RANKING FRAMEWORK IN EVALUATING MOBILE PATIENT MONITORING SYSTEMS AND ITS ARCHITECTURE COMPONENTS BASEDON BEST WORST METHOD AND ALSEKRITERIJUMSKA OPTIMIZACIJA I KOMPROMISNO RESENJE METHODS

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ALMAHDI ESAM MOTASHAR ADAY

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ALMAHDI ESAM MOTASHAR ADAY

DISSERTATION SUBMITTED IN FULFILLMENT OF THE REQUIREMENT FOR THE MASTER OF SCIENCE, (ARTIFICIAL INTELLIGENT) (MASTER BY RESEARCH)

FACULTY OF ART, COMPUTING & CREATIVE INDUSTRY
SULTAN IDRIS EDUCATION UNIVERSITY

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ABSTRACT

The purpose of this research was to develop a ranking framework in evaluating mobile patient monitoring systems (MPMSs) and its architecture components based on multi-criteria analysis. Ranking and selecting the best MPMSs in the telemedicine environment is a challenging task due to four issues, namely, multiple evaluation criteria, importance of criteria, data variation and unmeasurable values. The decision matrix was adopted from the most relevant studies and is found to be applicable, which is constructed on the basis of intersection between ‘evaluation criteria’ and ‘systems list’. The unmeasurable values (binominal values and multiple values) of the MPMS evaluation criteria in the adopted decision matrix are re-presenting based on four experts’ opinion by using the Best–Worst Method (BWM) to be mathematically applicable. The importance of the evaluation criteria based on the architecture components of the MPMS is determined by using the BWM with consistency value less than 0.1. The VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method is utilised to rank the MPMS according to the determined importance of the evaluation criteria and the adopted decision matrix. According to VIKOR, the set of alternatives are ranked by sorting the value Q in ascending order. The lowest value indicates the optimal performance. The obtained results are: the internal and external VIKOR group decision making are approximately the same, the best MPMS after ranking was ‘Yale–NASA’ and the worst MPMS was ‘NTU’. For the objective validation, the mean ± standard deviation in the first group of both the internal and external aggregation is 0.028, lower than the other two groups; this process indicates that the internal and external ranking results are 100% identical (due to alternatives with the minimum value are considered the optimal one according to the steps of the VIKOR). As conclusion, The BWM is suitable on quantifying the MPMS evaluation criteria preferences based on the architecture components of the MPMS. VIKOR is suitable in solving the MPMS ranking problem. The proposed framework helps the medical organization select the suitable MPMS, facilitate the healthcare professionals work and remote health monitoring to save patients life.

RANGKA KERJA KEDUDUKAN DALAM MENILAI SISTEM PEMANTAUAN PESAKIT MUDAH ALIH DAN KOMPONEN SENIBINA BERDASARKAN KAEDAH BEST-WORST METHOD DAN VLSEKRITERIJUMSKA OPTIMIZACIJA I KOMPROMISNO RESENJE

