical requirements that can satisfy the customer requirements: **(1)** error-free service, **(2)** safe and secure environment, **(3)** vehicle and stations capacity, **(4)** technical specification of vehicles, and **(5)** tangible features of the service area. Nevertheless, the other technical requirements were also highly prioritized to satisfy the customer requirements. **Figure 7.3** presents all the technical characteristics with their weights; at the bottom of the S.C.D., they have been ranked in importance.

7.3.2 Stage 2: Management Component Deployment M.C.D.

In order to satisfy the technical requirement listed in stage 1, the management component must be determined and evaluated. The following list is the evaluation of the management department: **(1)** the customer service department, **(2)** the fleet and facility department, **(3)** the planning and control department, **(4)** the risk management department, and **(5)** Buses Itineraries Management. **Figure 7.4** presents all the technical characteristics with their weights; at the bottom of the M.C.D., they have been ranked in importance.

7.3.3 Stage 3: Standards and Strategies Deployment S.S.D.

In the same way, to satisfy the management components listed in stage 2, a set of standards and strategies must be determined and evaluated. The following list is

the standards and strategies: **(1)** availability of micro-buses moving inside the neighborhoods, **(2)** providing special lanes for the public buses, **(3)** supporting transit use through improving pedestrian facilities and infrastructure, **(4)** physical improvements programs, and **(5)** park-and-ride facilities. **Figure 7.5** presents all the standards and strategies with their Weight and at the bottom of they have ranked in terms of importance.

Fig. (7.3):
Result of Stage 1: S.C.D.

A.H.P. Structure					Public Questionnaire Factors	User perception of Public Transportation	Fuzzy Global Weight	Importance	Minimum time on the ticketing process	Error-free services	Tangible features of the service area	Competent employees and drivers	Seatbelt and airbag	Advanced technical online services	Secure vehicle equipment	Transport network density	Pedestrian availability coefficient	vehicle and stations Capacity	Time scheduling activities	Periodic Maintenance	Information system	No. of buses in demanding routes	No. of buses at demanding Peak timings	Technical specifications of buses	Assortment of tickets (Seasonal tickets)	Safe and secure environment	Hospitality	Culture Orientation	Environmental sustainability
Cn	An	KPI	S-KPI																										
Cr1	A1	P11	SP111	F1	Displaying clear information on waiting time, routes, & schedules before and during a journey	0.0125	1	9	9	0	0	9	0	3	3	0	9	9	9	9	9	9	9	0	0	0	0	0	0
			SP112	F2	The ease to submit complaints, requests, and opinions on regular days or holidays with quick responding	0.0043	2	9	0	9	0	9	0	0	0	0	0	9	9	9	0	0	9	0	0	1	3	0	0
		P12	SP121	F3	Ticket reservation and payment via Mobile App.	0.0087	9	9	0	3	0	9	0	0	0	0	0	9	9	9	1	1	9	9	0	0	0	0	9
			SP122	F4	Ticket reservation and payment via Prepaid cards	0.0048	9	9	9	9	0	9	0	0	3	0	9	9	9	1	1	9	9	0	0	0	0	0	9
		P13	SP131	F5	Economical fare price	0.0147	0	0	0	0	0	1	0	0	0	0	9	0	9	1	0	0	9	9	0	0	0	9	0
			SP132	F6	First last mile connection (Economic means to reach the service)	0.0133	9	3	9	0	0	0	0	9	9	9	9	9	9	0	9	9	9	3	9	0	0	0	9
		P14		F7	Availability and continuity of the service	0.0183	3	9	1	9	0	0	3	9	9	9	9	9	9	3	9	9	9	9	1	0	9	0	0	9
	A2	P21		F8	A fixed and definite schedule of arrival & departure	0.0269	9	9	0	9	0	3	0	9	9	9	9	9	9	9	9	9	9	9	0	9	0	0	0
		P22		F9	Optimal waiting time at the stop	0.0213	3	9	0	9	0	3	0	3	9	9	9	9	3	9	9	9	9	9	0	0	0	0	0
		P23		F10	Fast transit time when crowded with passenger	0.0355	3	9	0	9	0	0	0	9	1	9	9	9	1	9	9	9	9	9	0	9	0	0	1
		P24		F11	Transport passengers straight to the desired point	0.0204	0	9	0	3	0	0	0	9	3	9	9	3	3	9	9	3	3	0	0	0	0	0	0
		P25		F12	Optimal walking time to reach a stop	0.0243	9	1	9	0	0	0	0	1	9	9	9	3	9	9	9	9	9	9	3	9	0	9	9
	A3	P31		F13	Employees' knowledge, coordination, motivation, and handling medical emergencies (Competency)	0.0261	3	9	0	9	0	0	0	0	0	0	9	9	3	9	9	9	9	0	1	9	0	9	0
		P32		F14	Driver professionalism	0.0229	0	9	0	9	0	0	3	9	0	9	9	9	1	1	9	9	0	0	3	0	0	0	1
		P33		F15	Providing exceptional services for handicapped, females, elderly, and children at bus and station	0.0325	0	0	9	9	0	9	9	0	9	9	9	3	0	0	3	3	0	0	9	9	9	9	0
Cr2	A4	P41	SP411	F16	Easy to get on and off (height of vehicle step)	0.0104	0	0	9	0	0	3	9	0	0	9	0	9	9	9	0	0	9	0	9	0	3	0	
			SP412	F17	Seat capacity	0.0077	3	1	9	0	0	0	9	9	0	9	3	0	0	9	9	9	3	9	9	9	9	0	
			SP413	F18	Enough spacing between seats and legroom	0.0027	0	0	9	0	0	0	9	0	0	0	0	0	0	0	0	0	9	0	9	0	0	0	
			SP414	F19	Modern-looking vehicle and station	0.0054	0	0	9	0	0	0	9	0	0	3	0	9	0	0	0	0	9	0	9	0	9	3	
			SP415	F20	Comfortable seating	0.0047	0	0	9	0	3	0	9	0	0	9	0	9	3	0	0	9	1	0	9	9	9	0	
		P42	SP421	F21	Cleanness (interior and exterior hygiene & sanitary)	0.0121	0	1	9	9	0	3	3	0	0	9	0	9	3	0	0	9	0	9	9	9	9	9	
			SP422	F22	No engine noise disturbance when inside the vehicle	0.0062	0	9	9	0	0	3	3	0	0	9	0	9	3	0	0	9	0	9	3	9	9		
			SP423	F23	Air quality and temperature inside the vehicle and stations	0.0119	0	9	9	0	0	9	3	0	0	9	0	9	3	0	0	9	0	3	9	9	9		
		P43		F24	Car parking availability	0.0190	3	3	9	0	0	0	0	9	9	9	9	9	1	9	9	9	9	9	9	0	9	3	
		P44		F25	Availability of special facilities for serving handicapped	0.0410	0	0	9	0	3	3	9	9	9	9	9	9	9	0	0	0	1	0	3	9	9	1	
	A5	P51	SP511	F26	No traffic accidents	0.0591	0	9	0	9	3	0	9	9	0	0	3	3	0	9	9	0	0	0	0	0	0	0	
			SP512	F27	No breaking down of the vehicle	0.0228	0	9	0	9	9	9	9	9	0	9	3	9	1	9	9	9	9	0	9	0	0	9	

			SP513	F28	Seat belts and airbags	0.0352	0	3	0	0	9	0	0	0	0	0	9	0	0	0	9	0	9	0	0	0		
			SP514	F29	Safe stand when inside the vehicle	0.0387	0	9	9	0	3	0	9	1	0	9	0	0	0	0	0	9	0	9	0	9	0	
			P52	SP521	F30	Easy escaping out of the vehicle in emergency cases	0.0393	0	9	9	3	1	3	9	0	0	9	0	9	9	0	0	9	0	9	0	0	0
				SP522	F31	Availability and ease of using emergency equipment, e.g., first aid, phone, etc.	0.0337	0	9	9	0	3	1	9	0	0	9	0	9	9	0	0	9	0	9	0	0	3
				SP523	F32	Firefighting systems inside vehicle and stations	0.0404	0	9	9	0	3	9	9	0	0	9	0	9	9	0	0	9	0	9	0	0	9
			P53	SP531	F33	Safety from theft, robbery, and pickpocketing at auto stops and inside the vehicle	0.0379	0	9	0	9	0	9	9	1	0	9	0	0	9	0	0	9	0	9	0	3	0
				SP532	F34	Privacy inside the vehicle and station	0.0132	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0
				SP533	F35	Availability of Anti-virus partitions between seats, such as COVID-19 shields	0.0089	0	3	3	0	0	0	0	0	0	0	9	0	0	3	0	0	9	0	9	3	9	0
			P54		F36	Safe stop at the station	0.1083	0	9	9	9	9	3	9	3	0	9	0	1	1	3	3	9	0	9	0	0	0
			C r3	A6	P61	F37	Providing free services such as Wi-Fi, water, and access to app. when offline	0.0306	9	3	9	0	0	9	0	0	0	9	9	0	1	0	0	0	9	9	9	9	0
P62	F38	Aligning with the local cultural values			0.0715	0	3	3	3	0	0	0	0	3	9	0	0	0	0	0	0	0	3	9	9	9		
A7	P71	F39		Level of emission, noise pollution, and sight pollution	0.0134	0	3	3	0	0	9	3	9	9	0	0	9	0	9	9	9	9	0	1	0	3	9	
	P72	F40		The Technology inside the fleet and station	0.0078	9	9	9	0	0	9	1	0	9	9	9	9	9	9	9	9	9	0	9	3	9	9	
	P73	F41		Level of congestion impact or disruption caused by P.T. system	0.0148	0	9	1	0	0	0	1	9	9	9	0	0	9	9	9	9	0	9	0	0	9		
	P74	F42		Level of road deterioration caused by public transportation means	0.0135	0	0	0	0	0	0	9	3	0	0	0	0	9	9	9	0	0	0	0	9			
	P75	F43		The economic impact of energy (electricity and fuel) on the environment caused by public transportation means	0.0122	0	1	3	0	0	3	1	9	9	3	0	3	9	9	9	9	0	9	0	0	9		
Importance							1.45	6.24	4.96	4.31	2.19	2.93	4.77	3.51	2.57	7.47	3.40	3.94	4.22	3.96	3.96	5.98	1.01	6.37	1.98	3.70	2.82	81.7273
Normalized Importance							1.78%	7.63%	6.06%	5.28%	2.68%	3.58%	5.84%	4.30%	3.14%	9.14%	4.17%	4.82%	5.16%	4.85%	4.85%	7.31%	1.23%	7.80%	2.42%	4.53%	3.44%	

Fig. (7.4):
Result of Stage 2: M.C.D.

		Importance	Maintenance Management Department	Planning & Control Department	Human Resource Management department	Fleet & facility management department	Cost Control department	Marketing Department	Buses Itineraries Management	Customer Service Department	Risk Management Department	
TECHNICAL REQUIREMENT		Weight										
1	Minimum time on the ticketing process	0.0178	0	0	0	0	3	3	0	9	0	
2	Error-free services	0.0763	3	9	3	1	0	0	9	3	9	
3	Tangible features of the service area	0.0606	9	0	0	9	3	9	0	3	3	
4	Competent employees and drivers	0.0528	0	0	9	0	0	9	0	9	0	
5	Seatbelt and airbag	0.0268	9	0	0	9	0	0	0	9	9	
6	Advanced technical online services	0.0358	0	0	0	0	1	9	3	9	0	
7	Secure vehicle equipment	0.0584	9	0	0	9	0	3	0	9	9	
8	Transport network density	0.0430	0	9	0	3	0	1	9	9	3	
9	Pedestrian availability coefficient	0.0314	9	3	0	9	3	9	9	9	9	
10	vehicle and stations Capacity	0.0914	0	9	0	3	9	3	9	9	1	
11	Time scheduling activities	0.0417	0	9	3	9	3	3	9	9	0	
12	Periodic Maintenance	0.0482	9	9	0	9	9	0	1	9	3	
13	Information system	0.0516	3	9	9	3	9	9	9	9	9	
14	No. of buses in demanding routes	0.0485	3	9	0	3	3	1	9	1	3	
16	No. of buses at demanding Peak timings	0.0485	3	9	0	3	3	3	9	3	3	
17	Technical specifications of buses	0.0731	9	1	3	9	9	3	0	3	9	
18	Assortment of tickets (Seasonal tickets)	0.0123	0	0	3	0	9	9	0	9	0	
21	Safe and secure environment	0.0780	9	3	0	9	3	1	3	1	9	
22	Hospitality	0.0242	0	0	3	0	9	3	0	9	0	
23	Culture Orientation	0.0453	0	0	3	0	9	0	0	9	0	
24	Environmental sustainability	0.0344	3	3	0	3	0	3	3	3	0	
IMPORTANCE		1.0000	4.17	4.55	1.76	4.79	4.13	3.54	4.38	6.23	4.40	37.9404
			11%	12%	5%	13%	11%	9%	12%	16%	12%	

Fig. (7.5):
Result of Stage 3: S.S.D

Fig. (7.5):
Result of Stage 3: S.S.D

		Importance	Physical improvements	Bicycle/walking programs	Employer-based incentives	Park-and-ride facilities	Providing a sufficient number of parking spaces	Introducing the university pass program	Marketing campaign directed at university students and employees	Marketing program focusing on behavioral changes	Partnerships with universities (special passes)	Prior coordination with the authorities responsible for social events	Cooperation with business parks	Supporting transit use through improving pedestrian facilities and infrastructure.	Strict parking policies, especially in downtown	Procedures to limit car access	Policies to make driving more expensive	Policies prioritizing public transportation	Bus priority system, and reducing automobile lanes in favor of transit)	Reviewing the existing transit system map and suggesting new strategies if required	quality and sustainability management	Special lanes for buses	availability of micro-buses inside the neighborhoods	Optimized buses route network	Rewards and special offers for riders	
PARTIES REQUIREMENT		Weight																								
1	Maintenance Management Department	0.1098	9	3	0	9	0	0	0	0	0	0	0	9	0	0	0	0	0	3	3	9	9	3	0	
2	Planning & Control Department	0.1198	3	9	3	9	9	9	3	3	3	3	3	9	9	9	9	9	9	9	9	9	9	9	3	
3	Human Resource Management department	0.0463	0	0	9	0	0	1	9	3	9	3	3	0	0	0	0	0	0	0	0	0	0	0	3	
4	Fleet & facility management department	0.1263	9	9	0	9	9	0	0	0	0	0	0	9	3	0	0	0	0	0	3	3	9	3	0	
5	Cost Control department	0.1089	9	9	0	9	1	9	9	9	9	0	9	1	1	1	1	1	1	9	3	9	9	9	9	
6	Marketing Department	0.0933	0	0	0	3	1	9	9	9	9	9	9	9	9	9	9	9	9	0	3	9	9	0	9	
7	Buses Itineraries Management	0.1155	3	9	0	1	1	0	0	0	0	9	0	9	9	9	9	9	9	9	3	9	9	9	0	
8	Customer Service Department	0.1642	9	9	9	9	9	9	3	3	3	3	3	3	3	0	1	1	1	3	3	9	9	0	9	
9	Risk Management Department	0.1159	9	9	0	1	0	0	0	0	0	1	0	1	1	1	1	1	1	3	3	9	9	3	0	
IMPORTANCE		1.0000	6.33	7.08	2.25	6.17	4.01	4.42	3.09	2.81	3.09	2.99	2.81	5.80	4.05	3.18	3.35	3.35	3.35	4.27	3.58	7.83	8.58	4.15	3.80	100
			6%	7%	2%	6%	4%	4%	3%	3%	3%	3%	3%	6%	4%	3%	3%	3%	3%	4%	4%	8%	9%	4%	4%	

This chapter have presented the results and analysis of the public and expert questionnaires, then rank the criteria of the study framework in terms of importance. After that, it will present the results of the Q.F.D. stages. Two methods have been used to analyze the public questionnaire results. *The first method* is the Classical Likert Scale (C.L.S.) of 1-9 using the SPSS. *The second method* is the Fuzzy Number Conjoint Model (FnCM), which converts the (C.L.S.) into Fuzzy Likert Scale (F.L.S.). On the other hand, the Fuzzy A.H.P. technique was used to analyze the expert questionnaire.

CHAPTER 8

Discussion, Conclusion, & Recommendations

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8.1 Discussion and Conclusion

The problem of colossal dependency on private cars in Riyadh City can be solved by encouraging Riyadh's ridership to depend heavily on the new public transport system. A set of quality dimensions, attributes, and KPIs have been set and analyzed to highlight the most critical aspects that can achieve efficient use of the public transport system in Riyadh.

From reviewing the literature, the study dimensions, criteria, attributes, KPIs, and sub-KPIs, which are the ridership requirements, have been restructured with respect to the objective of this study. Additionally, the technical requirement, management requirement, and standards & strategies have been prioritized following the best international practices.

Two questionnaire types have been followed in this study. The first is a public questionnaire with a sample size of 385 participants, used for prioritizing the customer requirements from the users' perspective. The second questionnaire was an expert questionnaire with a sample size of 20 experts, used for prioritizing the customer requirements from the experts' perspective

Two methods have been used for analyzing the questionnaires. The first method was Fuzzy-AHP for prioritizing the experts' questionnaire. FnCM has been used for the public questionnaire. The second method was QFD for prioritizing the technical requirement, management requirement, and standards & strategies.

The FAHP has been integrated with the QFD model for the expert questionnaire analysis process. On the other hand, for the public questionnaire, the results generated from SPSS have been combined with the FnCM.

The analysis's result was as follows: "facility reliability, service reliability, and culture mobility" are essential dimensions that lead the public transportation in Riyadh City to work efficiently and effectively. Additionally, accessibility to the service, time quality, safety & security, and personnel quality are the most critical attributes for achieving the goal of public transportation.

Regarding the riders' requirements, which is the first objective of this study, the following list was the most critical factors from public users' perspectives, "no traffic accidents, no broken-down of vehicle, level of road deterioration caused by public transport mode, a fixed and definite schedule of arrival & departure, economical means to reach the service, transport passengers straight to the desired point, optimal waiting time at stops, driver professionalism, level of emission, noise pollution, & sight pollution, and displaying clear information on waiting time, routes, & schedules before and during journeys."

From the best international practices, a set of technical characteristics have been selected to satisfy the users' requirements, then correlated to the users' needs, which is the second objective of the study. The result showed that having an error-free service, a safe and secure environment, enough vehicle and station capacity, good technical specification of vehicles, and the tangible features of the service area are the critical technical requirements for satisfying the customer needs.

For the third objective of the study, which is management roles, they have been set and correlated with the technical specifications. The correlation result showed that the critical management departments for satisfying the technical needs are the customer service department, fleet and facility department, planning and control department, risk management department, and buses Itineraries Management.

The final stage of the QFD process was the deployment of standards & strategies that increased the number of public transportation riders, which is the forth objective of the study. The priority of the standards & strategies was as follows: availability of micro-buses moving inside the neighborhoods, (2) providing special lanes for the public buses, supporting transit use through improving pedestrian facilities and infrastructure, physical improvements programs, and park-and-ride facilities.

After that, the FAHP-QFD model has been developed as an optimization model that will lead RPTS to work efficiently and effectively.

