A CAUSE AND EFFECT DIAGRAM AND FAHP BASED METHODOLOGY FOR THE SELECTION OF QUALITY IMPROVEMENT PROJECTS IN HEALTHCARE

KALİTE İYİLEŞTİRME PROJELERİNİN SEÇİMİNDE NEDEN SONUÇ DİYAGRAMI VE BULANIK AHP TEMELLİ BİR YÖNTEM

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This work named “**A Cause and Effect Diagram and FAHP Based Methodology for the Selection of Quality Improvement Projects in Healthcare”** by **AMIR SHAYGAN** has been approved as a thesis for the Degree of **MASTER OF SCIENCE IN INDUSTRIAL ENGINEERING** by the below mentioned Examining Committee Members.

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ETHICS

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ABSTRACT

A CAUSE AND EFFECT DIAGRAM AND FAHP BASED METHODOLOGY FOR THE SELECTION OF QUALITY IMPROVEMENT PROJECTS IN HEALTHCARE

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In any healthcare organization, having an appointment system which is impeccable or with fewer errors that works with the desired speed and quality is of great importance. In order to achieve such system, prioritization and correction of the under-performance causes are necessary. In this study, an integrated decision framework based on Cause and Effect Diagram and Fuzzy Analytic Hierarchical Process (FAHP) methodology for the application of organizations in project selection is proposed. The developed solution which expert opinions and domain knowledge are taken into account, may help to compare the alternative projects and evaluate tradeoffs among the different alternatives. The proposed approach is then implemented in a famous Turkish university hospital. Since the appointment system of the hospital performs poorly and causes various problems both for hospital and patients, an investigation was required. After observing existing system and making several meetings with the staff in person, administration and patients, problems which were causing the poor performance were identified. The identified causes and their sub causes were listed with the help of "Cause and Effect" diagram and then ranked by the application of FAHP method to decide the order of importance of the causes. Each bone on the cause and effect diagram serves as a project to be selected based on Six Sigma principles. The fuzzy approach is used in order to take human cognition and linguistic variables into account which the AHP method lacks. Fuzzy membership functions, triangular fuzzy numbers and fuzzy arithmetic operations are used in order to replace the AHP method and “1-9” scale. By using the obtained fuzzy weights, the causes for the hospital’s subpar performance are prioritized and solving the cause with the highest weight is recommended as the quickest solution. The same thing is done for other causes and their sub causes in terms of finding fuzzy weights and prioritization. Finally the obtained weights and priorities from both AHP and FAHP methods are analyzed and compared followed by some recommendation for future research.

Key Words: Healthcare Service Quality Improvement, Healthcare services, Project selection, six sigma, Analytical Hierarchical Processes, Fuzzy Analytical Hierarchical Processes, DMAIC

ÖZET

BULANIK AHP VE KULLANARAK PROJE SEÇİMİ: BİR HASTANE UYGULAMASI

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Kalite sistemlerinde, problemlerin tanımlanması ve süreç iyileştirmede proje seçimi Altı Sigma prensibi altında gerçekleşmektedir. Bu amaçla balık kılçığı diyagramı kullanılarak projeler tanımlanabilir. Ancak, bu yöntem ile projeler arasında bir sıralama ya da üstünlük belirlenememektedir. Bir çok kriterli karar yöntemi olan Analitik Hiyerarşi Süreci, ağırlıklandırma algoritması üzerinde durarak projelerin önceliklendirilmesine olanak tanımaktadır. Önceliklendirmede ikili karşılaştırmalar kullanılmakta ve bu karşılaştırmalar uzman görüşlerinden yararlanmılarak yapılmaktadır. Uzman görüşleri kişilerin tecrübeleri ve bireysel görüşelrine göre değişebileceğinden kesin olmayan veriler içermektedir. Matematiksel olarak kesin olmayan durumların modellenmesinde kullanılan bulanık mantık, analitik hiyerarşi yöntemi üzerinde uygulanarak subjektif görüşlerin matematiksel olarak ifade edilmesini sağlamaktadır. Bu çalışmada, randevu sisteminde sorunları olan bir hastane için çözüm önerisi bulanık analitik hiyerarşi süreci kullanılarak geliştirilmiştir. Soruna neden olan faktörler hastane yöneticileri tarafından belirlenmiş ve balık kılçığı oluşturulmuştur. Herbir kılçıktaki neden, Altı Sigma prensibine uygun olarak, çözülmesi gereken bir proje olarak ele alınmılştır. Projelerin önceliklendirilebilmesi için hastane yöneticisi ve birim yöneticilerinden görüşlerine göre ikili kaşılaştırma matirsleri oluşturulmuş ve bulanık analitik hiyerarşi süreci uygulanmıştır. Bu yöntemde uzman görüşleri 1-9 skalasında değerlendirilmek yerine bulanık sayılar olarak alınmış ve üyelik fonksiyonları kullanılarak

bulanık aritmetik işlemlerle süreç devam etmiştir. Sonuçta elde edilen bulanık ağırlıklar yardımıyla randevu sistemindeki aksaklığın nedenlerin önem sırası belirlenmiş ve ağırlığı en yüksek olan neden sorunun çözümünde en hızlı çözüme ulaştıracak neden olarak önerilmiştir. Diğer nedenler de benzer şekilde ağırlıklandırılarak önem sıralaması yapılmıştır.

Anahtar Kelimeler: Proje Seçimi, Neden Sonuç Diyagramı, AHP, Bulanık AHP, Sağlık İşletmeciliği

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SYMBOLS AND ABBREVIATIONS

Symbols

$\cap$	Intersection operator
$\cup$	Union operator
$-$	Complement operator
$\in$	Is an element of
$\notin$	Is not an element of
$\forall$	For all
$\sum$	Summation
$\mu_A(x)$	Membership degree of x in the fuzzy set A.
l	The lower bound of the triangular fuzzy number
m	Mean of the triangular fuzzy number
u	Upper bounds of the triangular fuzzy number

Abbreviations

AHP	Analytical Hierarchical Process
ANP	Analytic Network Process
CI	Consistency Index
CR	Consistency Ratio
DEMATEL	Decision Making Trial and Evaluation Laboratory
FAHP	Fuzzy Analytic Hierarchical Process
FMEA	Failure Mode and Effect Analysis
QFD	Quality Function Deployment
RI	Random Index
TFN	Triangular Fuzzy Number
TQM	Total Quality Management

1. INTRODUCTION

Lean and Six Sigma, in the past decade, have been some of the main grounds of development especially in quality analysis area of expertise [1]. The proliferation in competition for reliable, cheap, high quality products and service is proving to be irrepressible. Companies, organizations and factories are in constant exertion in order to boost the quality and work rate while trying to remain as cost effective as possible [2]. One of the main fields being affected by the rise of globalization and the recent ever-increasing vying environment is the system with the goal of decreasing service cycles and costs while bolstering patient contentment. Many challenges varying from cost-effectiveness, customer (patient) satisfaction and access, healthcare service quality to safety are the just some of the factors hindering an optimal healthcare service [3]. This can be an even bigger challenge for a populated country such as Turkey with the yearly population growth rate of 1.21 based on the data provided by “World Bank”. Many tools and methods have been proposed and discussed in the field of healthcare decision making which some of them are evaluated and reviewed by [4]. [5] Employed the analytical hierarchical process to evaluate the potential substitution of human based delivery system by mobile robots. Furthermore [6] used a combination of analytic network process and DEMATEL technique which facilitates the conclusion and prioritization of critical Six Sigma project assessment. Method such as the cause and effect diagram is used by [7] to develop a method for determining the common sense of detrimental results in an emergency department.

1.1 General Description of the Problem

Due to increased costs and requirements for high quality products and services, many new solutions for quality improvement have been investigated and implemented in both service and manufacturing industries. In today’s vying situations, deployment of an effective quality strategy is one of the key factors for a long-run business success. Montgomery and Woodall [8] characterize quality as a competitive tool that can provide a significant advantage to the organization employing its key principles. Project oriented approaches, which are the popular tools used in quality improvement, have been applied in many new programs backing continuous improvement, quality management and reengineering since 1980s [9].

Six Sigma methodology used in quality improvement, is a systematic and project oriented management strategy which comprises total quality management (TQM) philosophy, strong customer focus, and advanced data analysis tools (Linderman, et al. [10], Kwak and Anbari

[11]). Six Sigma as a project based methodology, often deploys statistical methods and scientific tools during whole project life cycle; from earlier project defining efforts until to the project closure. Since Six Sigma approach is very useful in decreasing variability, eliminating waste and improving processes, it has gained a significant popularity in the business world [8]. Furthermore, Six Sigma characteristics are used for introducing a new model for evaluating projects by using mathematical optimization modeling techniques which is proposed by [12]. Moreover [13] proposes a fish bone diagram, brainstorming and AHP method in order to eliminate the redoing and consequently reduce the wastes during production of soap. [14]Also captures the quality aspect of identifying causes for crane accident by using the fishbone diagram and analyze them quantitatively through analytical hierarchical process. Details and benefits of Six Sigma philosophy have been investigated in numerous researches and books in the literature (see for example; Pyzdek and Keller [15], Coronado and Antony [16], Harry and Schroeder [17], Hoerl [18] [19], Antony [20], and Montgomery and Woodall [8]).

For many situations in quality improvement, the question is how to implement a successful Six Sigma project. Selecting a project is a difficult but crucial issue for the effective implementation of a Six Sigma project. Project selection, referred to a multiple criteria decision making application, is a complex decision making system. Although different methodologies and approaches may be useful, less expensive or easy to implement for different situations, impact of Six Sigma methodology is usually higher than the impacts of other quality improvement methods. However, even in a Six Sigma oriented project, wrong project selection will be concluded with undesirable outcomes and an unsuccessful six sigma implementations. Kumar, et al. [21] Also stated that the main reason why a project fails is usually “wrong project selection”. This project selection can sometimes represent itself as a wrong way to approach a problem in a system.

In most cases, project selection requires optimizing more than one objective function involving maximum efficiency with minimum effort at the shortest time. Therefore, decision maker may have to use multi-criteria decision making methods to handle the situation. Various multi-criteria decision making methods such as analytical hierarchy process (AHP), analytic network process (ANP), failure mode and effect analysis (FMEA), quality function deployment (QFD) can be used in selecting projects (Kumar et al.,2008; [22] and Öztürkcan, 2010). More discussions investigating the selection of Six Sigma Projects are available in the literature (see for example; Fundin and Cronemyr [23], Antony [20], Anbari and Kwak

[24], Montgomery [9], Moorman [25], Gijo and Rao [26], and Nonthaleerak and Hendry [27]). Selection of the correct project is one of the most sensitive element in the deployment of Six Sigma. Despite the complexity of handling further steps of projects, simple-to-implement analytical tools are needed to select suitable projects for improvement among the alternatives.

In this study, an integrated decision framework based on Cause and Effect Diagram and Fuzzy Analytic Hierarchical Process (FAHP) methodology for the use of organizations in project selection is proposed. The developed solution where expert opinions and domain knowledge are taken into account, may help to compare the alternative projects and evaluate tradeoffs among the different alternatives.

The proposed approach is then implemented in a well-known Turkish university hospital. Since the appointment system of the hospital performs poorly and causes various problems both for hospital and patients, an investigation was required. After observing existing system and making several meetings with staff in person, administration and patients, problems causing poor performance are identified. These problems and their sub reasons are listed as reasons causing bad effects on appointment system with the help of Cause and Effect Diagram and then ranked with the help of FAHP method to decide the order of importance of the problems. FAHP uses a range of values to express the decision maker's uncertainty [28].

1.2 Importance of Healthcare Service Quality

In today's world many challenges in the healthcare industry such as patient access, safety, healthcare quality and cost effectiveness are being encountered which with the accelerated proliferation in healthcare, can have direct influence on countries economy as well as its norm of living [3]. In healthcare systems, managers and the personnel in service sectors, like many other businesses, are bearing the pressure of a customer driven performance in which they need to continuously improve the provided performance [22]. With the constant realization of service and product similarity by organizations and companies, the importance of comprehending the essence of service or products and the role of service quality has become an imminent pillar of success. In a developing and populated country such as Turkey the concept of healthcare service quality is without a doubt an important one with healthcare being a very crucial and critical service sector. Therefore, concluding the main problem causers and obstacles in running a smooth healthcare service system and spotting the main service quality factors can be beneficial and even critical to both service users and servers. Problems and errors are defined by [29] as the lack of success in carrying out and action as desired or the implementation of amiss plan trying to achieve a goal. [17] Improved a method in order to identify the error sources and discussed the approaches of getting rid of them by setting sights on improving the design of quality. Furthermore author's previous work proposes an AHP and cause and effect methodology in selecting projects for healthcare service quality improvement by prioritizing the problems which are needed to be solved in a cost and time effective manner [30]. [31] Discusses that leaving the bottlenecks unattended in healthcare service would lead to bigger problems such as increase in discontented patients, rise of capacity complications and bottlenecks, breach in service and the whole system not being optimal. In order to identify and then prioritize the quality service factors in healthcare, firstly the problems are identified by brainstorming and expert domain. The obtained problems and bottlenecks are used to form a cause and effect diagram. Finally analytical hierarchical process and Fuzzy analytical hierarchical process are used in this study to prioritize the problem causing bottlenecks.

AHP methodology developed by Saaty [32] [33], is a mathematics and psychology based decision making system and used to prioritize different alternatives when there are multiple criteria in the form of a hierarchy or set of joined levels. Rather than obtaining the right decision, AHP tends to find an optimum one. In order for AHP to be depicted in a more understandable and comprehensive way, Cause and effect diagram (Ishikawa [34] [35]). Also called Ishikawa or fishbone diagram- is used. The mentioned tool helps professionals to decide and classify potential reasons causing poor performance for a specific process. The diagram also identifies relationships between causes and their undesirable effects which in this paper shows the obstacles of a smooth service system in the hospital and their sub-problems.

In spite of its popularity, the AHP is often blamed due to its failure to incorporate the built-in uncertainty and imprecision related to modelling the decision-maker's judgements accurately using numbers [36].

In traditional AHP, human's acumen is represented by an exact number. However, in many pragmatic situations, the linguistic evaluation of human cognition and perceptions are vague and it is not reasonable to be represented using only terms of precise numbers. Hence, with a more confident approach in giving interval judgments compared to the fixed value judgments, the decision maker's acumen can be improved [37]. Fuzzy AHP approach adequately takes the uncertainty of the human preferences into account. Therefore, this method is more desirable and helpful in the evaluation of projects or alternatives. [22] Fuzzy set theory [38] is a mathematical theory designed to model the fuzziness of human cognitive [39]. In addition, it is designed to model the vagueness or imprecision of human cognitive processes. The main essence of fuzzy set theory is that based on [40], It possesses the advantage of mathematical delineation of uncertainty and vagueness by providing tools for dealing with the inaccuracy intrinsic to many problems [22]. It can propose a more flexible and robust model which is needed for the decision maker to understand the decision problem. These meritorious feature of the developed approach would facilitate its use in real-life and pragmatic situations for making productive decisions [37].

This paper is organized as follows: In Chapter 2, cause and effect diagram and AHP methodology, Fuzzy logic and Fuzzy analytical hierarchical processes are summarized and main properties of these tools are discussed, respectively. Integrated methodology and implementation is explained in details in Chapter 3. Since the proposed methodology is implemented in the appointment system of a hospital, a brief introduction to the quality projects in the healthcare industry is made and importance of appointment system is discussed in the beginning of Section 3.2. The proposed solutions for project selection is implemented in healthcare industry and illustrated by a real-world application in Sections 3.1 through 3.6. In addition, Analysis of implementations and results are discussed in Chapters 4 and 5 respectively followed by the depiction of results by the Sunburst diagram in Chapter 6. Finally, conclusion and future remarks are given in the Chapter 8.

2. METHODOLOGY

In this following chapter, the different parts of the integrated Cause and effect diagram and AHP and FAHP methodology will be discussed individually in details. What follows is the explanation of the Cause and Effect Diagram followed by the Analytical Hierarchical Process. The chapter is continued by Fuzzy Logic and Fuzzy Analytical Hierarchical Process.

2.1. Cause and Effect Diagram

Cause and effect diagram, also called as Ishikawa or fishbone diagram, helps professionals to decide and classify potential reasons causing poor performance for a specific process. The diagram also identifies relationships between causes and their undesirable effects. The tool became renowned by an important quality guru Kaoru Ishikawa from Tokyo University, in the 1960s (Ishikawa [34] [35]).

In cases where reasons of a poor performance are not clear, the cause and effect diagram is a very useful tool to detect and identify potential variables causing this poor performance. It is defined as one of the seven basic tools used in quality control problem solving processes [41]. It works as a brain storming method and analyzes different factors and their relationships for a specific effect or problem.

Montgomery [41] summarized construction of a cause and effect diagram in seven steps. After defining the problem to be investigated at the beginning step, potential causes of the problem must be uncovered through brainstorming and other analysis. Then, as a third step, a center line is drawn and effect box is located at the head of this line. In step four, major potential cause categories are identified and connected to the center line, respectively. After major causes are determined, possible sub-causes are defined and classified into the major categories created in step five. In step six, causes are ranked according to their importance and finally corrective action is taken in step seven.

The following example given in Figure 1, represents the basic cause and effect diagram. The diagram shaped as a fishbone; the effects are indicated on the fish head of the main bone and major causes (Cause 1-4) are shown in the branches connected to the main bone. Each of the branches represent a cause and may be divided into smaller sub-causes to enhance the detail level of the diagram. For example, Cause 1 given as a major cause in the diagram, may be detailed to 1.a, 1.b, and 1.c as its sub causes. Moreover, sub-cause 1.b may comprise more detailed sub-causes which are given in Figure 1 as cause 1.b.i and 1.b.ii.

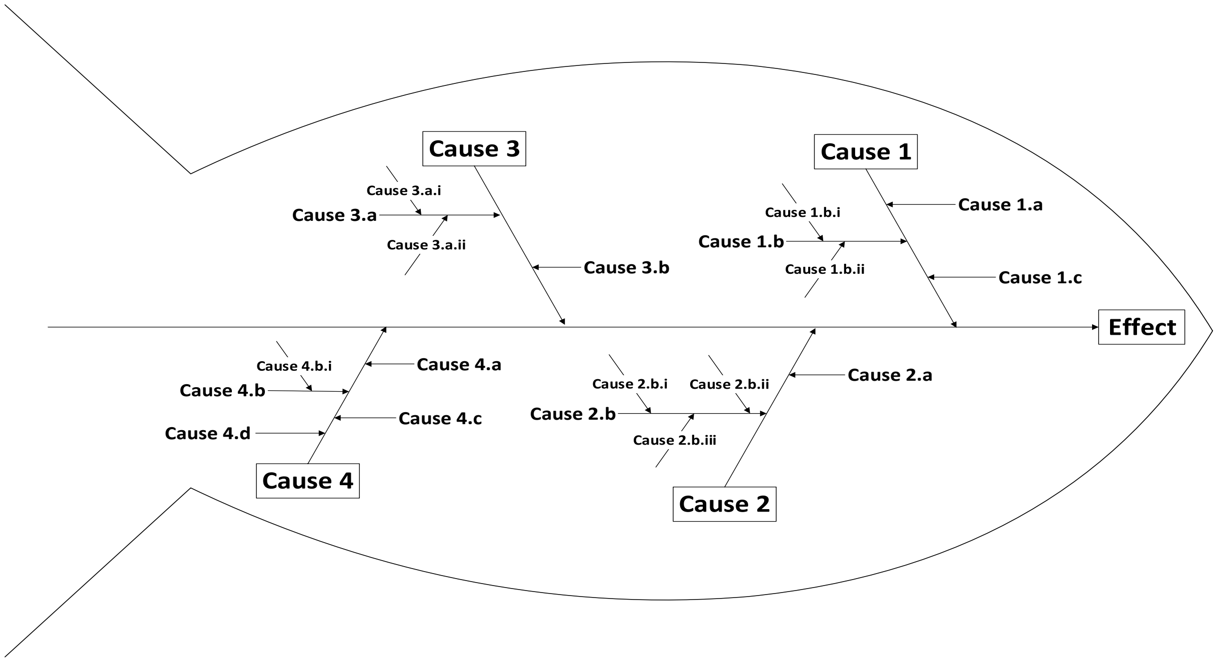

Figure 1- Basic Cause and Effect Diagram

The methodology provided in this thesis is an advanced version of the traditional Cause and Effect Diagram. As Montgomery [41] indicated, the causes shown in diagram need to be ranked in the final step according to their importance. Ranking the possible causes described in the branches of fishbone according to their importance is a difficult and very complex task. However, despite its importance, it mostly depends on the subjective observations or nonscientific methods in its present use. In this thesis, ranking causes according to their importance is advanced by integration of AHP methodology to Cause and Effect Diagram in which each cause is scored by using expert opinions in a scientific way.