ABSTRAK

Kajian ini mencadangkan rangka kerja kedudukan dalam menilai sistem pemantauan pesakit mudah alih (MPMS) dan komponen seni binanya berdasarkan analisis multi kriteria. Peringkat dan memilih MPMS terbaik dalam persekitaran *telemedicine* adalah tugas yang mencabar kerana empat isu, iaitu, kriteria penilaian yang banyak, kepentingan kriteria, variasi data dan nilai yang tidak dapat diukur. Data sekunder membentangkan matriks keputusan yang diambil dari kajian yang paling relevan dan didapati terpakai untuk kajian ini, yang dibina berdasarkan persimpangan antara 'kriteria penilaian' dan 'senarai sistem'. Nilai tak terukur (nilai binominal dan pelbagai nilai) kriteria penilaian MPMS dalam matriks keputusan yang diterima pakai adalah penyampaian semula berdasarkan empat pendapat ahli dengan menggunakan Kaedah Terbaik-Terburuk (BWM) untuk digunakan secara matematik. Kepentingan kriteria penilaian berdasarkan komponen-komponen arkitek MPMS ditentukan dengan menggunakan BWM dengan nilai konsisten kurang daripada 0.1. kaedah VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) digunakan untuk pangkat MPMS sesuai dengan kriteria penilaian yang ditentukan dan matriks keputusan yang diadopsi. Menurut VIKOR, satu set alternatif disusun dengan mengasingkan nilai Q dalam urutan menaik. Nilai terendah menunjukkan prestasi optimum. Keputusan yang diperolehi adalah: pengambilan keputusan kumpulan dalaman dan luaran VIKOR adalah kira-kira sama, MPMS terbaik selepas kedudukan adalah 'Yale-NASA' dan MPMS terburuk adalah 'NTU'. Bagi pengesahan objektif, sisihan standard ± min dalam kumpulan pertama kedua-dua pengagregatan dalaman dan luaran adalah (0.028), lebih rendah daripada dua kumpulan yang lain, proses ini menunjukkan bahawa kedudukan kedudukan dalaman dan luaran adalah 100% sama (kerana alternatif dengan nilai minimum dianggap sebagai yang optimum mengikut langkah-langkah VIKOR). Kesimpulannya, BWM sesuai untuk mengkuantifikasi keutamaan kriteria penilaian MPMS berdasarkan komponen-komponen seni bina MPMS. VIKOR sesuai untuk menyelesaikan masalah kedudukan MPMS. Rangka kerja yang dicadangkan membantu organisasi perubatan memilih MPMS yang sesuai, memudahkan kerja profesional penjagaan kesihatan dan pemantauan kesihatan jauh untuk menyelamatkan nyawa pesakit.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces the map of this study. Section 1.2 presents the background of the study. Section 1.3 discusses the study problem. Section 1.4 describes the five objectives of this study. Section 1.5 presents the research questions. Section 1.6 links the research questions and objectives. Section 1.7 explains the importance of this study. Section 1.8 presents the thesis organisation.

1.2 Background of the study

At present, mobile health has attracted considerable attention due to the increasing number of high-performance mobile devices and wireless access technologies. Mobile health is part of electronic health (E-health) which uses mobile devices (smart phones and personal digital assistants (PADs)) and communication technologies (wireless and Global Positioning System (GPS) technologies) to enhance traditional medical services (Cameron, Ramaprasad, & Syn, 2017). The mobile health (M-health) pattern guarantees real-time patient monitoring, diagnostic and therapy support, disease tracking, tele-consultation and awareness services.

A mobile patient monitoring system (MPMS) is a particular type of M-health service with various functions, such as measurement, collection and transmission of biological data through wearable sensors from patients to hospitals or other healthcare organisations (P. Pawar, Jones, Van Beijnum, & Hermens, 2012). Study (Bratan & Clarke, 2006) classified remote patient monitoring systems to identify the most important M-Health stakeholders and their requirements for a comprehensive system architecture.

The qualifications of any MPMS can be improved by using the network resources of all available wireless networks in various multi-access environments. The benefits of such systems can be utilised through the mobility between different radio access networks. Reliable mobility management can be accomplished by assigning application flows to convenient interfaces through the use of intelligent decisions and adaptability based on available network resources (De la Oliva, Bernardos, Calderon, Melia, & Zuniga, 2011a).

MPMSs are used to provide doctors or healthcare organisations with bio-signals from wearable sensors (Varga, Bokor, & Takács, 2014). Recently, mobile devices and wireless sensor technologies have been utilised in the development of MPMSs using wireless sensors (Y. Ren, Werner, Pazzi, & Boukerche, 2010a; Villarreal, Urzaiz, Hervas, & Bravo, 2011).

The literature review shows that MPMSs have attracted considerable research attention and that numerous companies have started to develop new systems for healthcare. The elderly population and patients with chronic diseases especially need MPMSs to provide accurate healthcare services and aid decision makers (caregivers and doctors) in saving lives. However, the selection of MPMSs involves many aspects that should be considered (A. Hussain, Wenbi, da Silva, Nadher, & Mudhish, 2015; V. Jones, Gay, & Leijdekkers, 2010; P. Pawar et al., 2012). Many studies have attempted to evaluate and compare MPMSs to assist users in selecting suitable MPMSs. However, their evaluation and comparison focused on one or several criteria of MPMSs.