8.2 Recommendations for future work

The study found that accessibility to the stations of public transportation in Riyadh and time factors were critical factors that led the transportation system to work efficiently and effectively. Therefore, its recommended to provide micro-buses that frequently move inside the neighborhood to transport the public users to the nearest station. Hence, studying the effect of implementing this project on the increasing number of riders per trip would be a future study.

Programming Taxi Applications, such as Uber, Kareem, Blink, and Bolt, for reasonably priced transport passengers to the nearest stations and avoid walking in fluctuating weather. Hence, studying the effect of implementing this partnership on the increasing number of riders per trip would be a future study.

One of the objectives of this study was to reduce road congestion in Riyadh City. Therefore, it is recommended to provide a seasonal ticket at a reasonable price for students and employees to be used in the public transport system; accordingly, the number of private cars will dramatically decrease. In other words, partnerships with universities, schools, and companies may help reduce road congestion in Riyadh

City. Consequently, studying the effect of implementing this partnership on the increasing number of riders per trip would be a future study.

Regarding quality improvement, it is recommended to develop a control chart that can measure the service KPIs, then compare it with the best international practices, i.e., a systematic benchmarking analysis is recommended to be applied.

8.3 New knowledge we have contributed to the study's field

Integration between the Fuzzy-AHP method and the QFD model is the methodology used in this study. Consequently, a new software application has been developed that electronically calculates the priority of an AHP structure quickly. Also, the software application can deal with a consensus in the FAHP method, which can aggregate the participants' answers and present them in one matrix called A Collective Judgment Matrix (CJM). Moreover, the software application can integrate the FAHP results with the QFD model by exporting the results obtained from the CJM to the first stage of the QFD. Additionally, it can customize the QFD stages with respect to the application users' needs.

On the other hand, the five dimensions of the SERVQUAL model, proposed by [\(Parasuraman et al., 1988\)](#), have been modified into three main dimensions, called criteria; then, these criteria have been divided into seven attributes, and these attributes have been subdivided into forty-three KPIs. As shown in **Chapter 4, Section 4.1, Table 4.1**

Regarding the QFD model, the original phases of the model have been modified from four into three, as shown in **Chapter 5, Section 5.6.2, Figure 5.10**

In conclusion, this thesis has been done to deeply understand the concept of the Analytical Hierarchy Process (AHP), which is one of the Multi-Criteria Decision

Making (MCDM) approaches, in addition to the concept of the Quality Function Deployment (QFD). Ultimately, by using the AHP method, we have prioritized the most critical customer requirements that lead to the efficient use of the new public transportation system in Riyadh City. Then, through the QFD model, the most vital technical needs and management departments have been prioritized. Finally, the optimal standards & strategies have been highlighted to operate the new public transportation system in Riyadh City efficiently and effectively.

This chapter have presented the conclusion of the research. In the beginning, it will clearly state the answer to the main research question. Then, it summarized the method used in the study. After that, it has highlighted the most critical customer requirement, technical requirements, and standards, & strategies that lead the new public transportation system in Riyadh City to work efficiently and effectively. After that, some recommendations will be provided for related future work. At the end of this chapter, a presentation of the new knowledge that contributed to the Multi-Criteria Decision Making (MCDM) and in Quality Function Deployment (QFD).

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Appendix A

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A5.1 Public and Expert Questionnaires Design

A5.1.1 Public Questionnaire Design:

The purpose of conducting the public questionnaire was to determine the most critical factors that led to the efficient use of the Riyadh Public Transport system. As well as to help the study achieves the following points:

- Identify the factors that affect the performance of the Riyadh Public Transport Service
- Develop an optimization model to use RPTS efficiently and effectively
- Reduce the traffic congestion in Riyadh City
- Reduce the heavy dependency on private cars

The software application used in this study is Statistical Package for Social Sciences (SPSS) software application to prioritize the key performance indicators (KPIs) and the sub-KPIs used in this study, shown in **Chapter 4, Table 4.1**

The general questionnaire was designed on a Likert scale from 1-9, shown in **Table A5.1** The questionnaire has been distributed online via emails, WhatsApp, Telegram, Snapchat, and Instagram.

Table (A5.1): Likert scale 1-9

Strongly Unimportant	1
Very Unimportant	2
Moderately unimportant	3
Fairly unimportant	4
Neutral	5
Fairly important	6
Moderately important	7
Very important	8
Strongly important	9

Making an online questionnaire forces the participants to complete all the questions before submitting their answers. However, this may cause uncertainty in their responses, and to solve this problem, a fuzzy method was used to convert the Likert Scale (LS) into Fuzzy Likert Scale (FLS) to obtain more accurate results and solve the uncertainty problem using the Fuzzy Number Conjoint Model (FNCM), explained in details in **Chapter 7**



University of Bahrain
College of Engineering
Engineering Management Master Program
Master Thesis - IEN598

Public Questionnaire

ABOUT THIS QUESTIONNAIRE

You are invited to participate in this research project by a master's student in the Department of Engineering Management at the University of Bahrain.

I hope you participate in this questionnaire and complete all the questions. The survey should take no more than 10 minutes, and I wish to receive 300 participants

The survey will not collect any identifiable information, and no one will be able to identify the source of the responses. Your anonymity is further protected by not asking you to sign and return a consent form. Please keep this cover letter for future reference.

THE IMPORTANCE OF THIS QUESTIONNAIRE

The purpose of this research is to find out the most important factors that lead to the efficient use of the Riyadh Public Transport system

Your accuracy in answering the survey will help us to:

- Identify the factors that affect the performance of the Riyadh Public Transport Service
- Develop an optimization model to use RPTS efficiently and effectively
- Reduce the traffic congestion in Riyadh City
- Reduce the heavy dependency on private cars

PERSONAL INFORMATION

Name (Optional):

Contact Number (Optional):

*Gender: ☐ Male ☐ Female

*Age: ☐ 15-19 ☐ 20-29 ☐ 30-39 ☐ 40-49 ☐ 50-59 ☐ 60-69 ☐ Above 70

*Student: ☐ Yes ☐ No If yes, your current grade:

*Employee: ☐ Yes ☐ No If yes, Position:, Years of experience:

*Education: ☐ Less than high school ☐ High School ☐ Diploma ☐ Bachelor's degree ☐ Master's degree ☐ Ph.D.

*Nationality: ☐ Saudi ☐ Non-Saudi

If you have any questions about this study, you may call/email me at [+966580001051](tel:+966580001051) – 20189555@stu.uob.edu.bh

Thank you for your participation.

As a user of Riyadh Public Transportation, to what extent the following factors are important for you on a scale "of 1" to "5"? Where "1" Extremely NOT Important and 5 Extremely Important		1	2	3	4	5	6	7	8	9
Displaying clear information on waiting time, routes, & schedules before and during a journey		1	2	3	4	5	6	7	8	9
Availability of information in case of emergency, delay, or cancellation of service		1	2	3	4	5	6	7	8	9
The ease to submit complaints, requests, and opinions on regular days or holidays with quick responding		1	2	3	4	5	6	7	8	9
The online and manual reservation system		1	2	3	4	5	6	7	8	9
Ease of payment via Mobile App.		1	2	3	4	5	6	7	8	9
Economical fare price		1	2	3	4	5	6	7	8	9
Economical means to reach the service		1	2	3	4	5	6	7	8	9
Availability and continuity of the service		1	2	3	4	5	6	7	8	9
A fixed and definite schedule of arrival & departure		1	2	3	4	5	6	7	8	9
Optimal waiting time at the stop		1	2	3	4	5	6	7	8	9
Fast transit time when crowded with passenger		1	2	3	4	5	6	7	8	9
Transport passengers straight to the desired point		1	2	3	4	5	6	7	8	9
Optimal walking time to reach a stop		1	2	3	4	5	6	7	8	9
Employees' knowledge, coordination, motivation, and handling medical emergencies (Competency)		1	2	3	4	5	6	7	8	9
Driver professionalism		1	2	3	4	5	6	7	8	9
Crew behavior and neatness		1	2	3	4	5	6	7	8	9
Providing exceptional services for disabled females, elderly, and children at bus and station		1	2	3	4	5	6	7	8	9
Easy to get on and off (height of vehicle step)		1	2	3	4	5	6	7	8	9
Seat capacity		1	2	3	4	5	6	7	8	9
Modern-looking vehicle and station		1	2	3	4	5	6	7	8	9
Enough spacing between seats and legroom		1	2	3	4	5	6	7	8	9
Comfort seat		1	2	3	4	5	6	7	8	9
Cleanness (interior and exterior hygiene & sanitary)		1	2	3	4	5	6	7	8	9
No engine noise disturbance when inside the vehicle		1	2	3	4	5	6	7	8	9
Air quality and temperature inside the vehicle and stations		1	2	3	4	5	6	7	8	9
Pleasant feeling		1	2	3	4	5	6	7	8	9
Car parking at the stop		1	2	3	4	5	6	7	8	9
Availability of special facilities for serving disorders		1	2	3	4	5	6	7	8	9
No accidents		1	2	3	4	5	6	7	8	9
No broken-down of vehicle		1	2	3	4	5	6	7	8	9
Seat belts and Airbags		1	2	3	4	5	6	7	8	9
Safe stand when inside the vehicle		1	2	3	4	5	6	7	8	9
Easy escaping out of the vehicle in emergency cases		1	2	3	4	5	6	7	8	9
Availability and ease of using emergency equipment, e.g., first aid, phone, etc.		1	2	3	4	5	6	7	8	9
Firefighting systems inside vehicles and stations		1	2	3	4	5	6	7	8	9
Safety from theft, robbery, and pickpocketing at auto stops and inside the vehicle		1	2	3	4	5	6	7	8	9
Privacy inside the vehicle and station		1	2	3	4	5	6	7	8	9
Anti-virus partitions between seats		1	2	3	4	5	6	7	8	9
Safe stop at a station		1	2	3	4	5	6	7	8	9
Providing free services such as water and Arabic coffee		1	2	3	4	5	6	7	8	9
Separating singles seats from families seats		1	2	3	4	5	6	7	8	9
Luxury vehicle and station		1	2	3	4	5	6	7	8	9
Aligning with the local cultural values		1	2	3	4	5	6	7	8	9
Level of emission, noise pollution, and sight pollution		1	2	3	4	5	6	7	8	9
The technology inside the fleet and station		1	2	3	4	5	6	7	8	9
Level of congestion impact or disruption caused by this mode		1	2	3	4	5	6	7	8	9
Level of road deterioration caused by public transport mode		1	2	3	4	5	6	7	8	9
The economic impact of energy on the environment		1	2	3	4	5	6	7	8	9
Do you want to add any other factors?		1	2	3	4	5	6	7	8	9
		1	2	3	4	5	6	7	8	9
		1	2	3	4	5	6	7	8	9

A5.1.2 Expert Questionnaire Design

The objectives mentioned in the public questionnaire are the same as those for conducting the experts' questionnaire. However, the difference between the expert questionnaire and the public questionnaire is that in the public questionnaire the choice was based on the evaluation of the factor itself, based on a Likert scale from 1-9. While in the expert questionnaire, the evaluation process was based on a comparison of all factors with each other using the concept of Pairwise Comparison Matrices (PCMs) of the Analytical Hierarchy Process AHP method, explained in details in Chapter 5

The software application used in the analysis of the public questionnaire is Microsoft Excel because of the following reasons:

1. One expert questionnaire consists of 19 PCMs of different sizes and has been distributed to 20 experts to evaluate it. Accordingly, we had 380 matrices to be analyzed. Hence, customized matrices and excel-subroutines were required to handle this analysis in an easy matter.
2. Applying this analysis to MS Excel facilitated the use of the AHP equations for the software application developed in this study, explained in **Chapter 6**.
3. MS Excel is more available than MATLAB or Expert choice applications
4. MS Excel is an easy application to implement multiple functions at a time and in one spreadsheet

The expert questionnaire differed from the public questionnaire as it was designed with respect to the AHP method. Since the target was to compare the factors to one another two at a time, unlike the public questionnaire. As explained in chapter 5, to fill the PCM, we need at least the upper or lower diagonal of the PCM to be filled with one of the numbers of Saaty's scale, shown in **Table 5.1**. Because when the upper diagonal is filled, the lower diagonal will be its reciprocal value. To illustrate, let us have **Matrix A5.1** as an illustrative example; assume that C_1 is

more important than C_2 by 5 times; then, the importance of C_2 is less important than C_1 by 5 times as well. I.e., its reciprocal value. Inversely, the matrix also shows that C_1 is less important than C_3 by 7 times thus, it's presented as the reciprocal value in the upper diagonal.

Matrix A5.1: an illustrative form of the reciprocal values

Goal	C_1	C_2	C_3
C_1	1	5	$\frac{1}{7}$
C_2	$\frac{1}{5}$	1	3
C_3	7	$\frac{1}{3}$	1

Accordingly, to translate this matrix to a simple questionnaire and avoid asking the participant six comparison questions as shown in **Matrix A5.1**. [Goepel, K. D.](#), proposed a simple way to construct the questionnaire simplest, especially when we have a matrix bigger than 3×3 because the number of comparisons exponentially increases when the matrix size is increased. For example, when we have a matrix of size 4×4 , the number of comparisons for the items that should be compared in the PCM is 12, a 5×5 PCM will have 20 comparisons, a 6×6 PCM will have 30 comparisons, and so on. Therefore, to reduce the comparison process in the PCM, we need to provide a questionnaire form that targets filling only the upper diagonal of a PCM, as the lower diagonal is the reciprocal value of the upper. To illustrate, consider **Matrix A5.2** an example; the participant will be asked to fill only the upper diagonal. Therefore, the number of comparisons will be reduced from 12 to only six.

Matrix 7.2: Questionnaire results of the upper diagonal

Goal	C ₁	C ₂	C ₃	C ₄
C ₁	1	3	2	$\frac{1}{5}$
C ₂		1	$\frac{1}{4}$	1
C ₃			1	$\frac{1}{3}$
C ₄				1

In other words, the participants will be asked only to compare the items of the upper diagonal.

Assume the participant provided the following answers in **Matrix A5.2**

C ₁ is more important than C ₂ by 3 times
C ₁ is more important than C ₃ by 2 times
C ₄ is more important than C ₁ by 5 times
C ₃ is more important than C ₂ by 4 times
C ₂ has equal importance as C ₄
C ₄ is more important than C ₃ by 3 times

Therefore, to avoid providing the PCM to the experts, it will be confusing for them, and the filling process will be a bit difficult for them. The following questionnaire form, shown in **Table A5.2**, is easy for the expert to clearly read the question and recognize their answers concerning which goals.

Table (A5.2): Expert questionnaire form

Question: With respect to the Goal "X," which of the following criterion is more important, and how much more on a scale le 1 to 9?										
1	☒ C ₁	1	2	☒ 3	4	5	6	7	8	9
	or									
	☐ C ₂									
2	☒ C ₁	1	☒ 2	3	4	5	6	7	8	9
	or									
	☐ C ₃									
3	☐ C ₁	1	2	3	4	☒ 5	6	7	8	9
	or									
	☒ C ₄									
4	☐ C ₂	1	2	3	☒ 4	5	6	7	8	9
	or									
	☒ C ₃									
5	☐ C ₂	☒ 1	2	3	4	5	6	7	8	9
	or									
	☐ C ₄									
6	☐ C ₃	1	2	☒ 3	4	5	6	7	8	9
	or									
	☒ C ₄									

After copying an expert's answers to the upper diagonal of the PCM, shown in **Matrix A5.2**, the lower diagonal will automatically be filled with the reciprocal values of the answers, as shown in **Matrix A5.3**

Matrix 7.5: Questionnaire results of the lower diagonal

Goal	C ₁	C ₂	C ₃	C ₄
C ₁	1			
C ₂	$\frac{1}{3}$	1		
C ₃	$\frac{1}{2}$	4	1	
C ₄	5	1	3	1

Generally, to generalize the form of the expert questionnaire with any PCM size, the following equation will help provide the minimum number of questions and cells in the questionnaire and PCM, respectively.

$$Q_{no.} = \frac{(i-1) \times i}{2} \dots\dots\dots \text{Equation A5.1}$$

Where:

$Q_{no.}$: is the minimum number of cells that must be filled by the expert in the PCM, which is the question in the questionnaire form.

i: Matrix size

For example, assume we have a PCM of size 7×7 , which consists of 30 comparisons, that is, 15 for the upper diagonal and 15 for the lower. Hence, instead of asking the participants to compare 30 items with each other, using **Equation A5.1**, the number of comparisons will reduce from 30 to only 21 comparisons.



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Engineering Management Master Program
Master Thesis - IEN598

Experts' Questionnaire

ABOUT THIS QUESTIONNAIRE

This questionnaire was designed for a master thesis ***"to investigate the factors that lead to efficient use of Riyadh Public Transport Service."*** Provided by Eng. Omar Abdullah is a master's student in the Department of Engineering Management at the University of Bahrain.

We kindly ask you to participate in this survey and complete all the questions.

The survey should take no more than 10 minutes

Note: This survey will not collect any information that can identify the participant. Your anonymity is protected by not requiring you to sign and return the questionnaire to us.

THE IMPORTANCE OF THIS QUESTIONNAIRE

Your accuracy in answering the questions will help us achieve the following goals:

- Identify the factors affecting the performance of Riyadh Public Transport Service, which in turn will achieve the expectations and satisfaction of passengers
- Develop an optimization model for the performance of the transportation system
- Achieve environmental sustainability by reducing the heavy reliance on private cars, which will reduce the traffic congestion in Riyadh City

PERSONAL INFORMATION

Name (Optional):

Contact Number (Optional):

*Gender: ☐ Male ☐ Female

*Age: ☐ 15-19 ☐ 20-29 ☐ 30-39 ☐ 40-49 ☐ 50-59 ☐ 60-69 ☐ Above 70

*Education: ☐ High School ☐ Diploma ☐ Bachelor's degree ☐ Master's degree ☐ Ph.D.

*Employee: ☐ Yes ☐ No If yes, *Position: *Years of experience:

*Student: ☐ Yes ☐ No If yes, *Your current grade:

*Nationality: ☐ Saudi ☐ Non-Saudi

If you have any questions about this study, please don't hesitate to call/email me at [+966580001051](tel:+966580001051)/
20189555@stu.uob.edu.bh

Thank you for your participation.

