BUFFER SIZING MODEL WITH FUZZY ASSESSMENT ON CONCRETE GRAVITY DAM AND HEPP PROJECTS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

ŞEMSETTİN BALTA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CIVIL ENGINEERING

JUNE 2014

Approval of the thesis:

BUFFER SIZING MODEL WITH FUZZY ASSESSMENT ON CONCRETE GRAVITY DAM AND HEPP PROJECTS

submitted by **ŞEMSETTİN BALTA** in partial fulfillment of the requirements for the degree of **Master of Science in Civil Engineering Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen ___________
Dean of Graduate School of **Natural and Applied Sciences**

Prof. Dr. Ahmet Cevdet Yalçıner ___________
Head of Department, **Civil Engineering**

Prof. Dr. Mustafa Talat Birgönül ___________
Supervisor, **Civil Engineering Department, METU**

Prof. Dr. İrem Dikmen Toker ___________
Co-Supervisor, **Civil Engineering Department, METU**

Examining Committee Members:

Assoc. Prof. Dr. Rıfat Sönmez
Civil Engineering Department, METU ___________

Prof. Dr. Mustafa Talat Birgönül
Civil Engineering Department, METU ___________

Prof. Dr. İrem Dikmen Toker
Civil Engineering Department, METU ___________

Asst. Prof. Dr. Aslı Akçamete
Civil Engineering Department, METU ___________

Gülşah Dağkıran, M.Sc.
Gama Holding ___________

Date: **20.06.2014**

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name : Şemsettin BALTA

Signature :

ABSTRACT

BUFFER SIZING MODEL WITH FUZZY ASSESSMENT ON CONCRETE GRAVITY DAM AND HEPP PROJECTS

Balta, Şemsettin

M.Sc., Department of Civil Engineering

Supervisor : Prof. Dr. M. Talat Birgönül

Co-Supervisor : Prof. Dr. İrem Dikmen Toker

June 2014, 167 pages

Timely completion of dam and HEPP projects is indispensable for the country, they are constructed due to economical, political and social consequences of them. Since various uncertainties and variations existed on the construction of dam and HEPP projects because of their complex nature, robust and stable schedules should be created in the beginning of the projects in order to eliminate or minimize the negative effects of them. Among the various techniques; usage of time buffer is considered as one of the most effective methods for the robust and stable scheduling; however, traditional time buffer sizing methods prone from the several deficiencies.

The study introduces improved buffer sizing model with fuzzy assessment in order to calculate the sizes of the time buffers more accurately for the concrete gravity dam and HEPP projects by considering the activities' durations, activities' characteristics, activities' interdependencies and project's characteristics.

Fuzzy logic concepts form the main part of the study and Fuzzy Logic Toolbox^{TM}, built on MATLAB, is used in order to develop the model. 89 causes of delay were found for the concrete gravity dam and HEPP projects by making detailed literature review and brainstorming with the experts. Frequency of occurrence and severity values of them were taken into account as inputs for the model. Applicability of the methodology proposed in this study was illustrated in the hypothetical project. Also, by following the methodology proposed in this study; sizes of the time buffers can be calculated for the other types of the projects.

Keywords: Time Buffer, Buffer Sizing Model, Fuzzy Logic, Causes of Delay

ÖZ

BETON AĞIRLIK BARAJ VE HES PROJELERİNİN BULANIK DEĞERLENDIRME İLE YEDEK ZAMAN BOYUTLANDIRMA MODELİ

Balta, Şemsettin

Yüksek Lisans, İnşaat Mühendisliği Bölümü

Tez Yöneticisi : Prof. Dr. M.Talat Birgönül

Ortak Tez Yöneticisi : Prof. Dr. İrem Dikmen Toker

Haziran 2014, 167 sayfa

Baraj ve HES projelerinin zamanında tamamlanmaları; ekonomik, sosyal ve politik sonuçlarından dolayı inşaa edildikleri ülkeler için elzemdir. Kompleks yapılarından dolayı baraj ve HES projelerinin inşaatında çeşitli belirsizlikler ve sapmalar mevcuttur ve bu sebeple oluşabilecek olumsuz etkileri bertaraf etmek ya da azaltmak adına kuvvetli ve güvenilir iş programlarının, projelerin başlangıcında oluşturulması gerekmektedir. Kuvvetli ve güvenilir iş programlarının oluşturulabilmesi için; yedek zaman kullanımı çeşitli teknikler arasında en etkili yöntemlerden biri olarak kabul edilmesine karşın; yedek zaman boyutlarının hesaplandığı geleneksel yöntemlerde çeşitli eksiklikler mevcuttur.

Bu çalışmada iş kalemlerinin süreleri, iş kalemlerinin karakteristikleri, iş kalemlerinin aralarındaki bağlar ve proje özellikleri düşünülerek; beton ağırlık baraj ve HES projelerindeki yedek zaman boyutlarının daha doğru bir şekilde hesaplanabilmesi için gelişmiş bulanık değerlendirme ile yedek zaman boyutlandırma modeli önerilmiştir.

Bulanık mantık kavramları bu çalışmanın ana parçasını oluşturmaktadır ve modeli geliştirebilmek için MATLAB'da oluşturulan Fuzzy Logic Toolbox^{TM} kullanılmıştır. Detaylı literatür taraması ve uzmanlarla beyin fırtınası yapılarak, beton ağırlık baraj ve HES projeleri için 89 tane gecikme nedeni bulunmuştur. Modelin girdileri olarak gecikme nedenlerinin meydana gelme sıklıkları ve şiddet değerleri kullanılmıştır. Bu çalışmada önerilen yöntemin uygulanabilirliği farazi bir proje üzerinden örneklendirilmiştir. Ayrıca; bu çalışmada önerilen yöntemin izlenmesi ile birlikte diğer proje tiplerinde de yedek zamanların boyutları hesaplanabilir.

Anahtar Kelimeler: Yedek Zaman, Yedek Zaman Boyutlandırma Modeli, Bulanık Mantık, Gecikme Nedenleri

To Melek BALTA, Mehmet Fahri BALTA and Gülsüm Çağıl KÖSEOĞLU

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor Prof. Dr. M. Talat Birgönül and my co-supervisor İrem Dikmen Toker for their invaluable guidance, encouragements, advices and insight during the entire study.

I would also like to thank the examining committee members, for their invaluable ideas.

I would also like to thank Fevzi Özdemir for his valuable help.

Additionally, thanks to my graduate colleagues who support me to achieve the finish line and to those who contributed to my research.

Special thanks to Çağdaş Bilici, Emre Yılmaz, Gözde Bilgin and Murat Altun for their advices and encouragement through my study.

Also, thanks to my friends Ahmet Emre Topbaş, Alican Cömert, Eyüp Ensar Altaş, Mehmet Dincer, Onur Ata, Orçin Akgönül and Uğur Koç for their true friendship and sharing joyful times with me throughout my thesis period.

Sincere thanks to my mother Melek Balta, my father Mehmet Fahri Balta and Gülsüm Çağıl Köseoğlu for their love, support and patience to me. I could not have finished this study without them by my side.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF SYMBOLS

$\mu_A(x)$	Membership Function of x into A
$\cap$	Intersection Operator
$\cup$	Union Operator
-	Complement Operator
$\in$	Element
$\notin$	Not an Element
F_k	Frequency of Occurrence of the Arbitrary Cause of Delay
I_k	Importance Value of the Arbitrary Cause of Delay
IW_k	Importance Weight of the Arbitrary Cause of Delay
S_k	Impact of the Arbitrary Cause of Delay
TI	Total Importance of the all Causes of Delay

ABBREVIATIONS

APD	Adaptive Procedure with Density
APRT	Adaptive Procedure with Resource Tightness
C&PM	Cut and Paste Method
CCM	Critical Chain Method
CPM	Critical Path Method
FB	Feeding Buffer
FIS	Fuzzy Inference System
FNA	Fuzzy Network Analysis
HEPP	Hydro Electric Power Plant
IT	Information Tool
MEP	Mechanical, Electrical and Plumbing
PB	Project Buffer
PERT	Program Evaluation and Review Technique
RB	Resource Buffer
RSEM	Root Square Error Method
TBEM	Time Buffer Evaluation Model
TOC	Theory of Constraint
WCD	World Commission on Dams

CHAPTER 1

INTRODUCTION

1.1 Introduction and Problem Statement

Encountering uncertainties, variations and delays on construction projects are inevitable due to complex nature of them. Since uncertainties, variations and delays cause various negative effects to construction projects, such as negotiations and lawsuits between parties, loss of money, interruption of works etc., all project participants try to minimize the negative effects of them.

Construction of the dam and HEPP projects are more sensitive to uncertainties, variations and delays when compared with the other construction projects because of their operational size. Moreover; they are composed of many activities which are required special expertise; therefore, various different parties and engineering groups are involved in the construction of the dam and HEPP projects which increase the potential occurrence of the delay.

Dam and HEPP projects are crucial for the countries where they are constructed; therefore, special importance was given to them. Also, due to complexity and size of the construction; uncertainties, variations and delays in these projects can cause immense negative economic and political effects.