A large number of studies have investigated MPMSs in terms of architecture. Study (A. Hussain et al., 2015) proposed a new platform for the healthcare of the elderly and people with disabilities and compared it with other previous systems. A new system based on a user-centred design methodology was presented in (Martínez-Alcalá, Muñoz, & Monguet-Fierro, 2013) according to a review of the advantages and disadvantages of seven systems. Study (Paliwal & Kiwelekar, 2013) compared MPMSs to identify their similarities and differences by using a set of functional and non-functional requirements. Study (P. Pawar et al., 2012) introduced a generic architecture-associated terminology and a classificatory framework. Study (V. Jones et al., 2010) described and compared two mobile health solutions on the basis of their different aspects.

Thus, important evaluation criteria should be simultaneously evaluated and compared to satisfy all user requirements. To the best of our knowledge, no study has provided an integrated platform to compare MPMSs with multiple criteria. The present study presents a framework to compare and rank MPMSs on the basis of generic architecture evaluation criteria. This study aids users in the selection of the best MPMSs that meet user requirements.

2.3 Problem of the study

Recently, many MPMSs have been developed to provide healthcare services to patients. Each of these MPMSs comprises various components depending on its architecture and thus presents different characteristics. Most existing studies, such as Study (Bonney, 2016; A. Hussain et al., 2015; V. Jones et al., 2010; Paliwal & Kiwelekar, 2013; P. Pawar et al., 2012), have compared MPMSs on the basis of their individual aspects while disregarding other characteristics. Thus, such comparison does not completely reflect the quality of these systems. Comparing MPMSs is difficult because multiple criteria should be considered.

As shown in figure 1.1, the ranking of MPMSs is a challenging task. These MPMSs should be compared and ranked to aid patients and other users in selecting the best MPMSs.