With respect to Service Quality of Public Transportation Service:										
Q1	Which of the following criterion is more important than the other?	How much is more important?								
1	☐ Reliability, accuracy, and continuity of the service or ☐ Safety, security, and comfortability of the service	Equal	2	3	4	5	6	7	8	9
2	☐ Reliability, accuracy, and continuity of the service or ☐ Empathy and respecting the local cultural values	Equal	2	3	4	5	6	7	8	9
3	☐ Safety, security, and comfortability of the service or ☐ Empathy and respect the local cultural values	Equal	2	3	4	5	6	7	8	9

With respect to Service Reliability:										
Q2	Which of the following attribute is more important than the other?	How much is more important?								
1	☐ Gaining passengers' trust and fulfilling their expectations about the service or ☐ Being punctual and regular for the advertised trips	Equal	2	3	4	5	6	7	8	9
2	☐ Gaining passengers' trust and fulfilling their expectations about the service or ☐ Having professional drivers, and efficient staff	Equal	2	3	4	5	6	7	8	9
3	☐ Being punctual and regular for the advertised trips or ☐ Having professional drivers, and efficient staff	Equal	2	3	4	5	6	7	8	9

With respect to Facilities Reliability:										
Q3	Which of the following attribute is more important than the other?	How much is more important?								
1	☐ Physical & mental comfort for all passengers or ☐ Assuring safe (less accident rate) and secure (less crime rate) trips	Equal	2	3	4	5	6	7	8	9

With respect to Culture Mobility:										
Q4	Which of the following attribute is more important than the other?	How much is more important?								
1	☐ Being empathetic and respecting the local cultural values or ☐ Considering the environmental sustainability issues	Equal	2	3	4	5	6	7	8	9

With respect to Operation Quality:										
Q5	Which of the following performance indicators is more important than the other?	How much is more important?								
1	☐ Providing sufficient and precise information about the provided service or ☐ Providing an easy ticketing process	Equal	2	3	4	5	6	7	8	9
2	☐ Providing sufficient and precise information about the provided service or ☐ Economical fare price	Equal	2	3	4	5	6	7	8	9
3	☐ Providing sufficient and precise information about the provided service or ☐ Availability and continuity of the service at 24/7 hr.	Equal	2	3	4	5	6	7	8	9
4	☐ Providing an easy ticketing process or ☐ Economical fare price	Equal	2	3	4	5	6	7	8	9
5	☐ Providing an easy ticketing process or ☐ Availability and continuity of the service at 24/7 hr.	Equal	2	3	4	5	6	7	8	9
6	☐ Economical fare price or ☐ Availability and continuity of the service at 24/7 hr.	Equal	2	3	4	5	6	7	8	9

With respect to Service Information:										
Q6	Which of the following performance indicators is more important than the other	How much is more important?								
1	☐ Displaying clear information on schedules, routes, waiting time, expected delays, emergencies, or service cancellations before and during a journey or ☐ Ease of submitting complaints, requests, and opinions on regular days and holidays with quick response	Equal	2	3	4	5	6	7	8	9

With respect to the Ticketing process:										
Q7	Which of the following performance indicators is more important than the other	How much is more important?								
1	☐ Online ticket reservation & payment via mobile App. or ☐ Manual ticket reservation & payment via prepaid cards	Equal	2	3	4	5	6	7	8	9

With respect to Affordability :														
Q8	Which of the following performance indicators is more important than the other					How much is more important?								
1	☐ Providing economical fare price or ☐ Availability of economic means to reach the service					Equal	2	3	4	5	6	7	8	9

With respect to Time Quality :															
Q9	Which of the following performance indicators is more important than the other						How much is more important?								
1	☐ Fixed and definite arrival & departure schedule or ☐ Optimal waiting time at the stop						Equal	2	3	4	5	6	7	8	9
2	☐ Fixed and definite arrival & departure schedule or ☐ Fast transit time when crowded with passenger						Equal	2	3	4	5	6	7	8	9
3	☐ Fixed and definite arrival & departure schedule or ☐ Transport passengers straight to the desired point						Equal	2	3	4	5	6	7	8	9
4	☐ Fixed and definite arrival & departure schedule or ☐ Optimal walking time to reach a stop						Equal	2	3	4	5	6	7	8	9
5	☐ Optimal waiting time at the stop or ☐ Fast transit time when crowded with passenger						Equal	2	3	4	5	6	7	8	9
6	☐ Optimal waiting time at the stop or ☐ Transport passengers straight to the desired point						Equal	2	3	4	5	6	7	8	9
7	☐ Optimal waiting time at the stop or ☐ Optimal walking time to reach a stop						Equal	2	3	4	5	6	7	8	9
8	☐ Optimal waiting time at the stop or ☐ Fast transit time when crowded with passenger						Equal	2	3	4	5	6	7	8	9
9	☐ Optimal waiting time at the stop or ☐ Optimal walking time to reach a stop						Equal	2	3	4	5	6	7	8	9
10	☐ Optimal waiting time at the stop or ☐ Optimal walking time to get a stop						Equal	2	3	4	5	6	7	8	9

With respect to Personnel Quality :														
Q10	Which of the following performance indicators is more important than the other					How much is more important?								
1	○Employees' knowledge, coordination, motivation, and handling a medical emergency, i.e. (Competency, Behavior, and Neatness) or ○ Driver professionalism					Equal	2	3	4	5	6	7	8	9

2	☐ Employees' knowledge, coordination, motivation, and handling a medical emergency, i.e. (Competency, Behavior, and Neatness) or ☐ Providing special services for disabled females, elderly, and children at bus and station	Equal	2	3	4	5	6	7	8	9
3	☐ Driver professionalism or ☐ Providing special services for disabled females, elderly, and children at bus and station	Equal	2	3	4	5	6	7	8	9

With respect to the Physical Quality of the service:										
Q11	Which of the following performance indicators is more important than the other	How much is more important?								
1	☐ Passenger physical comfort or ☐ Passenger mental comfort	Equal	2	3	4	5	6	7	8	9
2	☐ Passenger physical comfort or ☐ Availability of car parking at the stop	Equal	2	3	4	5	6	7	8	9
3	☐ Passenger physical comfort or ☐ Availability of special facilities for serving disorders	Equal	2	3	4	5	6	7	8	9
4	☐ Passenger mental comfort or ☐ Availability of car parking at the stop	Equal	2	3	4	5	6	7	8	9
5	☐ Passenger mental comfort or ☐ Availability of special facilities for serving disorders	Equal	2	3	4	5	6	7	8	9
6	☐ Availability of car parking at the stop or ☐ Availability of special facilities for serving disorders	Equal	2	3	4	5	6	7	8	9

With respect to Passenger Physical Comfort:										
Q12	Which of the following performance indicators is more important than the other	How much is more important?								
1	☐ Easy to get on and off (height of vehicle step) or ☐ Enough number of seats	Equal	2	3	4	5	6	7	8	9
2	☐ Easy to get on and off (height of vehicle step) or ☐ Modern looking of vehicle and station	Equal	2	3	4	5	6	7	8	9
3	☐ Easy to get on and off (height of vehicle step) or ☐ Enough spacing between seats and legroom	Equal	2	3	4	5	6	7	8	9
4	☐ Easy to get on and off (height of vehicle step) or ☐ Comfort seat	Equal	2	3	4	5	6	7	8	9
5	☐ Enough number of seats or ☐ Modern looking of vehicle and station	Equal	2	3	4	5	6	7	8	9
6	☐ Enough number of seats or ☐ Enough spacing between seats and legroom	Equal	2	3	4	5	6	7	8	9

7	☐ Enough number of seats or ☐ Comfort seat	Equal	2	3	4	5	6	7	8	9
8	☐ Modern looking of vehicle and station or ☐ Enough spacing between seats and legroom	Equal	2	3	4	5	6	7	8	9
9	☐ Modern looking of vehicle and station or ☐ Comfort seat	Equal	2	3	4	5	6	7	8	9
10	☐ Enough spacing between seats and legroom or ☐ Comfort seat	Equal	2	3	4	5	6	7	8	9

With respect to Passenger Mental Comfort :										
Q13	Which of the following performance indicators is more important than the other	How much is more important?								
1	☐ Cleanliness, hygiene & sanitization (interior and exterior) or ☐ No engine noise disturbance when inside the vehicle	Equal	2	3	4	5	6	7	8	9
2	☐ Cleanliness, hygiene & sanitization (interior and exterior) or ☐ Perfect air quality and temperature inside the vehicle and stations	Equal	2	3	4	5	6	7	8	9
3	☐ No engine noise disturbance when inside the vehicle or ☐ Perfect air quality and temperature inside the vehicle and stations	Equal	2	3	4	5	6	7	8	9

With respect to Physical Safety & Security :										
Q14	Which of the following performance indicators is more important than the other	How much is more important?								
1	☐ Assuring safe travel conditions during the journey or ☐ Availability of emergency requirements	Equal	2	3	4	5	6	7	8	9
2	☐ Assuring safe travel conditions during the journey or ☐ Assuring security & privacy for passengers	Equal	2	3	4	5	6	7	8	9
3	☐ Assuring safe travel conditions during the journey or ☐ Safe stop at a station	Equal	2	3	4	5	6	7	8	9
4	☐ Availability of emergency equipment or ☐ Assuring security & privacy for passengers	Equal	2	3	4	5	6	7	8	9
5	☐ Availability of emergency equipment or ☐ Safe stop at a station	Equal	2	3	4	5	6	7	8	9
6	☐ Assuring security & privacy for passengers or ☐ Safe stop at stations	Equal	2	3	4	5	6	7	8	9

With respect to Safe travel conditions during the journey:										
Q15	Which of the following performance indicators is more important than the other	How much is more important?								
1	☐ No traffic accidents or ☐ No broken-down of vehicle	Equal	2	3	4	5	6	7	8	9
2	☐ No traffic accidents or ☐ Seat belt and Airbags	Equal	2	3	4	5	6	7	8	9
3	☐ No traffic accidents or ☐ Safe stand when inside the vehicle	Equal	2	3	4	5	6	7	8	9
4	☐ No broken-down of vehicle or ☐ Seat belt and Airbags	Equal	2	3	4	5	6	7	8	9
5	☐ No broken-down of vehicle or ☐ Safe stand when inside the vehicle	Equal	2	3	4	5	6	7	8	9
6	☐ Seat belt and Airbags or ☐ Safe stand when inside the vehicle	Equal	2	3	4	5	6	7	8	9

With respect to Emergency Requirements:										
Q16	Which of the following performance indicators is more important than the other	How much is more important?								
1	☐ Easy escaping out of the vehicle in emergency cases or ☐ Availability and ease to use of emergency equipment such as first aid, phone, etc.	Equal	2	3	4	5	6	7	8	9
2	☐ Easy escaping out of the vehicle in emergency cases or ☐ Firefighting system inside vehicles and stations	Equal	2	3	4	5	6	7	8	9
3	☐ Availability and ease to use of emergency equipment such as first aid, phone, etc. Or ☐ Firefighting system inside vehicles and stations	Equal	2	3	4	5	6	7	8	9

With respect to Passenger Security & Privacy:										
Q17	Which of the following performance indicators is more important than the other	How much is more important?								
1	☐ Safety from theft, robbery, pickpocketing at auto stop and inside the vehicle or ☐ Privacy inside the vehicle and station	Equal	2	3	4	5	6	7	8	9
2	☐ Safety from theft, robbery, pickpocketing at auto stop and inside the vehicle or ☐ Availability of Anti-virus partitions between seats, such as COVID-19 shields	Equal	2	3	4	5	6	7	8	9
3	☐ Privacy inside the vehicle and station or ☐ Availability of Anti-virus partitions between seats, such as COVID-19 shields	Equal	2	3	4	5	6	7	8	9

With respect to local cultural values :										
Q18	Which of the following performance indicators is more important than the other	How much is more important?								
1	☐ Providing free services such as water, coffee, or others or ☐ Separating singles seats from families	Equal	2	3	4	5	6	7	8	9

With respect to Environmental Sustainability :										
Q19	Which of the following performance indicators is more important than the other	How much is more important?								
1	☐ Level of emission, noise pollution, and sight pollution caused by public transportation means or ☐ Availability of technology inside the fleet and stations	Equal	2	3	4	5	6	7	8	9
2	☐ Level of emission, noise pollution, and sight pollution caused by the public transportation means or ☐ Level of congestion impact or disruption caused by the public transportation means	Equal	2	3	4	5	6	7	8	9
3	☐ Level of emission, noise pollution, and sight pollution caused by the public transportation means or ☐ Level of road deterioration caused by the public transportation means	Equal	2	3	4	5	6	7	8	9
4	☐ Level of emission, noise pollution, and sight pollution caused by the public transportation means or ☐ The impact of energy (electricity and fuel) caused by public transportation means on the environment	Equal	2	3	4	5	6	7	8	9
5	☐ Availability of technology inside the fleet and stations or ☐ Level of congestion impact or disruption caused by the public transportation means	Equal	2	3	4	5	6	7	8	9
6	☐ Availability of technology inside the fleet and stations or ☐ Level of road deterioration caused by the public transportation means	Equal	2	3	4	5	6	7	8	9
7	☐ Availability of technology inside the fleet and stations or ☐ The impact of energy (electricity and fuel) caused by public transportation means on the environment	Equal	2	3	4	5	6	7	8	9
8	☐ Level of congestion impact or disruption caused by the public transportation means or ☐ Level of road deterioration caused by the public transportation means	Equal	2	3	4	5	6	7	8	9
9	☐ Level of congestion impact or disruption caused by the public transportation means or ☐ The impact of energy (electricity and fuel) caused by public transportation means on the environment	Equal	2	3	4	5	6	7	8	9
10	☐ Level of road deterioration caused by the public transportation means or ☐ The impact of energy (electricity and fuel) caused by public transportation means on the environment	Equal	2	3	4	5	6	7	8	9

End of Experts' Questionnaire

A5.2 Fuzzy Theory

Zadeh (1965) is the first researcher who set the fuzzy theory. His study defined fuzziness: "The concept of a fuzzy set gives a great starting point for constructing a conceptual framework that is parallel in many aspects to the framework used in standard sets, such as Saaty and Likert scales. However, generally, this framework provides a natural way to deal with conditions of inconsistency or (lack of knowledge) and absence of specific criteria rather than the presence of random variables."

Fuzzy logic is a logical representation where the actual value of a case is not binary true or false, as in classical logic. Still, the real value is zero and completely wrong. 1" Exactly. Fuzzy logic allows us to do fuzzy programming, a function of expressing different ideas in results using human-understandable rules rather than mathematical logic. This type of work is common in control applications that use and measure access and then perform many simple controls using fuzzy logic-based processes. However, fuzzy logic is not just a management technique. It can be used in any decision-making process, such as a financial institution deciding to issue a loan to someone based on personal and financial information. Therefore, many applications only use complex logic to answer essential questions. It can be used to define edges and shapes, for example, to answer the question of how many pixels in an area have density compared to the area of the edge. Also, you need a model to create a hypothesis, which works well for complex operations where the underlying process is unclear. You can create rules if you have experience and understanding of the system. It can be used. It is powerful and can be used in many different ways

The fuzzy theory imposes strict mathematical restrictions. In other words, there is nothing fuzzy in the fuzzy group theory, and it can be viewed as a linguistic model

in the form that fits the fuzzy and unclear relationships. The use of this theory grew in the seventies (1970s), especially in Japan, in the industrial fields such as washing machines, cameras, and subway trains. [Al-Shamry H. and Hamza A. \(2018\)](#). The fuzzy group can be defined as follows:

$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) | x \in X\}$ It is a set of ordered pairs

Where:

X: is a subset of the real numbers R.

$\mu_{\tilde{A}}(X)$: is the membership function

A 5.2.1 Fuzzy AHP

The objective of using FAHP is the same as using classical AHP. However, [Buckley \(1985\)](#) and [Chang \(1996\)](#) have integrated the fuzzy concept in the classical AHP to solve the uncertainty problem of the classical AHP by using fuzzy numbers instead of crisp numbers, as explained above. Considering the fuzzy concept, the same approach followed in the classical AHP will be followed here. Two methods were widely used in the literature for solving the FAHP problem. The first method is the FRGMM, proposed by [Buckley \(1985\)](#), and the second is the EAM, proposed by [Chang \(1996\)](#). The following section will present the prioritization equations for both methods

A 5.2.2 Triangular Fuzzy Number (TFN)

The Triangular Fuzzy Number (TFN) is one of the most common and used applications because of the ease of performing its calculations, especially concerning efficiency. It is usually used to find the inaccuracy of parameters associated with decision-making processes. One fuzzy number consists of three values (lower, middle, upper). For example, instead of saying the outside temperature is just "hot,"

we can range the evaluation of the weather by saying, "**not too much hot,**" "**medium hot,**" or "**extremely hot.**" These linguistic scales represent the TFN's **lower, middle, and upper values.** **Figure 5.4** shows a graphical presentation of TFN.

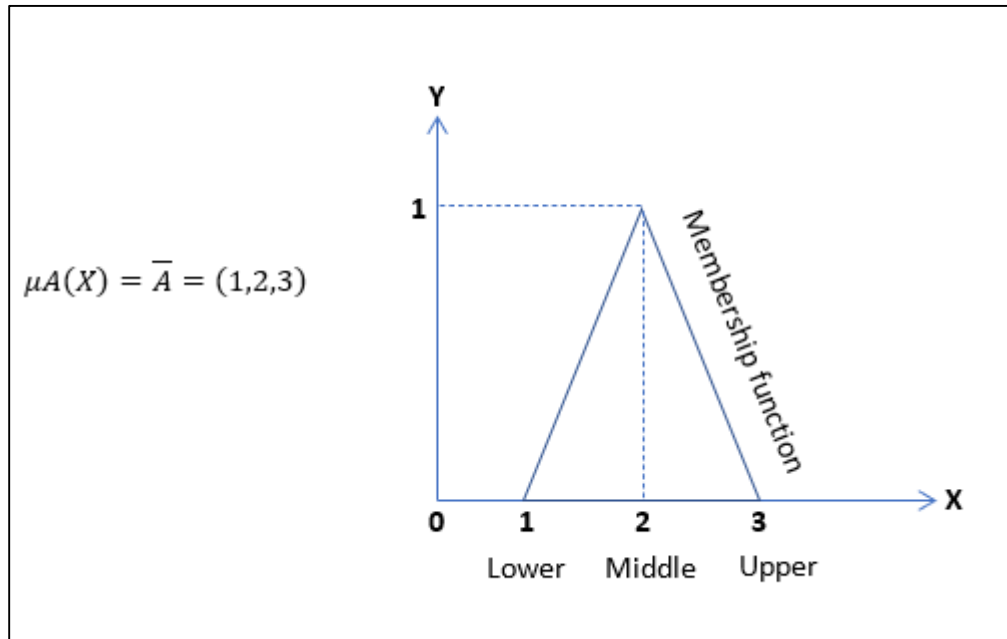


Figure A5.1. Membership function

The equation of triangular fuzzy number can be derived per the following equation:

$$\mu \tilde{A}(X) = \tilde{A} = (l, m, u) = \begin{cases} \frac{X - al}{am - al}, & al \leq X \leq am \\ \frac{X - au}{am - au}, & am \leq X \leq au \\ 0, & \text{Otherwise} \end{cases} \dots \dots \dots (A5.2)$$

Where:

m : is the middle value of the function

l : is the lower value of the function

u : is the upper value of the function

With the help of MS Excel functions, the above equation (A5.2) has applied to convert the Saaty scale into fuzzy numbers, as shown in **Table 5.1** and graphically in **Figure A5.1**

To illustrate the concept of the TFN, let's have an example with the different arithmetic operations of two fuzzy numbers, namely $\tilde{A}One$ and $\tilde{A}2$.