Robust planning and scheduling are proposed in order to deal with uncertainties, variations and delays. Many studies exist and several techniques are recommended in the literature about robust planning and scheduling. Among these techniques, buffers are the most widely used and reliable method. Several types of buffers exist; however, only time buffers are concern of this study.

Although there are various methods used in order to calculate the size of the time buffer on the schedule of the construction projects, they are prone from several deficiencies. As a result of this, there exists a need to develop a buffer sizing model in order to create a robust and stable schedule for the construction of the dam and HEPP projects in order to minimize the negative effects of uncertainties, variations and delays.

1.2 Objective and Scope

The main aim of this study is to develop a model in order to calculate the size of time buffer optimally for the construction of the concrete gravity dam and HEPP projects. The model is constructed by using fuzzy logic concepts in the Fuzzy Logic Toolbox™ which is built on the MATLAB. In order to achieve this aim, the thesis has the following objectives:

1) To study and understand the uncertainties, variations and delays on the construction projects.

2) To study the techniques used in order to calculate the size of the time buffer.

3) To determine the causes of delay encountered on concrete gravity dam and HEPP projects by making literature review and brainstorming with the experts.

4) To determine the frequency of occurrence and severity of the causes of delay encountered on concrete gravity dam and HEPP projects by making online survey.

5) To determine the fuzzy membership functions & linguistic variables, fuzzy rules and aggregation & defuzzification methods by making literature review and consulting the experts.

6) To present a buffer sizing model with fuzzy assessment.

7) To test the proposed model on the hypothetical concrete gravity and HEPP project.

1.3 Disposition

The thesis is composed of six chapters as follows:

In Chapter 1, a brief introduction and contribution of the research are given with the objectives and scope of the study.

In Chapter 2, detailed literature survey is made about the uncertainty, variation and delay. The previous studies, found in the literature, about the definitions of uncertainty, variation and delays on the construction projects, effects of delays to construction projects, causes of delay and types of delay on construction projects are presented in this chapter.

In Chapter 3, brief information is given about the definitions and types of the buffers used on the construction projects. Also, time buffer design and management techniques are discussed and reviewed in this chapter.

In Chapter 4, general information about the fuzzy logic concept, which is required in order to construct the proposed buffer sizing model with fuzzy assessment, advantages of fuzzy logic and preview studies for fuzzy logic concepts, found on the literature, are given.

In Chapter 5, causes of delay on the concrete gravity dam and HEPP projects are determined and presented. Moreover; online survey results and description of the proposed buffer sizing model with fuzzy assessment are given. Also, applicability and reliability of the proposed model are illustrated and tested in a hypothetical project with the experts' opinion. At the end of the chapter; the findings with the interpretations of them can be found.

In Chapter 6, conclusion of the study with the findings is given and recommendations of the future works are discussed.

Following the main text, this thesis also includes two appendices. These appendices are given as follows:

In Appendix A, a sample of the questionnaire used throughout the online survey is presented.

In Appendix B, the results found in the Rule Viewer, which is one of the graphical user interface tool in the Fuzzy Logic Toolbox™, can be found.

CHAPTER 2

UNCERTAINTY AND DELAY ON CONSTRUCTION PROJECTS

2.1 Definitions of Uncertainty

The term of uncertainty is used in a number of fields; namely, philosophy, physics, statistics, economics, finance, insurance, psychology, sociology, engineering, information science etc..

Miscellaneous definitions can be made based on the fields that uncertainty is used. However, according to the Oxford English Dictionary; uncertainty can be defined generally as “the state of not being definitely known or perfectly clear, doubtfulness or vagueness” (Oxford English Dictionary, 2014).

Additionally, researchers in project management defined the term uncertainty as “events having a negative impact on the project’s outcomes, or opportunities” (Perminova et al., 2008).

2.2 Uncertainties on Construction Projects

If multiple consequences can occur and likelihood of the occurrence of each consequences cannot be predicted accurately enough, then uncertainty may be originated. Also, there is a direct proportion between complexity and uncertainty which means that if number of the activities and relationships between them increase, uncertainties on the project automatically increase (Meyer et al., 2001).

Under the light of these information, it can be said that there are numerous uncertainties exist on construction projects due to nature of them since construction projects are unique; in other words, each construction project has own characteristics; therefore, it is very hard, sometimes impossible to find historical or statistical data for them. Besides; in construction industry, projects are composed of numerous activities that are connected to each other with their own cost, time, quality and sequence issues (Flanagan and Norman, 2000).

Variation represents any change in the original works. All construction works have a possibility to be at variance with initial planned works. Variation of the activities' properties such as time, cost and quality is the apparent area of the uncertainty on construction projects (Ward and Chapman, 2003).

Uncertainties and variations on construction projects are especially important and should be well managed as they could affect a company's overall performance (Ribeiro et al., 2013).

Time overrun of the construction projects can be considered as one of the most important effect of uncertainties and variations because time equals money in today's world. Also, completed the project on promised time shows the reputation of the company carried out the relevant construction projects. In other words, major criterion of construction project success is considered as timely completion of a project (Rwelamila and Hall, 1995). Scheduling and planning process may have a substantial impact on estimating construction activity duration and network calculations (Farag, 2010). As a result of this, robust planning and scheduling are essential for construction projects in order to reduce the negative impact of uncertainties and variations.

2.3 Definitions of Delay

Generally, delay occurs if something happens later than it should be or expected to take place. In other words, the term delay is used in order to express size of the time loss.

It is very common to encounter delays on construction projects due to inherent nature of them that was mentioned above. Delay on construction projects can be defined as the exceeded time from the completion date on the contract or from the agreed project delivery date that the parties have previously settled on (Assaf and Al-Hejji, 2006). Also; in the study of Zack (2003), construction delay was defined as an action which causes to exceed the time needed to perform or complete the contracted work in terms of working days.

2.4 Effects of Delays to Construction Projects

Delays on construction projects have various negative effects. According to Haseeb et al. (2011) and Tumi et al., (2009) delays can cause disputes, negotiations and lawsuits between parties, increase completion time, time related cost and abandonment of the project, interruption of work and decrease in productivity.

Since effects of delays on construction projects are crucial, it is essential to deal with them. Various different methods have been suggested on the literature to deal with delays and minimize the effects of them; however, the primary step of all methods depend on finding causes of delay because if project managers know the basis of the delays, proactive precaution can be taken by them.

2.5 Causes of Delay on Construction Projects

As was mentioned above, in order to deal with effects of delays on construction projects, the basic step is determining the causes of delay. For this reason, the causes of delay encountered on construction projects have been investigated by respectable amount of researchers. However; due to uniqueness of the construction projects, finding information and statistical data can be difficult at the beginning; therefore, it is common to use expert's ideas to get initial signs about the project. For that reason, survey and questionnaire are common methods used in the literature in order to get the expert's ideas about the causes of delay encountered on construction projects. Some of the previous studies are summarized below:

Mansfield et al. (1994) studied the causes of delay and cost overruns in Nigeria. 16 causes of delay were found in this study. The most important factors for delays are; delay in financing and payment for ongoing and complete activities, poor contract management, shortage of materials, fluctuations in overall prices and improper planning and estimating.

Odeh and Battaineh (2002) studied causes of delay on construction projects with traditional type contracts in Jordan. By looking large projects that had been done in Jordan, 28 causes of delay were compiled under 8 major categories; namely, client, contractor, consultant, material, labor and equipment, contract, contractual relationships and external factors for delays. A questionnaire was distributed to contractors and consultants in order to determine most important causes of delay. According to the results obtained from the questionnaire, perceptions to the causes of delay of contractors and consultants show differences. Seven causes of delay are among the top ten most significant factors for both contractors and consultants. They are; inadequate financing and payments of completed work, owner interference, slow decision-making by owners, improper subcontractors, inadequate contractor experience, improper planning and low level of labor productivity.

Frimpong et al. (2003) studied the causes of delay and cost overruns on groundwater projects in Ghana. According to the previous surveys, delays occurred in 33 water drilling projects out of a total of 47 projects between 1970 and 1999. This means that delays in water related project in Ghana cause significant problems. As a result of this, survey was conducted in order to find causes of delay and their relative importance index. According to the results, the most important causes of delay are monthly payment difficulties from agencies, poor contractor management, material procurement, poor technical performances and escalation of material prices.

Assaf and Al-Hejji (2006) identified 73 causes of delay on construction projects in Eastern Province of Saudi Arabia by making literature review and discussion with some parties. These causes of delay were classified into 9 main groups; namely, project, owner, contractor, consultant, design, materials, equipment, labors and external causes. Frequency of occurrence, severity and importance of these causes of delay were found by making questionnaire to three different parties; as follows, owners, contractors and consultants. Also, differences in perceptions of these parties to cause of delays on construction projects were presented in this study. Based on the perceptions of these parties; only delay cause of change orders by owner during construction is considered as an extensive source of delay. Besides, many causes of delay are considered as common between two parties; such as delay in progress payments, ineffective planning and scheduling by contractor, poor site management and supervision by contractor, shortage of labors and difficulties in financing by contractor.