2.2. Analytical Hierarchical Processes

AHP methodology developed by Saaty [32] [33], is a mathematics and psychology based decision making system and used to prioritize different alternatives when there are multiple criteria in the form of a hierarchy or set of joined levels. Rather than obtaining the right decision, AHP tends to find the optimum one. Note that, here optimum refers to the best decision in terms of the decision maker's goals and the way he/she understands the problem. The optimum decision may only be found through modeling the problem on an inclusive, analytical and realistic groundwork. More technically AHP is an Eigen value approach to the pair-wise comparison and tends to introduce a way to calibrate a numeric extend for both quantitative and qualitative performances [42]. Additionally, AHP is a good methodology to assess problem's components, represent their relationships with main goal and evaluate different solution alternatives. AHP is a popular and powerful multi criteria decision making methods for decision making that has been used for years in service quality assessment [43].

Since AHP methodology has significant advantages in project selection and prioritization techniques, it may be implemented in various fields. Hierarchical structure of AHP empowers decision makers to characterize their high level strategic objectives. Additionally, pairwise comparisons among alternatives enable decision makers to measure both tangible and intangible factors. AHP combines quantitative and qualitative applications, thus it has ability to go beyond of financial investigation. Furthermore, it allows a decision maker to adjust the corresponding significance of projects from different aspects (cost, benefits, risks etc.) and allocate their resources in an optimum way. Even for harder and more complex problems, AHP has ability to be combined with other operation research models and tends to handle multi criteria conveniently [44].

The selected strategy or project is sometimes based on the choices and decisions. The preferred project should be considered upon being the best and able to periodically and systematically optimize the decisions as the environmental conditions change in terms of the financial, operational and human resources aspects. The AHP method can help to increase benefits of the selected alternative in the project selection phase.

Three important components of the AHP methodology are defined in the following sections.

2.2.1. Problem Modeling

Based on Saaty [45], the initial step in AHP is modeling the problem as a hierarchy. The decision maker should analyze different aspects of the problem, from the most obvious and broad ones to the smallest ones. To make the problem more perceptible, these aspects then need to be connected and form a hierarchy from general to detail.

Since AHP has a hierarchical structure, it provides an increased understanding and better focus for the practitioners through its benchmark and sub-criteria structure. The process starts with structuring the hierarchical criteria and eventually leads to allocating weights to the structured hierarchy and the criteria it contains.

When AHP hierarchy needs to be established with numerous elements, the decision maker should cluster these elements to avoid extreme difference between them [46], [47] .The input element in AHP model is the result of the conducted survey of researcher or decision maker. These criteria will be quantitatively and qualitatively assessed with the hierarchical way with goals, sub-goals or alternatives [48].

In the implementation part of this research, the main causes of the problems and the underperformance of hospital are reckoned as the broadest elements in the hierarchy and by enumerating each of their sub-causes, a gradual and hierarchical move from the most general to the most detailed problems is obtained. As it will be discussed, in this research, goal part of AHP serves as the effect element in the cause and effect diagram while the sub-goals are the causes of the effect. By causes, the projects which are the causes of sub-par performance of the system to be chosen and solved are triggered. By taking a slightly different approach comparing to the orthodox AHP methodology, this study does not use the alternative part of the AHP method as the alternatives are already the causes which need to be prioritized. Details regarding to the implementation will be described in implementation section.

2.2.2. Pairwise Comparison

Pairwise comparison process is the act of comparing criteria in pairs according to certain criteria such as importance or value. The term was mentioned for the first time in [49] by Thurston. Since the method is based on a proportion extent, it does not require any measurement units for comparisons. The results of the comparisons are eventually recorded in a positive reciprocal matrix. Note that, reciprocal means dividing a number to one, for example reciprocal of *5* equals to *1/5*. Multiplication of a number and its reciprocal is resulted with *1 (5x 1/5 = 1).*

When implementing the AHP method, the results of pairwise comparisons should be recorded in a positive reciprocal matrix. Thus, in AHP, reciprocal matrices are refereed as pairwise comparison matrices [50]. Positive reciprocal matrix, or comparison matrix, is an [n x n] matrix where for every recorded value a_{ij}, there is a reciprocal a_{ji} equals to $1/a_{ij}$ $(a_{ij}>0)$ for every row *(i)* and column *(j)* in R_n^+ [51]. The comparison of importance between compared pairs is always a positive number and the assigned values in pair-wise comparison matrix are relative to each other. A reciprocal matrix is a matrix that if it is multiplied with its inverse, the result would be identity matrix [52]. Note that, the diagonal elements of the matrix are always equal to 1. An empirical 3x3 pairwise comparison matrix is given as an example in the following Table 1.

Table 1- An empirical 3x3 pairwise comparison matrix structure

	1	2	3
1	*1*	a_{12}	a_{13}
2	$1/a_{12}$	*1*	a_{23}
3	$1/a_{13}$	$1/a_{23}$	*1*

In the given comparison matrix, for example, 1, 2 and 3 is compared according to their importance for a given criteria. For example, 1^{st} is "a_{12}" as important as 2^{nd} one and since this is a reciprocal matrix, 2^{nd} is $1/a_{12}$ (as important) of 1^{st}. By using this approach, all of the criteria are pair-wise compared and the matrix is formed.

Using the transitivity rule, it is known that, for example while comparing L, M and N, if L is twice as important as M and M is twice as important as N, L would be four times as important as *N (2x2=4)*. Please remember that this rule is only valid if the matrix is completely consistent as in the given empirical comparison matrix. However, this is something that hardly ever happens due to the inconsistency in the universe. Note that a system of linear equations is called as inconsistent if it has no solutions. Otherwise, if the system has a solution, it is called as consistent. The same principle applies for matrices. As a conclusion, pairwise comparisons are required to be realized in a way that ensures consistency index (*CI*) of the comparison matrix is close to 0 as possible. Details regarding to CI will be explained in following sections.

Webber et al. [53] stated that the record orders of the comparisons to the matrix must be considered, because it may affect the successive judgments. One should keep in mind that, when the criteria which will be prioritized are not in the same scale, pair-wise comparisons should be used. Since some pairs like cost and risk cannot be compared in the same scale, pair-wise comparison facilitates decision makers' job by comparing each two criterion by their level of importance to the goal in mind.

In some special cases like currency exchange, matrices that are not reciprocal can be used [54]. The upside to this comparison is due to the fact that numerical acumen is not being used. Instead, analogous rhetorical acknowledgement and verbal appreciation, which is much more mundane and relatable to our everyday life, will do just fine.

2.2.3. Structuring the Hierarchy for Evaluation and Computing

The purpose of decision makers is to show the synergy between different factors for complicated and disorganized situations. As mentioned in previous section, using the pair-wise comparison would ease the prioritization of criteria that do not share a common scale.

All in all, one must identify one's objectives and find the answer why the problem must be solved. Then, it is necessary to define some ways to achieve the established goals. Then, regulation and setting of evaluation criteria for each of those ways should be in order. After structuring the hierarchy and constructing the pair-wise comparison matrix for each level, a nominal scale is used for the evaluation. This scale, for example, can be discrete and take values from 1 to 9 [50].

The scale that is used as a comparison tool between criteria is the level of importance of let's say *A* to *B* can be viewed in Table 2 [55]. The values in the scale have their unique meaning; for example when number *9* is assigned to the comparison of *A* and *B*, it means that A is absolutely more important than *B*. This scale is also the scale which is used during the comparisons in the implementation part of this research. Details for the implementation efforts will be explained in following sections.

Table 2 -The (1-9) scale used for comparisons in AHP

Level of importance *A* according to *B*	Comparing value
Equally important	*1*
Weakly more important	*3*
Strongly more important	*5*
Very strongly more important	*7*
Absolutely more important	*9*

As it is described in previous section, the pairwise comparison matrix is constructed according to the relative importance of one criteria over another one. In order to normalize these relative weights, each of the values in the matrix are divided by the sum of the values in the related column (a_{ij} is divided by the sum of the values in j^{th} column; for i= row, j= column).

After mentioned calculations are done for each member of the matrix, the normalized (or standardized) matrix is obtained. Note that, in the normalized matrix, the sum of each column must be equal to one. Once having the normalized matrix, the average of each row, may be referred as the Eigen vector, weights vector or priority vector, is calculated. Based on these averages, the importance of each row can be determined [50].

As mentioned previously, after obtaining the importance of criteria by using above calculations, one needs to check the consistency. The consistency of the result should be checked by first finding the principal Eigenvalue (λ_{max}) and then calculating the Consistency Ratio (*CR*) using the following steps [56]:

1. First step is multiplying the pair-wise comparison matrix [n x n] (not normalized one) by the priority vector *[n x 1]*.
2. The second step follows by dividing the elements of resulted matrix by the elements in respected rows of the priority vector.
3. The average of the elements in the final matrix would give λ_{max}.
4. After obtaining λ_{max}, the equation 2.1 should be used to calculate Consistency Index (*CI*). Note that (*n*) represents the size of [*n x n*] comparison matrix.

$$CR = \frac{\lambda_{MAX} - n}{n-1} \tag{2.1}$$

5. Eventually the consistency ratio (*CR*) is resulted by dividing the *CI* to the random index (*RI*), see the equation 2.2.

$$CR = \frac{CI}{RI} \tag{2.2}$$

The upper bound for pairwise comparison matrix to be considered as compatible is indicated by Saaty [57]. Saaty [32] calculated the RI values as given in the following Table 3. The value for *CR* should not go over 0.1 for matrices larger than *4x4*, see the following for the upper bound values of compatible pairwise comparison matrices. One who need RI values may use this table as a reference.

Table 3-Reference RI values calculated by Saaty [32]

n	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	*0.58*	*0.90*	*1.12*	*1.24*	*1.32*	*1.41*	*1.45*	*1.49*

2.2.4. Disadvantages Pertaining to AHP

Although the analytical hierarchical process has many benefits such as its capability in construction of problems possessing various attributes, it should be mentioned that this method possesses some deficiencies. One of the first weak points which comes to mind is that the data required for this method needs experience, judgement and knowledge and is subject to be labeled as idiosyncratic according to each project or situation. Furthermore, the implementation of AHP does not concern factors such as risk or uncertainties pertaining to the investigated performance [58]. Another deficiency concerning the AHP can be related to its artificial limitations of the use of the 9 point comparison system. This can turn into an arduous burden for the decision maker as distinguishing and comparing the importance of alternatives can sometimes prove to be a daunting task. Based on the study done by the author prior to this research, the AHP method was used to find the causes of underperformance of Hacettepe University Hospital [59]. In order to mitigate some of the problems related to the AHP method and improve the decision making done in this research by encompassing the importance of uncertainty and risks, the Fuzzy *AHP* method is further investigated in order to give a more comprehensive and intelligible result. The fuzzy logic and its applications in the healthcare system are discussed in the coming chapter.

2.3. Fuzzy logic

As mentioned in the previous chapters and based on [36], *AHP* is often reprimanded due to its lack of success in infusing the innate uncertainty and imprecision related to the decision-maker's intuition in a precise way by using numbers. Fuzzy *AHP* approach adequately handles the uncertainty of the human preferences; this method is more desirable and helpful for evaluation [22].Since fuzziness is a common characteristic of decision-making problems, the FAHP method was developed in order to address the problem of capturing the notions which AHP lacks [60].Hence, it allows decision-makers to express approximate or flexible preferences by using fuzzy numbers where adding fuzziness to the input, implies adding fuzziness to the judgment [61].

Fuzzy set theory [38] is a mathematical theory designed to model the fuzziness of human cognitive [39]. The characteristic function of a classical (non-fuzzy) set appoints either *0* or *1* to each particular member of the universal set acknowledging each of them as members or non-members. As a result of the generalization of the mentioned characteristic function, the mentioned elements of the universal set fall inside a particularized range. This means that instead of the absolute 0 and 1 membership assignment, elements can now have membership grades with the larger values possessing higher grades of the set membership (membership function) [62]. The membership function $\mu_A(x)$ of a fuzzy set operates over the range of real numbers, generally scaled to the interval [0, 1]. If the value assigned is one, the element belongs completely to the set (it has total membership) and if it is zero, it demonstrates the complete non-membership statue of the element to the set. Finally, if the value lies within the interval, the element has a certain degree of membership (it belongs partially to the fuzzy set) [63]. In other words in fuzzy set theory, each element is membership in fuzzy set up to a degree [64]. Equation (2.3) shows the membership equation of $\mu_A(x)$ based on crisp set theory.

$$\mu_A(x) = \begin{cases} 1 & if \quad x \in A \\ 0 & if \quad x \notin A \end{cases} \tag{2.3}$$

As an example, consider the waiting times for a healthcare service by the patients. One might consider that waiting for less than 10 minutes is "Acceptable". This consideration can be shown as "$Acceptable = \{x \mid x \leq 10\}$" which is shown as a classical set in Figure 2.

Figure 2-Membership function for the set "Acceptable waiting time"

Compared to the conventional set theory, Fuzzy set theory is designed to model the ambiguity or inaccuracy of human cognition. Fuzzy set theory is essentially a generalization of set theory where the classes lack sharp boundaries [65]. Continuing the healthcare service example, a waiting time of 11 minutes can also be considered "Acceptable" according to the fuzzy set methodology with a lesser degree of membership than 10 minutes waiting time. The 11 minutes waiting time would be have been a "0" in terms of membership degree in the classical crisp theory which meant that 11 minutes of waiting time is not “Acceptable at all”. As it can be seen in Figure 3, 11 minutes of waiting time is considered as a member with lesser degree of membership (2.4).

$$\mu_{Acceptable}(x = 11) = 0.85 \tag{2.4}$$

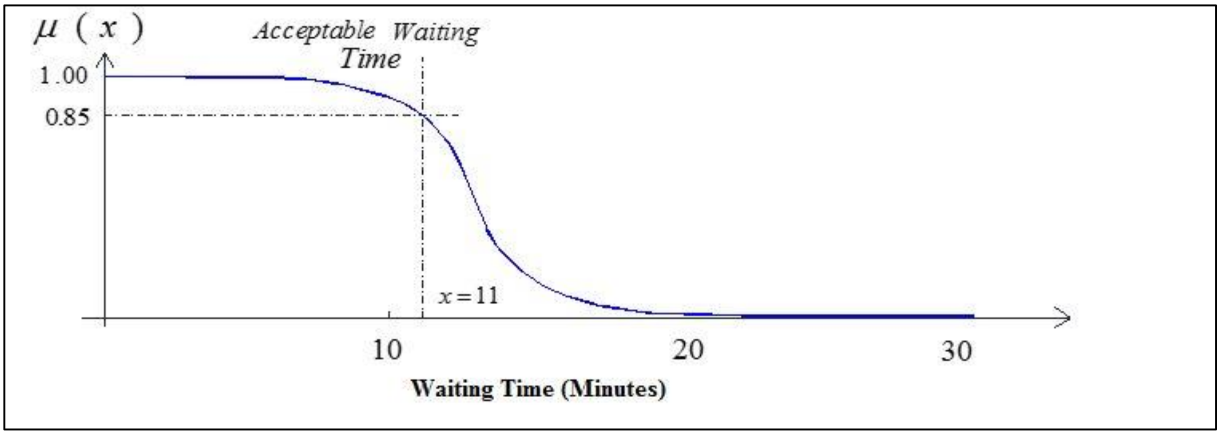

Figure 3-Membership function for the fuzzy set “Acceptable waiting time”

The decision-maker is free to select a range of values that reflects his confidence. Alternatively, he can specify his attitude in general terms as optimistic, pessimistic or moderate, representing high, low, and middle ranges of values respectively [66].An expert’s uncertain judgment can be represented by a fuzzy number.

A triangular fuzzy number is a special kind of fuzzy number whose membership function is defined by three real numbers (*l*, *m*, *u*). This membership function is illustrated in Figure 4 and described mathematically in Equation (2.5) [67].

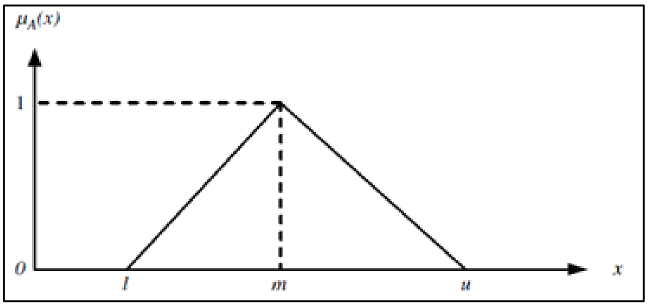

Figure 4-Fuzzy triangular number *A*= *(l, m, u)*

Thus, *l*, *m*, and *u* are the lower, mean and upper bounds of the triangular fuzzy number. The membership function μ (shown in equation 2.5) represents the degree to which any given element *x* in the domain *X* belongs to the fuzzy number A.

$$\mu_A(X) = \begin{cases} \frac{(x-l)}{(m-l)}, & 1 \le x \le m \\ \frac{(u-x)}{(u-m)}, & m \le x \le u \\ 0 & Otherwise \end{cases} \tag{2.5}$$

Another important concept in understanding the fuzzy logic is the "Linguistic variable" term which was introduced by [68]. This term is used when linguistic expressions are used as values instead of numerical values such as "Acceptable waiting time" in the healthcare service example as shown in Table 4. Other linguistic expressions for the mentioned example can be "Moderately Acceptable", "Slightly Acceptable" and "Unacceptable" each of them having their own membership functions. Although these terms are rather abstract, one might interpret them as the Table 4.

Table 4-*Linguistic expressions for the healthcare service example*

Linguistic Expression	Condition
Acceptable	Waiting time of under 10 minutes
Moderately Acceptable	Waiting time of about 15 minutes
Slightly Acceptable	Waiting time of about 20 minutes
Unacceptable	Waiting time of over 25 minutes

For instance the membership functions of "Moderately Acceptable" and "Slightly Acceptable" are shown with Equations (2.6) and (2.7) respectively:

$$\mu_{ModeratelyAcceptable}(x) = \begin{cases} 1 - \frac{|x-15|}{5} & if \quad 10 < x < 20 \\ 0 & Otherwise \end{cases} \tag{2.6}$$

$$\mu_{SlightlyAcceptable}(x) = \begin{cases} 1 - \frac{|x-20|}{5} & if \quad 15 < x < 25 \\ 0 & Otherwise \end{cases} \tag{2.7}$$

As it can be understood from the functions, waiting time of “19” minutes is partially present in both membership functions. By using the (x=19) in both functions; $\mu_{ModeratelyAcceptable}(x=19)=0.2$ and $\mu_{SlightlyAcceptable}(x=19)=0.8$ are resulted. This means that waiting for 19 minutes can be 20% as “Moderately Acceptable” and 80% as “Slightly Acceptable”.

The main fuzzy operations are defined by [38]. Here a summary of the basic fuzzy operations is given.