Where,

$$l1 \leq m1 \leq u1 \text{ and } l2 \leq m2 \leq u2$$

Addition:

$$\tilde{A}1 + \tilde{A}1 = (l1, m1, u1) + (l2, m2, u2) = (l1 + l2, m1 + m2, u1 + u2)$$

Subtraction

$$\tilde{A}1 - \tilde{A}1 = (l1, m1, u1) - (l2, m2, u2) = (l1 - l2, m1 - m2, u1 - u2)$$

Multiplication

$$\tilde{A}1 \times \tilde{A}1 = (l1, m1, u1) \times (l2, m2, u2) = (l1 \times l2, m1 \times m2, u1 \times u2)$$

Division

$$\tilde{A}1 \div \tilde{A}1 = (l1, m1, u1) \times (l2, m2, u2) = (l1 \div u2, m1 \times mu, u1 \times l2)$$

Reciprocal

$$\tilde{A}^{-1} = \left(\frac{1}{u1}, \frac{1}{m1}, \frac{1}{l1} \right)$$

Multiplication by a scaler k

$$k \times \tilde{A}1 = \begin{cases} (kl1, km1, ku1) & k > 0 \\ (ku1, km1, kl1) & k < 0 \end{cases}$$

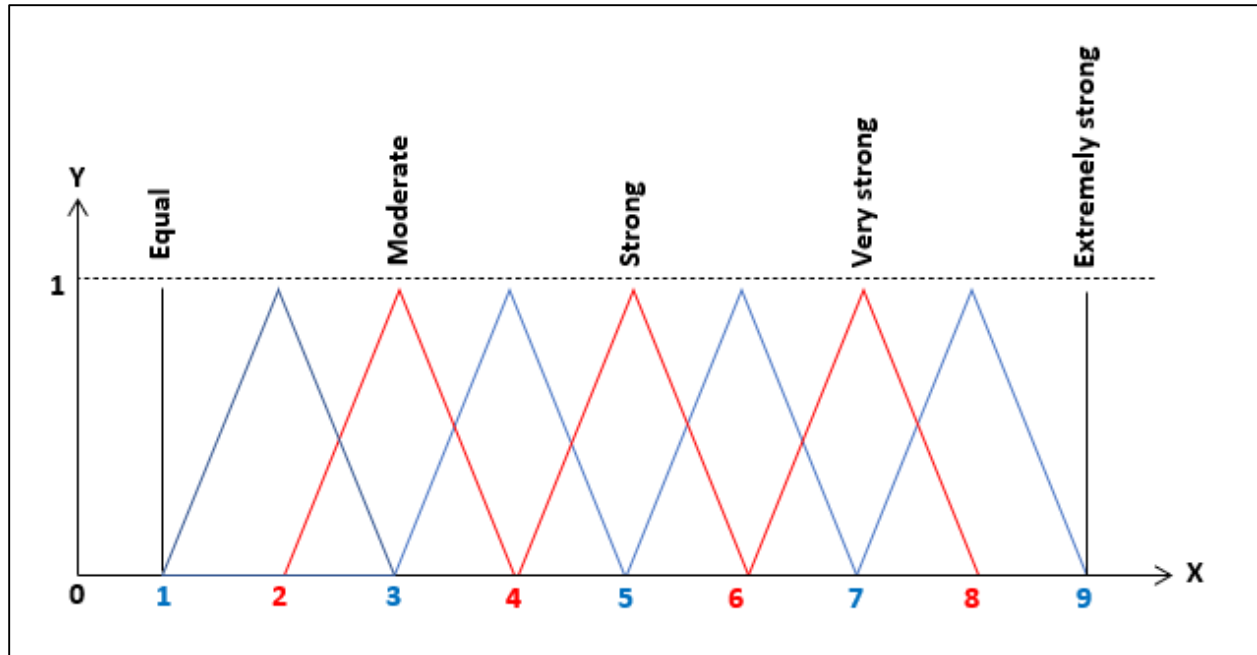


Figure A5.2. FAHP scale, Buckley, and others

created by MS Excel

A5.2.3 Comparison Between AHP and FAHP

In the classical AHP, the participants' answers are assumed to be exact, and they have only crisp numbers for evaluation, i.e., a range from 1-9, shown in **Table 5.1**. The linguistic variables may lead to uncertainty in the evaluation process. On the other hand, fuzzy AHP gives a range for the evaluation to be more accurate, and this range is the conversion of crisp numbers into the triangular fuzzy number (TFN), as explained above, shown in **Table 5.4**

[El-Din, H. et al. \(2019\)](#) claimed that "The conventional AHP is insufficient for dealing with fuzziness and uncertainty in multi-criteria decision-making (MCDM) because of the inability of AHP to deal with the imprecision in the pairwise comparison process."

Both techniques follow the same steps up to the consistency ratio checking step. In AHP, if the CR is less than ten percent (10%), calculation of priority is performed.

While in FAHP if the CR is less than ten percent, extant analysis method is conducted [Mulubrhan F. et al \(2014\)](#). **Figure A5.2** illustrated the differences between the two methods.

The reason for conducting EAM is to synthesize the pairwise comparison matrix's extant value (Si).

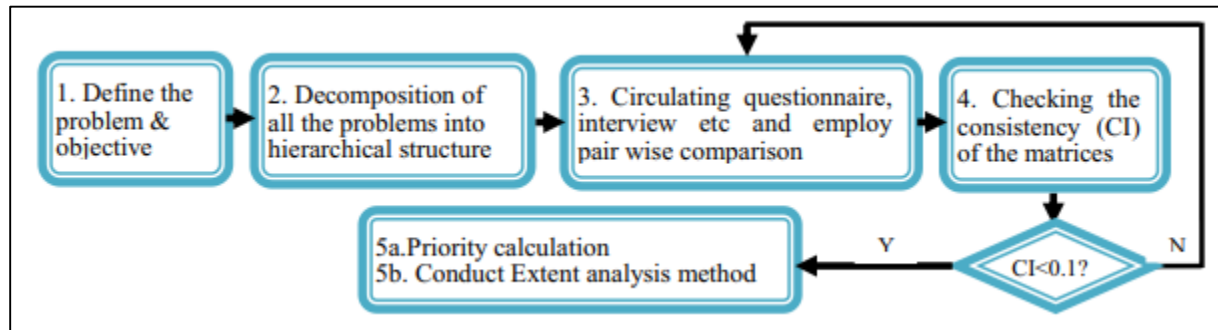


Figure A5.2 AHP and FAHP comparison

Source: [Mulubrhan F. et al., \(2014\)](#)

To sum up, this study used RGMM for both AHP and FAHP. Accordingly, the differences between the two methods can be concluded in the following two points:

1. In AHP, the criteria' weight is immediately calculated after determining the Row Geometric Mean (RGM) of the Pairwise Comparison Matrix (PCM). The consistency index is calculated using the Geometric Consistency Index (GCI), shown in detail in the illustrative example in the next section. Having done that, CR is calculated.
2. In FAHP: the weight of the criteria is calculated after fuzzing the crisp numbers using Triangular Fuzzy Number (TFN), then the fuzzy numbers shall be de-fuzzified into crisp numbers. After that, these crisp numbers should be normalized to ensure their total is 100%, and then apply the GCI. Having done that, CR is calculated.

The problem of this study has been solved in both techniques, and the compared results have been drawn graphically in **Figure 5.7**

A 5.3 Consensus Model in AHP

This section will present the concept of consensus in group decision-making. Then, it will show our approach to calculating the collective judgment matrix and its consistency Index.

([Saaty 1980](#), [Ramanatham and Ganesh 1994](#), [Forman and Peniwati 1998](#), [Moreno-Jiménez et al. 2005](#)) They proposed two approaches for solving a group decision making problem in AHP.

The first approach is the *Aggregate Individual Judgment (AIJ)*, which constructs a new pairwise comparison matrix to collect all participants' results in that matrix. Then the prioritization procedure is calculated following the traditional priority equation, either the Saaty approach to evaluate CI or Row Geometric Mean Method (RGMM).

The second approach is *Aggregation of Individual Priorities (AIP)*, aggregating individual priorities. [Altuzarra A. et al. \(2010\)](#) claimed, "The weighted geometric mean is the usual aggregation procedure used."

Therefore, [Barzilai and Golany \(1994\)](#) claimed that if RGM is the selected method for determining prioritization, AIJ and AIP are equivalent. Hence, AIJ will be chosen in this study to combine all participants' results in the Collective Judgment Matrix (CJM).

A5.4 The Illustrative Numerical Example

Assume we have a set of five experts (E_n) providing the following judgment matrices $\{A^{(1)}, \dots, A^{(5)}\}$ on a set of four alternatives (C_n), and each expert has an individual weight (ΔE_n). The weight of the experts are assumed to be equal i.e. $\frac{1}{5}$. Illustrated in Table A5.3

Table (A5.3): Experts' weights and criteria

$E(n)$	$\Delta E(n)$	Criteria
E1	0.2	C1
E2	0.2	C2
E3	0.2	C3
E4	0.2	C4
E5	0.2	

Let $w^{(k)} = (w_1^{(k)}, \dots, w_4^{(k)})^T$ be the individual priority vector derived from judgment matrix $A_{(k)}$.

As explained in Chapter 5, this numerical example will be solved using the four methods, RGMM-CI; RGMM-GCI; FRGMM-GCI; & EAM, by using the steps and equations explained in **Chapter 5 in the following sections, 5.3.2, 5.3.3, 5.3.4, respectively.**

A5.4.1 Using RGMM with Saaty CI approach to check the consistency. $A^{(k)}$ and $w^{(k)}$ ($k= 1,2,...,5$) are listed below:

EXPERT 1											
	P11	P12	P13	P14			RGM	Wi	λ max	CI	CR
P11	1	4	6	7	18.00		3.6002	0.6145	4.120	0.0402	1.14%
P12	1/4	1	3	4	8.25		1.3161	0.2246			
P13	1/6	1/3	1	2	3.50		0.5774	0.0985			
P14	1/7	1/4	1/2	1	1.89		0.3656	0.0624			
	1.56	5.58	10.50	14.00			5.8592			Δ -CR	0.20

EXPERT 2											
	P11	P12	P13	P14			RGM	Wi	λ max	CI	CR
P11	1	5	7	9	22.00		4.2129	0.7190	4.722	0.2408	6.83%
P12	1/5	1	4	6	11.20		1.4802	0.2526			
P13	1/7	1/4	1	2	3.39		0.5170	0.0882			
P14	1/9	1/6	1/2	1	1.78		0.3102	0.0529			
	1.45	6.42	12.50	18.00			6.5202			Δ -CR	0.20

EXPERT 3											
	P11	P12	P13	P14			RGM	Wi	λ max	CI	CR
P11	1	3	5	8	17.00		3.3098	0.5649	4.078	0.0260	0.74%
P12	1/3	1	4	5	10.33		1.6069	0.2742			
P13	1/5	1/4	1	2	3.45		0.5623	0.0960			
P14	1/8	1/5	1/2	1	1.83		0.3344	0.0571			
	1.66	4.45	10.50	16.00			5.8133			Δ -CR	0.20

EXPERT 4											
	P11	P12	P13	P14			RGM	Wi	λ max	CI	CR
P11	1	4	5	6	16.00		3.3098	0.5649	3.914	(0.0288)	(0.01)
P12	1/4	1	3	3	7.25		1.2247	0.2090			
P13	1/5	1/3	1	2	3.53		0.6043	0.1031			
P14	1/6	1/3	1/2	1	2.00		0.4082	0.0697			
	1.62	5.67	9.50	12.00			5.5470			Δ -CR	0.20

EXPERT 5											
	P11	P12	P13	P14			RGM	Wi	λ max	CI	CR
P11	1	1/2	1	2	4.50		1.0000	0.1707	3.190	(0.2702)	(0.08)
P12	2	1	1/2	3	6.50		1.3161	0.2246			
P13	1	2	1	4	8.00		1.6818	0.2870			
P14	1/2	1/3	1/4	1	2.08		0.4518	0.0771			
	4.50	3.83	2.75	10.00			4.4497			Δ -CR	0.2

Collective Judgement Matrix											
	P11	P12	P13	P14			RGM	Wi	λ max	CI	CR
P11	1.0000	2.6052	4.0201	5.7059			2.7803	53.11%	4.060	0.0200	0.57%
P12	0.3839	1.0000	2.3522	4.0428			1.3822	26.40%			
P13	0.2487	0.4251	1.0000	2.2974			0.7021	13.41%			
P14	0.1753	0.2474	0.4353	1.0000			0.3706	7.08%			
	1.81	4.28	7.81	13.05			5.2353				

A5.4.2 Using Fuzzy RGMM with Saaty's CI approach to check the consistency. $A^{(k)}$ and $w^{(k)}$ ($k= 1,2,...,5$) are listed below:

EXPERT 1											
	C1	C2	C3	C4			RGM	Wi	λ_{max}	GCI	CR
C1	1	4	6	7	18.00		3.6002	0.6145	4.120	0.1349	3.83%
C2	1/4	1	3	4	8.25		1.3161	0.2246			
C3	1/6	1/3	1	2	3.50		0.5774	0.0985			
C4	1/7	1/4	1/2	1	1.89		0.3656	0.0624			
	1.56	5.58	10.50	14.00			5.8592			Δ -CR	0.20

EXPERT 2											
Q#5	C1	C2	C3	C4			RGM	Wi	λ_{max}	GCI	CR
C1	1	5	7	9	22.00		4.2129	0.6604	4.337	0.2358	0.07
C2	1/5	1	4	6	11.20		1.4802	0.2320			
C3	1/7	1/4	1	2	3.39		0.5170	0.0810			
C4	1/9	1/6	1/2	1	1.78		0.3102	0.0486			
	1.45	6.42	12.50	18.00			6.5202			Δ -CR	0.20

EXPERT 3											
Q#5	C1	C2	C3	C4			RGM	Wi	λ_{max}	GCI	CR
P11	1	3	5	8	17.00		3.3098	0.5188	3.745	0.1194	0.03
P12	1/3	1	4	5	10.33		1.6069	0.2519			
P13	1/5	1/4	1	2	3.45		0.5623	0.0881			
P14	1/8	1/5	1/2	1	1.83		0.3344	0.0524			
	1.66	4.45	10.50	16.00			5.8133			Δ -CR	0.20

Collective Judgement Matrix											
Q#5	C1	C2	C3	C4			RGM	Wi	λ max	GCI	CR
C1	1.0000	2.6052	4.0201	5.7059			2.7803	52.21%	4.116	0.153	0.04
C2	0.3839	1.0000	2.7019	4.6440			1.4814	27.82%			
C3	0.2487	0.3701	1.0000	3.1037			0.7311	13.73%			
C4	0.1753	0.2153	0.3222	1.0000			0.3321	6.24%			
	1.81	4.19	8.04	14.45			5.3250				

Expert 4																
Q#1	Cr1			Cr2			Cr3			Cr4						
Cr1	1	1	1	3	4	5	4	5	6	5	6	7				
Cr2	1/5	1/4	1/3	1	1	1	2	3	4	2	3	4				
Cr3	1/6	1/5	1/4	1/4	1/3	1/2	1	1	1	1	2	3				
Cr4	1/7	1/6	1/5	1/4	1/3	1/2	1/3	1/2	1	1	1	1				
	1.510	1.617	1.783	4.500	5.667	7.000	7.333	9.500	12.000	9.000	12.000	15.000				
	1.637			5.722			9.611			12.000						

Fuzzy RGM			Fuzzy Wi			Crisp Wi	Norm. Wi	Crisp λ max	RI = 0.9	GCI	CR
l	m	u	l	m	u						
2.7832	3.3098	3.8068	0.4172	0.5967	0.8439	0.6192	0.5888	0.7018	0.17018	4.83%	
0.9457	1.2247	1.5197	0.1418	0.2208	0.3369	0.2331	0.2217				
0.4518	0.6043	0.7825	0.0677	0.1089	0.1735	0.1167	0.1110				
0.3303	0.4082	0.5623	0.0495	0.0736	0.1247	0.0826	0.0785				
4.5110	5.5470	6.6713	0.6762	1.0000	1.4789	1.0517	1.0000				

Expert 5																
Q#1	Cr1			Cr2			Cr3			Cr4						
Cr1	1	1	1	1/3	1/2	1	1	1	1	1	2	3				
Cr2	1	2	3	1	1	1	1/3	1/2	1	2	3	4				
Cr3	1	1	1	1	2	3	1	1	1	3	4	5				
Cr4	1/3	1/2	1	1/4	1/3	1/2	1/5	1/4	1/3	1	1	1				
	3.333	4.500	6.000	2.583	3.833	5.500	2.533	2.750	3.333	7.000	10.000	13.000				
	4.611			3.972			2.872			10.000						

Fuzzy RGM			Fuzzy Wi			Crisp Wi	Norm. Wi	Crisp λ max	RI = 0.9	GCI	CR
l	m	u	l	m	u						
0.7598	1.0000	1.3161	0.1314	0.2247	0.3942	0.2501	0.2267	0.7000	0.22818	6.47%	
0.9036	1.3161	1.8612	0.1562	0.2958	0.5574	0.3365	0.3050				
1.3161	1.6818	1.9680	0.2275	0.3780	0.5894	0.3983	0.3610				
0.3593	0.4518	0.6389	0.0621	0.1015	0.1914	0.1183	0.1073				
3.3388	4.4497	5.7842	0.5772	1.0000	1.7324	1.1032	1.0000				

FGM-CJM-EVM																
Q#1	Cr1			Cr2			Cr3			Cr4						
Cr1	1	1	1	1.6438	2.4022	3.3935	3.4375	4.0201	4.5803	4.5216	5.7059	6.7106				
Cr2	2/7	2/5	3/5	1	1	1	1.6438	2.3522	3.3145	3.1291	4.1930	5.2319				
Cr3	2/9	1/4	2/7	1/3	3/7	3/5	1	1	1	1.2457	2.2974	3.3227				
Cr4	1/7	1/6	2/9	1/5	1/4	1/3	1/3	3/7	4/5	1	1	1				
	1.662	1.840	2.120	3.137	4.066	5.321	6.382	7.808	9.698	9.896	13.196	16.265				
	1.874			4.175			7.962			13.119						

Fuzzy RGM			Fuzzy Wi			Crisp Wi	Norm. Wi	Crisp λ max	RI = 0.9	GCI	CR
l	m	u	l	m	u						
2.2482	2.7245	3.1958	0.3534	0.5222	0.7614	0.5457	0.5155%				
1.1096	1.4235	1.8022	0.1744	0.2728	0.4294	0.2922	27.61%				
0.5352	0.7021	0.8757	0.0841	0.1346	0.2086	0.1424	13.46%				
0.3043	0.3673	0.4881	0.0478	0.0704	0.1163	0.0782	7.38%				
4.1973	5.2173	6.3617	0.6598	1.0000	1.5157	1.0585	1.0000				

A5.4.4 Using Extent Analysis Method. $A^{(k)}$ and $w^{(k)}$ ($k= 1,2,...,5$) are listed below:

EXPERT 1																
Q#1	Cr1			Cr2			Cr3			Cr4						
Cr1	1	1	1	3	4	5	6	7	6	7	8					
Cr2	1/5	1/4	1/3	1	1	1	2	3	4	3	4	5				
Cr3	1/6	1/5	1/4	1/4	1/3	1/2	1	1	1	2	3					
Cr4	1/7	1/6	1/5	1/4	1/3	1/2	1	1	1	1	1					
	1.468	1.560	1.700	4.450	5.583	6.833	8.333	10.500	13.000	14.000	17.000					
	1.671			5.622			10.611			14.000						