Sambasivan and Soon (2007) studied the causes and effects of delays on construction projects in Malaysia. 28 causes of delay were found and categorized under 8 primary groups; namely, client related, contractor related, consultant related, material related, labor and equipment related, contract related, contract relationship related and external factors related. Relative importance index of each causes of delay were also found in this study and according to the results ten most important causes of delay on construction projects in Malaysia are as follows: contractor's improper planning, contractor's poor site management, inadequate contractor experience, inadequate client's finance and payments for completed work, problems with subcontractors, shortage in material, labor supply, equipment availability and failure, lack of communication between parties and mistake during the construction stage.

El-Razek et al. (2008) examined the construction projects in Egypt. Firstly, 87 causes of delay had been found by making literature review. Then, questionnaire was made. Some of the causes of delay were considered as irrelevant for the construction projects in Egypt and 32 causes of delay were determined. They were grouped under 9 major categories; namely, financing, materials, contractual relationship, changes, rules and regulations, manpower, scheduling and control, equipment and environment. Difference in perception of the causes of delay between client, contractor and consultant were given in this paper. According to the results that they have found; the most important causes of delay are financing by contractor during construction, delays in contractor's payment by owner and design changes by owner or his agent during construction.

Ghoddosi et al. (2008) used fuzzy identification and evaluation methods in order to find causes of cost and time overruns on construction of the dam projects in Iran. 39 causes of delay were found for dam construction projects in this study with 5 main groups; namely, regulation-related, employer-related, consultant-related, contractor-related and other causes of delay. According to this study, top five important causes of delay are be summarized as; concentrate on winning the project with lowest bid and not taking care of completion of the project, incompetence of responsible manager of contractor, problems in providing enough budget for project in appropriate time, deficiencies in rules and regulations related to assigning the work to contractors and problems in technical and managerial abilities of contractor, difficulty in support of project agents and participation of governmental contractors.

Tumi et al. (2009) conducted a study on the major causes of delay on construction projects in Libya through a survey to owners, consultants and contractors. Also, effects of delays and recommended solutions in order to deal with causes of delay can be found in this study. Causes of delay were grouped under six major categories as follows; design-related, construction-related, financial-economical related, management-administrative related, code related and acts of God. According to the results of this survey; improper planning, problems in communication, design errors, shortage of materials, financial problems and slow decision procedures are considered as some of the most significant causes of delay.

Kazaz et al. (2012) compiled the causes of delay in the Turkish construction industry and their relative importance index. Besides, comparison between the delays in Turkey and other countries were given in this study. 34 causes of delay were found from the literature and grouped under seven categories; namely, environmental factors, financial factors, labor-based factors, managerial factors, project-based factors, resource-based factors and owner-based factors. According to the relative importance index, the most significant causes of delay are; changes in design and material, delay of payments, problems in cash flow, problems in contractor's financial situation, poor labor productivity, estimation problems, lack of feasibility studies, construction defects, unbalanced number of workers and fluctuation in material prices. Also, labor related factors and managerial related factors are critical factors for Turkey when compared to other 16 countries.

Gündüz et al. (2013) compiled the 83 causes of delay on construction projects in Turkey by making interviews with experts on Turkish firms and literature review.

Besides, these causes of delay were showed on Ishikawa Diagram and categorized into nine groups; namely, consultant-related factors, contractor-related factors, design-related factors, equipment-related factors, externality-related factors, labor-related factors, material-related factors, owner-related factors and project-related factors. By making questionnaire with 64 experts, relative importance index for the causes of delay were determined. According to the results, some of the most important causes of delay are as follows; insufficient contractor experience, inadequate project planning and scheduling, improper site management and supervision, changes in design during construction by owner and agent, late delivery of materials, unreliable subcontractors and delay in performing inspection and testing.

2.6 Types of Delay on Construction Projects

According to Tumi et al. (2009) in order to determine the delay damages, delays can be categorized into two groups; namely, excusable delays and inexcusable delays. Excusable delays can also be classified in itself as excusable with compensation delays and excusable without compensation delays.

Excusable delays can be defined as delays that are due to unforeseen events; therefore, neither contractors nor subcontractors are responsible for the problem. Adverse weather conditions and illnesses are given as examples for the excusable delays.

Excusable with compensation delays occur due to client's behavior and contractor can demand time extension and monetary compensation from the client. Late instruction given to contractor by the client can be given as an example to excusable with compensation delays. Excusable without compensation delays are those that neither client nor the contractor is responsible for the problem. Only time extension can be given to the contractor because of this type of delays. Force majeure can be given as an example for this type of delays (Yusof et al., 2007).

Inexcusable delays are those that either contractor is responsible or contractor is not responsible for the problem; however, it is expected that this type of delays should have been foreseen by the contractor. Neither time extension nor monetary compensation are given to the contractor because of these delays. Late performance of subcontractors can be given as an example for inexcusable delays (Mubarak, 2005).

Beside excusable and inexcusable delays, delays are sometimes classified as concurrent delays. Concurrent delays means that delay situations when two or more delays occur at the same time or overlap with each other with some degree (Majid, 2006).

In the next section; buffers, which are used in the construction industry in order to reduce or eliminate the negative impacts of uncertainties, variations and delays, will be defined, types of buffer will be presented and time buffer design and management techniques will be introduced.

CHAPTER 3

BUFFERS ON CONSTRUCTION PROJECTS

Since construction industry is schedule-driven; robust and stable schedule of construction projects have been tried to construct by engineers and researchers in order to control and minimize the negative impact of uncertainties, variations and delays occurred on construction projects.

Using buffers on construction schedule is considered as one of the most important methods for robust and stable scheduling. As a result of this; several types of buffers have been used on construction schedule and many attempts have been done in order to determine the most effective positioning and sizing of buffers in order to control and minimize the negative impact of uncertainties, variations and delays occurred on construction projects.

3.1 Definitions of Buffer

Several definitions of buffer exist in the literature. In fact, those definitions depend on the aims and functions of the buffer. Some of the definitions of buffer used on construction industry are tried to be summarized at this section.

In the study of Howell and Ballard (1994) buffer was defined as a significant apparatus that allows two or more activities progressed independently with each other.

Sakamoto et al. (2002) defined buffer as a technique to deal with the negative impact of the uncertainty and variations on construction project by consuming the problems and perturbations.

Kim et al. (2006) wrote that buffers can be considered as a cushion in the form of money, time, information, and so on, that shield the original construction schedule from the negative impacts of the uncertainty and variation.

Hopp and Spearman (2008) wrote that buffers have to be used on a production system against uncertainty and variability in order to deal with loss of throughput, wasted capacity, inflated cycle times, larger inventory levels, long lead times and poor customer service.

According to Jaskowski and Biruk (2010) buffers are operated in order to be sure for the timely completion of the construction activity or project.

3.2 Types of Buffer on Construction Projects

As it was mentioned above; several different types of buffer have been defined and used on the construction literature. Ballard and Howell (1995) identified plan buffer. Gonzalez et al. (2004) proposed technical buffer. Hopp and Spearman (2008) defined three types of buffer; namely, inventory, capacity and time buffers. After doing detailed literature review; types of buffer can be classified into 5 major categories; namely, inventory buffers, capacity buffers, contingency buffers, plan buffers and technical buffers. Contingency buffers are also classified into two subcategories. The subcategories of the contingency buffers are time buffers and financial (cost) buffers. Detailed definitions of these 5 types of buffer can be found in the Table 1, below.

Although there are several types of buffer used on the construction projects; the focus of this thesis is only the study of time buffer which are used as a reserved time on construction schedule in order to deal with negative impacts of uncertainties, variations and delays encountered during the construction and design phase of the construction projects.

Table 1: Types of Buffer and Their Definitions

Type of Buffer	Definitions of Buffer
Inventory Buffer	When material stockpiles or inventories are used in order to deal with uncertainties, variations and delays on construction projects; they are called as inventory buffers. The critical thing is that large inventory buffers can cause congestions to the construction area; therefore, cause delays on the ongoing works. On the other hand, inventory buffers which are too low can lead to stoppage and disruption of works. As a result of this; size of the inventory buffers should be calculated carefully (Horman and Thomas, 2005).
Capacity Buffer	If labor and equipment are used in order to protect the project from variable project demands, they are called as capacity buffers (Gonzalez et al., 2004). Optimum usage of the capacity buffers increase the operation ability and provides the rapidly response to the unexpected situations (Horman and Thomas, 2005).
Contingency Buffer	Contingency buffers composed of time buffer and financial (cost) buffer. Time buffer is a buffer that added to the initial schedule as spare time in order to protect the schedule from uncertainties, variations and delays which can be occurred during the construction and design phase. Its purpose is to guarantee the completion of an activity or project on time (Jaskowski and Biruk, 2010). Financial (cost) buffer means that reserved budgets added in order to protect the construction project from unforeseen costs occurred due to uncertainties, variations and delays on the construction projects.
Plan Buffer	Workable assignments are considered as plan buffers. In other words, plan buffers are backlogs of the workable assignments. In cases where planned activities cannot be carried out or are finished earlier than expected, plan buffers identify alternative activities to be performed on the right work order (Ballard and Howell, 1995).
Technical Buffer	Gonzalez et al., (2004) proposed technical buffer which reduces uncertainties and variations in the early stages of the construction projects with using experience of the engineers, concepts and information tools (IT). For example, 4D Planning and Scheduling Models are used at the beginning of the project in order to see the possible uncertainties and variations which can be occurred during the construction; therefore, precautions can be taken in order to eliminate and minimize the possible negative impacts of them.