If we assume $A=(l_1, m_1, u_1)$ and $B=(l_2, m_2, u_2)$ as triangular fuzzy numbers, the basic arithmetic and functions between the two mentioned numbers can be depicted as follows (Equation (2.8) through (2.17)):

-Inverse:

$$A^{-1}=(\frac{1}{u_1},\frac{1}{m_1},\frac{1}{l_1}) \tag{2.8}$$

-Addition:

$$A+B=(l_1+l_2, m_1+m_2, u_1+u_2) \tag{2.9}$$

-Subtraction:

$$A-B=(l_1+u_2, m_2-m_1, u_1-l_2) \tag{2.10}$$

-Multiplication:

$$AB=(l_1l_2, m_1m_2, u_1u_2) \tag{2.11}$$

-Multiplication by scalar “k”:

$$\forall k>0, kA=(kl_1, km_1, ku_1) \tag{2.12}$$

$$\forall k<0, kA=(ku_1, km_1, kl_1) \tag{2.13}$$

-Division:

$$\frac{A}{B} = (\frac{l_1}{u_2}, \frac{m_1}{m_2}, \frac{u_1}{l_2}) \tag{2.14}$$

The intersection of two membership functions (Represented by 'AND') such as A and B is defined by:

$$\mu_{A \cap B}(x) = min\ [\mu_A(x), \mu_B(x)] \tag{2.15}$$

The union operation (OR) is represented by:

$$\mu_{AUB}(x) = max\ [\mu_A(x), \mu_B(x)] \tag{2.16}$$

Furthermore the operator showing complement (NOT) is formulated as:

$$\mu_{\bar{A}}(x) = 1 - \mu_A(x) \tag{2.17}$$

Formulas 2.15 to 2.17 are shown depicted in Figure 5 taken from [69].

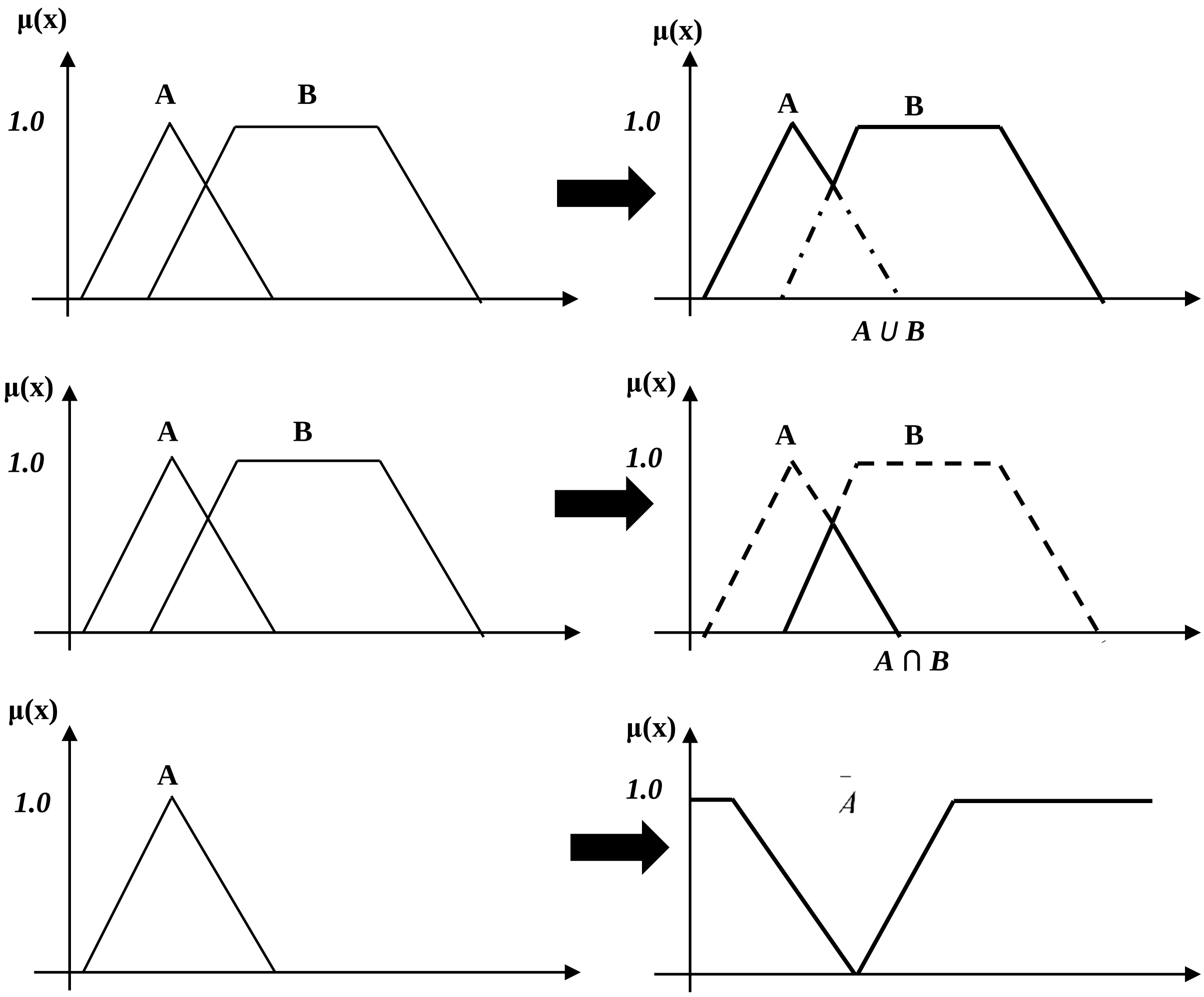

Figure 5-Union, intersection and complement arithmetic functions for fuzzy sets [69]

2.4. Fuzzy AHP (FAHP)

As it has been mentioned in this study, despite the fact that the *AHP* method is developed to capture the way a person and in most cases an expert thinks, it still cannot grasp the vagueness existing in the way human think. As a solution or improvement, the extension of the *AHP* method which is its combination with the fuzzy sets theory is developed and studied by different authors such as [44]. Many *FAHP* methods based on triangular fuzzy numbers have been proposed [70].

Van Laarhoven and Pedrycs [71] proposed a comparison method which uses fuzzy numbers with triangular membership function to represent the fuzzy comparison judgement. This study was later continued as [72] developed the method with trapezoidal membership function. *FAHP* uses a range of values to express the decision maker's uncertainty [28].

Chang [73] innovates a new method which uses the triangular membership function to form fuzzy comparison matrices which leads to the extent analysis of the comparison matrix. Other researches such as [74] which the acquirement of AHP weights and fuzzy weighted analysis is done by a fuzzy subjective and objective method. Kahraman [75] uses the FAHP multi attribute comparison of catering companies in Turkey providing the most customer satisfaction. This was done based on interviewing customers about the deciding attributed on which they choose these firms. Moreover in this research the means of triangular fuzzy numbers obtained by opinions of experts and customers are used in comparison matrices. More healthcare driven use of the fuzzy analytical hierarchical process method is used by [22] in which the service quality of healthcare system is analyzed and the proposed service quality framework is evaluated by the aforementioned method. Moreover FAHP and its derivatives are used by [76]as a method deciding the potential site of a hospital. A FAHP approach for determining the weight significance of customer needs in the use of quality function has been proposed by [77] while [78]uses the approach which targets the decisions which are made by a group when thorough information is absent by the use of triangular fuzzy analytical hierarchy process and geometric operations and taking it to practice by applying it to small hydropower investment project selection. Another use of *FAHP* in project selection was studied in [79] where the constraints which should be taken into account in *FAHP* are the core of concentration in order to reach a reliable system. Sensitivity analysis for the allotment of nonprofit systems' performance is the main focus in [80] where a computational method is proposed in order to aid the decision makers in evaluating the organizational service quality for both academic and commercial aims.

In what follows, the steps of this used method [81] are shown and explained. By letting the object set "*X*" as $X = \{x_1, x_2, ..., x_n\}$ and goal set as $U = \{u_1, u_2, ..., u_m\}$ and according to the aforementioned method, analysis is done for each goal which is "g_i" resulting in m extent analysis for each member of the set demonstrated as equation (2.18) (note that $M_{g_i}^{y}$ *(y=1,2,…,m)* is a triangular fuzzy number.)

$$M_{g_i}^{1}, M_{g_i}^{2}, ..., M_{g_i}^{m} \quad i = 1,2,..., n \tag{2.18}$$

The procedure according to Chang's extent analysis is as Equation (2.19):

$$S_i = \sum_{j=1}^{m} M_{g_i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j}\right)^{-1} \tag{2.19}$$

The value of $\sum_{j=1}^{m} M_{g_i}^{J}$ is calculated by applying the fuzzy addition rule for a specific matrix such that meet the following criterion as shown in equation (2.20):

$$\sum_{j=1}^{m} M_{g_i}^{J} = \left(\sum_{j=1}^{m} l_j , \sum_{j=1}^{m} m_j , \sum_{j=1}^{m} u_j \right) \qquad (2.20)$$

And the value of $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j}\right)^{-1}$ is calculated by following the fuzzy addition rule of $M_{g_i}^{j}$ (j=1, 2, …, m) according to Equation (2.21).

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{i=1}^{n} l_i , \sum_{i=1}^{n} m_i , \sum_{i=1}^{n} u_i \right) \qquad (2.21)$$

And eventually in the last part of the first step the inverse vector of the previous equation is calculated by Equation (2.22):

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i} , \frac{1}{\sum_{i=1}^{n} m_i} , \frac{1}{\sum_{i=1}^{n} l_i} \right) \qquad (2.22)$$

In the Second step of the Chang's extent analysis method the degrees of possibility should be calculated. Based on this method, $M_1 = (l_1, m_1, u_1) \geq M_2 = (l_2, m_2, u_2)$ is delineated as Equation (2.23):

$$V(M_1 \geq M_2) = \sup_{y \geq x} [\min(\mu_{M_1}(x), \min(\mu_{M_2}(y))] \qquad (2.23)$$

Which would lead to the calculation of $V(M_1 \geq M_2) = hgt(M_2 \cap M_1) = \mu_{M_1}(d)$ by Equation (2.24):

$$\begin{cases} 1, & if \quad m_1 \geq m_2 \\ 0, & if \quad l_2 \geq u_1 \\ \dfrac{l_2 - u_1}{(m_1 - u_1) - (m_2 - l_2)}, & Otherwise \end{cases} \qquad (2.24)$$

In Equation (2.24), "d" is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2} (Figure 6). In order to be able to compare M_1 and M_2, both of the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$ should be obtained.

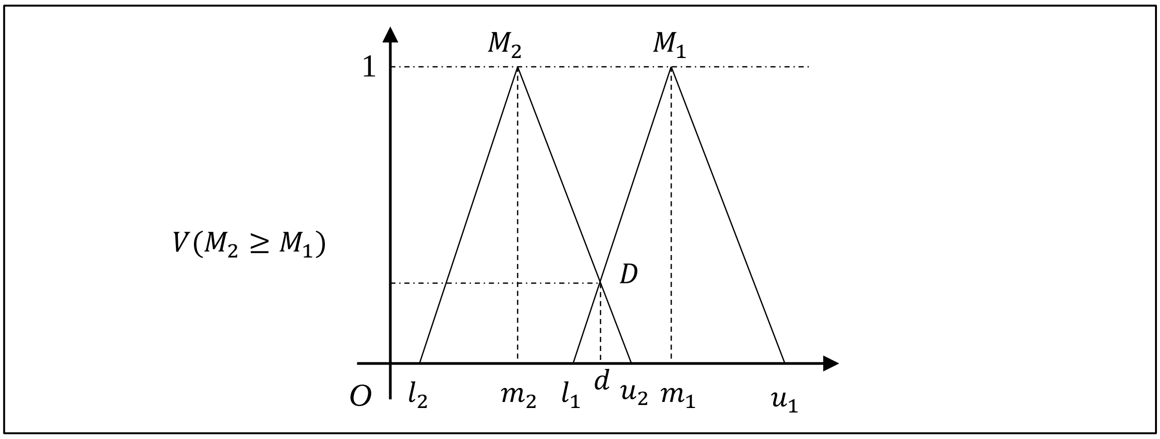

Figure 6-Degrees of possibility between μ_{M_1} and μ_{M_2} *[73]*

In the third step of the method, the degree possibility for a convex fuzzy number in order to be greater than k convex fuzzy numbers *Mi* = $V(M \geq M_1, M_2, ..., M_K)$ for (*i=1, 2, 3,…, k*) is delineated by:

$$V[M \geq M_1) and (M \geq M_2) and ... and (M \geq M_K)] \quad (2.25)$$

And would lead to Equation (2.26):

$$\min V(M \geq M_i), i = 1,2,3,...,k \quad (2.26)$$

By assuming that for *j=1, 2,…, n;* $j \neq i$*:*

$$d'(A_i) = \min V(S_I \geq S_j). \quad (2.27)$$

The weight vector is obtained by Equation (2.28):

$$W' = (d'(A_1), d'(A_2), ..., d'(A_n))^T, \quad (2.28)$$

Where A_i *(i=1, 2,…, n)* are elements. In the final step the normalized vectors are obtained through normalization by Equation (2.29):

$$W = (d(A_1), d(A_2), ..., d(A_n))^T \quad (2.29)$$

The result of the normalization for ”*W*” is a non-fuzzy number.

3. IMPLEMENTATION

As stated before, cause and effect diagram compiles both the main and sub-causes together. In project selection, in order to achieve the fastest and the most effective solution for the problem, the most important reason causing the case should be determined. Although a well conducted cause and effect diagram will present the major and sub-causes, any superiority among them will not going to be included Therefore, the cause from which to begin should be decided. If we were able to conduct a cause and effect diagram including the superiorities, we would select the most important project related to solution and we would start from this project(s) to accelerate the result.

3.1. Development of Integrated Cause and Effect Diagram and FAHP Based Methodology

Dagger et al. [82] defines some criteria for the evaluation of healthcare services and defines the criterion “Responsiveness” as readiness and eagerness to grant accurate and dependable services and aids to customers. Moreover Lee and Yom [83] states another criterion as “Timeliness” which refers to delivering the guaranteed services on schedule as well as the ability of organizing the medical services such as appointment waiting list and waiting time and facile changeability of appointments and operation schedules.

A hospital should be responsive to the problems they are facing and willingly come up with a solution in order to smoothly serve its customers [84]. Another demanding topic in Healthcare quality and appointment system is the collaborative transmission of information between hospital staff and customers defined as “empathy” [85]. Based on literature audits the other criteria determining the quality in healthcare are “tangibles” which consist of physical equipment and accessibility of the hospital [86], “Reliability” which refers to delivering the guaranteed service attentively and meticulously (for example diagnose of disease or veracity of the cost of service), “assurance” and “professionalism” [87].

In this study, firstly, on the basis of expert or domain expert opinions, the weights assigned to each cause is determined using the *AHP* method, considering that the main causes (main bones of fish) can be appropriately compared by hospital managers, where for sub-causes more domain experts should be consulted. *AHP* is mostly used to compile subjective opinions of experts, depending on their own experiences or aspects via pairwise comparison matrices. Once calculating the weights as given in Section 4, the weights of main comparison matrix are placed on main bones of the diagram, then the calculated sub-causes' weights under each main criteria are placed on associated bones. Therefore, determined main and sub-causes with their weights are presented on a fishbone diagram at once. Afterwards, considering completely the main and sub-bones, associated weights are ranked in ascending order, to determine the highest weight which identifies the most important cause.

Secondly, in order to take a more pellucid approach into account, the fuzzy analytical hierarchical method is applied on the collected data. The *FAHP* method is applied to capture (even small amount) of human cognition in order to potentially give more justifiable and comprehensive results both in improving the quality of the appointment system in hospital and being more cost effective in dealing with the problems causing the underperformance of the hospital. Although having a deep understanding of processes, demography, governments, providers, payers and organization is needed to enumerate all of the problem causing bottlenecks, the *FAHP* gives an intelligible account of the main problems which are prioritized by experts opinion and the Fuzzy analytical hierarchical method. Lastly the most problem causing bones and sub-bones of the fishbone diagram are identified in a more perceivable fashion.

3.2. Implementation of the Proposed Project Selection Methodology

Since the quality of healthcare services is directly related with the health status of humans, improvements of healthcare processes have gained a significant importance and have become a major field for researchers [85]. Although Six Sigma projects are originated from and common in the manufacturing world, interest to their applications have also increased in service industries such as healthcare management recently [20].

There are many application areas of process improvement in healthcare; such as flow of patients in hospitals, appointment systems, medication processes, medication quality improvement, billing processes and maintenance processes [3]. For Six Sigma projects, appointment systems are one of the major considerations of organizations delivering healthcare services. Modelling the appointment systems, detecting reasons of poor performance, identifying possible improvements, and implementing new solutions are the main research topics related with appointment systems. By common belief, the physician's time is more valuable than a patient's time. Consequently, the appointment systems have been often designed to minimize physicians' idle time overlooking patients' waiting time.

Long waiting times for treatment in the outpatient (a patient who attends a hospital for treatment without staying there overnight) department followed by short consultations has long been a complaint. This is not an acceptable application in today's consumer oriented society. Nowadays, customers use waiting time as a decisive factor in choosing a service provider [88].

3.3. Deployed Strategy

The proposed project selection methodology is implemented at a well-known university hospital, in Turkey. Here, appointment system as a major problem for hospital administration is considered. Figure 7 shows the strategy deployed for implementation efforts.

First, the reasons of poor performance were investigated and potential reasons were defined as alternative Six Sigma Project topics. Then, the developed Cause and Effect and AHP Integrated Methodology was implemented in poor performing appointment system of hospital to rank these identified alternatives according to their importance.

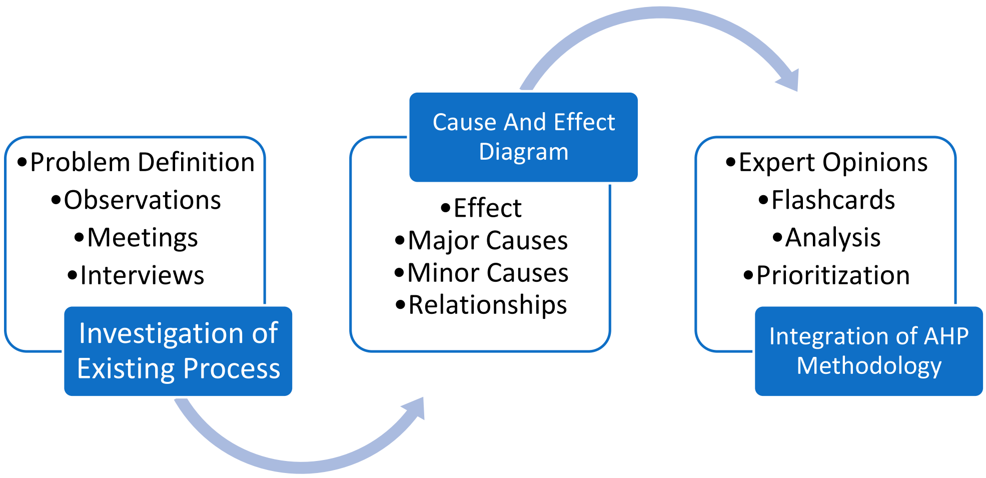

Figure 7 - Deployed Strategy for the Implementation Efforts

In the first steps of the implementation efforts, problems of the appointment system causing poor performance were investigated in details through observations, meeting with administrative departments, and face to face interview with staff had roles in appointment process. In the second step, all the identified causes and their relationships, both for major and minor ones, are described with Cause and Effect Diagram. The next question was challenging, how to begin a Six Sigma project. Since each cause has its own requirements and may be defined as a Six Sigma project topic itself, there was a requirement for a scientific method which may help to prioritize causes. This prioritization could help to define the orders of separate Six Sigma projects according to the importance from the University Hospital administration. *AHP* which is a methodology that has been used several time in healthcare and medical decision making field, was selected as a proper tool for prioritization. During *AHP* efforts, major and minor causes are evaluated based on the gathered information from domain experts and hospital administration. Instead of using surveys, an information flashcard system is developed and used during information collection. Prioritizations for Six Sigma project topics are obtained after analyzing the collected data through AHP based calculations. Finally, AHP results and Cause and Effect Diagram are integrated in a new diagram and reports are presented to the hospital administration.

Following the results of the AHP, the fuzzy approach of the mentioned process is implemented. As it can be seen from figure 8, almost all of the steps for the deployment of the implemented efforts are the same with the difference of the fact that the integration is done by the cause and effect *FAHP* methodology. The integration part of the methodology consists of the including the decision vagueness for the data which have been gathered in the meetings and interviews in order to give a closer sense of understanding in terms of human cognition. In this step of the implementation, the data collected for the *AHP* methodology are translated into the triangular fuzzy scale and then the results which are obtained by the algorithm discussed in the "*FAHP*" part are prioritized and analyzed, respectively. In addition, the results obtained in both methods are compared.