L_i	M_i	U_i	DoP Wi	Fuzzy - crisp Wi	Normalized Wi
0.3893	0.5688	0.8316	0.8427%	53.66%	56.26%
0.1609	0.2607	0.4032	5.73%	27.69%	28.12%
0.0621	0.1106	0.1861	0.00%	11.96%	11.28%
0.0430	0.0539	0.0930	0.00%	6.72%	6.35%
			100.00%	106.04%	100.00%

EXPERT 2																
Q#1	Cr1			Cr2			Cr3			Cr4						
Cr1	1	1	1	4	5	6	6	7	8	9	9	9				
Cr2	1/6	1/5	1/4	1	1	1	3	4	5	5	6	7				
Cr3	1/8	1/7	1/6	1/5	1/4	1/3	1	1	1	2	3					
Cr4	1/9	1/9	1/9	1/7	1/6	1/5	1/3	1/2	1	1	1	1				
	1.403	1.454	1.528	5.343	6.417	7.533	10.333	12.500	15.000	18.000	20.000					
	1.462			6.431			12.611			18.000						

L_i	M_i	U_i	DoP Wi	Fuzzy - crisp Wi	Normalized Wi
0.4533	0.5734	0.7255	100.00%	58.43%	56.86%
0.2080	0.2919	0.4006	0.00%	30.02%	29.21%
0.0528	0.0864	0.1360	0.00%	9.24%	8.99%
0.0360	0.0463	0.0639	0.00%	5.07%	4.94%
			100.00%	102.76%	100.00%

[illegible]

A 5.5 The Component of House of Quality (HoQ)

A5.5.1 Customer requirement

Generally, market research is used to determine the user's requirements. However, in this study, the customer requirements have been selected from the previous related studies. These requirements are placed in the left room of the house of Quality. The importance evaluation of each requirement can be determined through a public questionnaire or any other method to evaluate the level of importance of these requirements. In this study, the importance of each requirement is based on the prioritized results obtained from the FAHP analysis. Shown in **Figure A5.3**

		Importance	Minimum time on traveling process	Error-free services	Timely features of service area	Compliant employees and drivers	Seatbelt and airbag	Advanced technical online services	Secure vehicle equipment	Transport network density	Population availability	Vehicle and stations Capacity	Time scheduling activities	Periodic Maintenance	Information system	No. of buses in demanding routes	No. of buses at demanding Peak	Transportation specifications of buses	Assessment of towers (seasonal loads)	Safe and secure environment	Hospitality	Culture orientation	Environmental sustainability		
User perception of Public Transportation		Fuzzy Global Weight																							
A1	P1	SP1111	Displaying clear information of waiting time, routes, & schedules before and during	0.0139	3	3	3	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3		
		SP1112	The ease to submit complaints, requests, opinions, on normal days or holidays with	0.0048	0	3	3	0	3	0	0	0	1	3	3	0	0	3	0	0	1	3	0		
		SP121	Ticket reservation and payment via Mobile App.	0.0096	3	3	0	3	0	3	0	0	3	3	3	3	1	1	3	3	0	0	3		
		SP122	Ticket reservation and payment via Prepaid cards	0.0054	3	3	3	3	0	3	0	3	3	3	3	3	1	1	3	3	0	0	3		
A2	P2	SP131	Economical fare price	0.0162	0	0	0	0	1	0	0	0	3	0	3	1	0	0	3	3	0	0	3		
		SP132	First last mile connection (Economic means to reach the service)	0.0147	3	3	3	0	0	0	3	3	3	0	3	3	3	3	3	3	0	0	3		
		P14	Availability and continuity of the service	0.0203	3	3	1	3	0	3	3	3	3	3	3	3	3	3	1	0	3	0	3		
		P15	Fixed and definite schedule of arrival & departure	0.0201	3	3	0	3	0	3	3	3	3	3	3	3	3	3	0	3	0	0	3		
A3	P16	P21	Optimal waiting time at stop	0.0234	3	3	0	3	0	3	0	3	3	3	3	3	3	3	0	0	0	0	3		
		P22	Fast transit time when crowded with passenger	0.0233	3	3	0	3	0	0	3	1	3	3	1	3	3	3	0	3	0	0	3		
		P23	Optimal waiting time to reach stop	0.0249	3	1	3	0	0	0	1	3	3	3	3	3	3	3	3	0	3	0	3		
		P24	Employee knowledge, coordination, motivation, and handling medical emergency	0.0219	3	3	0	3	0	0	0	0	3	3	3	3	3	3	0	1	3	0	3		
A4	P3	P31	Error professionalism	0.0254	0	3	0	3	0	0	3	3	3	3	1	3	3	0	3	0	0	1	3		
		P32	Providing special services for handicapped, female, elderly, and children at bus and	0.0168	0	0	3	3	0	3	0	3	3	3	0	3	3	0	3	0	3	0	3		
		P33	Easy to get on and off (height of vehicle, step)	0.0116	0	0	3	0	0	3	3	0	0	3	3	3	0	3	0	3	0	3	0		
		SP412	Safe capacity	0.0045	3	1	3	0	0	3	3	0	0	0	3	3	3	3	3	3	3	3	0		
A5		SP413	Modern looking vehicle and station	0.0029	0	0	3	0	0	0	3	0	0	3	0	0	0	3	0	3	0	3	3		
		SP414	Comfortable seating	0.0052	0	0	3	0	3	0	3	0	0	3	0	3	0	3	1	0	3	3	0		
		SP421	Cleanliness (interior and exterior hygiene & comfort)	0.0124	0	1	3	3	0	3	0	0	3	0	3	3	0	3	0	3	3	3	3		
		SP422	No engine noise disturbance when inside the vehicle	0.0049	0	3	3	0	0	3	3	0	0	3	0	3	0	3	0	3	3	3	3		
A6		SP423	Air quality and temperature inside the vehicle and stations	0.0132	0	3	3	0	0	3	3	0	0	3	0	3	0	3	0	3	3	3	3		
		P43	Car parking availability	0.0218	3	3	3	0	0	0	3	3	3	3	1	3	3	3	3	0	3	3	3		
		P44	Availability of special facilities for serving handicapped	0.0454	0	0	3	0	3	3	3	3	3	3	0	0	1	0	3	3	3	1	3		
		SP511	No accidents and no breaking down	0.0055	0	3	0	3	3	3	0	3	3	3	3	1	3	3	0	3	0	0	3		
A7		SP512	Safe stand when inside the vehicle	0.0029	0	3	3	0	3	0	3	1	0	3	0	0	0	3	0	3	0	3	0		
		SP521	Easy escaping out of the vehicle in emergency cases	0.0035	0	3	3	3	1	3	3	0	0	3	0	3	0	3	0	3	0	0	3		
		SP522	Availability and ease to use emergency equipment, e.g., first aid, phone, etc.	0.0174	0	3	3	0	3	1	3	0	0	3	0	3	0	3	0	3	0	0	3		
		SP523	Firefighting system inside vehicle and stations	0.0047	0	3	3	0	3	3	3	0	3	0	3	0	3	0	3	0	3	0	3		
A8		SP531	Safety from theft, robbery, pickpocketing at safe stop and inside the vehicle	0.0021	0	3	0	3	0	3	3	1	0	3	0	0	3	0	3	0	3	0	3		
		SP534	Privacy inside the vehicle and station	0.0146	0	3	3	0	0	0	0	0	3	0	3	0	3	0	3	0	3	3	0		
		P14	Safe stop at station	0.0208	0	3	3	3	3	3	3	3	0	1	1	3	3	0	3	3	3	0	3		
		P61	Providing free services such as, wifi, water, access to app, when offline	0.0239	3	3	3	0	3	0	0	0	3	3	0	1	0	0	3	3	3	3	0		
A9		P62	Respecting the local culture values	0.0092	0	3	3	3	0	0	0	3	3	0	0	0	0	0	3	3	3	3	3		
		P11	Level of emission, noise pollution, and sight pollution	0.0141	0	3	3	0	0	3	3	3	0	3	0	3	3	0	1	0	3	3	3		
		P12	Technology inside the fleet and station	0.0017	3	3	3	0	0	3	1	0	3	3	3	3	3	3	0	3	3	3	3		
		P13	Level of congestion impact or disruption caused by PT system	0.0164	0	3	1	0	0	0	1	3	3	3	0	3	3	3	0	3	0	0	3		
A10		P14	Economic impact of energy (electricity and fuel) on environment caused by public transportation means	0.0135	0	0	1	3	0	0	3	1	3	3	3	3	3	3	0	3	0	0	3		
		Weight		10000	1.71	6.38	5.41	4.43	2.24	3.61	4.81	3.42	2.77	8.47	3.30	4.08	4.52	3.82	3.82	6.56	1.05	7.06	2.21	3.85	3.47
		Normalized Weight			1.96%	7.32%	6.21%	5.15%	2.57%	4.14%	5.59%	3.92%	3.19%	9.72%	3.79%	4.68%	5.19%	4.39%	4.39%	7.53%	1.20%	8.11%	2.54%	4.43%	3.99%

Figure A5.3 The House of Quality

A5.6.2 Technical Characteristics

Determining how the customer requirements can be translated into technical characteristics by setting a set of technical characteristics of the service and correlating the relationship between each customer requirement and the technical

characteristic. In this study, the technical characteristics set have been selected from the previous studies

A5.6.3 Relationship Matrix

To assess to what extent each customer requirement is fulfilled by the technical characteristics, building a matrix of relationships between the customer's needs and technical characteristics is the next step in the house of the quality stage. By another meaning, to evaluate to what extent the technical requirement meets the customer's needs. The strength of this relationship is determined according to a specific scale. In this study, the scale is shown in **Table A5.4**. To illustrate this concept, as shown in **Figure A5.3**, there is a strong positive relationship between "Displaying clear information of waiting time, routes, & schedules before and during the journey" and "minimum time on the ticketing process." On the other hand, its relationship with "Competent employees and drivers" is strongly negative.

Table A5.4 Weighted values for the relationship matrix

Relationships		
Weighted Value		
9	++	Strong Positive
3	+	Medium Positive
1	-	Medium Negative
0	--	String Negative

A5.6.4 Weighted Points

Calculating the weighted points for each technical characteristic, where a value represents the relative weight of each item in the relationship matrix, as each item represents the strength of the relationship between the technical characteristics and

the customer requirement. Then, the value of each item in the relationship matrix is multiplied by the fuzzy weight assigned by the FAHP analysis. The weighted points are placed in a weighting row of relative importance, which is the row that is located at the bottom of the matrix of relationships between the customers' requirements and technical requirements in the House of Quality. Weighted points are used in evaluating the most critical technical needs.

A5.6.5 Competitive Assessment

Evaluation of competitors' products: In this part of the HOQ, we should evaluate to what extent our product or service meets the customer requirement compared to the other product or service providers. However, this step does not implement in our study because the service is new and has no previous experience to be compared with other companies. Consequently, the target value section is also not implemented; moreover, its recommended by transport experts to apply this and the next step after the operation of the project

A5.6.6 Trade-off Matrix

This matrix evaluates the relationships between the technical requirement and shows to what extent the organization performs its work to meet these characteristics and to what extent competitors are doing their work towards these technical characteristics. However, this step also does not implement in our study because it is going to be analyzed after the operation of the project

Appendix B

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B7.1 Public Participant information

B7.1.1 Gender of Public Participant

375 people participated in the questionnaire, the most significant percentage of the participants were males, as they constituted 80.3% of the total participants, and the female was 19.7%, as shown in **Table A7.1**

Table A7.1 Gender of participants

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	301	80.3	80.3	80.3
	Female	74	19.7	19.7	100.0
	Total	375	100.0	100.0	

B7.1.2 Age of Public Participant

30% of the participants were between the 20-25 years, while the ages of 30 and 39 comprised 26.7% of the participants. Young people of 15-19 years constituted 18.7%. As for the rest of the participants, their ages ranged from 40-70 years, and they comprised 23.9%, as shown in **Table A7.2**

Table A7.2 Age of the participants

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	15-19 Years	70	18.7	18.7	18.7
	20-29 Years	115	30.7	30.7	49.3
	30-39 Years	100	26.7	26.7	76.0
	40-49 Years	56	14.9	14.9	90.9
	50-59 Years	14	3.7	3.7	94.7
	60-69 Years	14	3.7	3.7	98.4
	Above 70 Years	6	1.6	1.6	100.0
	Total	375	100.0	100.0	

B7.1.3 Professions of Public Participants

Students formed the most significant percentage in the public questionnaire, making up 38.4% of the participants. The engineers followed them at 19.5%, shown in **Table B7.3**

Table B7.3 Position of the participants

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Student	144	38.4	38.4	38.4
	public employee	5	1.3	1.3	39.7
	Administrative Sector	39	10.4	10.4	50.1
	Engineering Sector	73	19.5	19.5	69.6
	Medical Sector	6	1.6	1.6	71.2
	Other Sectors	65	17.3	17.3	88.5
	Not working	43	11.5	11.5	100.0
	Total	375	100.0	100.0	

B7.1.4 Experience of Public Participant

About 50% of the participants had no work experience, while there was 22.4% of the participants had above 11 years of work experience. On the other hand, the workers with 1-5 years of experience constituted 16.8% of the participants, as shown in **Table B7.4**

Table B7.4 Years of experience of the participants

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No experience	187	49.9	49.9	49.9
	Less than one Year	12	3.2	3.2	53.1
	From 1-5 Years	63	16.8	16.8	69.9
	From 6-10 Years	29	7.7	7.7	77.6
	Above 11 Years	84	22.4	22.4	100.0
	Total	375	100.0	100.0	

B7.1.5 Education of Public Participants

46.4% of the participants hold a bachelor's degree, while high school holders constituted 18.9%, and holders of a master's degree constituted 17.6% of the total participants in the public questionnaire, shown in **Table B7.5**

Table B7.5 Education of the participants

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less than high school	14	3.7	3.7	3.7
	High School	71	18.9	18.9	22.7
	Diploma	42	11.2	11.2	33.9
	Bachelor degree	174	46.4	46.4	80.3
	Master degree	66	17.6	17.6	97.9
	PhD	8	2.1	2.1	100.0
	Total	375	100.0	100.0	

B7.2 Public Questionnaire Results, Using SPSS

The general results shown in Table A7.6 showed that all the factors are important from the users' perspective. Moreover, some factors have the same priority rank, i.e., the same weight.

Table B7.6 Descriptive statistics of the public questionnaire

		Mean	Median	Mode	Std. Deviation	Variance	Range
Public Questionnaire Factors							
F1	Displaying clear information on waiting time, routes, & schedules before and during a journey	8.736	9.000	9.000	0.587	0.345	2.000
F2	The ease to submit complaints, requests, and opinions on normal days or holidays with quick responding	6.683	7.000	5.000	1.559	2.431	5.000
F3	Ticket reservation & payment via mobile App.	8.283	9.000	9.000	1.119	1.251	4.000
F4	Ticket reservation & payment via prepaid cards	7.485	8.000	8.000	1.368	1.871	5.000
F5	Economical fare price	8.691	9.000	9.000	.774	.599	3.000
F6	Economical means to reach the service	8.773	9.000	9.000	.501	.251	2.000
F7	Availability and continuity of the service	8.693	9.000	9.000	.537	.288	2.000
F8	A fixed and definite schedule of arrival & departure	8.813	9.000	9.000	.477	.227	2.000
F9	Optimal waiting time at the stop	8.771	9.000	9.000	.507	.257	2.000
F10	Fast transit time when crowded with passenger	8.581	9.000	9.000	.688	.474	2.000
F11	Transport passengers straight to the desired point	8.773	9.000	9.000	.501	.251	2.000
F12	Optimal walking time to reach a stop	8.661	9.000	9.000	.774	.599	3.000
F13	Employees' knowledge, coordination, motivation, and handling medical emergencies (Competency)	8.072	8.000	9.000	.999	.997	3.000
F14	Driver professionalism	8.771	9.000	9.000	.694	.482	3.000
F15	Providing special services for disabled females, elderly, and children at bus and station	8.728	9.000	9.000	.815	.664	3.000
F16	Easy to get on and off (height of vehicle step)	7.760	8.000	9.000	1.407	1.980	5.000
F17	Seat capacity	7.909	8.000	9.000	1.150	1.323	3.000
F18	Modern-looking vehicle and station	7.456	7.000	9.000	1.343	1.805	5.000
F19	Enough spacing between seats and legroom	7.091	7.000	7.000	1.584	2.510	5.000
F20	Comfort seat	8.037	8.000	9.000	.983	.967	3.000
F21	Cleanness (interior and exterior hygiene & sanitary)	8.501	9.000	9.000	.637	.406	2.000

		Mean	Median	Mode	Std. Deviation	Variance	Range
Public Questionnaire Factors							
F22	No engine noise disturbance when inside the vehicle	7.763	8.000	9.000	1.123	1.262	3.000
F23	Air quality and temperature inside the vehicle and stations	8.611	9.000	9.000	.744	.554	3.000
F24	Car parking at the stop	6.357	7.000	9.000	2.266	5.134	7.000
F25	Availability of special facilities for serving disorders	8.453	9.000	9.000	.985	.970	4.000
F26	No traffic accidents	8.885	9.000	9.000	.420	.177	2.000
F27	No broken-down of vehicle	8.923	9.000	9.000	.267	.072	1.000
F28	Seat belts and Airbags	6.851	7.000	6.000	1.662	2.764	6.000
F29	Safe stand when inside the vehicle	8.429	9.000	9.000	1.042	1.085	4.000
F30	Easy escaping out of the vehicle in emergency cases	8.541	9.000	9.000	.793	.629	3.000
F31	Availability and ease of using emergency equipment, e.g., first aid, phone, etc.	7.808	8.000	9.000	1.208	1.460	4.000
F32	Firefighting systems inside vehicles and stations	8.541	9.000	9.000	.793	.629	3.000
F33	Safety from theft, robbery, and pickpocketing at auto stops and inside the vehicle	8.688	9.000	9.000	.675	.456	3.000
F34	Privacy inside the vehicle and station	7.776	8.000	9.000	1.365	1.864	4.000
F35	Anti-virus partitions between seats, such as COVID-19 shield	7.509	8.000	9.000	1.393	1.940	4.000
F36	Safe stop at a station	8.611	9.000	9.000	.692	.479	3.000
F37	Providing free services such as water and Arabic coffee	4.520	5.000	5.000	2.203	4.855	8.000
F38	Aligning with the local cultural values	7.752	8.000	9.000	1.499	2.246	6.000
F39	Level of emission, noise pollution, and sight pollution	7.971	8.000	9.000	1.184	1.403	4.000
F40	The technology inside the fleet and station	7.933	8.000	8.000	1.066	1.137	4.000
F41	Level of congestion impact or disruption caused by this mode	7.936	8.000	9.000	1.136	1.290	4.000
F42	Level of road deterioration caused by public transport mode	8.013	8.000	9.000	1.139	1.297	4.000
F43	The economic impact of energy on the environment	7.936	8.000	8.000	1.100	1.210	4.000