3.3 Design and Management of Buffers on Construction Projects

As it was mentioned; the thesis is only limited with time buffer; therefore, developing a convenient evaluation approach of time buffer on the construction schedule is the aim of this thesis. An illustration of activity time buffer used in scheduling can be seen in the Figure 1.

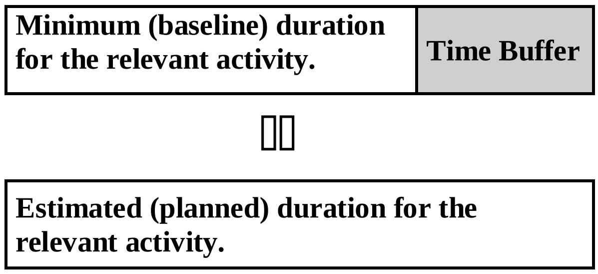

Figure 1: Activity Time Buffer

Although activity time buffer is looked very similar to the float in the activity; they are not the same. Float is also called as slack. Float is the amount of time that an activity may be delayed without causing a delay to the early start time of the successor activity or project completion date. Float is occurred accidently because of the network logic, and has nothing to do with the uncertainty and variation on the durations of the tasks in the chain (Leach, 2005). In other words; float cannot be succeed to protect the schedule from uncertainties and variations.

Various different methods have been suggested in the literature in order to design and manage time buffer. Some of these methods are based on using algorithms, simulations, optimizations and heuristic rules. Besides, some of them are only based on engineering judgment. After making detailed literature review; some of the methods, used in order to determine the optimum size of the time buffer and locations of them against uncertainties, variations and delays, are summarized below.

3.3.1 Engineering Intuition

In this method; either 25% or 50% of the total project duration should be taken as a time buffer size and add to the baseline schedule in order to find estimated schedule (Farag, 2010).

It is clear that this method is arbitrary. It does not consider the project and activities' characteristics; therefore, it does not give effective solution against uncertainties and variations.

3.3.2 Program Evaluation and Review Technique (PERT) / Critical Path Method (CPM)

In this method; buffers are added to each activity as a safety time to protect the baseline schedule from probable negative impacts of the future events that can be occurred during the construction. An illustration of the time buffer calculated by PERT / CPM method in hypothetical schedule is showed in the Figure 2.

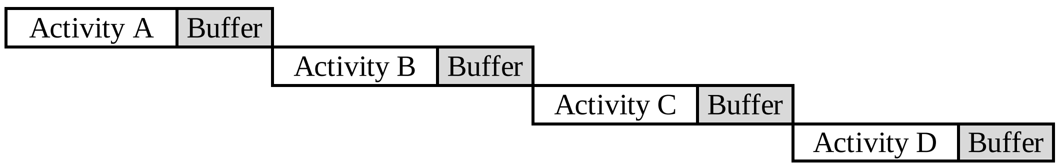

Figure 2: Usage of Buffer in PERT/CPM Method

Sizes of the buffers are calculated by using three point estimates of the duration; which are most optimistic estimate (X_o), most likely estimate (X_m) and most pessimistic estimate (X_p). The probability distribution of these three estimates and expected time can be found in the Figure 3.

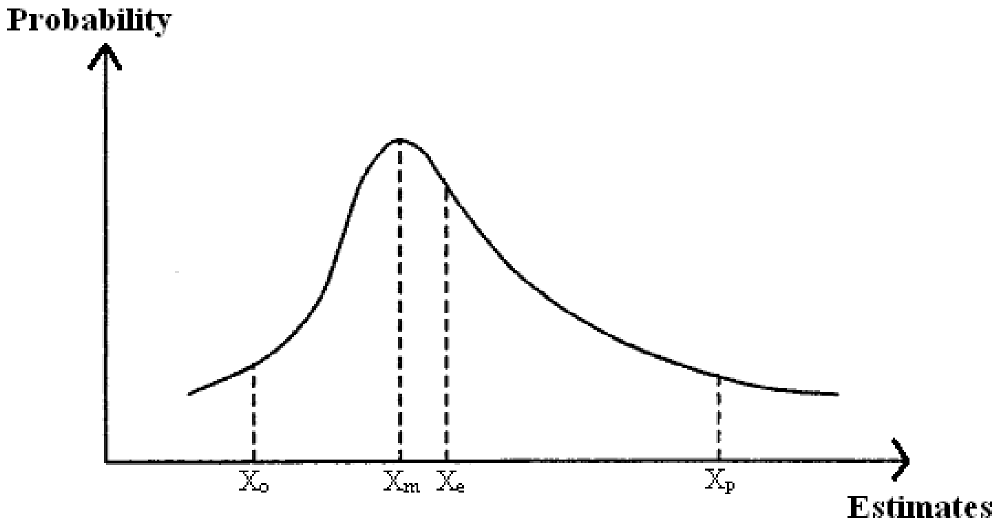

Figure 3: Beta Distribution of Activity Finishing Time

The expected time (X_e) and standard deviation of the relevant activity can be calculated from the given equations;

$$X_e = \frac{X_o + 4X_m + X_p}{6} \qquad \text{(Equation 1)}$$

$$\sigma = \frac{X_p - X_o}{3.2} \qquad \text{(Equation 2)}$$

After calculating expected times for the each activities and total standard deviations (obtained with the sum of the standard deviations for the each activity); total project duration is calculated by adding two or three standard deviations to the total estimated durations of the activities (obtained with the sum of the expected times for the each activity).

Although the method of PERT/CPM is very simple and applicable; there are some criticisms exist against this method. One of the criticisms of the PERT/CPM method is that it does not consider whether the activity is located on the critical path or not.

In other words; PERT/CPM tries to protect the each activity from the uncertainties and variations in the same way (Shou and Yeo, 2000). The other criticism is that this method is not perfect for dealing the non-precedence constraints, e.g. resource constraints (Chua and Shen, 2001).

3.3.3 Critical Chain Method (CCM)

According to the Dr. Goldratt, any manageable system is limited by at least one constraint which prevents system to achieve its purpose. Theory of Constraints (TOC) identifies these constraints and reschedules the rest of the system. In other words; TOC is used in order to enhance system improvement (Shu-Hui and Ping, 2006). The five steps within the scope of TOC were suggested in order to succeed continuous improvement. These five steps are given in Table 2.

Table 2: Five Steps within the Scope of TOC

Number of Steps	Name of Steps
1	Identify the system constraints
2	Decide how to exploit the system's constraints
3	Subordinate everything else to the above decision
4	Elevate the system's constraints
5	Do not allow inertia to cause a system constraint

In 1997, Goldratt introduce Critical Chain by using TOC as a new approach for project management in order to deal with uncertainties and variations in the construction project and complete the construction project faster. Using CCM also gives a robustness to the schedule against Student Syndrome (start the task as late as possible up to the deadline of the activity) and Parkinson’s Law (work for the relevant activity increases until time available for its completion).

Like a misunderstanding between float and time buffer; similar misconception exists between Critical Path and Critical Chain. Critical Path determines the minimum time to complete the project with a series of interconnected activities which have logical relationships between each other and without considering resource availability. On the contrary; Critical Chain is the longest path in the network diagram with considering the logical relationships of the activities and resource availability. There can be more than one candidate for the Critical Chain in the network diagram; therefore, selection of the Critical Chain is arbitrary.

Three types of buffers are introduced in CCM. These are called as Project Buffer (PB), Feeding Buffer (FB) and Resource Buffer (RB). PB is only used at the end of the project and just only one time. It is different than the buffers used in PERT/CPM method where buffers are placed at the end of each activity. The purpose of PB is protect the due date of the project from uncertainties and variations occurred in the Critical Chain. FB is used at the merging point between the Critical Chain and Non-Critical Chain in order to protect the Critical Chain from the disruptions occurred in the Non-Critical Chain. The other benefit of the FB is that it allows activities in the Critical Chain start early if nothing goes wrong. Despite the PB and FB; concept of the RB is different because RB is not used a spare time. RB is used as an advance signal against constraints of the resource. In other words; RB is used in order to be sure that resource is available when it is required for the tasks in the Critical Chain. A schematic representation of these buffers in the hypothetical schedule can be seen in the Figure 4, below.