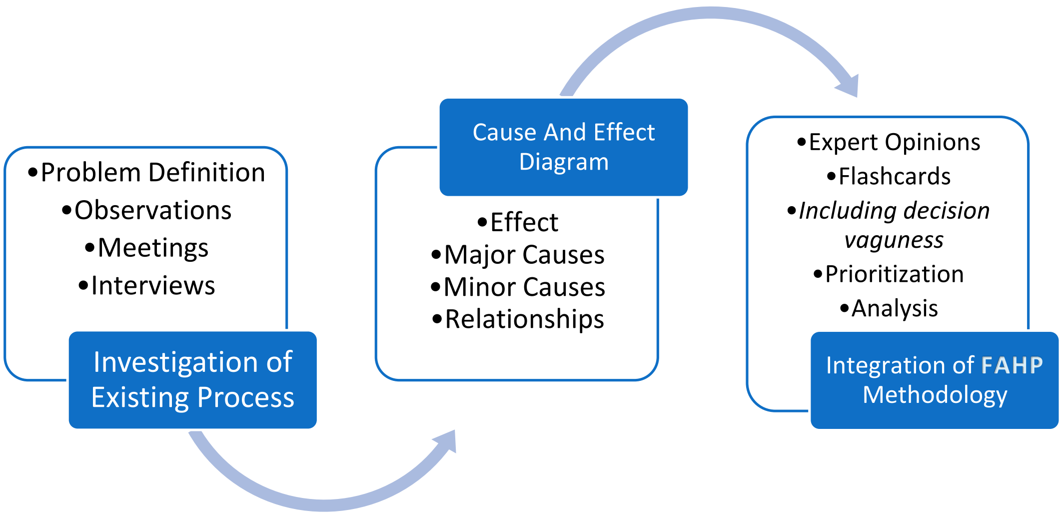

Figure 8- Deployed Strategy for the FAHP Implementation Efforts

Details regarding to the implementation efforts and results will be described in the following

3.4. Investigation of Existing Appointment System

First of all, existing appointment system was investigated in order to define the problems and observe how and why appointment process performs poor. After realizing initial observations and identifying poor performance, the causes of the poor performance were investigated trough detailed observations, meetings with hospital administration, and interviews with hospital staff. The problems of the appointment system were discussed and revised numerous times by considering suggestions and requests of experts which are basically hospital administration and staff.

Appointments are given through department secretaries or via call center of the hospital. Patients can schedule appointments through secretariats, by call or by directly visiting the relevant departments. Although an online appointment system has just been developed in the hospital, it was not in use during the time this study was conducted, due to the final adjustments.

The patients who prefer scheduling their appointments through the call center, are mostly complaining about accessibility problems. Although accessibility seems as the most obvious problem, there may be many additional factors that increase the poor performance. Responsiveness means willingness to help customers and provide prompt service accurately and consistently [84], is a really critical factor in determining the competency of a health-care system performance. From responsiveness point of view, the fact that there are hefty amount of issues surrounding the appointment system and the attainability of appointments by customers at an accurate and constant rate, is a testament to system underperforming. To add to that, timeliness is also an issue in this system as the lengthy waiting list and challenges of changing appointment times or canceling them are just more proof of the system's underperformance. These reasons among others can cause great amount of customer dissatisfaction and unsuccessful medical results. If patients which are unsuccessful in obtaining an appointment time have other options and are capable financially, they will consider other options and if financially incapable then wait is their only option which can have undermining results.

3.5. Implementing Cause and Effect Diagram

After a comprehensive investigation was accomplished with the help of hospital administration and domain experts, all the potential problems were identified and categorized under the following six main suspects: Capacity Problems, System and Connection Problems, Equipment Problems, Staff problems, Patients' Non-attendance, and During Appointment Problems. Moreover, major causes are more detailed with the identified several sub causes. The main causes and their relationships are presented through the traditional Cause and Effect Diagram given in Figure 16.

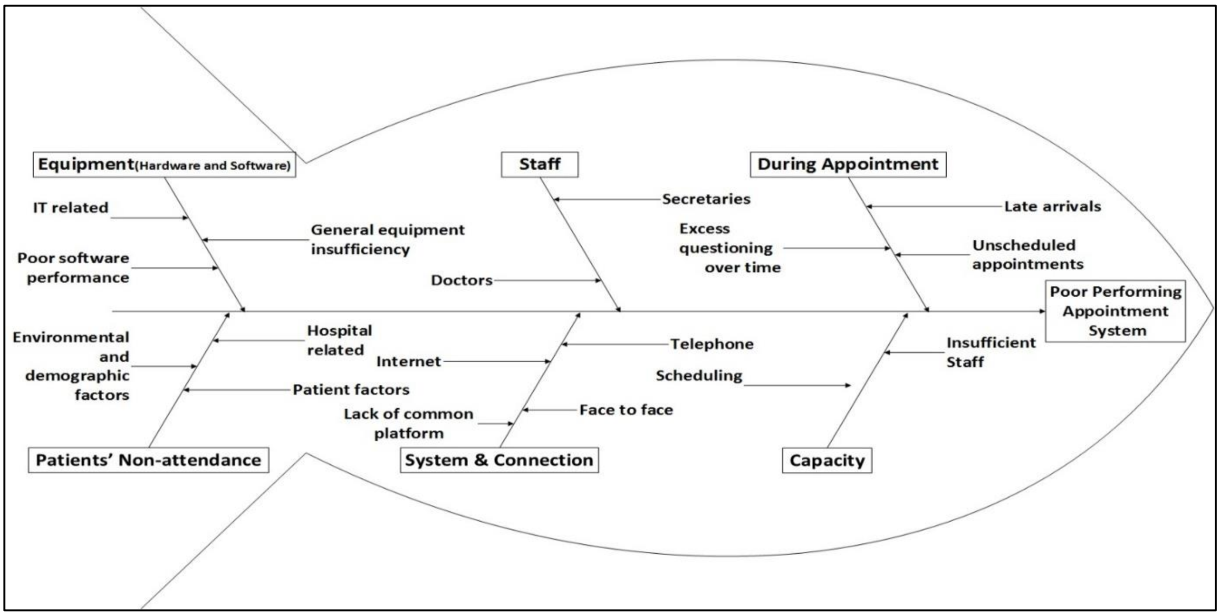

Figure 9-Two level cause and effect diagram for the appointment system

A two level version of the complete diagram is shown in Figure 9. The sub-causes for each bone can be seen in detail in Figures 10-15:

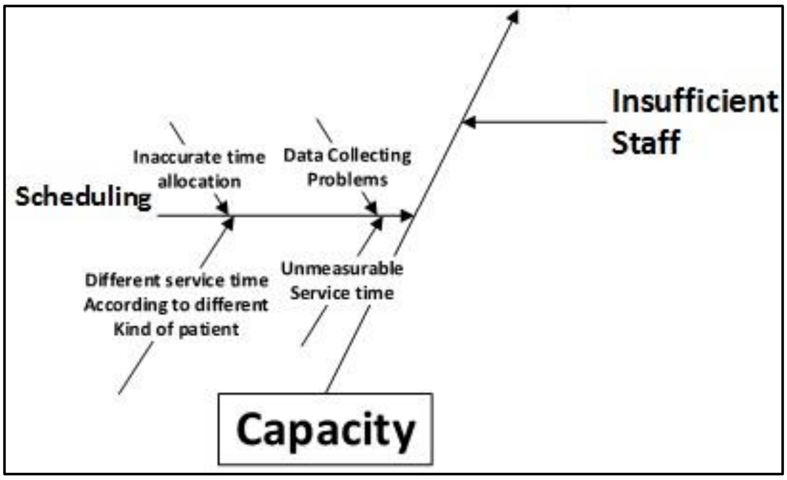

Figure 10-Capacity sub-causes

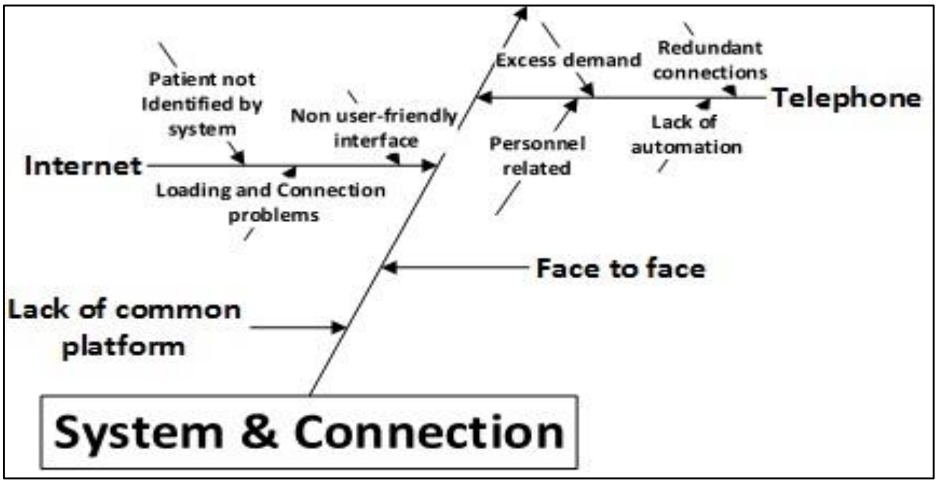

Figure 11-System and Connection sub-causes

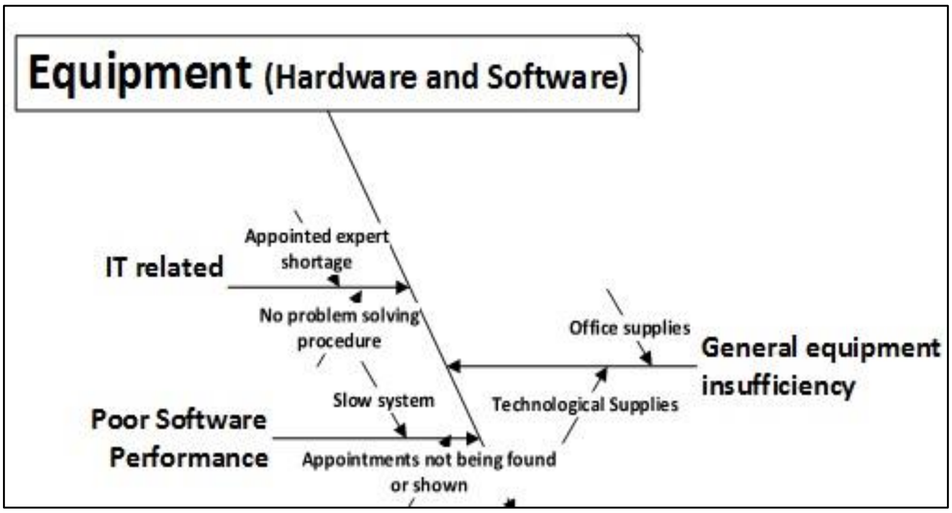

Figure 12- Equipment sub-causes

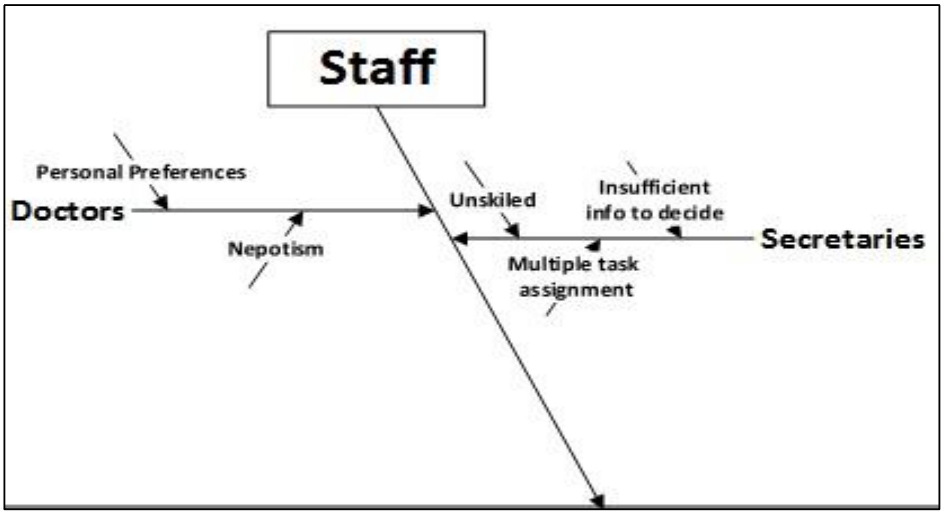

Figure 13-Staff sub-causes

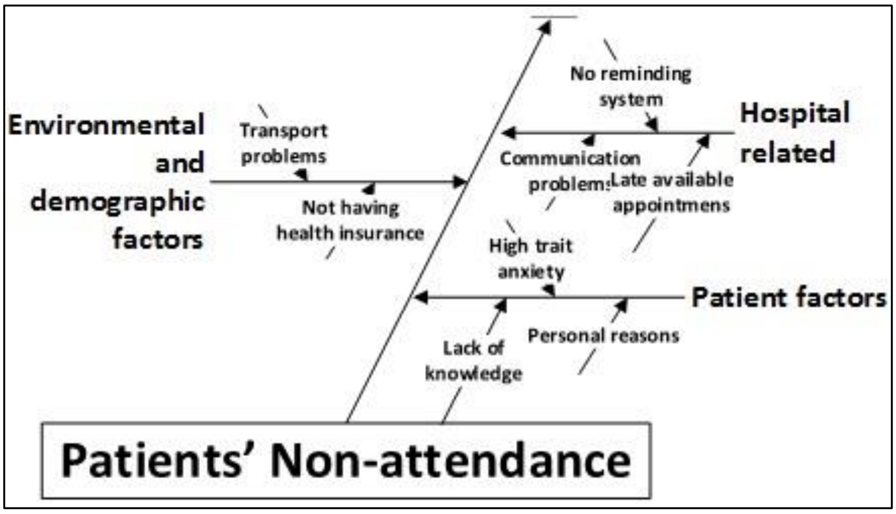

Figure 14- Patients' Non-attendance sub-causes

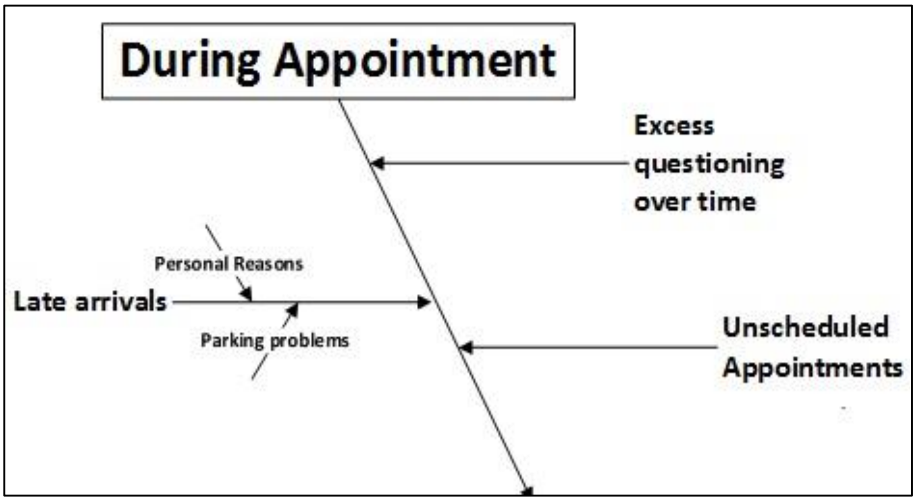

Figure 15-During appointment sub-causes

The complete cause and effect diagram as mentioned, is shown is Figure 16 but due to the limitations of the papers' space and the lack of clarity due to the shrinkage of the figure, it was as illustrated cut down to smaller parts and shown in individually.

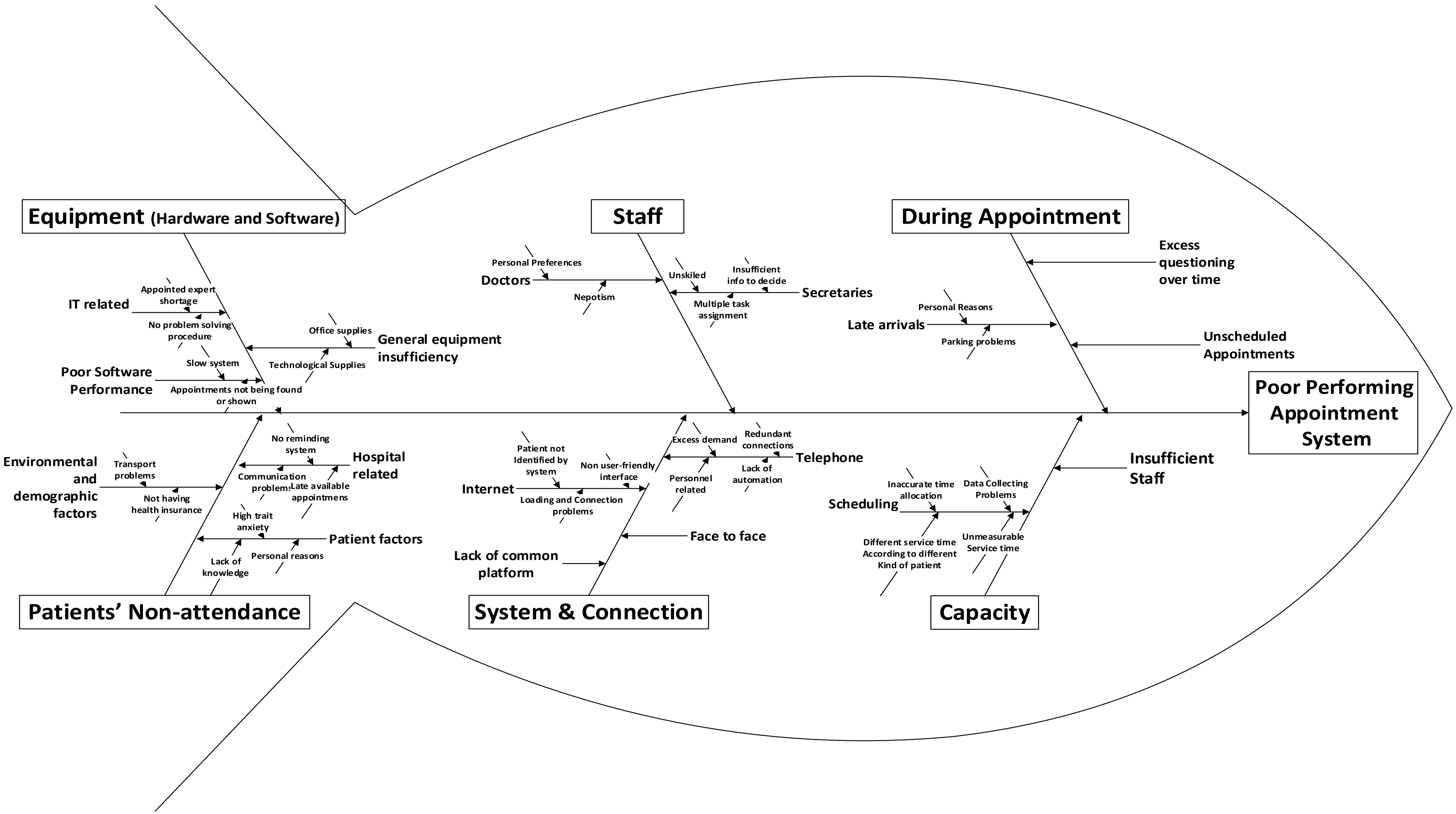

Figure 16 - Implementation of Cause and Effect Diagram

Figure 16 should be interpreted as major causes are representing the potential major Six Sigma Project alternatives. Each major cause comprises different sub causes that may also be presented as minor Six Sigma topics. All the causes, both major and sub-causes, are given in Table 5.