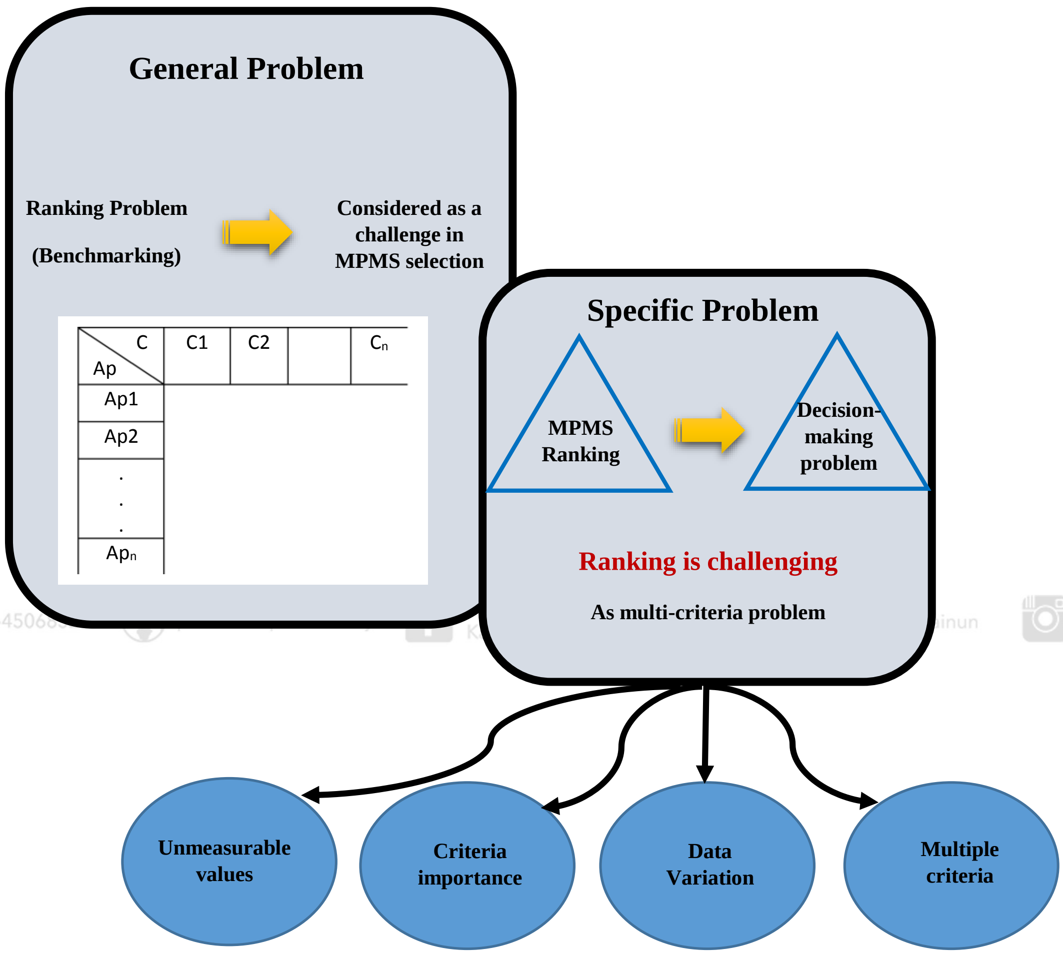

Figure 1.1. Research Problem

Many studies have attempted to evaluate and benchmark MPMSs to assist users in selecting suitable MPMS. However, their evaluation and benchmarking have focused on one or several aspects of MPMSs and neglected the rest. As shown in figure 1.1, benchmarking MPMSs is a challenging task due to multiple criteria. This task is considered a multi-criteria problem and includes the following issues.

(1) Involving multiple criteria means that each system should be evaluated by using a set of criteria based on specific aspects which must be considered during comparison. Performing an acceptable comparison that reflects all system specifications by simultaneously using all important criteria is difficult. This difficulty stems from the fact that each criterion only measures one specification of the system. For example, comparing MPMSs in terms of communication involves multiple criteria for communication in each system (e.g. extra-body area network (BAN) communication technology and back-end system (BESys) communication technology); thus, comparing those systems simultaneously according to various criteria is difficult (A. Hussain et al., 2015; V. Jones et al., 2010; Paliwal & Kiwelekar, 2013; P. Pawar et al., 2012).

(2) The importance of criteria is another issue that affects comparison becau of its tendency to vary. Thus, the researcher should determine the importance of each criterion on the basis of other criteria. Some criteria are more important than others in terms of the requirements of patients and other users. For example, wireless communication between the sensor front end (SFE) and mobile base unit (MBU) is an important criterion for patients as it gives them freedom in movement. By contrast, the extra-BAN communication protocol and technology criteria are important for specialists in terms of the quality of service (QoS) requirements and delivery bandwidth for bio-signals which are explicitly stated in some systems (Angood, Satava, Doarn, & Merrell, 2000; Gao et al., 2007; Lin et al., 2004).

(3) Data variation is another issue in comparing systems on the basis of multiple criteria (A. Hussain et al., 2015; V. Jones et al., 2010; Paliwal & Kiwelekar, 2013; P. Pawar et al., 2012). Data variation indicates that various values exist in each criterion with respect to each MPMS. As an example of data variation, the mechanism and type of communication between system components can be wired/wireless or both (V. M. Jones et al., 2008b), and the technology used in data transmission varies (bio-signal transmission). As criteria values vary from one system to another, identifying the best system is difficult (Albahri, Zaidan, et al., 2018).

(4) Unmeasurable data represent another issue in comparing systems. A comparison of systems must be based on measurable values to determine the preferences among the systems.

The comparisons carried out in the aforementioned studies do not completely reflect the performance of systems because they are carried out partially and thus fail to provide a clear picture of system operations. Thus, this condition is considered a multi-criteria problem (Kalid et al., 2018b; M. Qader et al., 2017; Yas, Zaidan, Zaidan, Rahmatullah, & Karim, 2017).

2.4 Research objectives

This section presents the objectives of our study.

1- To investigate existing technologies for ranking MPMSs in term of architecture components and highlights the weaknesses.

2- To re-present the unmeasurable values of MPMS evaluation criteria by adopting a decision matrix based on experts' opinion.
3- To determine the importance of the evaluation criteria based on the architecture components of MPMSs.
4- To develop a new framework for ranking MPMSs on the basis of the determined importance of the evaluation criteria and adopted decision matrix.
5- To validate the proposed framework.

2.5 Research questions

This section presents the study questions.