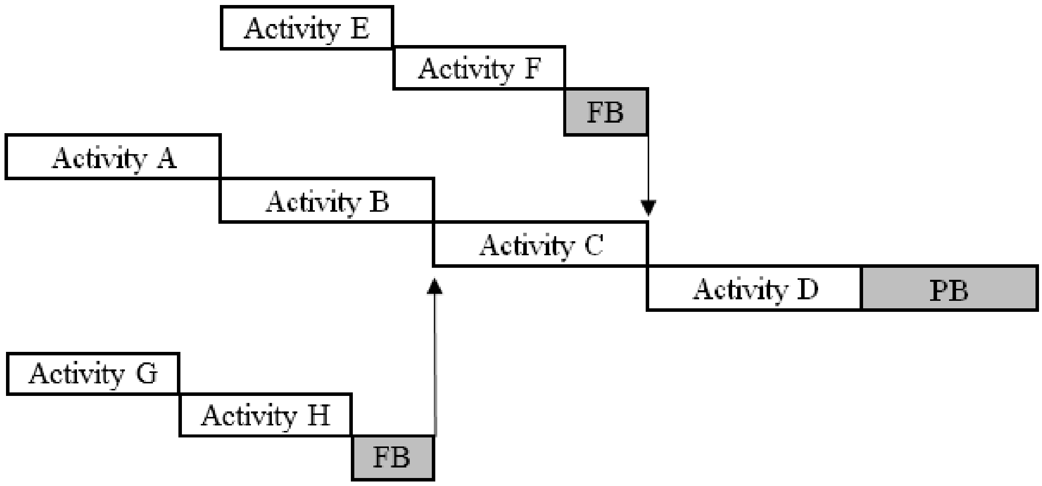

Figure 4: Representation of PB and FB in the Hypothetical Schedule

Size of the PB and FB has been the concern of the many researches; therefore, several methods exist in the literature. Summary of these methods used in order to calculate the most effective size of the PB and FB are tried to be summarized below.

<u>Goldratt Method</u>

This method is proposed by Goldratt. (Goldratt, 1997). [Tukel et al. (2006) also defined this method as Cut and Paste Method (C&PM). First, 50% of the activities duration is taken as the safety time in this method for both Critical Chain and Non-Critical Chain. Then, summation of these safety times is obtained and half of this is added as a PB for Critical Chain and FB for Non-Critical Chain.

Calculation of the PB in the Critical Chain by using this method is presented in the Figure 5. According to the example; duration of each activity is 30 days. 50% duration is cut from each activity and half of the summation of these cuts, which is 22.5 days, is added to the end of the chain.

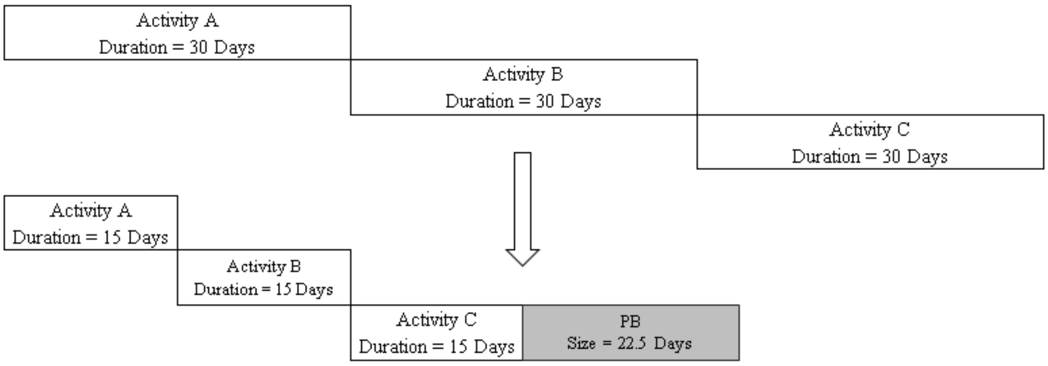

Figure 5: Example of PB Calculated with Goldratt Method

This method is very simple; however, it is linear. In other words, size of the time buffer increase with length of the Critical Chain and Non-Critical Chain without considering whether there are high level of uncertainties and variations exist on the construction project or not. For example; one-year PB could be added to the two-year project in this method. As a result of this; unrealistic schedules can be obtained.

Newbold Method

This method is proposed by Newbold (Newbold, 1998). This method is also known as Root Square Error Method (RSEM) (Tukel et al., 2006). This method uses the difference between safe estimate and 50% estimate of the activity duration. Newbold, (1998) also suggest that standard deviation is one half of the difference. This difference is called as an uncertainty and calculated for each activity. Then, time buffer size is twice as much as the standard deviation of the chain. Equations used in this method in order to find PB and FB are given below;

$$U_i = S_i - d_i \quad \text{(Equation 3)}$$

$$\sigma_i = \frac{U_i}{2} \quad \text{(Equation 4)}$$

$$Buffer\ Size = 2\left(\sum_{i=1}^{n} \sigma_i^{\,2}\right)^{1/2} \qquad \text{(Equation 5)}$$

In these Equations; U_i represents the uncertainty of activity i, n is the number of activities in the chain, S_i is used in order to show the safe estimate duration of activity i and symbol of d_i is used in order to show 50% estimate duration of activity.

If the example given in the Figure 5 is considered in this method; size of the PB is calculated as 25.98 days.

Advantage of this method against Goldratt Method is that it is not linear. In other words, very large or very small buffer sizes are not generated based on the length of the Critical Chain and Non-Critical Chain (Tukel et al., 2006). One disadvantage of this method is that activities of the project are assumed to be independent with each other without considering negative impacts of the external factors (Leach, 2005). The other disadvantage is that like Goldratt's Method, characteristics of projects are not taken into account; therefore, effective baseline schedule cannot be obtained with this method.

Adaptive Procedure with Density (APD)

This method is one of the two methods suggested by Tukel et al., 2006. With this method; project characteristics are taken into account by considering the Network Density. In briefly; buffer is considered as directly proportional with Network Density because uncertainty and variation levels are higher on schedules with large Network Density when compared to the schedule with small Network Density. Network density is taken into consideration as a ratio of total number of precedence relationships to the total number of activities on the schedule. In this method; buffer size is calculated by using the Equation 6.

$$Buffer\ Size = (1 + ND) \times \left(\sum_{i=1}^{n} VAR_i\right)^{1/2} \qquad \text{(Equation 6)}$$

In Equation 6; n is the number of activities in the chain and VAR_i is the variance of the activity.

Adaptive Procedure with Resource Tightness (APRT)

APRT is the other method suggested by Tukel et al. (2006). Despite the APD; project characteristics are reflected with Resource Tightness in this method. It means that if resource utilization is near to the total resource availability; large buffer size should be used because possibility of occurrence of delay is high. Resource Tightness is taken into account as the ratio of the total resource usage to the total resource availability for each resource. In this method; buffer size is calculated by using the Equation 7.

$$Buffer\ Size = (1 + RT) \times \left(\sum_{i=1}^{n} VAR_i\right)^{1/2} \qquad \text{(Equation 7)}$$

In Equation 7; n is the number of activities in the chain and VAR_i is the variance of the activity.

ADP and APRT are better choices when the level of uncertainty and variation in the project are low and shorter project duration is desired by a project manager or contractor. Besides, smaller time buffer size can be obtained by using ADP and APRT when compared with the time buffer sizes calculated with Goldratt and Newbold's Methods. Also, higher percentages of consumption of the time buffer sizes occur in ADP and APRT methods (Tukel et al., 2006).

Although; there are many benefits of ADP and APRT over the other methods; project activities are still assumed to be independent with each other and characteristics of these activities are not taken into account in these methods which prevent the methods to give perfect protection against uncertainties, variations and delays.

Scope of this thesis is find the optimum size of the time buffers in order to construct robust and stable scheduling against uncertainties, variations and delays on construction of the concrete gravity dam and HEPP projects. Since many deficiencies have been existed in the aforementioned methods with respect to buffer design and management; fuzzy logic is considered as a method to calculate the size of the time buffers in this thesis.

Activities' characteristics and activities' interdependencies are not taken into account on the aforementioned methods. Also, since every construction projects are unique; it can be hard, and sometimes impossible to find historical data for probability functions. On the other hand, with using fuzzy logic, it is expected to take project characteristic, activities' characteristics and activities' interdependencies into account. Besides, with using fuzzy logic, taking experts' knowledge and modeling complex systems become very simple. Therefore, next section will start with the explanation of the fuzzy logic concept and methodology in order to give sufficient background information for the model proposed in this thesis to calculate the optimum size of the time buffer against uncertainties, variations and delays.

CHAPTER 4

FUZZY LOGIC

Subject of fuzzy logic is too broad to be covered in this thesis. And, it is considered that covered all contents related with fuzzy logic is irrelevant for the readers of this thesis. As a result of this; contents were selected in order to give sufficient general information about fuzzy logic and its methodologies which were used in this thesis.

4.1 Fuzzy Theory

The concept of fuzzy theory began in 1965 with a seminar paper on fuzzy sets written by Prof. Zadeh (Zadeh, 1965).

The aim of the fuzzy theory is alleviation of the difficulties in developing and analyzing complex systems encountered by conventional mathematical tools (Yen and Langari, 1999). Fuzzy theory can also be used in order to deal with vague concepts such as uncertainties. At this point; there is a criticism that it is same as the probability theory. In fact, although there are some similarities between these theories, they are different from each other. The difference between the fuzzy theory and probability theory is that they deal with different types of uncertainty. Fuzzy theory considers imprecision of events; on the other hand, probability theory considers likelihood of occurrence (Yen and Langari, 1999).