Table 5- All the causes, both major and sub-causes

Code	Cause Name
1	Capacity
1.1	Scheduling
1.1.1	Data Collecting
1.1.2	Unmeasurable Service time
1.1.3	Inaccurate Time Allocation
1.1.4	Different service times for different patients
1.2	Insufficient Staff
2	System and Connection
2.1	Telephone
2.1.1	Excess Demand
2.1.2	Lack of Automation
2.1.3	Redundant connections
2.1.4	Staff related
2.2	Internet
2..2.1	Lack of user friendly interface
2.2.2	Loading and connection problems
2.2.3	Patients not being identified by system
2.3	Face to Face
2.4	Lack of common platform
3	Equipment
3.1	Poor Software Performance
3.1.1	Slow System
3.1.2	Appointments not being shown or found by the system
3.2	IT Related
3.2.1	Lack of Experts
3.2.2	Lack of solution Procedure
3.3	General Equipment Insufficiency
4	Staff
5	Patient no Shows
6	During Appointment

By having a deeper look to “Capacity Problems” as a major reason, sub-causes such as “Insufficient Staff” and “Scheduling” can be found. The research can go even further as the scheduling problems themselves divide into sub-causes such as “Inaccurate Time Allocation, Data Collection Problems, Giving different service time according to different kind of patients, and Unmeasurable service times.

System and connection problems consists of “Internet related Problems, Telephone related Problems, and lack of common problems, problems occurred during face to face appointment manner”. Furthermore, Internet related problems themselves include; patients not being identified by the system, non-user friendly interface and, loading and connection problems. Telephone related problems also contain excess demand, redundant connections, personnel related problems, and lack of automation.

Equipment problems are the hardware and software related problems. They have three sub-problems; IT related problems, poor software performance, and general equipment insufficiency such as printers not working. IT related problems can be caused by expert shortage, or insufficient problem solving procedures. Poor performance by software can be caused by a slow processing system or appointments not being found or shown by the system. Office supplies shortages and lack of technological supplies and can cause general equipment insufficiency.

Staff problems can be caused by doctors or secretaries. Personal preferences and nepotism are the problems caused by doctors whereas being inadequately skilled, having insufficient info, or being responsible with multiple assignments are some of the problems that secretaries face.

One of the other problems as mentioned was patients’ non-attendance occurs when a patient does not attend to his/her appointment. This problem can have different minor reasoning such as environmental and demographic factors (transport problems, not having a health insurance), hospital related factors (having no patient reminding system, communication problems or late available appointments) and patient related factors (high trait anxiety, lack of knowledge or personal reasons).

The last group of problems are the problems occurring during appointment problems which are occurred during doctor treatments. Their source can be trailed in late arrivals (Personal reasons, parking problems), unscheduled appointments, and excess questioning over the normal allocated time to each patient.

3.6. Implementation of AHP and FAHP Methodology

Each cause in the diagram given in the Figure 16, both major and their sub-causes, are considered as Six Sigma project topics by the hospital management. However, the question was how to prioritize and rank these causes, and where to start Six Sigma efforts. Firstly, AHP methodology was integrated with the developed Cause and Effect Diagram. Then, the FAHP method was implemented in order to get the results based on fuzzy sets rather than crisp sets.

AHP was chosen as a methodology because the problems that are required to be prioritized in terms of importance do not share a common measuring scale and they have their own sub-problems. By using more than one expert's opinion and aggregating them (The suitable aggregation of opinions is necessary.) These opinions can be prior or conditional probabilities, or even posterior probabilities [89]. Moreover, consulting more experts would reduce the chances of biasness that can exist in one opinion. It is necessary to consider different group of experts from different fields in the same system as well to have the chance of understanding the issue from different aspects [90]. Several AHP aggregating methods such as arithmetic mean method can be used [91].

The FAHP method is applied due to its advantage in representing ambiguity and uncertainty. Furthermore, compared to the AHP procedure, it adds the quality of dealing with some of the inaccuracy that AHP is prone to.

Based on the defined major and sub-causes, flashcards were prepared in order to facilitate the process of the questions that were going to be answered by the corresponding staff of related departments. Each interviewed staff had to compare the different pairs of major causes according to their importance. They also need to compare sub-category pairs in each branch of causes. Easy to understand flashcards were shown to them and further explanation were given to those who had difficulties with cards.

The classical survey method would be a challenging process to teach to survey contributors in a limited amount of time and the busy environment of the hospital. Thus, a more interactive and easier to understand method was implemented. In total, 60 pairwise comparisons are realized thus 60 different Flashcards were prepared, unique Flashcards for each pairwise comparison. Each flashcard resembles the importance comparison of two criteria. The more graphical approach compared to the conventional word-driven survey system would facilitate the quick understanding of the comparison question by the interviewee. The following (Figure 17) which is one of these 60 flashcards, is given as an example. All of the flashcards for the comparison of “Main causes” are shown in appendix c.

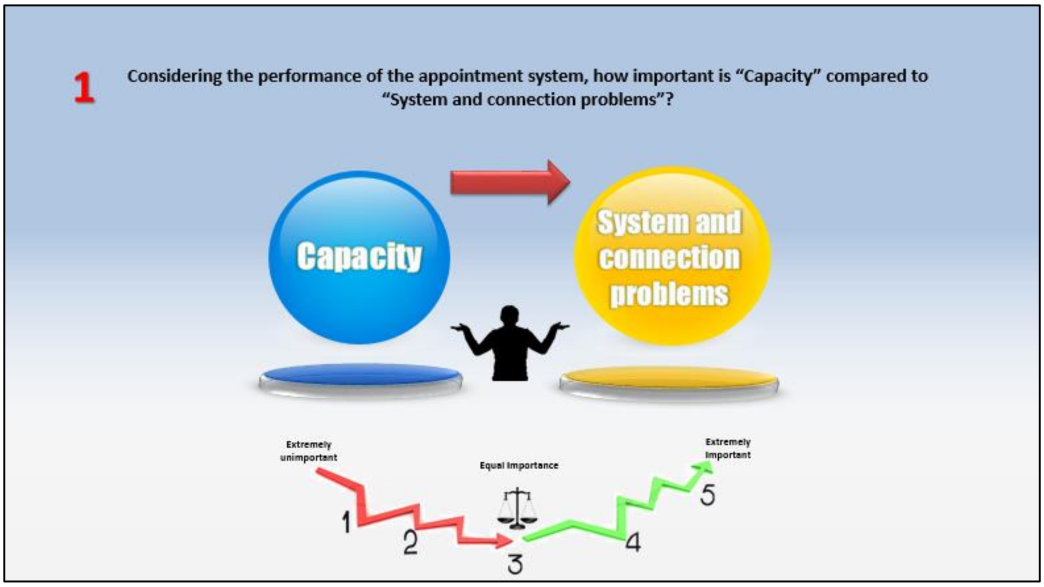

Figure 17 - An example Flashcard in which pairwise comparisons are asked to the domain experts

Following this, a group of domain experts consisting of both managerial and administrative staff were asked to evaluate the importance of the causes in the scale of 1 to 9, which is given in the Table 6; where 1 is equally important, 9 is extremely important and 1/9 is extremely unimportant. Each answer and questionnaire was documented. The recorded data were analyzed by the proposed integrated Cause and Effect Diagram and the AHP method. As it can be seen in the flashcards, the points are given between 1 and 5 in order to facilitate the comprehension of comparisons for the interviewees. The gathered data then is converted to the 1 to 9 scale based on [92].

For the cause and effect diagram FAHP method, the pairwise comparison matrix of the AHP version should be converted based on fuzzy triangular numbers. This is done by the concept called linguistic values defined by [93]. The linguistic values are really useful in dealing with complex and hard to define expression in conventional models. Different levels of importance which were shown from 1 to 9 in the AHP method are translated into the triangular fuzzy scale in Table 6. For example, the number “1” in the AHP method which represents the term “Equal importance” is translated into (1,1,1) in the triangular fuzzy scale or the term “Extremely Important” represented by “9” in the AHP model is presented as

(5/2,3,7/2). The linguistic scales for importance as suggested by [75] and [94] are presented in Table 6. This means that compared to the AHP comparison matrix which the important level of “System and connection” to “Capacity” which was obtained as “5” (Meaning the former is moderately more important than the latter), in the FAHP method their relevant field would be replaced by the “(3/2, 2, 5/2)” value.

Table 6- Linguistic scale for importance for the FAHP method

AHP Number	Linguistic scale for importance	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
1	Equally important	*(1,1,1)*	*(1,1,1)*
2		*(1/2,3/4,1)*	*(1,4/3,2)*
3	Slightly more important	*(2/3,1,3/2)*	*(2/3,1,3/2)*
4		*(1,3/2,2)*	*(1/2,2/3,1)*
5	Moderately more important	*(3/2,2,5/2)*	*(2/5,1/2,2/3)*
6		*(2,5/2,3)*	*(1/3,2/5,1/2)*
7	More important	*(5/,3,7/2)*	*(2/7,1/3,2/5)*
8		*(3,7/2,4)*	*(1/4,2/7,1/3)*
9	Extremely more important	*(7/2,4,9/2)*	*(2/9,1/4,1/7)*

4. ANALYSIS

In this section, the analysis and the different stages of the constructing the pair-wise comparison matrices are delineated step by step for both the analytical hierarchical process and fuzzy analytical hierarchical process for the main causes.

4.1. AHP Analysis

After identifying the relations of different problems based on the answers and replies of hospital staff at all levels, pairwise comparison matrices were created to find the levels of importance of different malfunction reasons in the hospital. Different points were given to show their pairwise importance relations (Extremely more important=9, More important=7, moderately more important=5, slightly more important=3, equally important=1). The following pairwise comparison matrix given as an example in table 7 is obtained for the 6 main causes of the fishbone. By using the mean of the collected answers in hospital for each of the pair-wise comparison, the respected matrix for each cause (Both main causes and their sub-cause) were constructed.

Table 7 - Pairwise Comparison Matrix for the 6 Main Causes

	1	**2**	**3**	**4**	**5**	**6**
1	*1*	*0.2*	*5*	*5*	*9*	*9*
2	*5*	*1*	*5*	*5*	*9*	*9*
3	*0.2*	*0.2*	*1*	*5*	*5*	*5*
4	*0.2*	*0.2*	*0.2*	*1*	*1*	*1*
5	*0.111*	*0.111*	*0.2*	*1*	*1*	*1*
6	*0.111*	*0.111*	*0.2*	*1*	*1*	*1*

1: Capacity
2: System and Connection
3: Equipment
4: Staff
5: Patients' Non-attendance
6: During Appointment

For example, based on the median of the answers and replies obtained which was about 0.2 for "Capacity (1)" compared to "System and Connection (2)". This means that "Capacity Problems (2)" is moderately less important than "System and Connection Problems (1). On the contrary, (2) is 5 (=1/0.2) compared to (1), which means that "System and Connection" is moderately more important than "Capacity", as it is expected.

With the same logic all of the pairwise comparison matrices were constructed (both for general causes and their sub-causes). In total, 14 pairwise comparison matrices are obtained through calculating the median values of the answers of domain experts.

4.2. FAHP Analysis

Based on the obtained medians of the answers to the flashcards completed by the domain experts and following the construction of the AHP comparison matrix, the fuzzy hierarchical comparison matrices are formed using the FAHP linguistic scale for importance. Table 7 represents the comparison matrix for the main causes of the poor performance of the hospital identified in the previous chapters. Again 14 comparison matrices were created and the relevant weights are obtained consequently.

For example, based on the median of the answers and replies obtained which was about 0.2 for “Capacity (1)” compared to “System and Connection (2)”. This means that “Capacity Problems (2)” is moderately less important than “System and Connection Problems (1). That is why the comparison value in the pairwise comparison matrix for (1) compared to (2) is represented by (*0.40, 0.50, 0.67*) which is the reciprocal value for *(3/2, 2. 5/2*) meaning that (1) is moderately less important than (2) and consequently system and connection (2) is moderately more important than capacity (1).

With the same logic all of the pairwise comparison matrices were constructed (both for general causes and their sub-causes). In total, 14 pairwise comparison matrix is obtained through calculating the median values of the answers of domain experts.

Table 8-FAHP Pairwise Comparison Matrix for the 6 Main Cause

	1			2			3			4			5			6		
1	***1.00***	***1.00***	***1.00***	*0.40*	*0.50*	*0.67*	*1.50*	*2.00*	*2.50*	*1.50*	*2.00*	*2.50*	*3.50*	*4.00*	*4.50*	*3.50*	*4.00*	*4.50*
2	*1.50*	*2.00*	*2.50*	***1.00***	***1.00***	***1.00***	*1.50*	*2.00*	*2.50*	*1.50*	*2.00*	*2.50*	*3.50*	*4.00*	*4.50*	*3.50*	*4.00*	*4.50*
3	*0.40*	*0.50*	*0.67*	*0.40*	*0.50*	*0.67*	***1.00***	***1.00***	***1.00***	*1.50*	*2.00*	*2.50*	*1.50*	*2.00*	*2.50*	*1.50*	*2.00*	*2.50*
4	*0.40*	*0.50*	*0.67*	*0.40*	*0.50*	*0.67*	*0.40*	*0.50*	*0.67*	***1.00***	***1.00***	***1.00***	*1.00*	*1.33*	*2.00*	*1.00*	*1.33*	*2.00*
5	*0.22*	*0.25*	*0.29*	*0.22*	*0.25*	*0.29*	*0.40*	*0.50*	*0.67*	*0.50*	*0.75*	*1.00*	***1.00***	***1.00***	***1.00***	*1.00*	*1.00*	*1.00*
6	*0.22*	*0.25*	*0.29*	*0.22*	*0.25*	*0.29*	*0.40*	*0.50*	*0.67*	*0.50*	*0.75*	*1.00*	*1.00*	*1.00*	*1.00*	***1.00***	***1.00***	***1.00***

5. RESULTS

In this section, the focus is the results for the AHP and FAHP approaches separately. With ease of understanding in mind, both approaches are done for the main causes and "System and connection" causes. Step by step tables delineate the algorithm which are already explained in details in previous sections.

5.1. AHP Results

In the next step, normalized comparison matrices and reason's weights were formed and calculated respectively after each weight calculation, the consistency index was checked to find out if the decision making process is consistent by finding the CI and RI values. All the calculations are accomplished according to the AHP methodology's calculations presented in details in Section 3.3.

After finding the importance weights for the major causes the following Table 9 were obtained:

Table 9 - Analysis Results of the Major Causes

Causes	**Weights**	**CI** *0.0462*
1	*0.2769*	**CR=CI/RI** *0.0373*
2	*0.4508*	1: Capacity Problems
3	*0.1480*	2: System and Connection Problems
4	*0.0482*	3: Equipment Problems
5	*0.0379*	4: Staff Problems
6	*0.0379*	5: Patients' Non-attendance 6: During Appointment Problems

As it is obvious the most of the problems are caused by System and Connection problems (about *45* percent) followed by about *27* percent of problems caused by Capacity issues which these two account for about *72* percent of whole problems. On the third place is equipment problems with *14* percent of whole problems. The other three problem types account for a miniscule amount of the whole problems. Note that, means that the obtained *CR* for this analytical process (*0.0373*) shows the consistency of this process. As mentioned previously, if the *CR* value is below *0.1* it means that the analysis is consistent.

Here, only the results of main causes is given due to the page limitations and similarity of analysis, but the complete results for the remaining matrices (sub causes) are available in appendix A. Since "System and Connection Problems" is *45* percent and will be projected first, details for its sub-causes is given in Table 10.

Table 10 - Analysis Results of the System and Connection Related Problems

Causes	Weights	CI	0.0869
1	*0.4724*	**CR=CI/RI**	*0.0966*
2	*0.1969*	1: Telephone Related	
3	*0.0470*	2: Internet Related	
4	*0.2835*	3: Face to Face Appointments	
		4: Lack of Common Platform	

In the System and Connection Problems, as expected and observed in the hospital, the biggest problem was "Telephone Related" (about 47 percent) followed by the "Internet Related" ones (19 percent). Going one level deeper in the "Telephone Related Problems, the result is not given, "lack of automation" was the main problem accounting for about 59 percent of all problems whereas for the "Internet related problems", "not being authorized by the system" and the "system not being user friendly" were the main reasons tied at the top with each having about 45 percent of the problems.

The obtained results show that the First priority of hospital for solving its problems and heading towards a better performing system is to re-think and solve their "System and Connection Problems". This can be possible by the implementation of a single platform for all of the appointment-taking systems. This can lead to the decrease of the problems sourcing from the lack of communication between the appointments taken by telephone, Internet and face to face. By applying a single platform for these different systems, the information will be updated as real-time data which avoids the miscommunication of data between different appointment-taking systems. Furthermore, as about half of the reasons for causing system and connection are "Telephone" related, many improvements can be taken in the call-center sector. The elimination of redundant connections and the improvement of automation system (making the call-center application more efficient) and better training of personnel can lead to solving the problem due to excess demand. This can make the telephone appointment-making system operate more smoothly and efficiently. To add to that, making a more user-friendly internet platform that is comprehensible and understandable for all range of end-users and customers and improving the performance of the website can have major impact on solving problems which are caused by Internet appointment-making system.

5.2. FAHP Results

Firstly, the main causes are the subject of test in the fuzzy analytical hierarchical approach. Based on Table 11, the fuzzy synthetic extent values were obtained for the main causes. Thus, *l*, *m*, and *u* which are the lower, mean and upper bounds of the triangular fuzzy number for each member of the comparison matrix are calculated based on Equation (2.19) and the results can be seen in Table 11.

Table 11- Fuzzy extent values for main causes

	l	*m*	*u*
1	*0.1949*	*0.2745*	*0.3812*
2	*0.2137*	*0.3050*	*0.4259*
3	*0.1077*	*0.1627*	*0.2393*
4	*0.0718*	*0.1050*	*0.1703*
5	*0.0571*	*0.0762*	*0.1031*
6	*0.0571*	*0.0762*	*0.1031*

In the next step the fuzzy number comparing principle is applied based on [81]. As a result, each element’s weight can be obtained as the minimum value of each row of the following matrix (shown in Table 12).

Table 12-Degrees of possibility for main causes

	MV1	MV2	MV3	MV4	MV5	MV6	min
MV1		*0.8459*	*1*	*1*	*1*	*1*	0.8459
MV2	*1*		*1*	*1*	*1*	*1*	1
MV3	*0.2839*	*0.1521*		*1*	*1*	*1*	0.1521
MV4	*0*	*0*	*0.5207*		*1*	*1*	0
MV5	*0*	*0*	*0*	*0.5208*		*1*	0
MV6	*0*	*0*	*0*	*0.5208*	*1*		0

As it has been depicted in the matrix in Table 12, the minimum value of the first row is 0.8459 which is representing first element’s weight which is the capacity related cause. Finally, by the use of normalization the normalized weights which are no longer fuzzy numbers can be obtained as shown in the following table which is the percentage of significance of each involved element in Table 13.

Table 13-Prioritization results for main causes

	1	2	3	4	5	6
Weights	*0.8313*	*1*	*0.0792*	*0*	*0*	*0*
Standard weight	*0.4233*	*0.5233*	*0.0414*	*0*	*0*	*0*

The same procedure is done for a level deeper in the cause and effect diagram. The analysis of the second level of the most significant problem causing bone in the fishbone diagram is the system and connection related causes. The l, m and u values are obtained and based on comparison of degrees of possibility, the involving elements are prioritized and standardized respectively.

Table 14-Fuzzy comparison matrix for system and connection causes

	1			2			3			4		
1	***1.00***	***1.00***	***1.00***	*1.50*	*2.00*	*2.50*	*3.50*	*4.00*	*4.50*	*0.50*	*0.75*	*1.00*
2	*0.40*	*0.50*	*0.67*	***1.00***	***1.00***	***1.00***	*1.50*	*2.00*	*2.50*	*3.00*	*1.33*	*2.00*
3	*0.22*	*0.25*	*0.29*	*0.40*	*0.50*	*0.67*	***1.00***	***1.00***	***1.00***	*0.40*	*0.50*	*0.67*
4	*3.00*	*1.33*	*2.00*	*0.50*	*0.75*	*1.00*	*1.50*	*2.00*	*2.50*	***1.00***	***1.00***	***1.00***

In the comparison matrix in Table 14, each of the numbers 1,2,3, and 4 represent each of the four subsets of system and connection related cause being telephone, internet, face to face appointments and "lack of a common platform" respectively. The next step is to find the fuzzy extent value of each of these subsets as shown in Table 15.