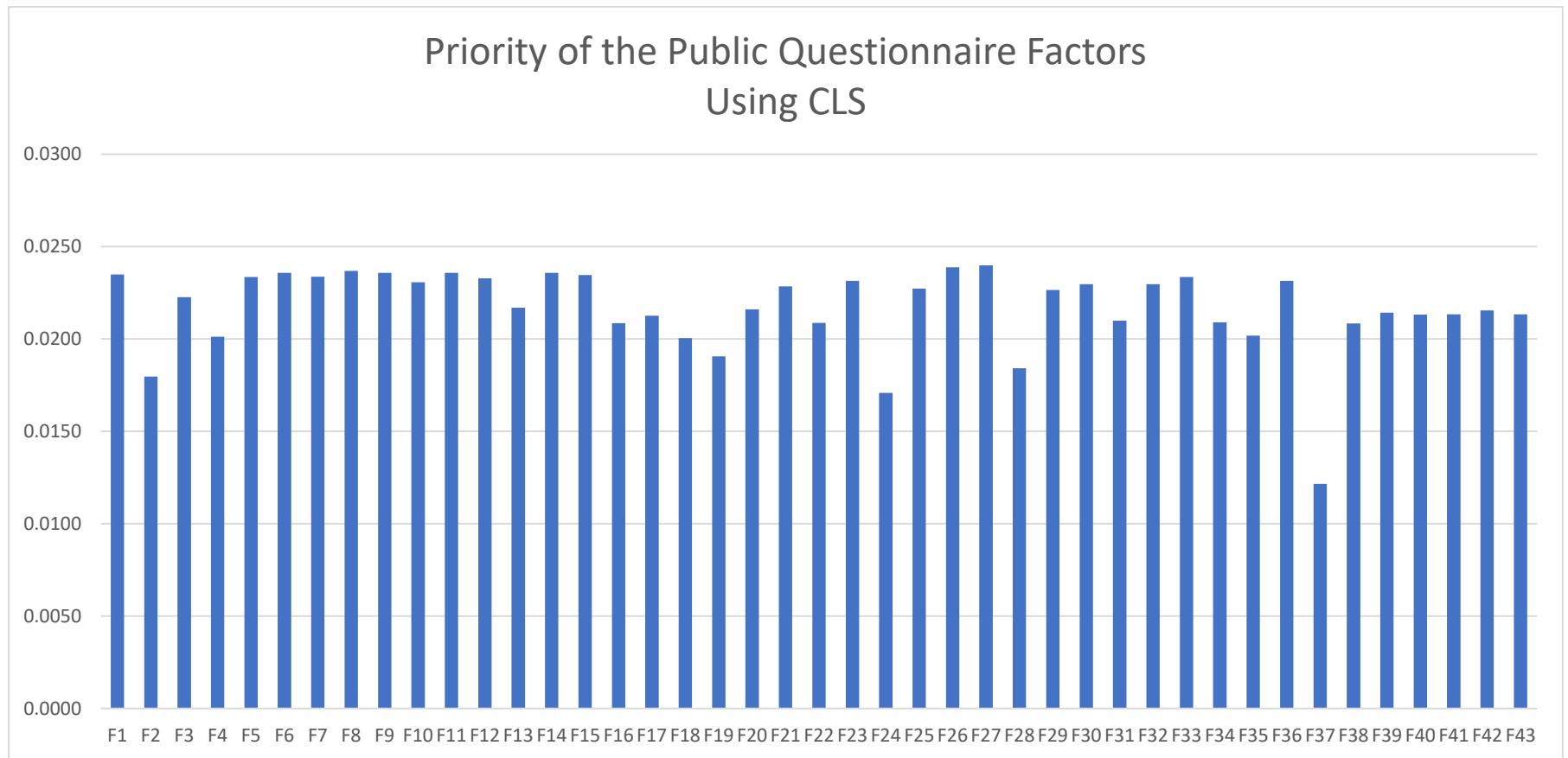


Figure B7.1 Priority of the public questionnaire factors, using CLS

Table B7.7 the factors have been ranked in terms of importance.

Table B7.7 The first ten high-priority factors generated from CLS

Factor No.	Mean	Rank	Factor No.	Mean	Rank
F27	8.9230	1	F13	8.0720	23
F26	8.8850	2	F20	8.0370	24
F8	8.8130	3	F42	8.0130	25
F6	8.7730	4	F39	7.9710	26
F11	8.7730	4	F41	7.9360	27
F9	8.7710	6	F43	7.9360	27
F14	8.7710	6	F40	7.9330	29
F1	8.7360	8	F17	7.9090	30
F15	8.7280	9	F31	7.8080	31
F7	8.6930	10	F34	7.7760	32
F5	8.6910	11	F22	7.7630	33
F33	8.6880	12	F16	7.7600	34
F12	8.6610	13	F38	7.7520	35
F23	8.6110	14	F35	7.5090	36
F36	8.6110	14	F4	7.4850	37
F10	8.5810	16	F18	7.4560	38
F30	8.5410	17	F19	7.0910	39
F32	8.5410	17	F28	6.8510	40
F21	8.5010	19	F2	6.6830	41
F25	8.4530	20	F24	6.3570	42
F29	8.4290	21	F37	4.5200	43

B7.3 MS Excel Spreadsheet for FnCM

Attach the excel here

B7.4 MS Excel Spreadsheet for FAHP

Attach the excel here

Appendix C

Appendix of chapter 6

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C6.1 User Experience Design (UX)

The following presentation shows how we designed the application before the programming work. We tried to make the application easy for users and avoid any technical words or methods of calculation appearing for users.

LOGO

Application Name

- Brief about the application

- How to use it, an illustrative example (Video)
- Why Fuzzy-AHP (Brief)

Select the required methods:

1. FAHP
2. FAHP – GDM
3. QFD
4. FAHP with QFD

No. of Experts:

Step 1

$\Delta E1$	0.5
$\Delta E2$	0.3
$\Delta E3$	0.2
Error if tot. $\neq 1$	

Or, assumed to
be equal for all
experts $\rightarrow$
 $\Delta E = \frac{1}{3}$

This will be
used in the
CJM

No. of PCMs, Crit., and goal

Step 2

# PCM	MS	Crit.	Goal
1	4×4	C1, C2, C3, C4	J
2	3×3	C5, C6, C7	R
3	2×2	C8, C9	D

The Pairwise Comparison Matrix (PCM)

If the matrix size is 4×4

This form facilitates the filling process
by filling the upper diagonal of the matrix

Wrt (Goal A), which of the following criterion
is more important? and by how much is
more?

C1	Equal	2	3	4	5	6	7	8	9
C2									
C1	Equal	2	3	4	5	6	7	8	9
C3									
C1	Equal	2	3	4	5	6	7	8	9
C4									
C2	Equal	2	3	4	5	6	7	8	9
C3									
C2	Equal	2	3	4	5	6	7	8	9
C4									

Step 3

The number of
comparisons is
determined using
this formula:

$$\frac{(i - 1) * i}{2}$$

Ex., If the matrix size
was 7×7 $\rightarrow 18$



Formulas

The results of the following PCM are obtained from the user data (**input**), as shown in

See step 3. In the application, these values will be filled in the upper diagonal of the matrix, then

The lower diagonal will automatically be the reciprocal value

4. Convert Crisp numbers into Fuzzy numbers

	C1	C2	C3	C4
C1	1	4	6	7
C2	1/4	1	3	4
C3	1/6	1/3	1	2
C4	1/7	1/4	1/2	1

Expert 1												
	l	m	u	l	m	u	l	m	u	l	m	u
Q#1	Cr1			Cr2			Cr3			Cr4		
Cr1	1	1	1	3	4	5	5	6	7	6	7	8
Cr2	1/5	1/4	1/3	1	1	1	2	3	4	3	4	5
Cr3	1/7	1/6	1/5	1/4	1/3	1/2	1	1	1	1	2	3
Cr4	1/8	1/7	1/6	1/5	1/4	1/3	1/3	1/2	1	1	1	1

5. CALCULATIONS

Fuzzy RGM			Fuzzy Wi			Crisp Wi	Norm. Wi	Crisp λ_{max}	RI = 0.9	
l	m	u	l	m	u				GCI	CR
Cr1	3.6002	4.0906	0.4449	0.6145	0.8411	0.6335	0.6079	4.2142	0.13791	3.91%
Cr2	1.3161	1.6069	0.1512	0.2246	0.3304	0.2354	0.2259			
Cr3	0.5774	0.7401	0.0628	0.0985	0.1522	0.1045	0.1003			
Cr4	0.3656	0.4855	0.0436	0.0624	0.0998	0.0686	0.0659			
	4.8636	5.8592	6.9231	0.7025	1.0000	1.4235	1.0420	1.0000		

Fuzzy RGM			Fuzzy Weight		
L	m	u	L	m	U
$(1 \times 3 \times 5 \times 6)^{1/4}$	$(1 \times 4 \times 6 \times 7)^{1/4}$	$(1 \times 5 \times 7 \times 8)^{1/4}$	$1/\sum u$	$1/\sum m$	$1/\sum L$

Crisp weight

$$\frac{(l + m + u)}{3}$$

Normalized Weight

$$\frac{w}{total}$$

$$GCI = \frac{2 \sum_{i < j \leq 1} (\ln(a_{ij}) - \ln(\frac{w_i}{w_j}))^2}{(n-1)(n-2)}$$

$$GCI = \frac{2}{(4-1)(4-2)} ((\ln(4) - \ln(\frac{0.6145}{0.2246}))^2 + (\ln(6) - \ln(\frac{0.6145}{0.0985}))^2 + (\ln(7) - \ln(\frac{0.6145}{0.0624}))^2 + (\ln(3) - \ln(\frac{0.2246}{0.0985}))^2 + (\ln(4) - \ln(\frac{0.2246}{0.0624}))^2 + (\ln(2) - \ln(\frac{0.0985}{0.0624}))^2)$$

$$= 0.1349$$

$$CR = \frac{GCI}{K(n)} = \frac{0.1349}{3.526} = 0.0383 = 3.83\% \leq 10\% ? \text{ OK}$$

If CR > 10% Error

6. CJM

E1												
	l	m	u	l	m	u	l	m	u	l	m	u
Q#1	Cr1			Cr2			Cr3			Cr4		
Cr1	1	1	1	3	4	5	5	6	7	6	7	8
Cr2	1/5	1/4	1/3	1	1	1	2	3	4	3	4	5
Cr3	1/7	1/6	1/5	1/4	1/3	1/2	1	1	1	1	2	3
Cr4	1/8	1/7	1/6	1/5	1/4	1/3	1/3	1/2	1	1	1	1

E2												
	l	m	u	l	m	u	l	m	u	l	m	u
Q#1	Cr1			Cr2			Cr3			Cr4		
Cr1	1	1	1	4	5	6	6	7	8	9	9	9
Cr2	1/6	1/5	1/4	1	1	1	3	4	5	5	6	7
Cr3	1/8	1/7	1/6	1/5	1/4	1/3	1	1	1	1	2	3
Cr4	1/9	1/9	1/9	1/7	1/6	1/5	1/3	1/2	1	1	1	1

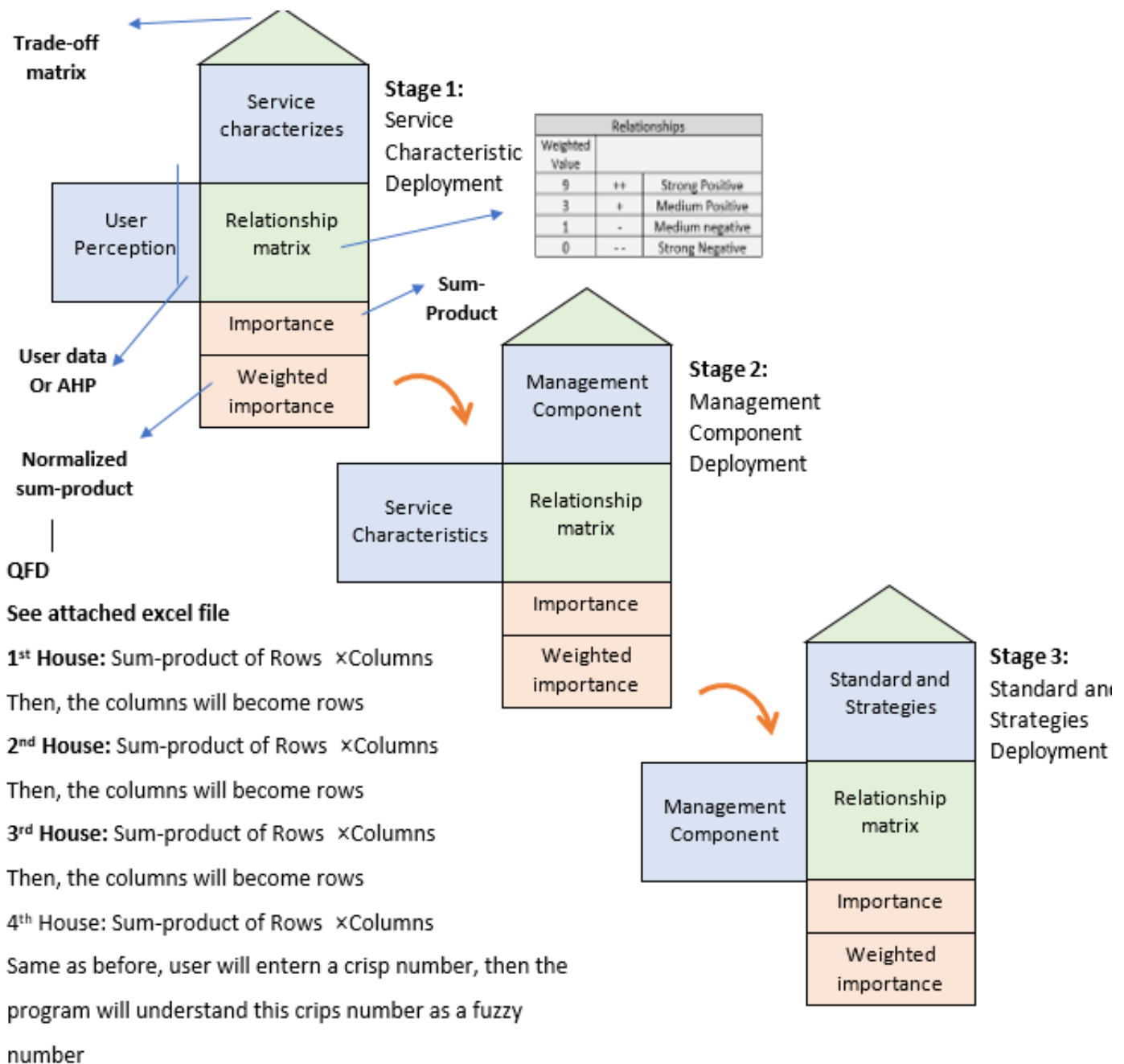
E3												
----	--	--	--	--	--	--	--	--	--	--	--	--

Expert 3												
	l	m	u	l	m	u	l	m	u	l	m	u
Q#1	Cr1			Cr2			Cr3			Cr4		
Cr1	1	1	1	1	2	3	4	5	6	7	8	9
Cr2	1/3	1/2	1	1	1	1	3	4	5	5	6	7
Cr3	1/6	1/5	1/4	1/5	1/4	1/3	1	1	1	1	2	3
Cr4	1/9	1/8	1/7	1/7	1/6	1/5	1/3	1/2	1	1	1	1

$(3)^{0.5} \times (4)^{0.3} \times (1)^{0.2} \rightarrow$ in case each expert has an individual weight

$(3 \times 4 \times 1)^{1/3} \rightarrow$ in case all experts have equal weights (experience)

CJM



C6.2 Coding System

The following figures have been screenshotted from Flutter during the programming of the software codes.

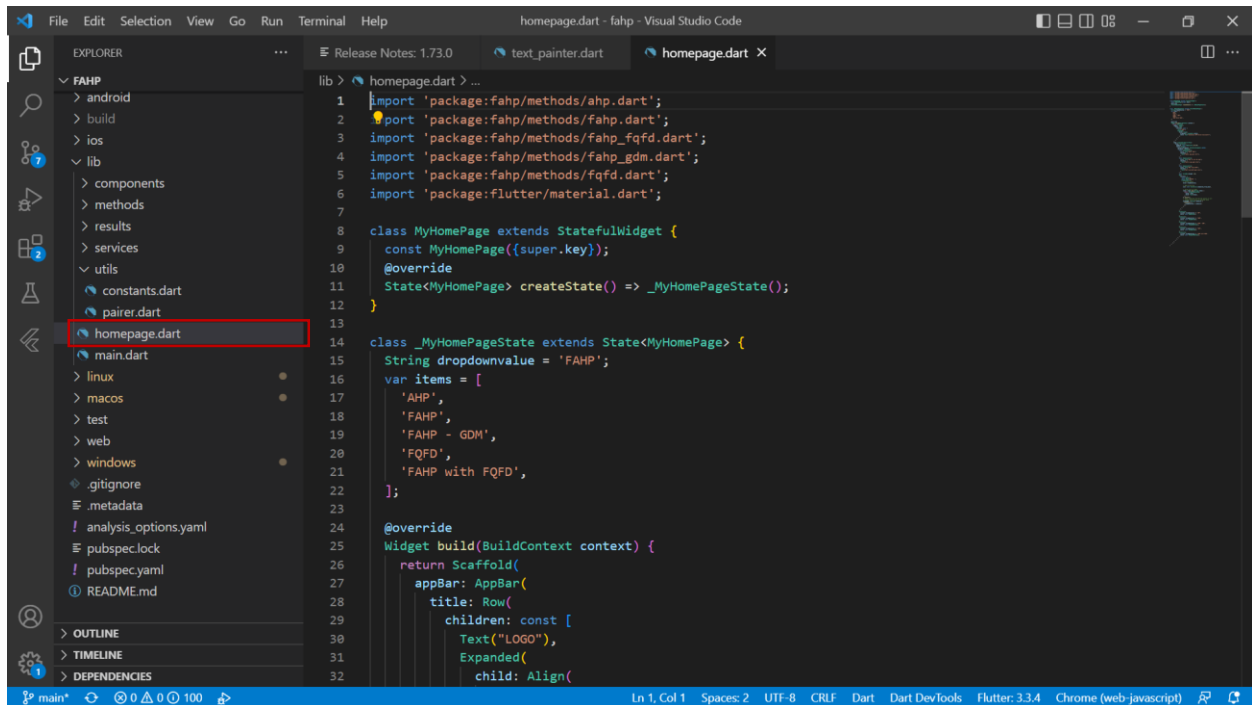


Fig. (C6.1): The homepage Dart is where the execution script is stored.