For example, if you toss a coin, there is 50/50 chance for each side of the coin to land up. In other words, probability of each side to come after toss a coin is ½ and summation of all probabilities is equal to 1. The uncertainty in this action comes from the fact that it cannot be known which sides come before tossing a coin. As a result, this type of uncertainty is called as a randomness and concern of the probability theory. However, what about the possibilities of an event are not known? For example, consider that you go to a restaurant. Can you decide the probabilities of the restaurant whether being beautiful or not? Since this type of uncertainty is subjective and likelihood of occurrence cannot be known; this is the concern of the fuzzy theory (Mukaidono, 2001).

Although fuzzy theory is composed of various theories and techniques; it is mainly composed of three concepts; namely, fuzzy sets, linguistic variables and modifiers with fuzzy sets and fuzzy if-then rules. Explanations of these three concepts are given below.

4.1.1 Fuzzy Sets

Fuzzy logic uses fuzzy set theory. Fuzzy sets are the sets whose boundaries are vague (not clear). In order to understand the concept of the fuzzy sets, concept of the classical sets also should be understood clearly because fuzzy sets can be considered as an extension of the classical set theory (Fuzzy Logic Toolbox™ User's Guide (2013), MATLAB, the MathWorks, Inc.).

The objects in a set are called as members of a set. In classical set theory, an element is either a completely member of a set or not at all. There is no middle point of it. In other words, classical set is a set with a sharp boundary. Basic notation in the classical set theory is given below;

$$\mu_A(\mathrm{x}) = \begin{cases} 1 & for\ x\ \in\ A \\ 0 & for\ x\ \notin\ A \end{cases} \qquad \text{(Equation 8)}$$

In Equation 8; μ_A is the membership function of a set A and $\mu_A(x)$ is the membership value of x in A. As it can be understood in the Equation 8; if element x is a member of the set A, the membership value of x is equal to 1; on the other hand, if element x is not a member of the set A, the membership value of x is equal to 0.

An example for the classical set theory is given in the Figure 6. According to the example; one might say that "a person who's age is bigger than 60 is considered as old age person". This statement can be represented in the form of classical set as old age = $\{x \mid x \geq 60\}$. The membership function of the old age people can be seen in the Figure 6.

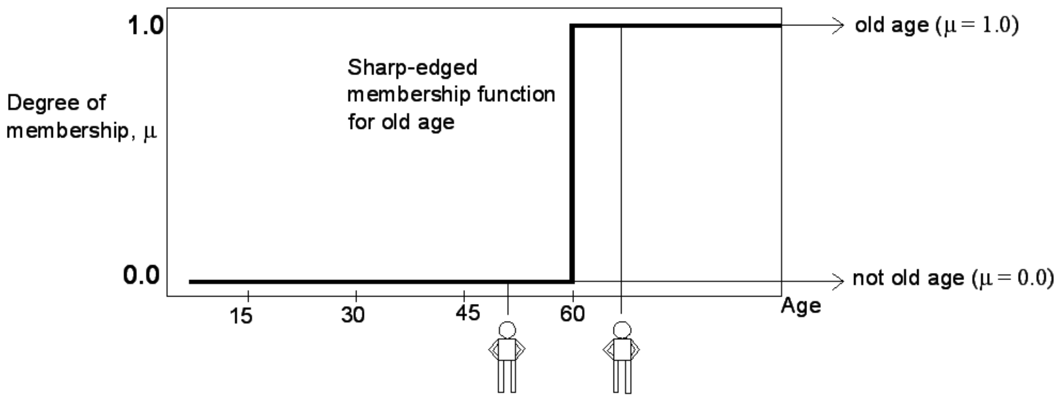

Figure 6: Membership Function for the Classical Set of Old Age People

In contrast to the classical set theory, fuzzy set has a smooth boundary. In fuzzy set, each element is assigned a degree of membership between 0 and 1; in which 0 means entirely not in a set, 1 means completely in a set and in between means partially in the set. Basic notation in the fuzzy set theory is given below;

$$A = \{(x, \mu_A(x)) \mid x \in A, \mu_A(x) \in [0, 1]\} \qquad \text{(Equation 9)}$$

In Equation 9; $\mu_A(x)$ is the membership value of x in fuzzy set A and specifies the degree to which an element x belongs to the fuzzy set A. A real number from the interval [0, 1] is assigned as a membership value of x. Larger values of $\mu_A(x)$ indicate higher degrees of membership.

Let's consider the example given for the classical set theory. According to the classical set theory; person whose age is bigger than 60 is considered as an old age person and a person whose age is smaller than 60 is considered as not old age person. At this point; consider two people whose ages are 61 and 59 respectively. If classical set theory is used, 61 years old person is considered as an old age person; however, 59 years person is not considered as an old age person. This is not logical and it causes serious problems; therefore, fuzzy set theory comes to the place and assigns possibility values as a membership values with smooth boundary. In Figure 7; it can be seen that 59 year person is also considered as an old age person like 61 year person but with a lesser degree of membership ($\mu_A(x{=}61){=}0.95$ and $\mu_A(x{=}59){=}0.90$). It can be said for the 59 years person is that this person is 90.0% old.

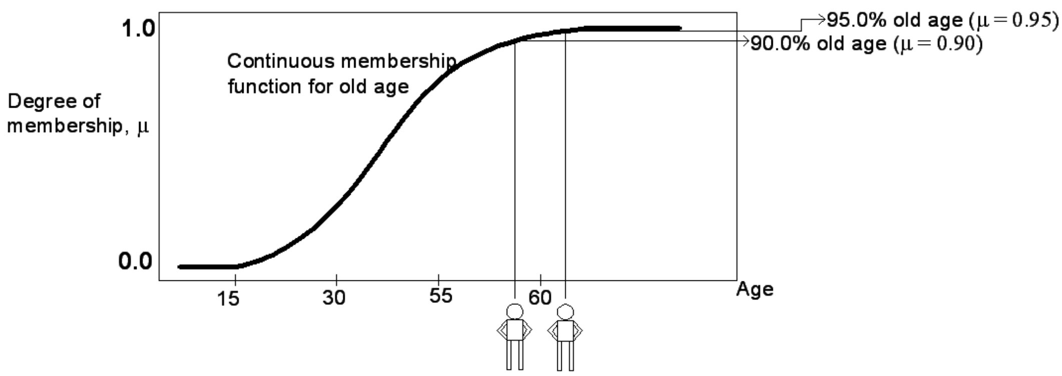

Figure 7: Membership Function for the Fuzzy Set of Old Age People

4.1.1.1 Memberships Functions of Fuzzy Sets

Membership function is a curve that defines the membership value of the elements of the fuzzy set. Membership functions should give smooth transition from regions completely outside a set to regions completely in the set and the range of the membership values must be between 0 and 1 (Yen and Langari, 1999).

The curve of the membership function can be any form; however, parameterizable functions are recommended in the literature because they are simple and can be changed easily with the corresponding changes in the related parameters of them.

As was mentioned, there are various forms exist for the membership functions; however, piecewise linear membership functions are preferable because of their simplicity. In the literature; most widely used piecewise linear membership function forms are triangular and trapezoidal membership functions. An illustration of the triangular and trapezoidal membership functions and their parameters for the fuzzy set 'A' can be seen in the Figure 8.

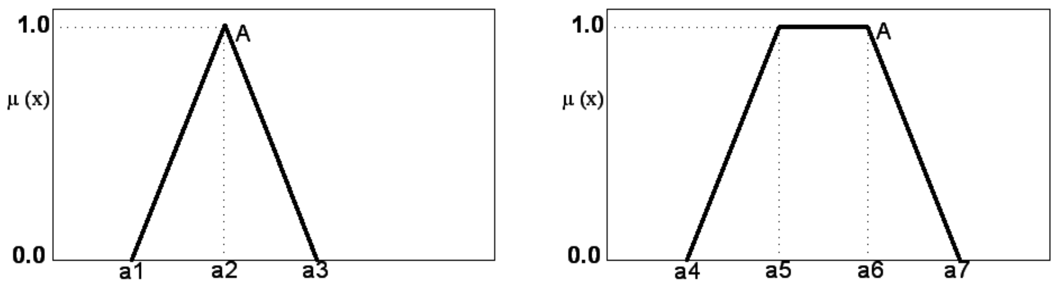

Figure 8: Triangular and Trapezoidal Membership Functions and Their Parameters, respectively

According to the Figure 8; triangular and trapezoidal membership functions are defined by using Equation 10 and Equation 11, respectively.

$$\mu_A(\mathrm{x}) = \begin{cases} (x-a1)/(a2-a1) & for\ a1 \le x \le a2 \\ (x-a3)/(a2-a3) & for\ a2 \le x \le a3 \\ 0 & otherwise \end{cases} \qquad \text{(Equation 10)}$$

$$\mu_A(\mathrm{x}) = \begin{cases} (x-a4)/(a5-a4) & for\ a4 \le x \le a5 \\ 1 & for\ a5 \le x \le a6 \\ (x-a7)/(a6-a7) & for\ a6 \le x \le a7 \\ 0 & otherwise \end{cases} \qquad \text{(Equation 11)}$$

4.1.1.2 Basic Operations in Fuzzy Sets

There are three fundamental operations in fuzzy sets; namely, intersection, union and complement.