Table 15-Fuzzy extent values for system and connection causes

	L	m	u
1	*0.2676*	*0.3891*	*0.4406*
2	*0.2400*	*0.2426*	*0.3019*
3	*0.0832*	*0.1129*	*0.1282*
4	*0.2470*	*0.2552*	*0.3182*

Following the obtainment of the fuzzy extent values, their degrees of possibility are compared for each of the understudy causes in the system and connection related causes subsets represented in table 16.

Table 16-Degrees of possibility for System and connection causes

	1	2	3	4
1	-	*1*	*1*	*1*
2	*0.1898*	-	*1*	*0.8139*
3	*0*	*0*	-	*0*
4	*0.2744*	*1*	*1*	-

Finally, the minimum values resulted from the degrees of possibility comparison would lead to be the weights of each subset. The standard weights show the value of each subset on the percent basis.

Table 17-Prioritization results for System and connection causes

	1	2	3	4
Weight	*1*	*0.1898*	*0*	*0.2744*
Standard Weight	***0.6829***	***0.1296***	***0***	***0.1874***

As it can be comprehended from the Table 17, Telephone related causes possess the biggest bulk of problem causing criteria with substantial figure of about 68 percent. Taking measures such as managing call overload, improving the call center automation. Eliminating call center system errors and Training call center staff can be of the first steps taken in order to palliate hospitals poor performance system. The prioritization for each branch of the cause and effect diagram is calculated by the introduced FAHP method.

5.3. Discussion of results

The results from both AHP and FAHP methods shows that the biggest chunk of hospital's appointment system is caused by the "System and connection" related causes with about 45% and 52% respectively. Based on the fuzzy triangular numbers, it can be seen that the significance of the main problem is emphasized compared to the AHP version of the results. The same trend can be seen in the second most important cause of underperformance of the appointment system, being the "Capacity" related causes with 27% and 42% for AHP and

FAHP respectively. The exact opposite trend is true for other types of problem causing elements as the 14% weight allocated to “Equipment” related causing is plummeted to about 4% according to the FAHP method. This can point to the fact that by taking more human cognition into account, solving the problems associated with equipment can serve little in terms of being beneficial to the improvement of the appointment system. The other three branches of the cause and effect diagram which had already insignificant portions of causing problems in the performance of the appointment system are omitted in terms of being considered as selection contenders using the FAHP method. These “0”s can be due to the fact that according to the FAHP method and further taking humanlike judgement into account, they can serve as being not cost effective and time effective enough or even feasible. The fact that the results give us a hint in not even considering the other three types of problem causers as selection candidates shows the advantages of FAHP to AHP in terms of acumen. These results can even benefit the system in terms of cost and time effectiveness.

First order of business in terms of improving the appointment system can be started by improving the telecommunication system which consists of such as managing call overload, improving the call center automation. Eliminating call center system errors and Training call center staff. Furthermore, while mitigating the deficiencies in the “System and connection department, measures can be taken in order to integrate the manual and computerized appointment systems in order to tackle the problem “Lack of a common interface”. Improving the IT system for internet appointments can be the next step in order to solve the problems with faced with the internet system which can include developing a user friendly interface, Improving the read and write access to the system and reducing the number of unrecognized patients by the system. Based on FAHP results, no actions are needed to be taken for “Face to face” causes since the resulted weight value is 0% compared to 4 percent in AHP results. Recommended solutions for causes of underperformance for all of the studied causes is shown is Table 18.

Table 18-Recommended solutions for causes of underperformance

	AHP Weights	Fuzzy Weights
1. Capacity related	**0.277**	**0.4233**
1.1. Improving the appointment schedule	0.8333	0.3737
1.1.1. Improving the data collection systems	0.0748	0.0000
1.1.2. Identifying the causes of variation in service times	0.0809	0.0360
1.1.3. Determining a fixed time to be allocated for each patient in the schedule	0.4043	0.1560
1.1.4. Determining variable times to be allocated for different types of patients in the schedule	0.44	0.1817
1.2. Reducing insufficiency of staff	0.1667	0.0495
2. System and accessibility related	**0.4508**	**0.5233**
2.1. Improving the telecommunication system	0.4724	0.3574
2.1.1. Managing call overload	0.2014	0.0786
2.1.2. Improving the call center automation	0.5903	0.1856
2.1.3. Eliminating call center system errors	0.118	0.0539
2.1.4. Training call center staff	0.0903	0.0392
2.2. Improving the IT system for internet appointments	0.197	0.0678
2.2.1. Developing a user friendly interface	0.4545	0.0339
2.2.2. Improving the read and write access to the system	0.091	0.0000
2.2.3. Reducing the number of unrecognized patients by the system	0.4545	0.0339
2.3. Eliminating the errors due to manual appointments	0.0471	0.0000
2.4. Integrating the manual and computerized appointment systems	0.2835	0.0981
3. Hardware and software related	**0.1481**	**0.0414**
3.1. Improving the software performance	0.4796	0.0226
3.1.1. Increasing the system speed	0.25	0.0071
3.1.2. Eliminating the software errors	0.75	0.0154
3.2. Improving the capabilities of IT department	0.4054	0.0167
3.2.1. Reducing software expert shortages	0.25	0.0053
3.2.2. Developing standards for solving problems	0.75	0.0114
3.3 Fulfilling general equipment deficiencies (office and technological supplies)	0.115	0.0021
4. Staff related	**0.0483**	**0.0000**
4.1. Reducing inefficiencies caused by doctors	0.9	0.0000
4.1.1. Reducing doctors' intervention to the appointments	0.875	0.0000
4.1.2. Preventing nepotism	0.125	0.0000
4.2. Reducing inefficiencies caused by secretaries	0.1	0.0000
4.2.1. Improving the recruitment process to hire more skilled secretaries	0.1578	0.0000
4.2.2. Reducing the multiple task assignments	0.1867	0.0000
4.2.3. Developing on the job training programs	0.6555	0.0000
5. Breaking an appointment related	**0.0379**	**0.0000**
5.1. Reducing external causes of no-show		
5.1.1. Reducing no-show due to transportation problems		
5.1.2. Preventing no-show due to health insurance problems		
5.2. Reducing hospital related causes of no-show		
5.2.1. Reducing misunderstandings related to appointment details		
5.2.2. Developing a reminder system for preventing no-show		
5.2.3. Improving availability of appointments for the short term		
5.3. Reducing effects of patient related no-show		
5.3.1. Managing no-show due to personal reasons		
5.3.2. Reducing lack of knowledge		
5.3.3. Reducing no-show due to anxiety		
6. Attending an appointment related	**0.0379**	**0.0000**
6.1. Reducing excessive questions asked by patients	0.1053	0.0000
6.2. Managing late arrivals	0.0969	0.0000
6.2.1. Managing late arrivals due to personal reasons	0.8333	0.0000
6.2.2. Reducing hospital related problems	0.1667	0.0000
6.3. Managing unscheduled appointments	0.7978	0.0000

6. SUNBURST CHART

Sunburst chart is a radial structured variation of a tree-diagram which additionally includes and associates hierarchical structure with information about quantity. This chart originates from interactive computer design used in the representation of graphic results of hierarchical data with the levels of information being its basis.

This study however, uses a modified version of the Sunburst chart. The main intention of the author for creating a new chart is the need for a chart that is capable of visualizing the numerical results of the proposed cause and effect diagram and AHP based methodology for selection of quality improvement projects. The cause and effect AHP sunburst chart is used in this research to graphically demonstrate the results of the AHP analysis that is applied for ranking the causes of the underperformance of hospital appointment system. The applied chart uses the innermost circle (the lowest radius) as the first level of the hierarchy being the “main causes” here.

As the chart moves away from the center to circles with bigger radiuses, the lower levels of the hierarchy are shown (sub causes). The standardized outcome weights for the outermost level of the AHP study is shown in a pie chart which is divided by its sub causes based on their standard weights itself in order to present a simpler and more comprehensible way of looking at the outcomes.

As seen in Figure 18, there are three circles in the chart and each circle represents a different cause level for the poor appointment system performance. The innermost circle, considered as the first level of the hierarchy, represents the six main causes described previously. The middle circle represents the second level of sub-causes studied by this research and the outermost circle represents the lowest level of hierarchy. Since the space for the modified sunburst chart is limited for this paper, only two levels of causes are shown in the chart. Each circle is divided into several regions and each region represents a cause. The space that a cause occupies is based on the AHP results and shows the importance of that cause, i.e. a larger region means a more important cause. Note that, the summation of the areas that causes have in a circle must be “1” in total.

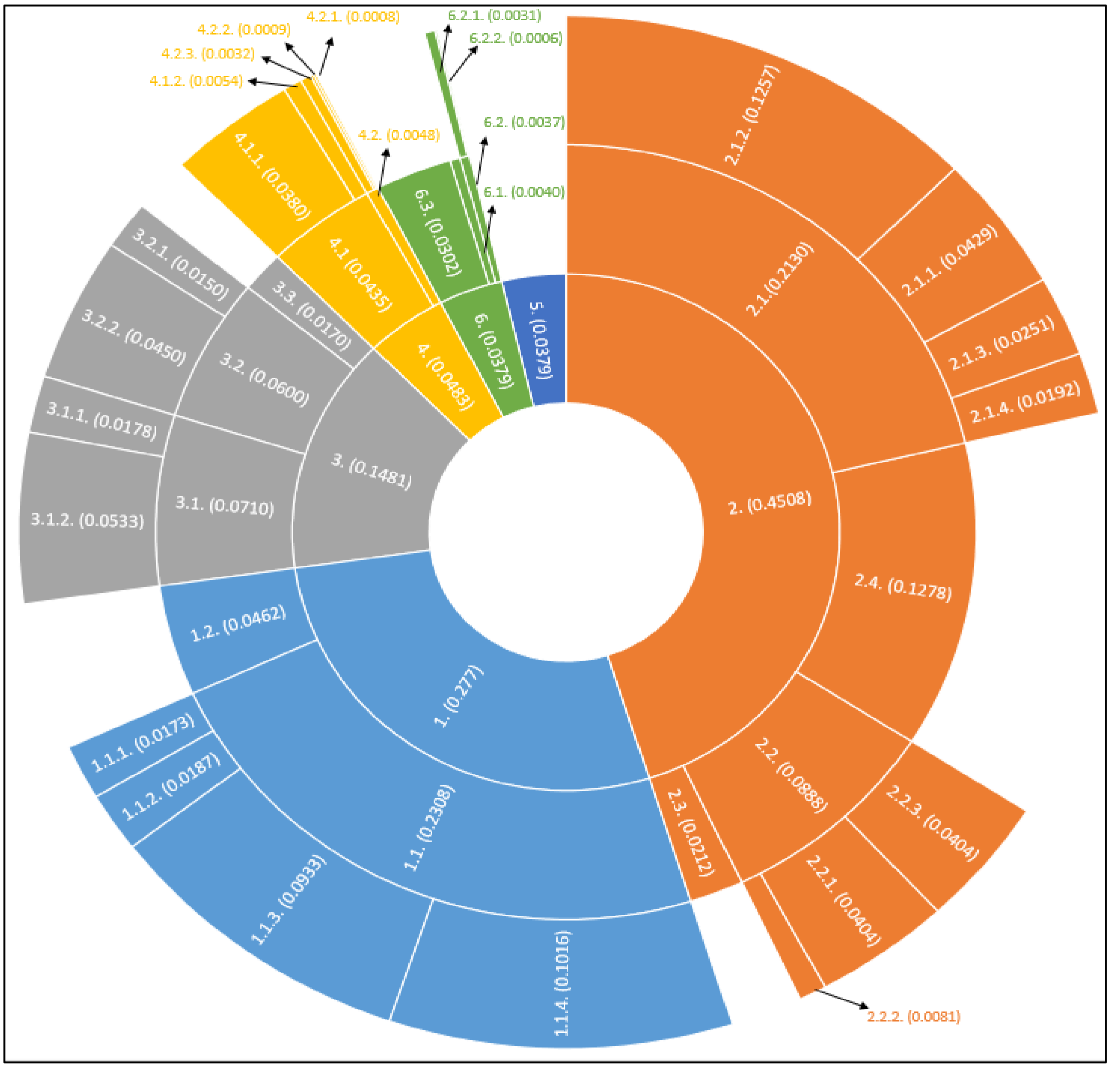

Figure 18*-Sunburst chart for AHP results*

The sunburst system has been used in order to depict the results of cause and effect fuzzy analytical hierarchical process as well as seen in figure 19. As only three of the six main causes obtained a value of more than zero, the resulted sunburst chart consists of three main colors. Color orange taking the biggest chunk of the chart which is associated with the second category of main causes which is "System and connection" causes. In the second place, 42 percent of the innermost layer of sunburst has been allocated to "Capacity" causes followed by roughly 4 percent in the "Equipment" related causes. The deeper level of each cause and effect bone has been shown by the outer levels of the sunburst chart.

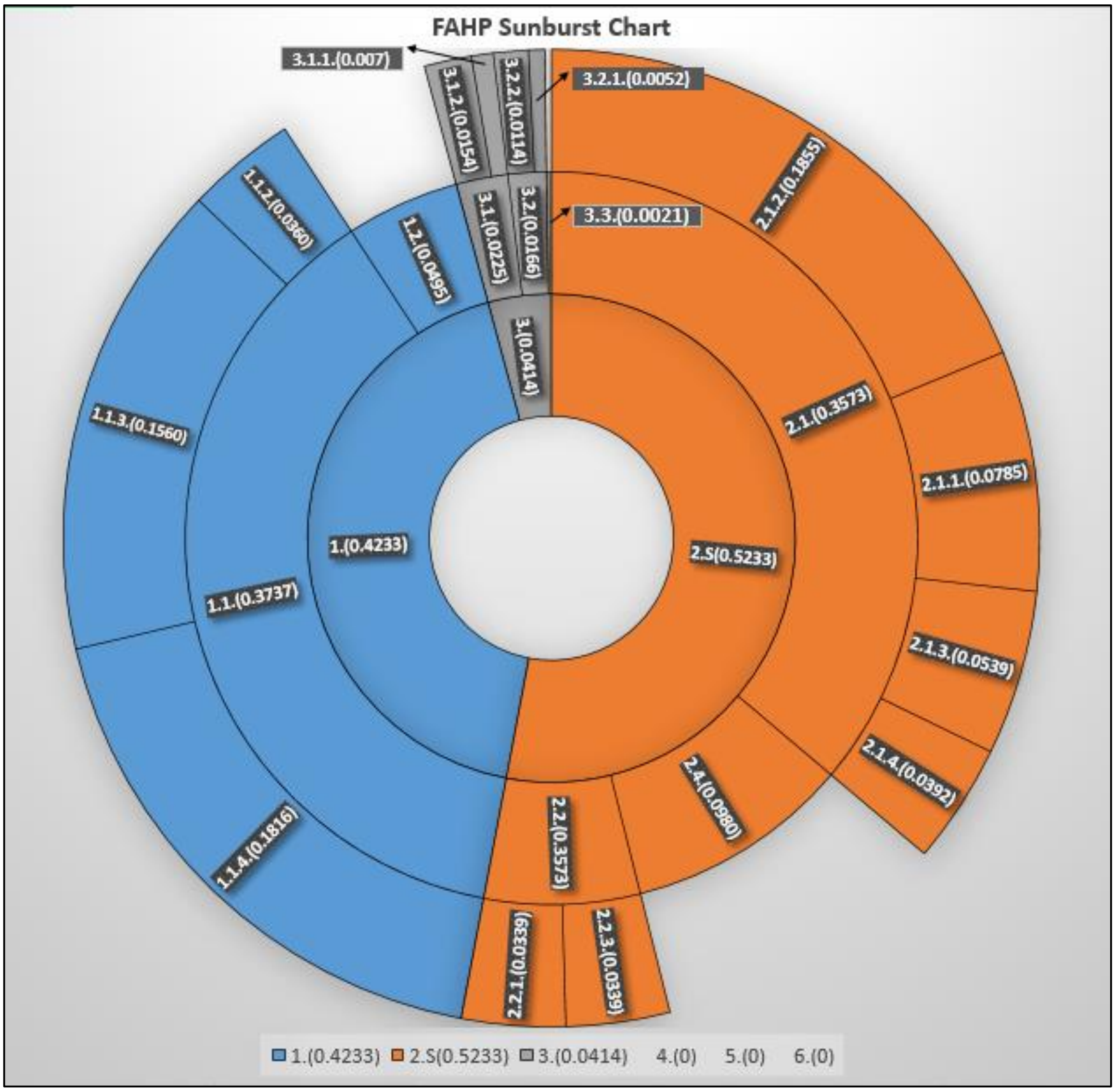

Figure 19-Sunburst chart for the FAHP results

7. CONCLUSIONS AND FUTURE RESEARCH

Concurrent to the advances of processes and products which are undeniably quintessential in the modern vying industries, effects of business decisions and allotment of limited resources in order to establish projects, therefore making the selection of a right project a decisive aspect of any organization's prosperity. One can find many ostensible means of development in a working organization, however, choosing the optimal development way which is based on prioritization technics, is decision makers' call to make. This call should be made by considering various, even disparate at times, perspectives. In fact, one of the most burdensome parts of project selection is to combine and make sense out of the multifarious information and data collected from various levels of an organization. Thus, the prioritization and eventually selection of projects can be based on measurable decision making and be used in order to select the best possible project in accordance to organization's strategy and vision. Project-oriented management approaches and result-oriented performance metrics such as Six Sigma favor improvements that should be completed in shorter durations. Consequently, process and product quality improvement studies in industry are often hypothesized in a hierarchical structure, where a breakdown of a project with a large scope is common. Furthermore, the use of fuzzy logic can mitigate some the decision making methods' shortcomings in terms of capturing the vagueness existing in the way humans think and decide.

In this study, the needed information for selecting the most affecting solution for hospital's sub-par performance are collected from different levels and departments of the mentioned hospital depicting different approaches represented by different levels of hospital employees. Moreover, the causes for the underperformance of hospital are represented as the projects to be selected in a three level hierarchy with the lowest level consisting of the subprojects that serve the goals of the upper levels within the hierarchy. As a powerful statistical process control tool, Cause-and-Effect diagram is used for creating the hierarchy of projects. To select the right projects, initially, AHP weights are integrated to invigorate decision makers' acumen for prioritizing projects by aggregating information from various levels and departments within an organization. Furthermore, FAHP is used to take into account interval judgements rather than fixed judgements in order to better capture the fuzzy nature of comparisons and give a closer perception according to the human brain. Proposed approach is then illustrated with a study performed to improve appointment system at a hospital. Suggestions for practical implementations such as flashcards for pairwise comparisons and sunburst charts for visualizing the priorities are given. Eventually, the “System and communication” related causes for the hospital’s problems in the appointment system is identified as the biggest problem based on both AHP and FAHP results and therefore selected as the first problem to tackle in terms of improving the service quality of the studied hospital. The same procedures are undertaken for deeper levels of the cause and effect diagram as well, making way for the selection of the next solution steps in terms of prioritization.

Future studies can be done in terms of determining the consequential effects of eliminating one of the causes of underperformance (by solving it) on other causes and the way it will change them by finding the correlation between problem causing causes and their sub-categories. The design of more effective socio-technical decision making systems based on the technological improvements in understanding the way human brain works which can be done by rethinking the industrial engineering in order to move forward. The application of human cognition and its behavioral and neurophysiological bases on decision making -by using the latest improvements in technology- in order to design more efficacious systems can seriously bolster service and product quality in the coming years.