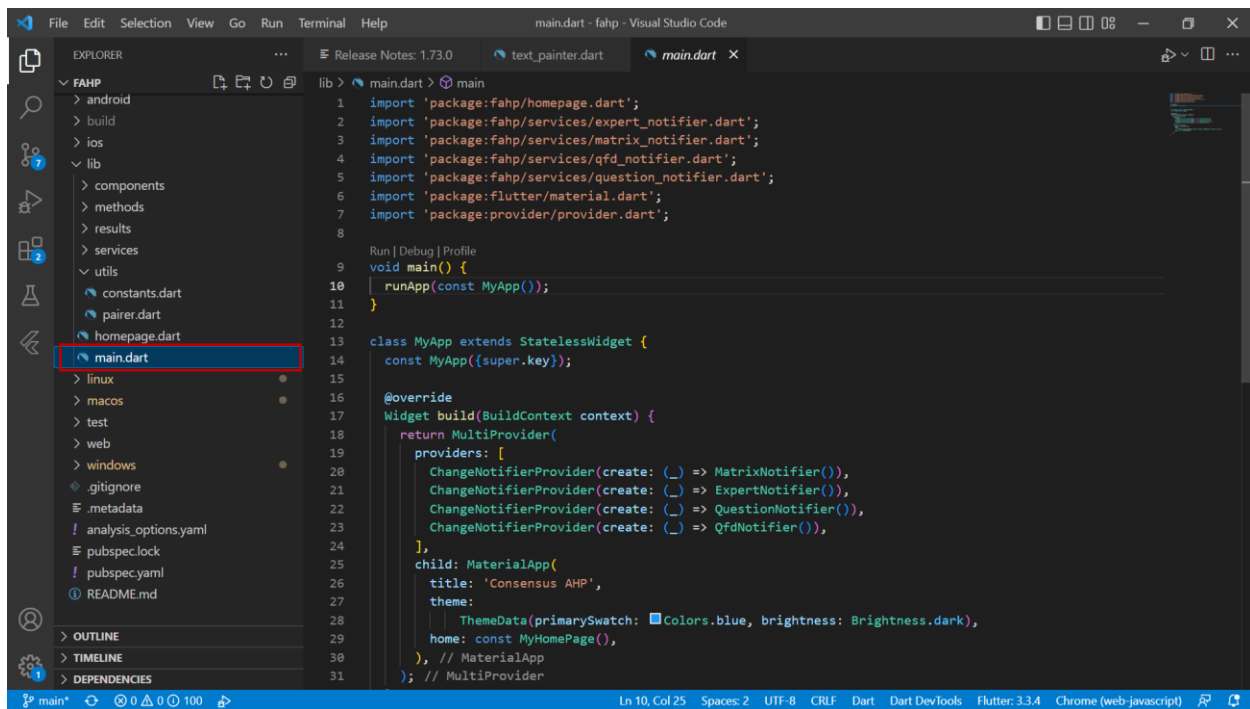


Fig. (C6.2): The main Dart is where the execution script is stored.

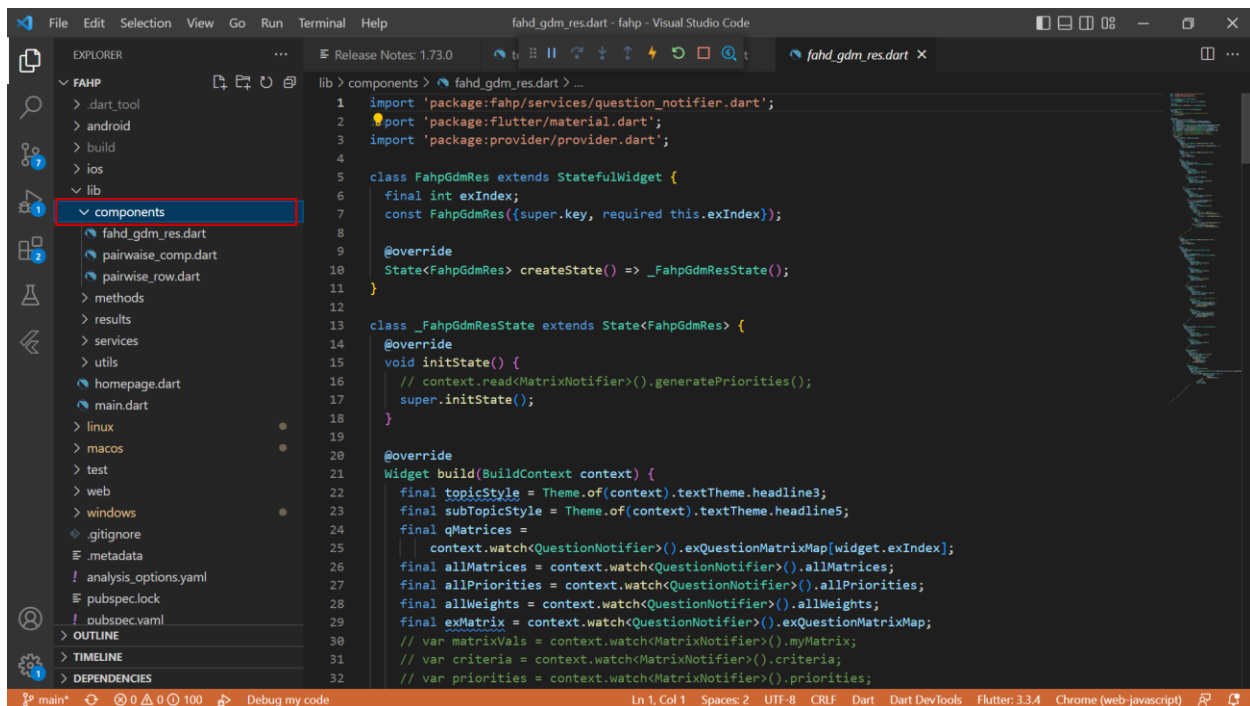


Fig. (C6.3): The components folder is used to store shared components like input fields, tables, etc., for code reuse.

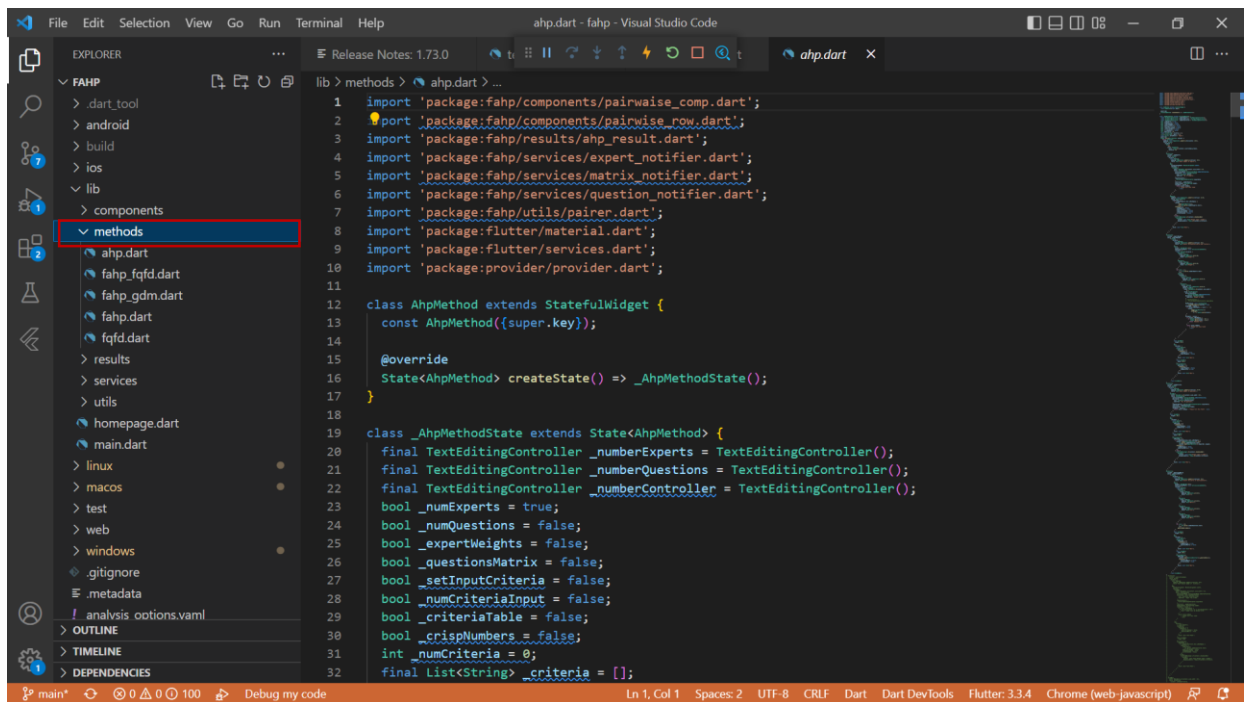


Fig. (C6.4): The user interfaces part of the code is stored in the methods folder for each method AHP, FAHP, etc.

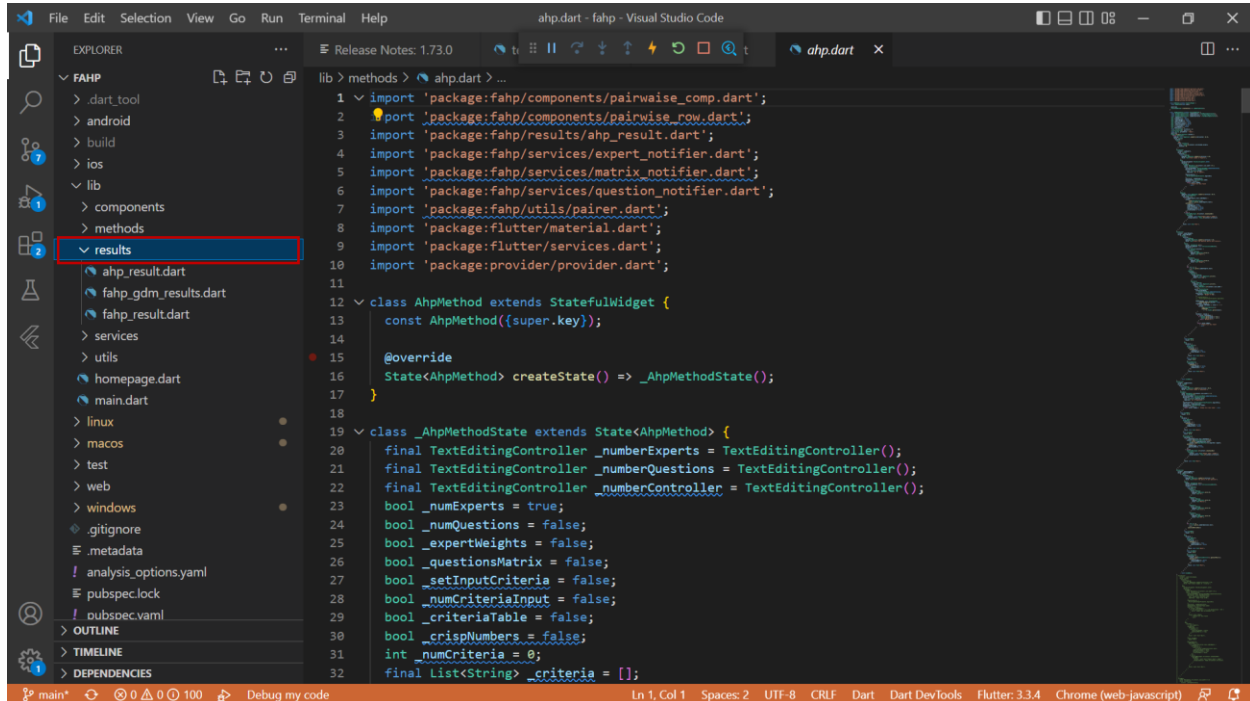


Fig. (C6.5): The results folder contains the files to illustrate the result to the user interface.

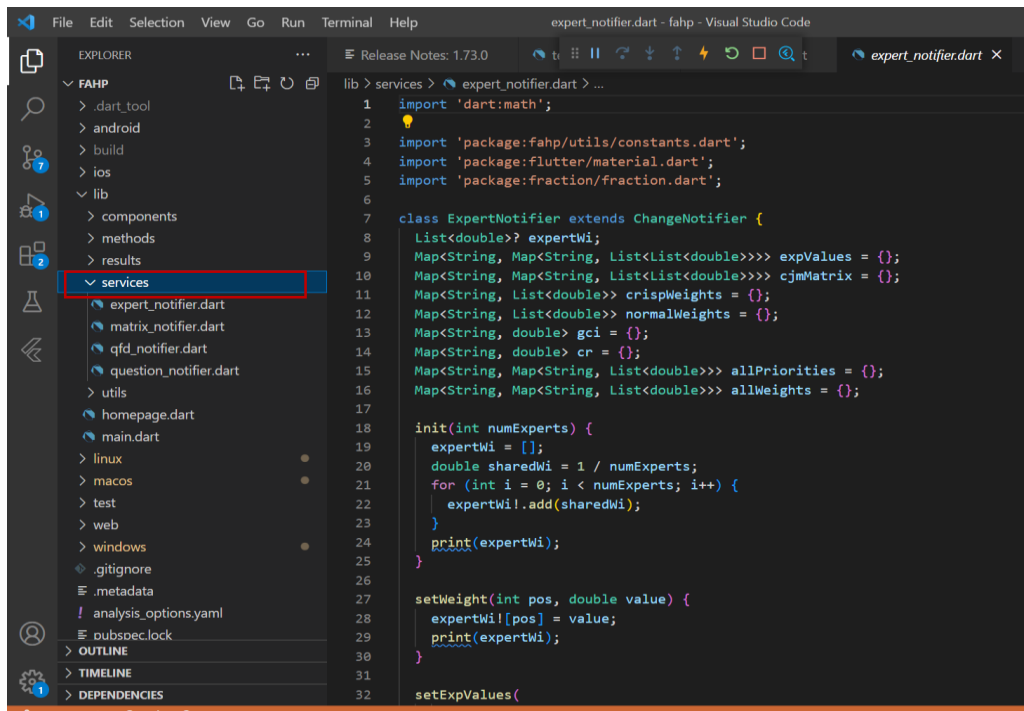


Fig. (C6.6): The functions that handle the calculations are stored in the services folder. For example, expert-related calculations are stored in services `expert_notifier.dart`.



Fig. (C6.7): This code is to get the fuzzy's lower, middle, and upper values.

C6.3 The User Manual (UM)

The following figures show a step-by-step explanation of using the application.

Figure C6.8 shows the home page for the web application that will display the users' information about the App.; how to use it; the advantages of using the concept; and which method to choose. This page is where the user starts and proceeds to use the application.