Consider A and B as two fuzzy sets with membership functions $\mu_A(x)$ and $\mu_B(x)$ respectively.

<u>Intersection Operation</u>

Fuzzy intersection operation is mathematically equivalent to the conjunction 'AND' operation because they have identical properties. Definition of fuzzy intersection operation can be seen in Equation 12, below.

$$\mu_{A \cap B}(x) = min\ \{\mu_A(x), \mu_B(x)\} \qquad \text{(Equation 12)}$$

For example; if $\mu_A(x)$ is 0.4 and $\mu_B(x)$ is 0.8, then $\mu_{AnB}(x)$ is equal to min(0.4, 0.8) which is 0.4.

Union Operation

Fuzzy union operation is mathematically equivalent to the disjunction 'OR' operation because they have identical properties. Definition of fuzzy union operation can be seen in Equation 13, below.

$$\mu_{A \cup B}(x) = max\ \{\mu_A(x), \mu_B(x)\} \qquad \text{(Equation 13)}$$

For instance; if $\mu_A(x)$ is 0.4 and $\mu_B(x)$ is 0.8, then $\mu_{AuB}(x)$ is equal to max (0.4, 0.8) which is 0.8.

Complement Operation

Fuzzy complement operation is mathematically equivalent to the negation 'NOT' operation because they have identical properties. Definition of fuzzy complement operation can be seen in Equation 14 and Equation 15, below.

$$\mu_{\bar{A}}(x) = 1 - \mu_A(x) \qquad \text{(Equation 14)}$$

$$\mu_{\bar{B}}(x) = 1 - \mu_B(x) \qquad \text{(Equation 15)}$$

To illustrate; if $\mu_A(x)$ is 0.4 and $\mu_B(x)$ is 0.8, then $\mu_{\bar{A}}(x)$ is equal to 0.6 and $\mu_{\bar{B}}(x)$ is equal to 0.2.

An illustration of these three fundamental fuzzy set operations can be seen in the Figure 9, below.

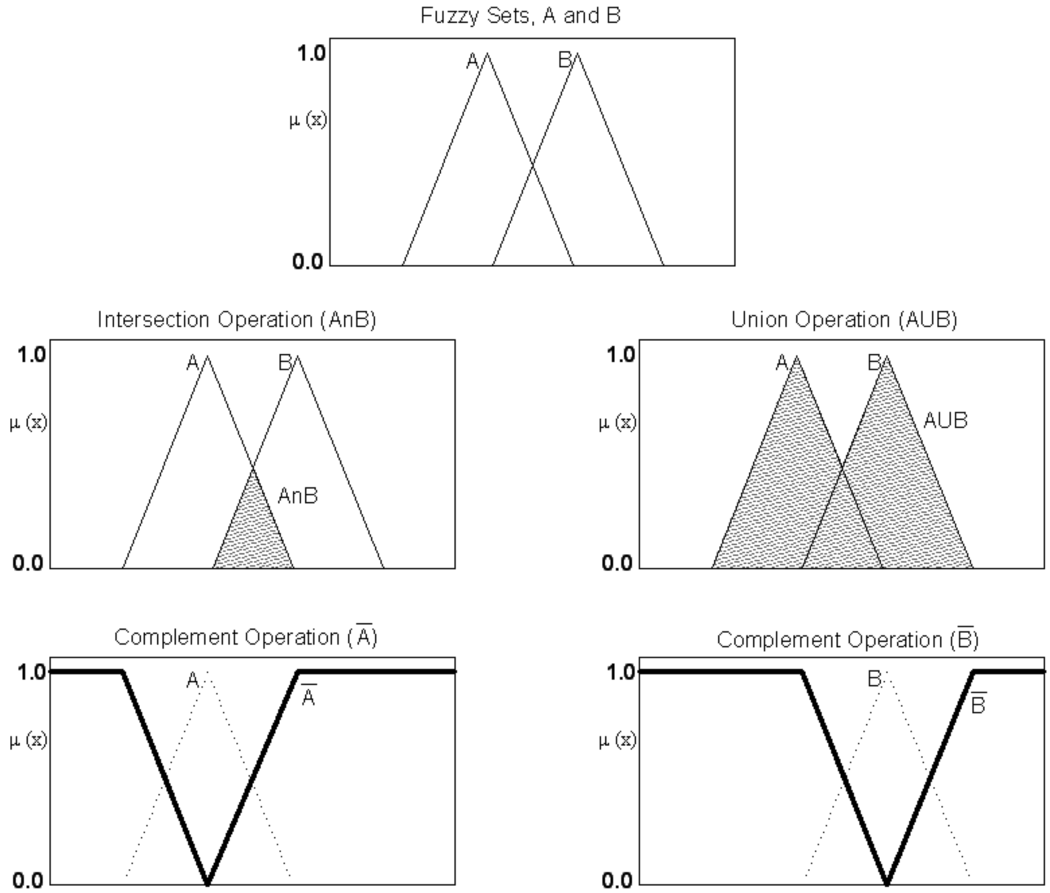

Figure 9: Fundamental Operations in Fuzzy Sets

4.1.2 Linguistic Variables and Modifiers

Linguistic Variables

Linguistic variable is the variable in which its value can be described both qualitatively by a linguistic term and quantitatively by a corresponding membership function. Linguistic term is used in order to express concepts and knowledge by words or sentences in human language (Yen and Langari, 1999).

An example for the linguistic variable is given in Figure 10. In this example, the linguistic variable is the safe speed of a car. Linguistic terms in order to express the safe speed of a car are 'very slow', 'slow', 'medium', 'fast' and 'very fast'. Also, as it can be seen in the Figure 10 that each linguistic value is represented by a membership function in order to express the value quantitatively. Although triangular and trapezoidal membership functions with the relevant characteristics are used in this example by using subjective judgment; characteristic and shape of the each membership function is dependent on the scope of the relevant problem.

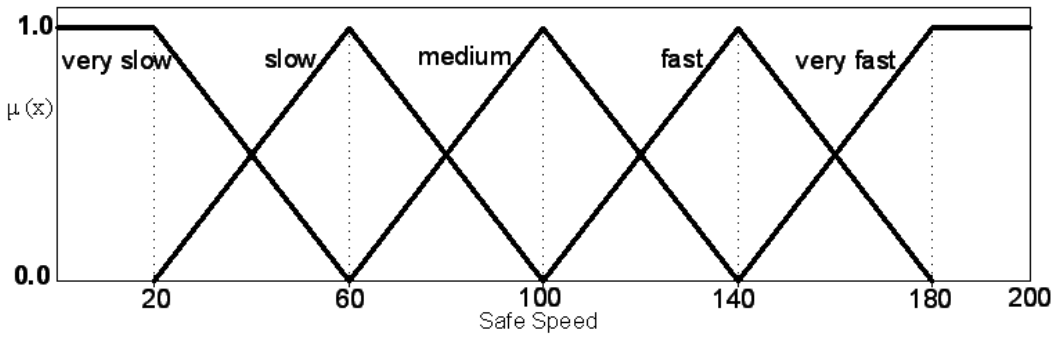

Figure 10: Terms of the Linguistic Variable Exam Grade

In a domain (universe of discourse) U = [0, 200], membership functions of the relevant linguistic terms are defined by using the following equations;

$$\mu_{very\ slow}(\mathrm{x}) = \begin{cases} 1 & for\ \ 0 \leq x \leq 20 \\ (60 - x)/(40) & for\ 20 \leq x \leq 60 \\ 0 & otherwise \end{cases} \quad \text{(Equation 16)}$$

$$\mu_{slow}(\mathrm{x}) = \begin{cases} (x - 20)/(40) & for\ 20 \leq x \leq 60 \\ (100 - x)/(40) & for\ 60 \leq x \leq 100 \\ 0 & otherwise \end{cases} \quad \text{(Equation 17)}$$

$$\mu_{medium}(\mathrm{x}) = \begin{cases} (x - 60)/(40) & for\ 60 \leq x \leq 100 \\ (140 - x)/(40) & for\ 100 \leq x \leq 140 \\ 0 & otherwise \end{cases} \quad \text{(Equation 18)}$$

$$\mu_{fast}(\mathrm{x}) = \begin{cases} (x-100)/(40) & for\ 100 \leq x \leq 140 \\ (180-x)/(40) & for\ 140 \leq x \leq 180 \\ 0 & otherwise \end{cases} \quad \text{(Equation 19)}$$

$$\mu_{very\ fast}(\mathrm{x}) = \begin{cases} (x-140)/(40) & for\ 140 \leq x \leq 180 \\ 1 & for\ 180 \leq x \leq 200 \\ 0 & otherwise \end{cases} \quad \text{(Equation 20)}$$

Linguistic Modifiers

Linguistic modifiers are also called as hedges. Hedges modify the meaning of the original fuzzy sets to create compound fuzzy sets in order to give more flexibility to the fuzzy sets. By using hedges; fuzzy sets become closer to the everyday language.