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APPENDIX A: RESULTING WEIGHTS FOR THE CAUSE AND EFFECT AHP METHODOLOGY

Comparison of Main Causes

Causes	Weights	CI	CI/RI	
1	0.2769	0.0462	0.0373	1. Capacity Related Problems
2	***0.4508***			2. System & Connection Related Problems
3	0.1480			3. Equipment Related Problems
4	0.0482			4. Staff Related Problems
5	0.0379			5. Patient's Non-attendance Related Problems
6	0.0379			6. During Appointments Problems

Capacity Problems

Causes	Weights	CI	CI/RI	
1	***0.8333***	0.0047	0.0052	1. Scheduling Problems
2	0.1666			2. Insufficient Staff

System & Connection Related Problems

Causes	Weights	CI	CI/RI	
1	***0.4724***	0.0869	0.0966	1. Telephone Appointments
2	0.1969			2. Internet Appointments
3	0.0470			3. Face-to-Face Appointments
4	0.2835			4. Lack of a Common Platform

Telephone Appointments

Causes	Weights	CI	CI/RI	
1	0.2013	0.1180	0.1311	1. Excess Demand
2	***0.5902***			2. Lack of Automation
3	0.1180			3. Redundant Connections
4	0.0902			4. Call Center's Personel Related Problems

Internet Appointments

Causes	Weights	CI	CI/RI	
1	***0.4545***	0	0	1. Non ıser friendly interface
2	0.0909			2. Loading and Connection Problems
3	***0.4545***			3. Patients are not automatically identified by the system (kind of membership)

Equipment Related Problems

Causes	Weights	CI	CI/RI	
1	***0.4795***	0.0145	0.0251	1. Poor Software Performance
2	0.4054			2. IT department related Problems
3	0.1149			3. General Equipment Insufficieny

Poor Software Performance

Causes	Weights	CI	CI/RI	
1	0.2500	Not Needed	Not needed	1. Slow running system
2	***0.7500***			2. Some Appointments are not displayed by hosptail automation

IT related Problems

Causes	Weights	CI	CI/RI	
1	0.2500	Not Needed	Not needed	1. No responsible experts
2	***0.7500***			2. No problem solving procedures

Staff Related Problems

Causes	Weights	CI	CI/RI	
1	***0.9000***	Not Needed	Not needed	1. Physicians
2	0.1000			2. Secretaries and other staff

Physicians

Causes	Weights	CI	CI/RI	
1	***0.8750***	Not Needed	Not needed	1. Personal Preferences
2	0.1250			2. Nepotism

Causes	Weights	CI	CI/RI	
1	0.1577	0.0146	0.0251	1. Unskiled staff
2	0.1867			2. Multi-task assignments
3	***0.6554***			3. Insufficient info and training to decide

During Appointments Problems				
Causes	**Weights**	**CI**	**CI/RI**	
1	0.1053	0.0035	0.0060	1. Excess questioning over time
2	0.0968			2. Late Arrivals
3	0.7978			3. Unscheduled arrivals (incoming patients without an appointment)

Late Arrivals				
Causes	**Weights**	**CI**	**CI/RI**	
1	0.8333	Not Needed	Not Needed	1. Personal Reasons
2	0.1666			2. Hosptail related physical problems such as parking problem

APPENDIX B: RESULTING COMPARISON MATRICES AND WEIGHTS FOR THE CAUSE AND EFFECT FAHP METHODOLOGY

1.Capacity						
	1			2		
1	1	1	1	1.25	1.75	2.25
2	0.44	0.57	0.8	1	1	1

	1	**2**
Weights	1	0.1325
St weights	**0.8829**	0.1170

1.1.Scheduling Causes												
	1			2			3			4		
1	***1***	***1***	***1***	0.5	0.75	1	0.4	0.5	0.67	0.29	0.33	0.4
2	1	1.33	2	***1***	***1***	***1***	0.4	0.5	0.67	0.4	0.5	0.67
3	1.5	2	2.5	1.5	2	2.5	***1***	***1***	***1***	1	1.33	2
4	2.5	3.5	4	1.5	2	2.5	0.5	0.75	1	***1***	***1***	***1***

	1	2	3	4
Weights	0	0.1983	0.8590	1
St weights	0	0.0964	0.4175	**0.4860**

2. System & Connection Related Problems												
	1			2			3			4		
1	1	1	1	1.5	2	2.5	3.5	4	4.5	0.5	0.75	1
2	0.4	0.5	0.67	1	1	**1**	1.5	2	2.5	3	1.33	2
3	0.22	0.25	0.29	0.4	0.5	0.67	**1**	**1**	**1**	0.4	0.5	0.67
4	3	1.33	2	0.5	0.75	1	1.5	2	2.5	**1**	**1**	**1**

	1	2	3	4
Weights	1	0.1898	0	0.2744
St weights	0.6829	0.1296	0	0.1874

2.1. Telephone Appointments

	1			2			3			4		
1	1	1	1	0.4	0.5	0.67	0.5	0.75	1	1.5	2	2.5
2	1.5	2	2.5	1	1	1	1.5	2	2.5	1.5	2	2.5
3	1	1.33	2	0.4	0.5	0.67	1	1	1	0.5	0.75	1
4	0.4	0.5	0.67	0.4	0.5	0.67	1	1.33	2	1	1	1

	1	**2**	**3**	**4**
Weights	0.4235	1	0.2904	0.2115
St weights	0.2199	**0.5193**	0.1508	0.1098

2.2. Internet Appointments

	1			2			3		
1	1	1	1	1.5	2	2.5	1	1	1
2	0.4	0.5	0.67	1	1	1	0.4	0.5	0.67
3	1	1	1	1.5	2	2.5	1	1	1

	1	**2**	**3**
Weights	1	0	1
St weights	**0.5**	0	**0.5**

3. Equipment Related Problems

	1			2			3		
1	1.00	1.00	1.00	0.50	0.75	1.00	1.50	2.00	2.50
2	1.00	1.33	2.00	1.00	1.00	1.00	0.67	1.00	1.50
3	0.40	0.50	0.67	0.67	1.00	1.50	1.00	1.00	1.00

	1	**2**	**3**
Weights	1	0.7392	0.095
St weights	**0.5451**	0.403	0.0518

3.1. Poor Software Performance

	1			2		
1	1.00	1.00	1.00	0.50	0.67	1.00
2	1.00	1.50	2.00	1.00	1.00	1.00

	1	**2**
Weights	0.4615	1
St weights	0.3157	**0.6842**

3.2. IT related Problems						
	1			2		
1	1.00	1.00	1.00	0.50	0.67	1.00
2	1.00	1.50	2.00	1.00	1.00	1.00

	1	**2**
Weights	0.4615	1
St weights	0.3157	**0.6842**

4. Staff Related Problems						
	1			2		
1	1.00	1.00	1.00	3.50	4.00	4.50
2	0.22	0.25	0.29	1.00	1.00	1.00

	1	**2**
Weights	1	0
St weights	1	**0**

4.1. Physicians						
	1			2		
1	1.00	1.00	1.00	2.50	3.00	3.50
2	0.29	0.33	0.40	1.00	1.00	1.00

	1	**2**
Weights	1	0
St weights	1	**0**

4.2. Secretaries and other staff									
	1			2			3		
1	1.00	1.00	1.00	0.40	0.50	0.67	0.40	0.50	0.67
2	1.50	2.00	2.50	1.00	1.00	1.00	0.50	0.67	1.00
3	1.50	2.00	2.50	1.00	1.50	2.00	1.00	1.00	1.00

	1	**2**	**3**
Weights	0	0.4972	1
St weights	0	0.3321	**0.6678**

6. During Appointments Problems									
	1			2			3		
1	1.00	1.00	1.00	0.67	1.00	1.50	0.29	0.33	0.40
2	0.67	1.00	1.50	1.00	1.00	1.00	0.22	0.25	0.57
3	2.50	3.00	3.50	3.50	4.00	4.50	1.00	1.00	1.00

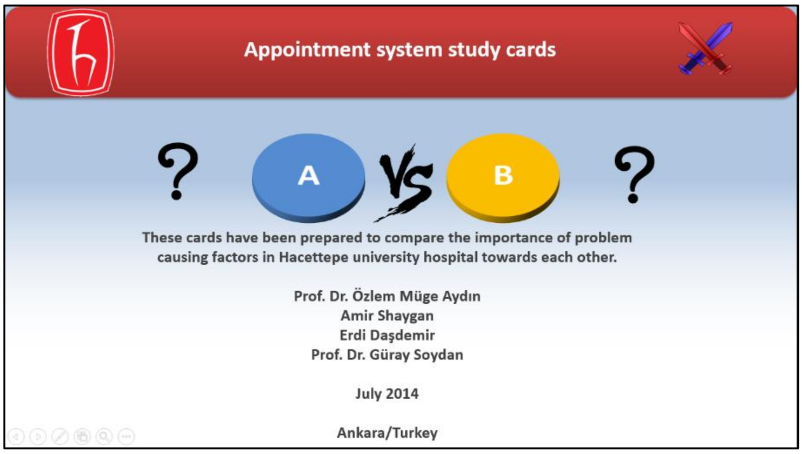
	1	**2**	**3**
Weights	0	0	1
St weights	0	0	**1**

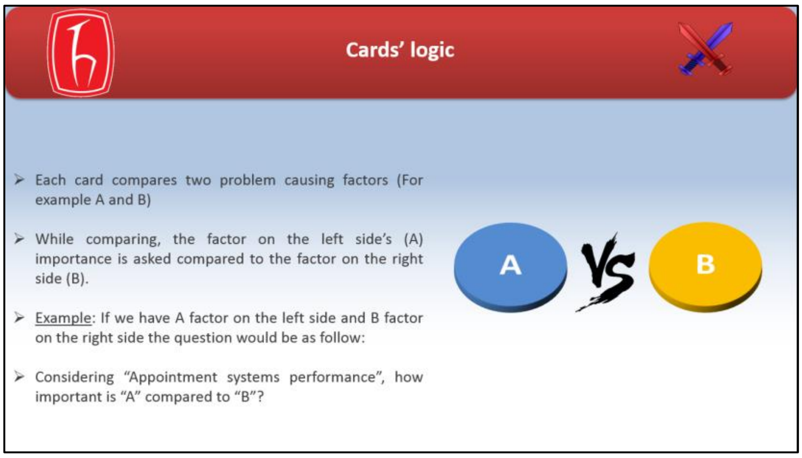
6.1. Late Arrivals

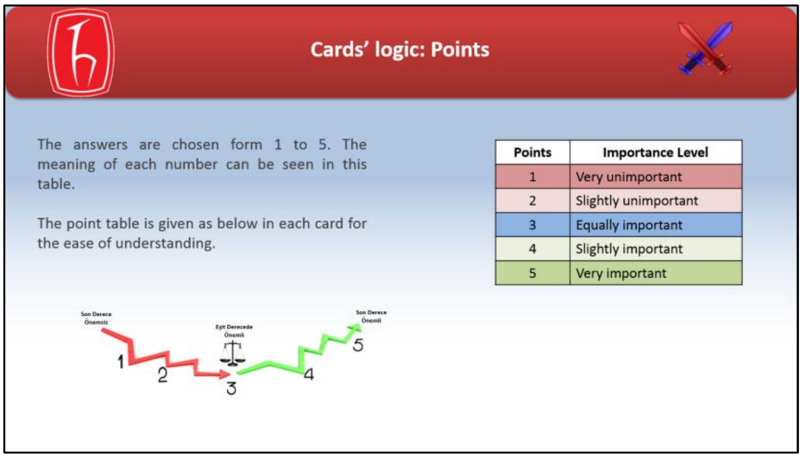
	1			2		
1	1.00	1.00	1.00	1.25	1.75	2.25
2	0.44	0.57	0.80	1.00	1.00	1.00

	1	**2**
Weights	1	0.1325
St weights	**0.8829**	0.1170

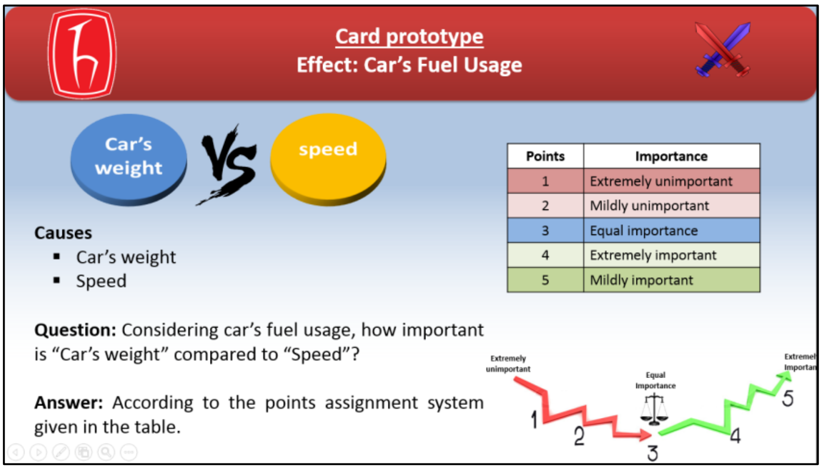
APPENDIX C: FLASHCARDS

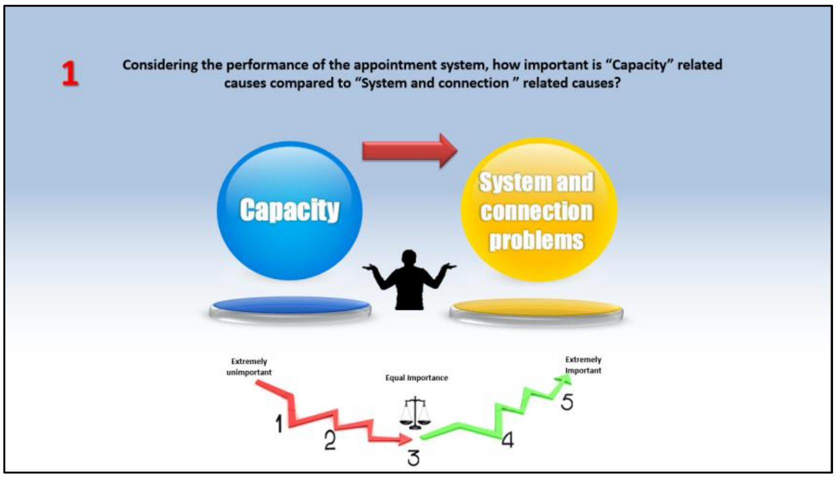


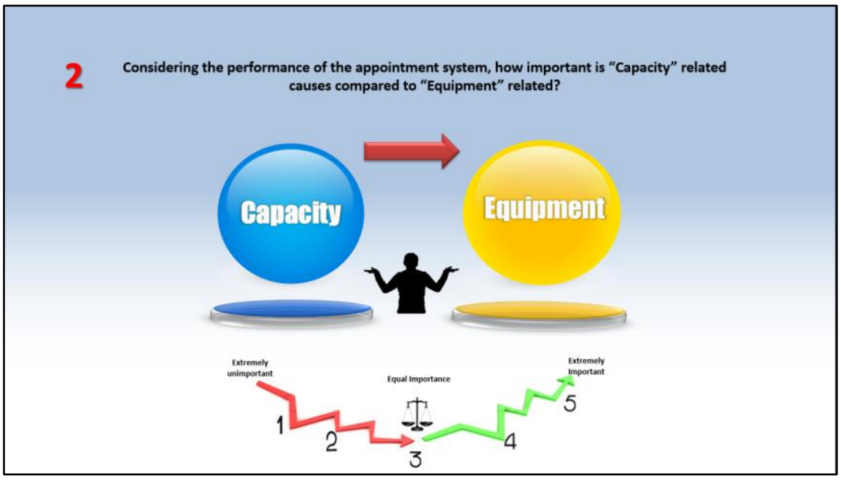


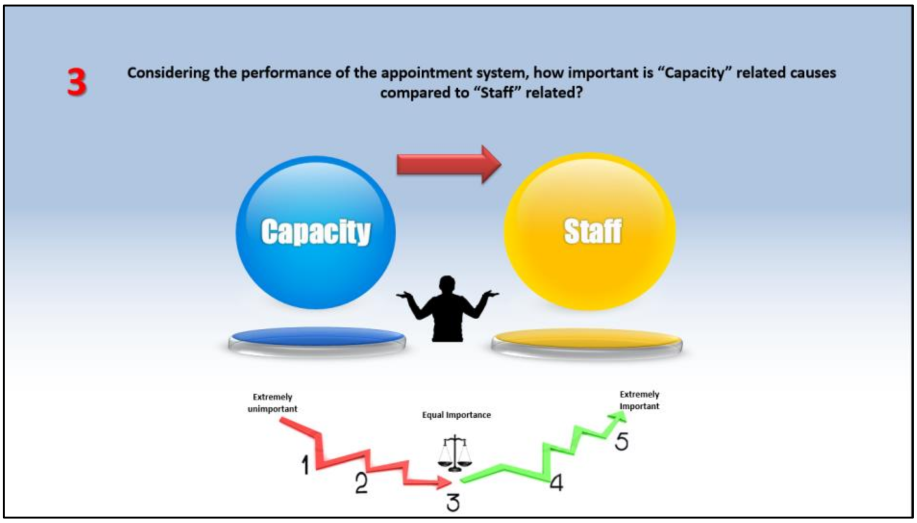


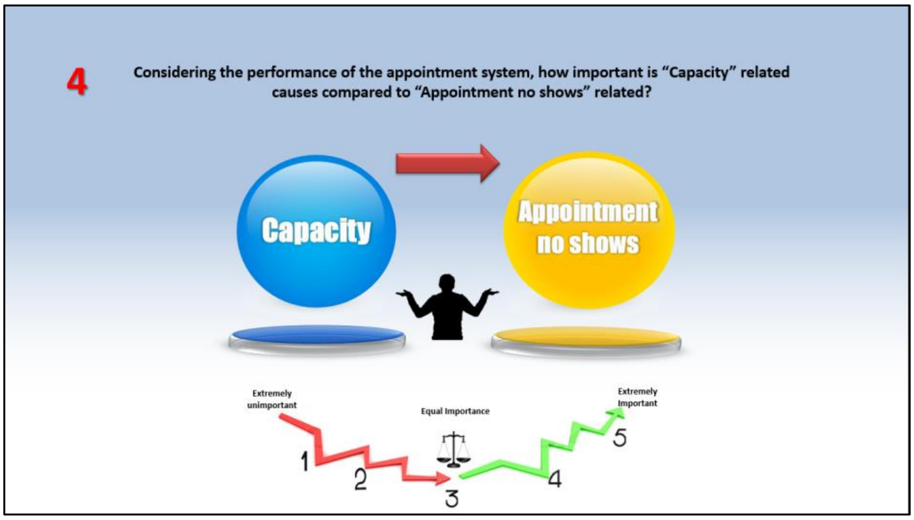
Points	Importance Level
1	Very unimportant
2	Slightly unimportant
3	Equally important
4	Slightly important
5	Very important

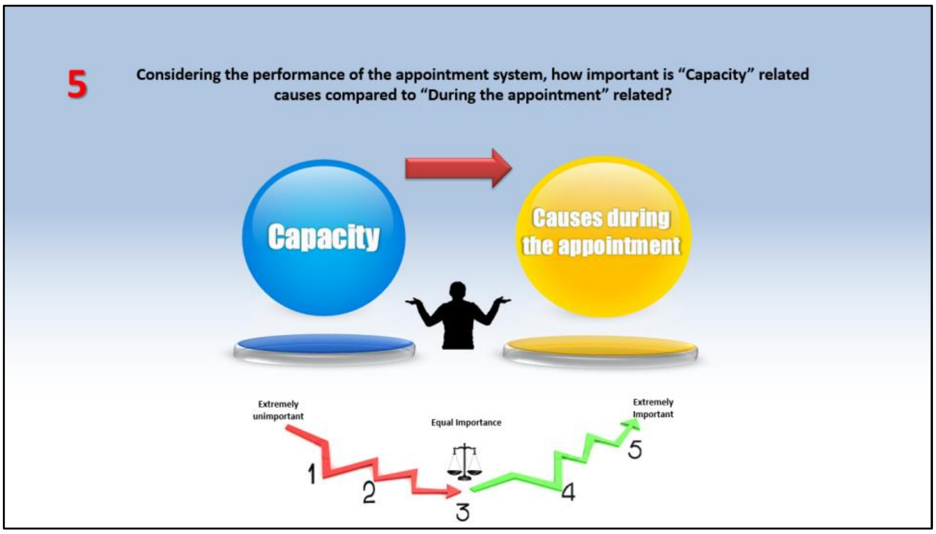

Card prototype
Effect: Car's Fuel Usage
Car's weight
VS
speed
Points
Importance
1 Extremely unimportant
2 Mildly unimportant
3 Equal importance
4 Extremely important
5 Mildly important
Causes
Car's weight
Speed
Question: Considering car's fuel usage, how important is "Car's weight" compared to "Speed"?
Answer: According to the points assignment system given in the table.
Extremely unimportant
Equal importance
1
2
3
4
5