1- What is the current technology being used to compare and rank MPMSs?
2- What are the main requirements of the proposed framework for ranking MPMSs?
3- What are the current problems and issues experienced in ranking MPMSs?
4- How can the unmeasurable values of the MPMS evaluation criteria values be re-presented?
5- How can the importance of available criteria be determined?
6- What are the appropriate techniques for developing a ranking framework for MPMSs?
7- Is the proposed framework valid?

2.6 Link between research questions and objectives

This section presents the link between the research questions and research objectives.

Table 1.1

Link Between Research Questions and Objectives

Research questions	Objectives
- What is the current technology being used to compare and rank MPMSs? - What are the main requirements of the proposed framework for ranking MPMSs? - What are the current problems and issues experienced in ranking MPMSs?	To investigate existing technologies for ranking MPMSs in term of architecture components and to determine their weaknesses.
- How can the unmeasurable values of the MPMS evaluation criteria be re-presented?	To re-present the unmeasurable values of the MPMS evaluation criteria by adopting a decision matrix based on experts' opinion.
- How can the importance of available criteria for MPMSs be determined?	To determine the importance of the evaluation criteria based on the architecture components of MPMSs.
- What are the appropriate techniques for developing a ranking framework for MPMSs?	To develop a new framework for ranking MPMSs on the basis of the determined importance of the evaluation criteria and adopted decision matrix.
- Is the proposed framework valid?	To validate the proposed framework.

2.7 Significant of the study

MPMSs save patients life by avoiding the stochastic arrival of patients and service overcrowding in emergency departments (EDs) (Othman et al., 2016). Patient information is stored in these systems and can be retrieved to monitor disease progress and be remotely accessed for multi-attribute decision making during emergencies (Kim, 2014). Remote health monitoring is important to provide healthcare to patients living far from hospitals and suffering from different chronic diseases (Kalid et al., 2018b). MPMSs play an increasingly important role in healthcare and provide considerable solutions to home healthcare, real-time tele-consultation and remote patient monitoring (Varga et al., 2014). For patients, using the proper MPMS encourages them to become ‘health consumers’ looking for improved health management, provides remote health monitoring, reduces the cost of doctor visits and saves the lives of patients suffering from chronic diseases. For healthcare organisations, MPMSs reduce the stochastic arrival of patients to EDs, assist doctors in following up on patients’ progress on the basis of vital signs and store records in BEsys.

Ranking MPMSs gives patients and healthcare organisations the flexibility to select the most appropriate ones. The early identification of critically ill patients and the reduction of admissions to EDs are important improvements in telemedicine. A comparison of systems based on multiple criteria can identify suitable candidate systems for monitoring specific diseases, as in (P. Pawar et al., 2012); and the specification of the advantages and disadvantages of each system can aid in ranking, as in (Martínez-Alcalá et al., 2013). Each user has different preferences. Thus, an MPMS should be tailored to the requirements of patients and health professionals.

2.8 Scope of the study

This study focuses on the development of a ranking framework for MPMSs. Figure 1.2 illustrates the general view of the study scope which consists of three parts, namely, the research method, research type and research domain. This study is a cross-domain one that involves the MPMS field and multi-criteria decision making (MCDM). The research solves the ranking and selection of MPMSs which is an entry disciplinary problem. The research method employed is an experimental approach to benchmarking and ranking MPMSs by using MCDM methods. The expected output from this research is a framework which can be used to rank MPMSs.