Then, the figures from C6.9 to C6.15 shwoing the steps to use the application

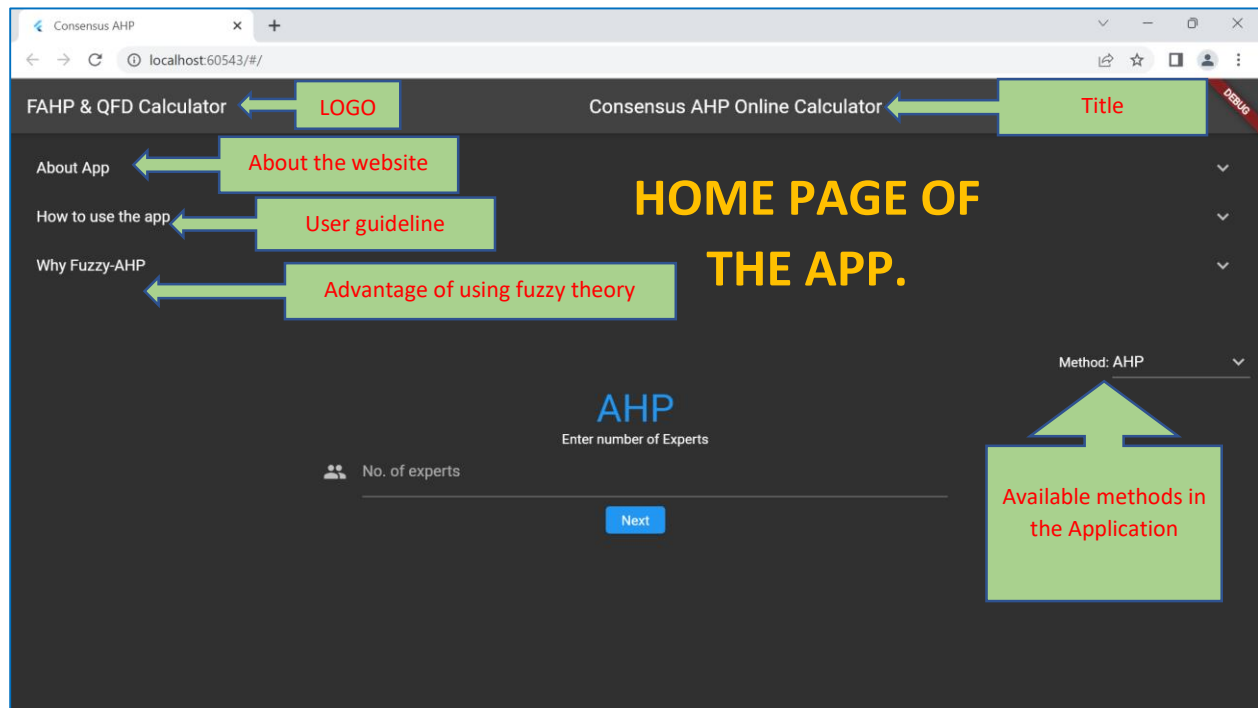


Fig. (C6.8): Home Page of the Application

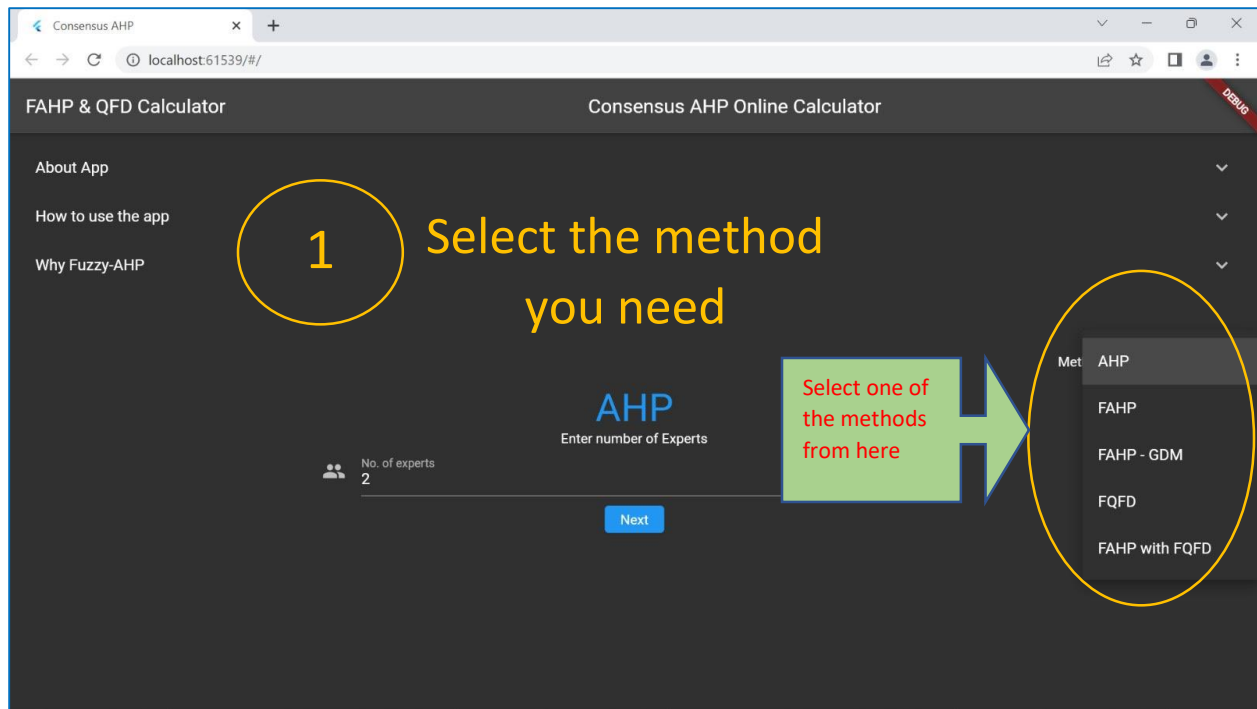


Fig. (C6.9): Method selection

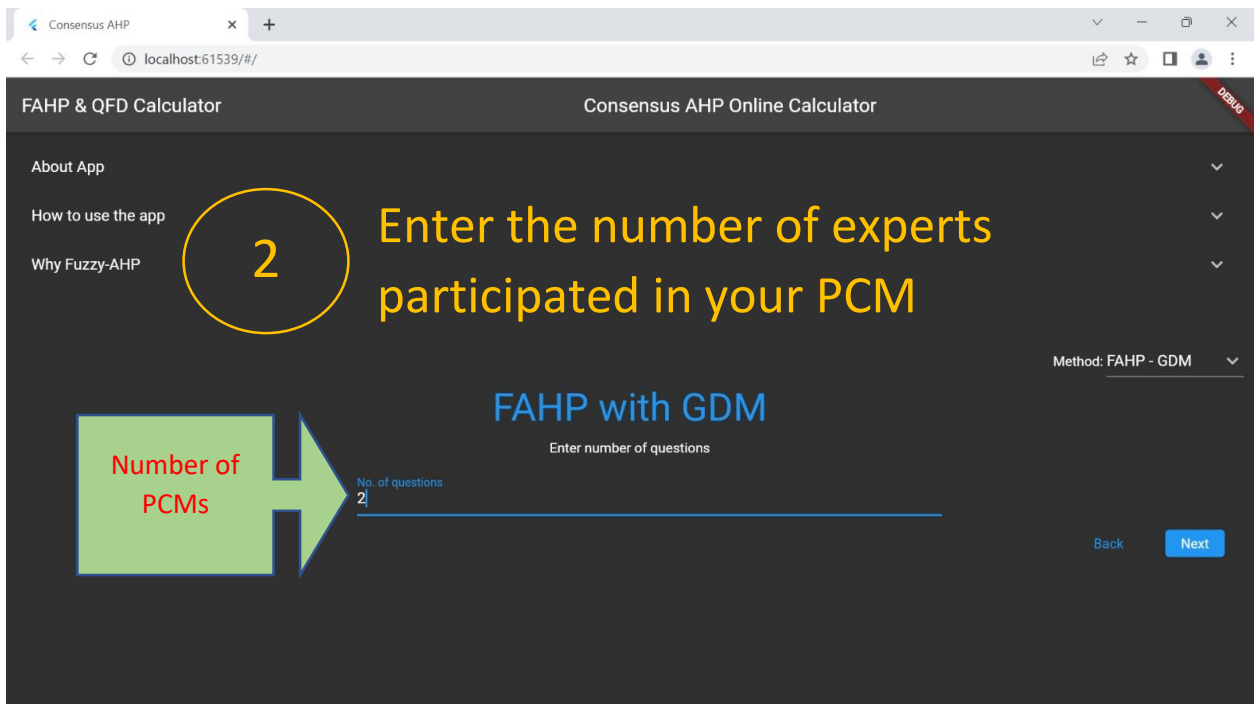


Fig. (C6.10): Number of experts

Consensus AHP

localhost:61539/#/

FAHP & QFD Calculator

Consensus AHP Online Calculator

About App

How to use the app

Why Fuzzy-AHP

3 Enter the weight of each expert participated in PCMs

Method: FAHP - GDM

Enter the experts' weight here; and make sure that the overall weight is 1

NOTIC: in case all experts' have equal weight, KEEP IT BLANK

FAHP with GDM

Insert the question matrix and criteria

Expert	Weight
$\Delta E1$	Weight of $\Delta E1$ 0.4
$\Delta E2$	Weight of $\Delta E2$ 0.6

Back Next

Fig. (C6.11): Experts' weights

Consensus AHP

localhost:61539/#/

FAHP & QFD Calculator

Consensus AHP Online Calculator

About App

How to use the app

Why Fuzzy-AHP

4 Enter the number of your PCMs

Method: FAHP - GDM

Number of PCMs

FAHP with GDM

Enter number of questions

No. of questions
2

Back Next

Fig. (C6.12): Number of PCMs

FAHP & QFD Calculator

Consensus AHP Online Calculator

About App

How to use the app

Why Fuzzy-AHP

Set the PCMs size; and then, fill the names of criteria and the goal of each PCM

Method: FAHP - GDM

FAHP with GDM

Insert the matrix of each question

Q	Matrix	Crit	WRT
1	3	Criteria 0 A	Criteria 1 B
		Criteria 2 C	Criteria G1
2	4	Criteria 0 D	Criteria 1 E
		Criteria 2 F	Criteria 3 H
			Criteria G2

Back Next

Fig. (C6.13): PCMs size; criteria names; and goal

Consensus AHP

localhost:61539/#/

FAHP & QFD Calculator

Consensus AHP Online Calculator

Expert 1

7

Do the comparison process of the PCM of each expert, as shown here, A is twice important than B

CONTINUE

CANCEL

Expert 1

With respect to G1, which of the following criterion is more important? and by how much is more?

1	☒ A ☐ B	☐ 1	☒ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
2	☒ A ☐ C	☐ 1	☐ 2 ☒ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
3	☒ B ☐ C	☐ 1	☒ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9

With respect to G2, which of the following criterion is more important? and by how much is more?

1	☒ D ☐ E	☐ 1	☒ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
2	☒ D ☐ F	☐ 1	☐ 2 ☒ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
3	☒ D ☐ H	☐ 1	☒ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
4	☒ E ☐ F	☐ 1	☐ 2 ☒ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
5	☒ E ☐ H	☐ 1	☒ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
6	☒ F ☐ H	☒ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9

Consensus AHP

localhost:61539/#/

FAHP & QFD Calculator

Consensus AHP Online Calculator

Expert 2

8

As mentioned in step 7

CONTINUE

CANCEL

Expert 2

With respect to G1, which of the following criterion is more important? and by how much is more?

1	☒ A ☐ B	☐ 1	☒ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
2	☒ A ☐ C	☐ 1	☐ 2 ☒ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
3	☒ B ☐ C	☐ 1	☒ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9

With respect to G2, which of the following criterion is more important? and by how much is more?

1	☒ D ☐ E	☐ 1	☒ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
2	☒ D ☐ F	☐ 1	☒ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
3	☒ D ☐ H	☐ 1	☐ 2 ☒ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
4	☒ E ☐ F	☐ 1	☐ 2 ☒ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
5	☒ E ☐ H	☐ 1	☒ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9
6	☒ F ☐ H	☒ 1	☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9

Back Calculate CJM

Fig. (C6.14): Comparison Process

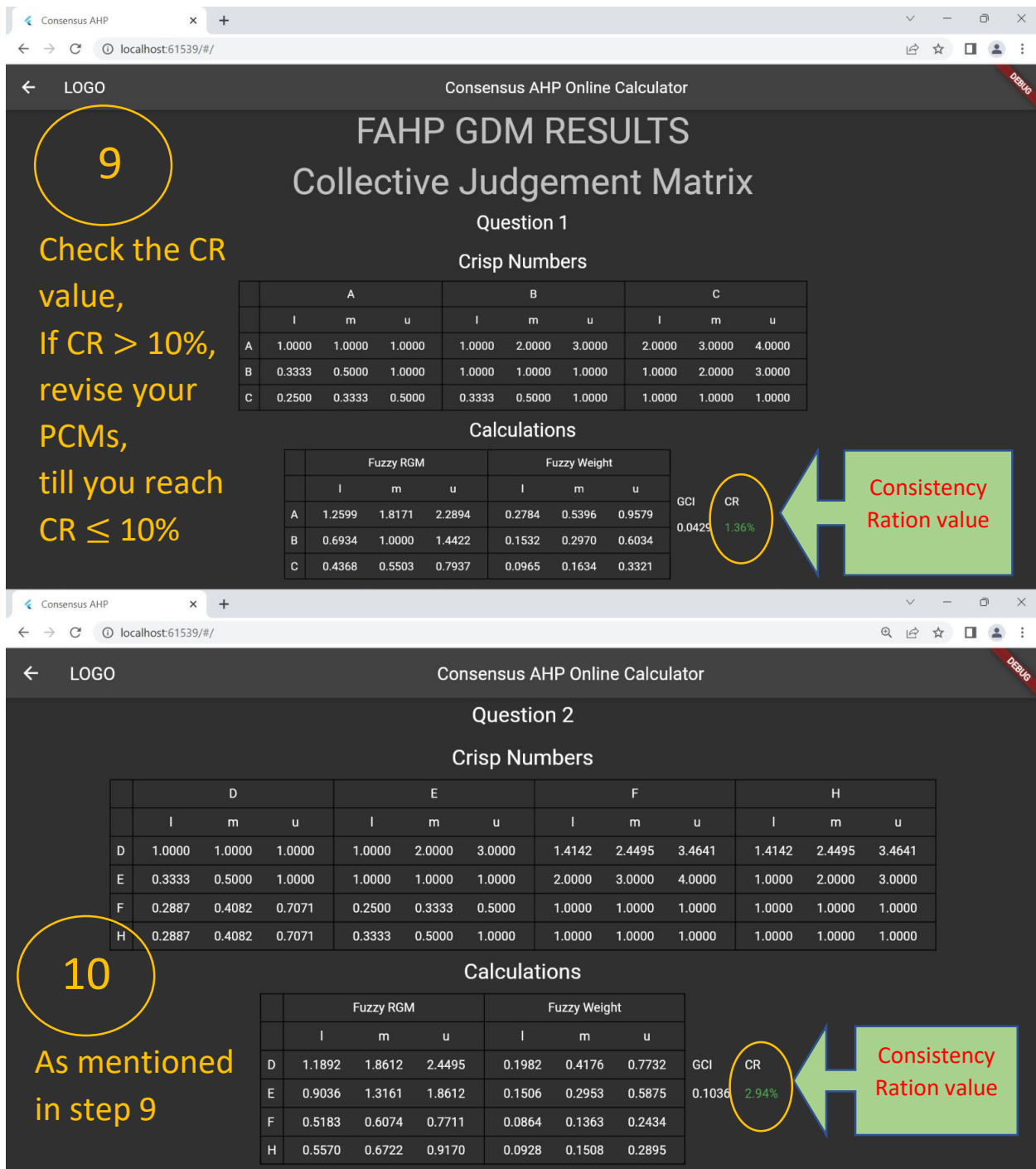


Fig. (C6.15): CR values Check

C6.4 Random Index (RI) for PCM bigger than 16×16

The previous studies on the RI values are presented in this section. Then, we will use the approach proposed by [Alonso J. & Lamata M. \(2006\)](#) to calculate the RI values for a PCM bigger than 16×16. Calculating these values aims to find the consistency index $K(n)$ proposed by [Aguaron J. & Jimenez J. \(2003\)](#). After obtaining the $K(n)$ values, the Consistency Ration (CR) can be obtained.

C6.4.1 Previous Studies on RI calculation

[Alonso J. & Lamata M. \(2006\)](#) reviewed the studies conducted on RI calculation and stated that "Saaty (at Wharton) and Uppuluri (at Oak Ridge) simulated the experiment with 500 and 100 runs, respectively. [Lane and Verdini \(1989\)](#), [Golden and Wang \(1990\)](#), and [Noble \(1990\)](#) carried out 2500, 1000, and 5000 simulation runs. [Forman \(1990\)](#) also provided values for matrices of size 3 through 7 using examples from 17672 to 77487 matrices. [Tumala and Wan \(1994\)](#) subsequently experimented with samples ranging from 4600 to 470000, obtaining the values shown in **Table C6.1**."

Table (C6.1): $RI(n)$ values from various authors.

[Alonso J. & Lamata M. \(2006\)](#)

	Oak Ridge	Wharton	Golden, Wang	Lane, Verdini	Forman	Noble	Tumala, Wan	Aguaron et al	Alonso, Lamata
	100	500	1000	2500		500		100000	100000
3	0.3820	0.5800	0.5799	0.5200	0.5233	0.4900	0.5000	0.5250	0.5245
4	0.9460	0.9000	0.8921	0.8700	0.8860	0.8200	0.8340	0.8820	0.8815
5	1.2200	1.1200	1.1159	1.1000	1.1098	1.0300	1.0460	1.1150	1.1086
6	1.0320	1.2400	1.2358	1.2500	1.2539	1.1600	1.1780	1.2520	1.2479
7	1.4680	1.3200	1.3322	1.3400	1.3451	1.2500	1.2670	1.3410	1.3417
8	1.4020	1.4100	1.3952	1.4000	1.3100	1.3260	1.4040	1.4056	
9	1.3500	1.4500	1.4537	1.4500	1.3600	1.3690	1.4520	1.4499	
10	1.4640	1.4900	1.4882	1.4900	1.3900	1.4060	1.4840	1.4854	
11	1.5760	1.5100	1.5117	1.4200	1.4330	1.5130	1.5141		
12	1.4760	1.5356	1.5400	1.4400	1.4560	1.5350	1.5365		
13	1.5640	1.5571	1.4600	1.4740	1.5550	1.5551			
14	1.5680	1.5714	1.5700	1.4800	1.4910	1.5700	1.5713		
15	1.5860	1.5831	1.4900	1.5010	1.5830	1.5838			

C6.4.2 RI Calculations for bigger PCMs

We calculate the RI values because users may need to compare more than 16 criteria in our software application. Hence, finding the RI values for matrices bigger than 16×16 is mandatory. From Table C6.1, we observed that the researchers found RI values up to a matrix of size 15×15 . [Alonso J. & Lamata M. \(2006\)](#) generated a new approach to calculate the RI values up to a matrix of size 39×39 . However, in this study, we need to find the RI values up to a matrix of size 100×100 because the software application can solve up to this matrix size.

The RI value in our study is used to find the consistency index $K(n)$ proposed by [Aguaron J. & Jimenez J. \(2003\)](#). On the other hand, [Saaty T. \(1980\)](#) developed a consistency index (CI) by using the maximum eigenvalue for a PCM, then using it to find the Consistency Ration (CR) of the PCM. Saaty's CI and CR equations are shown in **Chapter 5, Sections 5.3.2, Equations 5.4, and 5.6**, respectively. However, [Aguaron J. & Jimenez J. \(2003\)](#) claimed that Saaty's approach to evaluating the CI is not recommended when the RGMM is used as a prioritization method. Consequently, they suggested using GCI, proposed by [Crawford & Williams \(1985\)](#), to evaluate the consistency index when using RGMM as a prioritization method.

As explained in **Chapter 5, Section 5.3.2, Step 9**, to find the CR value of the PCM, we use **Equation 5.7**. However, $k(n)$ values are not given when the matrix size exceeds $n = 16$

Therefore, we will use the new approach proposed by [Alonso J. & Lamata M. \(2006\)](#) to calculate the values of the $k(n)$ as per the following equation:

$$CR = \frac{GCI}{k(n)} \dots\dots\dots (5.7)$$

$$GCI = \frac{2 \sum_{i < j \geq 1}^n (\ln(a_{ij}) - \ln(\frac{w_i}{w_j}))^2}{(n-1)(n-2)} \dots\dots\dots (5.5)$$

$$K_{(n)} = RI \times \frac{2n}{n-2} \dots\dots\dots (C6.1)$$

$$RI = \frac{\lambda_{\max} - n}{n-1} \dots\dots\dots (C6.2)$$

$$\lambda_{\max} = n (2.774) - 4.3764 \dots\dots\dots (C6.3)$$

By applying all the above equations, the k(n) values from n = 17 to n = 100 are presented in **Table C6.2**. The values from n = 2 to n = 16 are proposed by [Aguaron J. & Jimenez J. \(2003\)](#) and shown in **Chapter 5, Section 5.3.2, Table 5.3**

Table (C6.2): values of k(n) for n = 17, ..., 100

Alonso & Lamata (2006)			
Matrix size (n)	$\lambda^* \max$	RI (n)	K(n)
17	42.737	1.609	3.646
18	45.507	1.618	3.641
19	48.277	1.626	3.636
20	51.047	1.634	3.631
21	53.817	1.641	3.627
22	56.587	1.647	3.623
23	59.356	1.653	3.620
24	62.126	1.658	3.617
25	64.896	1.662	3.614
26	67.666	1.667	3.611
27	70.436	1.671	3.609
28	73.206	1.674	3.606
29	75.976	1.678	3.604
30	78.746	1.681	3.602
31	81.516	1.684	3.600
32	84.286	1.687	3.598
33	87.055	1.689	3.596

Alonso & Lamata (2006)			
Matrix size (n)	λ^* max	RI (n)	K(n)
34	89.825	1.692	3.595
35	92.595	1.694	3.593
36	95.365	1.696	3.592
37	98.135	1.698	3.590
38	100.905	1.700	3.589
39	103.675	1.702	3.588
40	106.445	1.704	3.587
41	109.215	1.705	3.586
42	111.985	1.707	3.585
43	114.754	1.708	3.584
44	117.524	1.710	3.583
45	120.294	1.711	3.582
46	123.064	1.713	3.581
47	125.834	1.714	3.580
48	128.604	1.715	3.579
49	131.374	1.716	3.578
50	134.144	1.717	3.578
51	136.914	1.718	3.577
52	139.684	1.719	3.576
53	142.453	1.720	3.575
54	145.223	1.721	3.575
55	147.993	1.722	3.574
56	150.763	1.723	3.574
57	153.533	1.724	3.573
58	156.303	1.725	3.572
59	159.073	1.725	3.572
60	161.843	1.726	3.571
61	164.613	1.727	3.571
62	167.383	1.728	3.570
63	170.152	1.728	3.570
64	172.922	1.729	3.569
65	175.692	1.730	3.569
66	178.462	1.730	3.569
67	181.232	1.731	3.568
68	184.002	1.731	3.568
69	186.772	1.732	3.567
70	189.542	1.732	3.567
71	192.312	1.733	3.567
72	195.082	1.734	3.566
73	197.851	1.734	3.566
74	200.621	1.735	3.565

Alonso & Lamata (2006)			
Matrix size (n)	λ^* max	RI (n)	K(n)
75	203.391	1.735	3.565
76	206.161	1.735	3.565
77	208.931	1.736	3.564
78	211.701	1.736	3.564
79	214.471	1.737	3.564
80	217.241	1.737	3.564
81	220.011	1.738	3.563
82	222.781	1.738	3.563
83	225.550	1.738	3.563
84	228.320	1.739	3.562
85	231.090	1.739	3.562
86	233.860	1.740	3.562
87	236.630	1.740	3.562
88	239.400	1.740	3.561
89	242.170	1.741	3.561
90	244.940	1.741	3.561
91	247.710	1.741	3.561
92	250.480	1.742	3.560
93	253.249	1.742	3.560
94	256.019	1.742	3.560
95	258.789	1.742	3.560
96	261.559	1.743	3.560
97	264.329	1.743	3.559
98	267.099	1.743	3.559
99	269.869	1.744	3.559
100	272.639	1.744	3.559