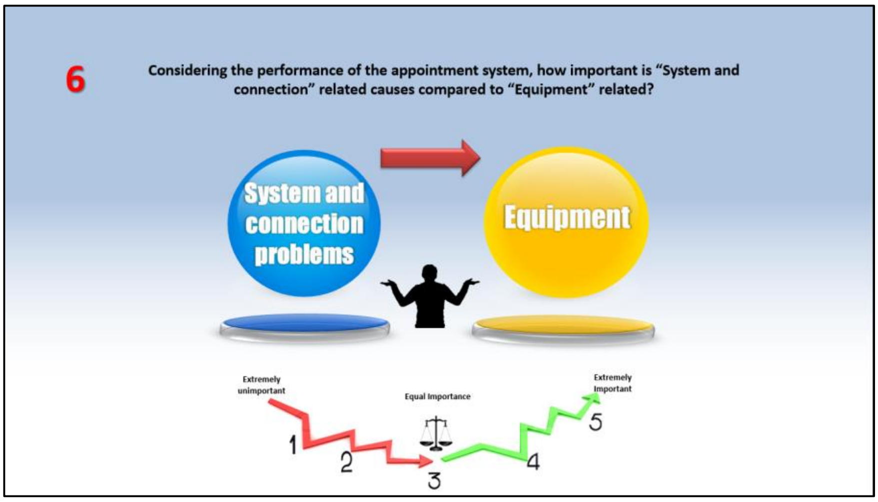

1
Considering the performance of the appointment system, how important is "Capacity" related causes compared to "System and connection " related causes?
Capacity
System and connection problems
Extremely unimportant
Equal importance
Extremely important
1
2
3
4
5

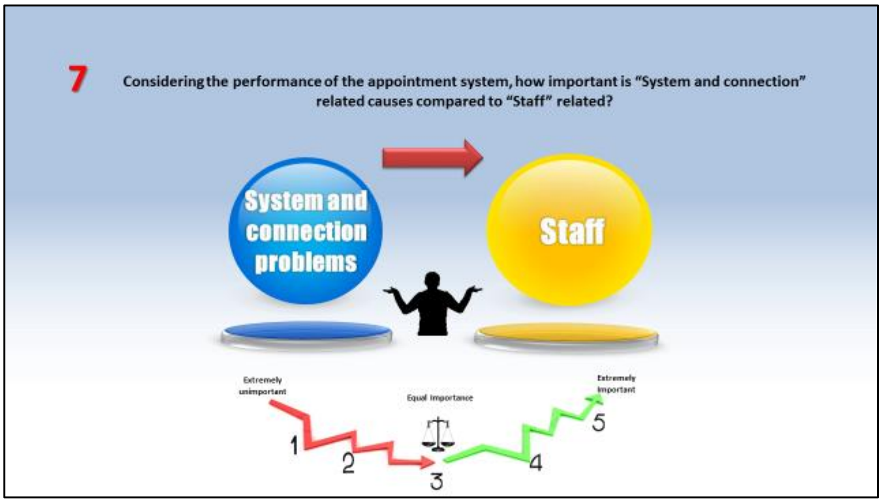

2
Considering the performance of the appointment system, how important is "Capacity" related causes compared to "Equipment" related?
Capacity
Equipment
Extremely unimportant
Equal importance
Extremely important
1
2
3
4
5

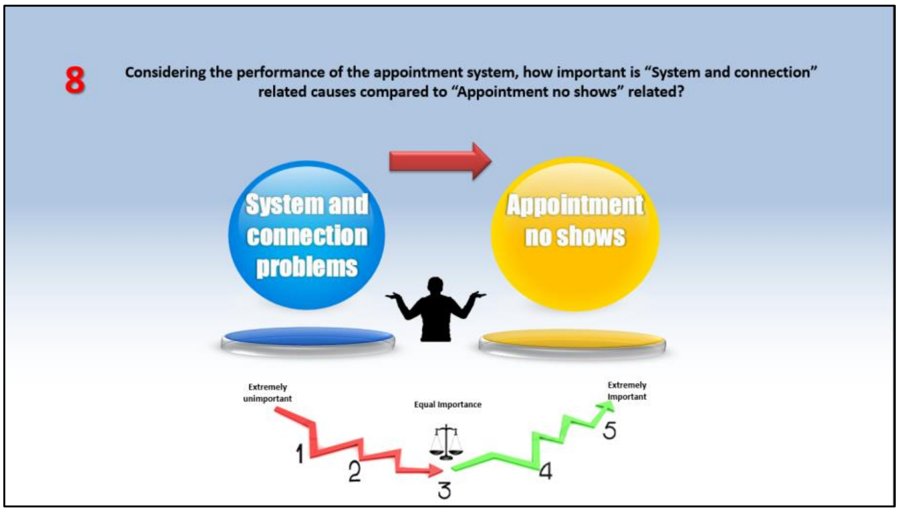

3
Considering the performance of the appointment system, how important is "Capacity" related causes compared to "Staff" related?
Capacity
Staff
Extremely unimportant
Equal Importance
Extremely Important
1
2
3
4
5

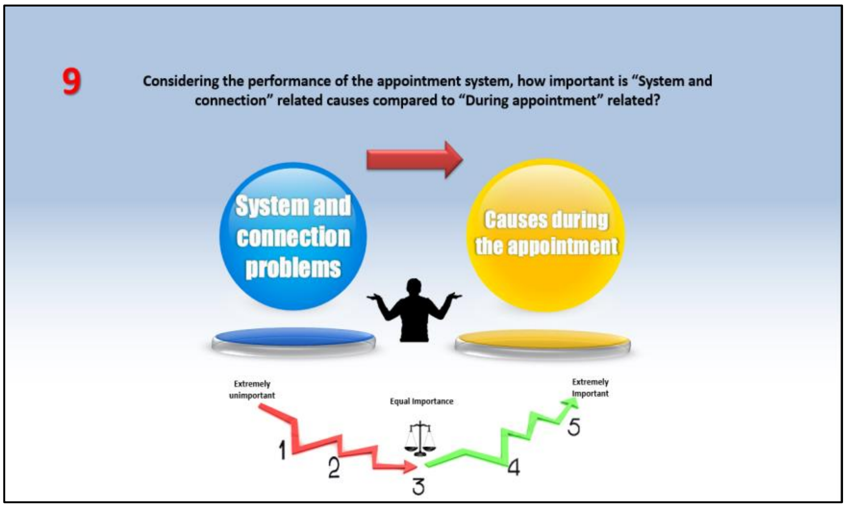

4
Considering the performance of the appointment system, how important is "Capacity" related causes compared to "Appointment no shows" related?
Capacity
Appointment no shows
Extremely unimportant
Equal Importance
Extremely Important
1
2
3
4
5

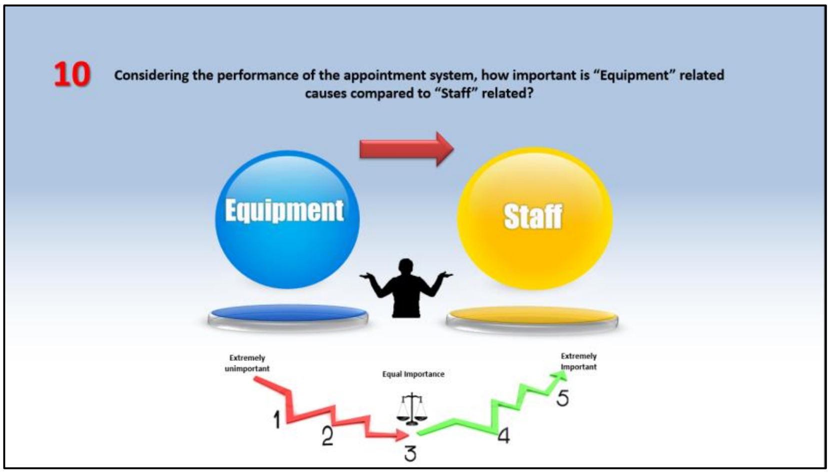

5
Considering the performance of the appointment system, how important is "Capacity" related causes compared to "During the appointment" related?
Capacity
Causes during the appointment
Extremely unimportant
Equal Importance
Extremely Important
1
2
3
4
5

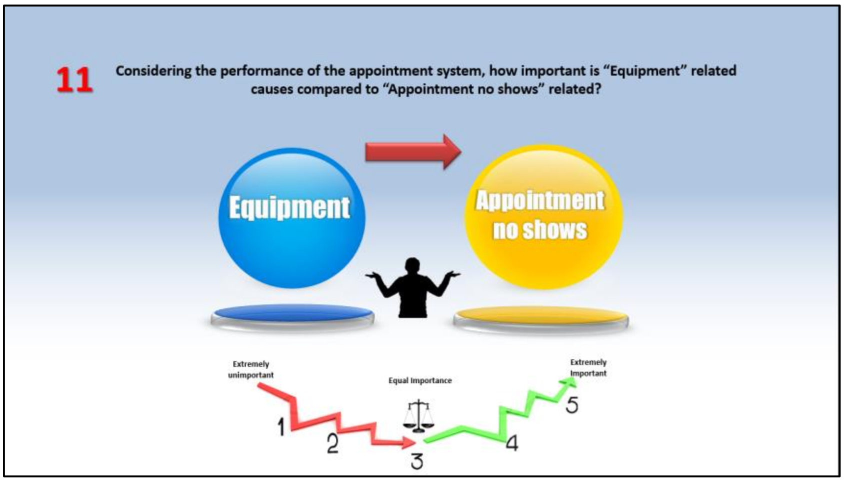

6
Considering the performance of the appointment system, how important is "System and connection" related causes compared to "Equipment" related?
System and connection problems
Equipment
Extremely unimportant
Equal Importance
Extremely Important
1
2
3
4
5

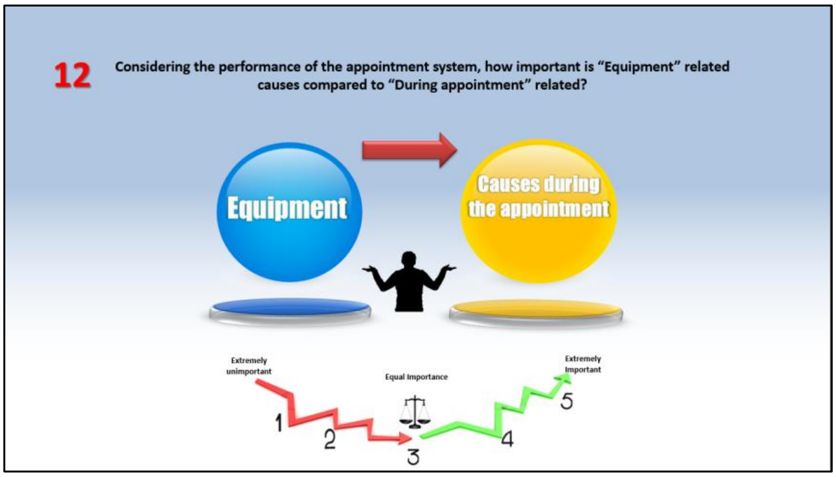

7
Considering the performance of the appointment system, how important is "System and connection" related causes compared to "Staff" related?
System and connection problems
Staff
Extremely unimportant
Equal Importance
Extremely Important
1
2
3
4
5

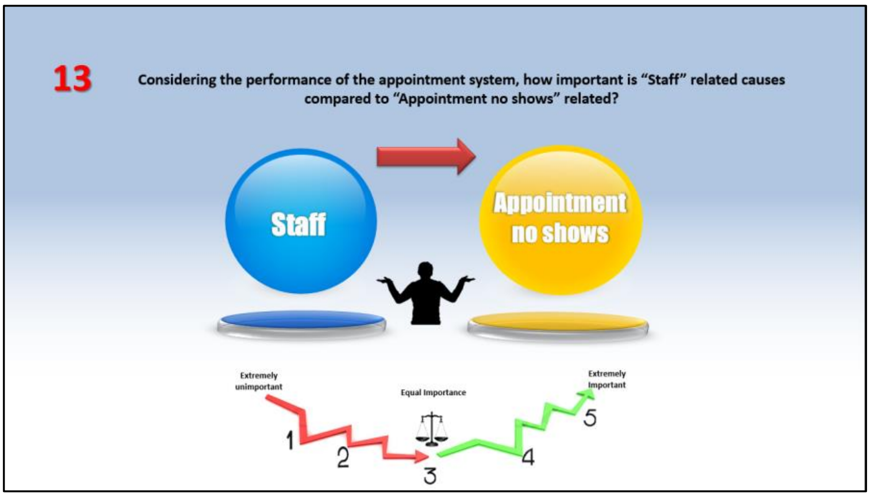

8
Considering the performance of the appointment system, how important is "System and connection" related causes compared to "Appointment no shows" related?
System and connection problems
Appointment no shows
Extremely unimportant
Equal Importance
Extremely Important
1
2
3
4
5

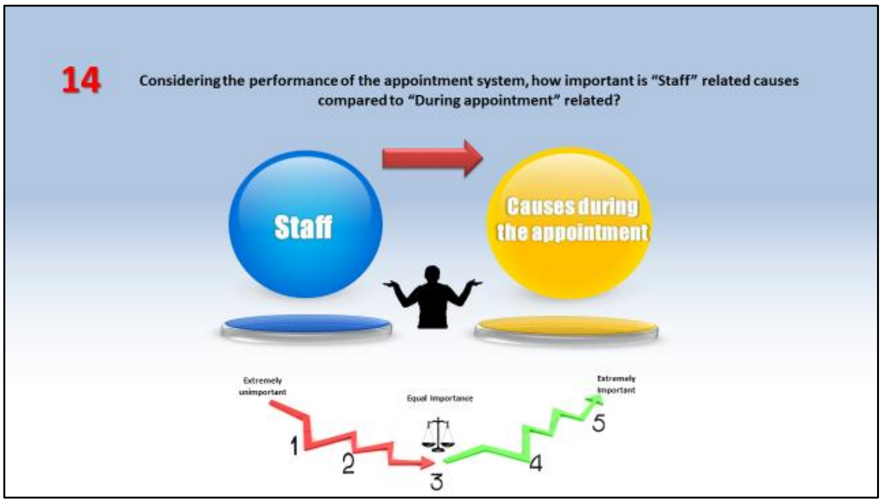

9
Considering the performance of the appointment system, how important is "System and connection" related causes compared to "During appointment" related?
System and connection problems
Causes during the appointment
Extremely unimportant
Equal Importance
Extremely Important
1
2
3
4
5

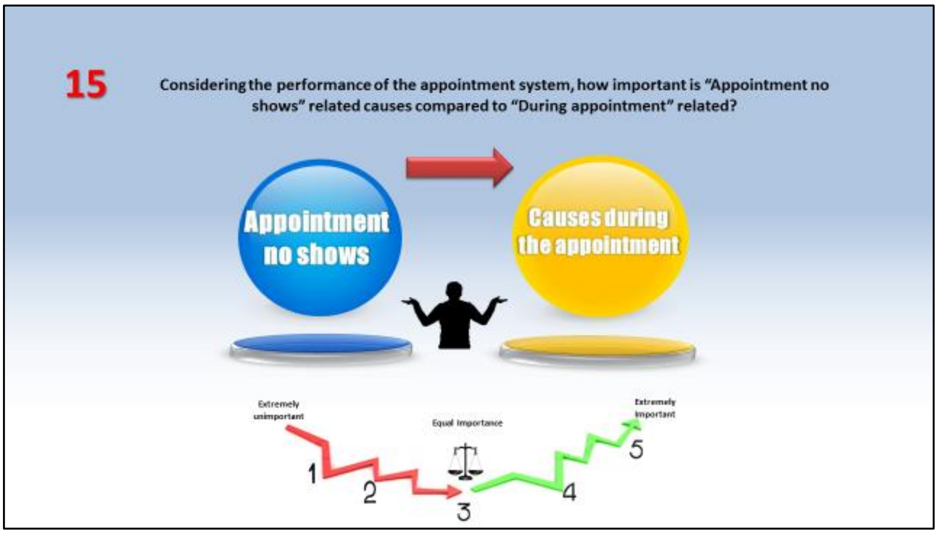

10
Considering the performance of the appointment system, how important is "Equipment" related causes compared to "Staff" related?
Equipment
Staff
Extremely unimportant
Equal Importance
Extremely Important
1
2
3
4
5


11
Considering the performance of the appointment system, how important is "Equipment" related causes compared to "Appointment no shows" related?
Equipment
Appointment no shows
Extremely unimportant
Equal Importance
Extremely Important
1
2
3
4
5


12
Considering the performance of the appointment system, how important is "Equipment" related causes compared to "During appointment" related?
Equipment
Causes during the appointment
Extremely unimportant
Equal Importance
Extremely Important
1
2
3
4
5


13
Considering the performance of the appointment system, how important is "Staff" related causes compared to "Appointment no shows" related?
Staff
Appointment no shows
Extremely unimportant
Equal Importance
Extremely Important
1
2
3
4
5


14
Considering the performance of the appointment system, how important is "Staff" related causes compared to "During appointment" related?
Staff
Causes during the appointment
Extremely unimportant
Equal Importance
Extremely Important
1
2
3
4
5


15
Considering the performance of the appointment system, how important is "Appointment no shows" related causes compared to "During appointment" related?
Appointment no shows
Causes during the appointment
Extremely unimportant
Equal Importance
Extremely important
1
2
3
4
5

CURRICULUM VITAE

Credentials

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Education

BSc. : Industrial Engineering, Mazandaran Institute of Technology

MSc. : Industrial Engineering, Hacettepe University-ongoing

Foreign Languages

- Persian (Native Speaker)
- English (Advanced)
  - ✓ IELTS score:8.5
  - ✓ GRE (Verbal 156)
- Turkish(Upper-Intermediate)
  - ✓ Ankara University TÖMER Diploma
  - ✓ Hacettepe University TÖMER Diploma

Work Experience

- Internship in IRAN ITOK Consulting Company (Bafgh steel Project – Project Control Department), Tehran, Iran / January2010-September2011
- Industrial development design Internship , Kalleh Dairy company, Amol, Iran/ January 2009-September 2009
- Farsi/Turkish conversation partner- Ankara University(Tömer) (Maryland

University flagship program),Ankara, Turkey /September 2012-2013

- Simulation based project development for "Basket" supermarket in EMU campus/May 2012
- Quality Control project for FAZA company, Amol, Iran / January 2011
- Industrial planning and layout design Project based on a water heater making company, Babolsar, Iran/ April 2009
- MIS system development for Basket supermarket , Gazimagusa , Northern Cyprus/ April 2012

Areas of Experience

Fuzzy AHP, Healthcare Engineering ,Multi-criteria Decision making ,Cloud Manufacturing, Production Planning, Supply chain management, Industrial Layout Design ,Project Control ,Engineering and Technology Management , Design and Management of Business Models ,Quality Management, Development Projects of New Products, Multi-agent Based Manufacturing Systems

Projects and Budgets

- Simulation based project development for "Basket" supermarket in EMU campus/May 2012
- Quality Control project for FAZA company, Amol, Iran / January 2011
- Industrial planning and layout design Project based on a water heater making company, Babolsar, Iran/ April 2009
- MIS system development for Basket supermarket , Gazimagusa , Northern Cyprus/ April 2012

Publications

- Cause and Effect Fuzzy AHP Project Selection: A Hospital Application-The 35th National Operations Research and Industrial Engineering Congress (ORIE 2015), Ankara, Turkey/September 2015
- Simulation platform for multi agent based manufacturing control system based on The Hybrid agent- 45th International Conference on Computers & Industrial Engineering (CIE45), Metz, France /October 2015
- A cause and effect diagram and AHP based methodology for selection of quality improvement projects- European Network for Business and Industrial Statistics(ENBIS)14 Conference, Linz/Austria/ September 2014

- Selecting Health Care Improvement Projects: A Methodology Integrating Cause-and-Effect Diagram and Analytical Hierarchy Process, Quality Management in Health Care (Submitted November 2015)

Oral and Poster Presentation

- Cause and Effect Fuzzy AHP Project Selection: A Hospital Application-The 35th National Operations Research and Industrial Engineering Congress (ORIE 2015), Ankara, Turkey/September 2015
- Simulation platform for multi agent based manufacturing control system based on The Hybrid agent- 45th International Conference on Computers & Industrial Engineering (CIE45), Metz, France /October 2015