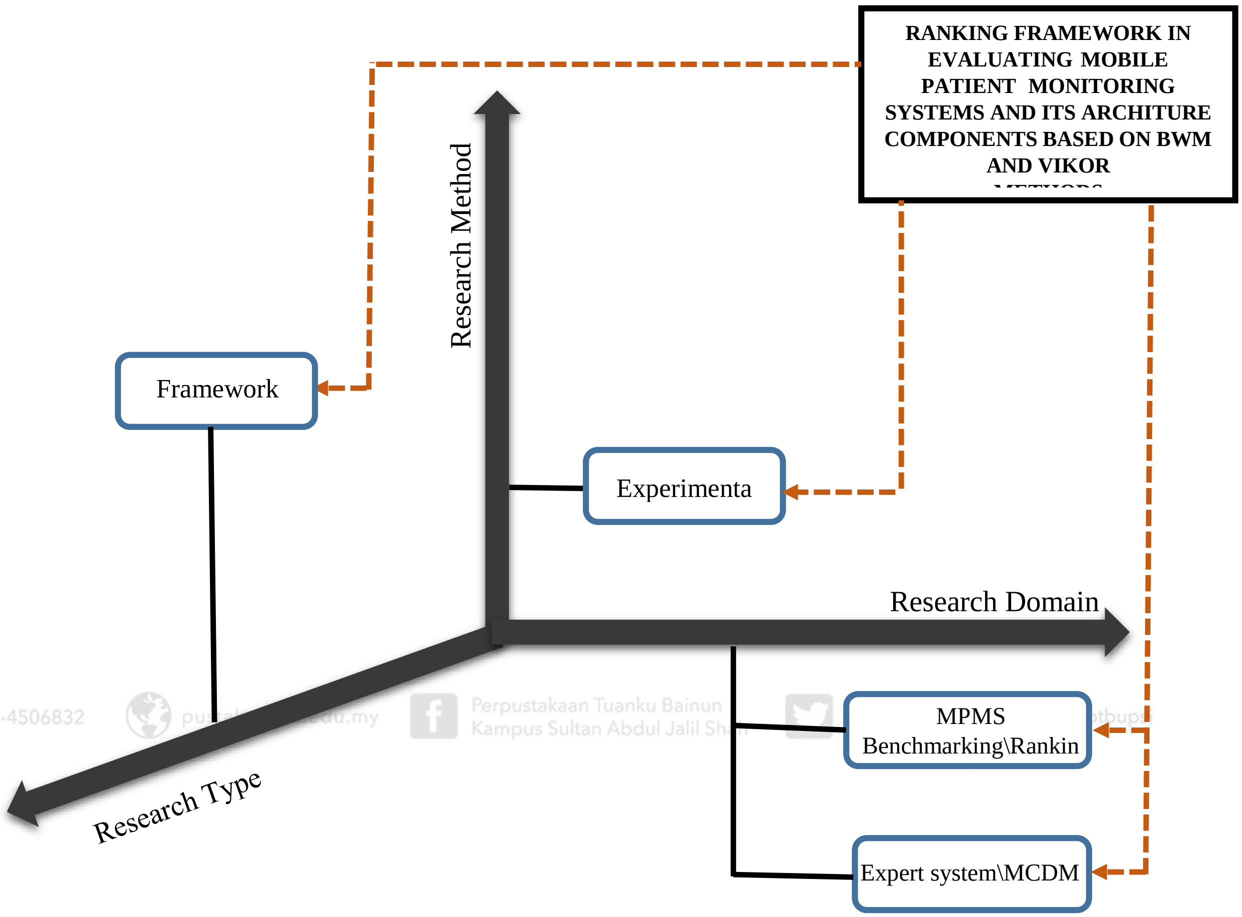

Figure 1.2. General View of the Research

Research type: Appropriate techniques are used to develop a ranking framework for MPMSs. Research method: This study is conducted to determine the evaluation criteria based on the architecture components of MPMSs. An experiment is performed by adopting the criteria data from relevant studies, re-presenting these data from experts to be mathematically accepted, a decision matrix is finally obtained. Research domain: The decision matrix is used from the mathematical and human perspectives. Two MCMD methods are used in this study to determine the weights for the evaluation criteria and to rank the MPMSs. Moreover, common MPMSs are compared by using MCDM, which is part of the expert system, to determine the best MPMS among them.

2.9 Thesis organisation

This thesis includes five chapters. Chapter 1 consists of the study background about M-health monitoring, the increasing interest in MPMSs and healthcare services, the study problem, the research questions, the research objectives and the relevance of the study.

Chapter 2 discusses the evolution of telemedicine and MPMSs, the general architecture of MPMSs and selected criteria, a critical review and analysis, challenges and open issues and the theoretical background of MCDM (recommended solution).

Chapter 3 reports the design of the research methodology and research flow. This chapter consists of five methodology phases, namely, investigation, identification and pre-processing, determination, development and validation phases.

Chapter 4 presents the results of and discussion on the proposed ranking framework for MPMSs. The results and discussion pertaining to data re-presentation, weighted criteria, ranking and validation of the proposed framework are provided.

Chapter 5 reports and explains this research’s conclusion, contributions, limitations and issues, future work and thesis conclusion.