Various hedges can be used for the fuzzy sets; however, the most commonly used hedges are 'Very' and 'More or Less'. Effect of the hedge 'Very' is narrowing the membership functions; on the other hand, the hedge 'More or Less' widens the membership functions (Yen and Langari, 1999). For the fuzzy set 'A'; mathematical expressions and graphical representation of these types of hedges are given in Equation 21, Equation 22 and Figure 11, respectively.

$$\mu_{Very\ A}(x) = [\mu_A(x)]^2 \quad \text{(Equation 21)}$$

$$\mu_{More\ or\ Less\ \ A}(x) = \sqrt{\mu_A(x)} \quad \text{(Equation 22)}$$

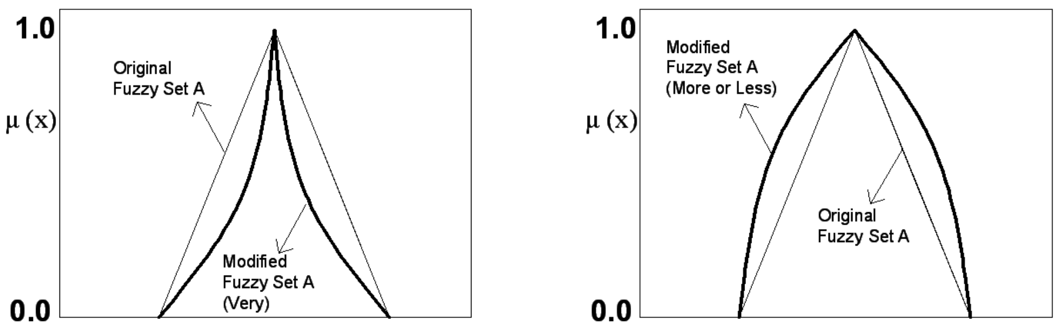

Figure 11: Examples of Linguistic Modifiers (Hedges)

4.1.3 Fuzzy If-Then Rules

Fuzzy if-then rule statements are used in order to formulate the conditional statements which constitute the fuzzy logic (Fuzzy Logic Toolbox™ User's Guide (2013), MATLAB, the MathWorks, Inc.). In other words; if-then rule statements are used in order to connect the input variables to the output variables with using linguistic variables.

An example for the simple fuzzy if-then rule statement is given below;

$$\text{If x is A THEN y is B} \qquad \text{(Equation 23)}$$

In Equation 23; A and B are linguistic values. The if-part of the rule "x is A" is called as the antecedent part and then-part of the rule "y is B" is called as a consequent part. "An antecedent part describes a condition, and the consequent parts describes a conclusion than can be drawn when the condition holds" (Yen and Langari, 1999). The difference between the antecedent part of the classical if-then rule statements and fuzzy if-then rule statements is that antecedent part of the fuzzy if-then rule statements gives flexibility to the condition. Examples for this situation are given in the Equation 24 and Equation 25, below.

If a salary of a person is greater than $20 000 THEN the person is rich.	(Equation 24)

If a salary of a person is high THEN the person is rich.	(Equation 25)

Equation 24 is an example for the classical if-then rule statement because condition has a sharp boundary (rigid); on the other hand, Equation 25 is an example for the fuzzy if-then statement because its condition can be satisfied to a degree for those people whose salary lies in the boundary of the fuzzy set ‘High’ which represents high salary.

By using fundamental fuzzy operators (AND, OR and NOT); antecedent part can be composed of several conditions. Equation 26 and Equation 27 are given as examples for this multiple conditions in a single antecedent part.

If a salary of a person is high AND car of the person is NOT cheap	THEN the person is rich	(Equation 26)

If a salary of a person is high OR house of the person is large	THEN the person is rich	(Equation 27)

More than one rule can be used in the fuzzy logic with depending on the number of the inputs and outputs of the system (Asmuni, 2008). Multiple fuzzy rules are combined by looking the weight of each rule’s condition. Moreover, conclusions inferred by all fuzzy rules are merged into a final outcome through using OR (max) operator and superposition.

Several methods exist in order to construct the fuzzy rules; however, Mamdani-Style method is the most commonly used method because of its user friendly and intuitive environment (Fuzzy Logic Toolbox™ User's Guide (2013), MATLAB, the MathWorks, Inc.). General formulization of the fuzzy if-then rule statement by using Mamdani-Style method is given in Equation 28.

$$\text{If } (x_1 \text{ is } A_{n1}) \text{ AND } (x_2 \text{ is } A_{n2}) \text{ AND } \ldots (x_r \text{ is } A_{nr}) \text{ THEN } y \text{ is } B_n \text{ for } n=1, 2, \ldots, i \qquad \text{(Equation 28)}$$

In Equation 28, i refers to the total number of rules, x_k (k=1, 2, …, r) are the input variables and y is the output variable with the fuzzy sets 'A_{nr}' and 'B_n'.

The basic properties of the Mamdani-Style method is that expected output membership functions in the consequent part must be the fuzzy sets. Fuzzy output is desirable because it can be interpreted easily. Also, it is suitable in order to capture the imprecise experts' opinions (Yen and Langari, 1999).

Defuzzification

Although fuzzy output is obtained from the Mamdani-Style method; it should be converted to the single crisp value (nonfuzzy value). The process of conversion of the fuzzy output to the single number is called as a defuzzification. There are several defuzzification methods such as center of area method, smallest of maxima and largest of maxima method, mean of maxima method and bisector of area method. In this thesis; the method of center of area is preferable because of its simplicity. Also, it is the most commonly used method. Mathematical expression and graphical illustration of this method are given in Equation 29 and Figure 12 respectively.

$$y = \frac{\sum_i \mu_A(y_i) \times y_i}{\sum_i \mu_A(y_i)} \qquad \text{(Equation 29)}$$

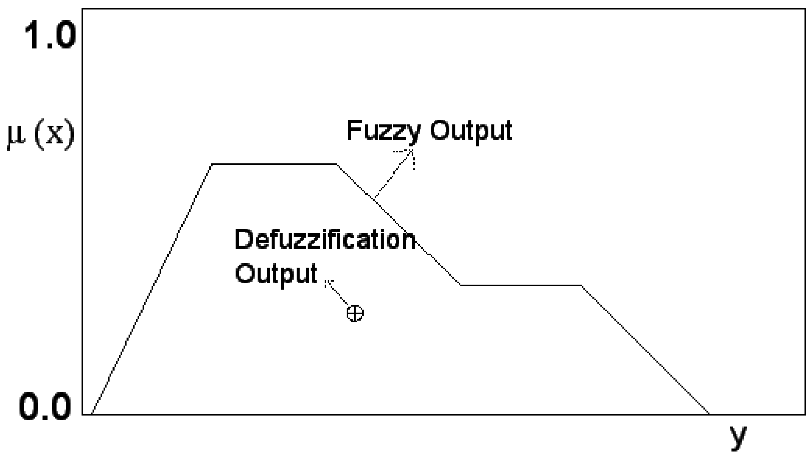

Figure 12: Center of Area Method for Defuzzification

4.2 Fuzzy Logic System

Typical fuzzy logic system is illustrated in the Figure 13, below.

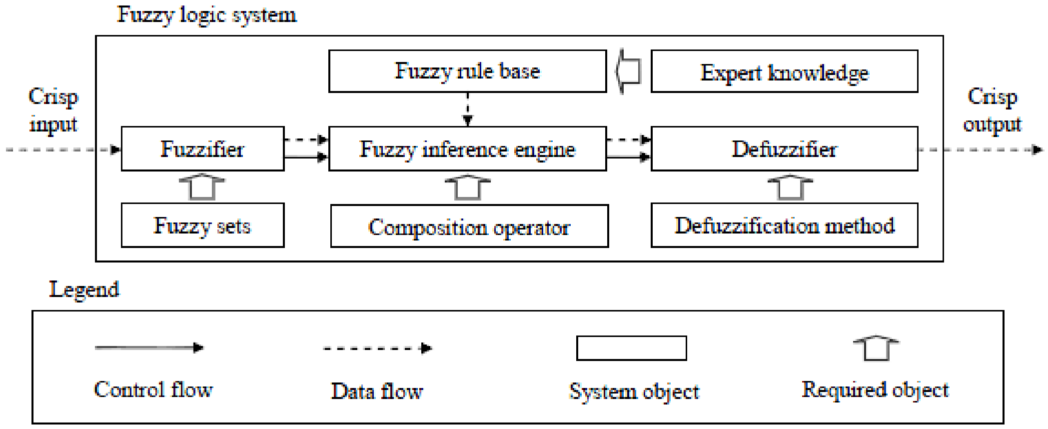

Figure 13: Typical Fuzzy Logic System (Ko and Chen, 2012)

According to the Figure 13; after analyzing and understanding the problem, the first step is determination of the inputs and outputs for the system. Then, the process of fuzzification is started. In this process; linguistic values and membership functions (fuzzy sets) are defined for each crisp input. After that; fuzzy if-then rules are constructed by using experts' knowledge and the degree to which the fuzzified input data match the condition of the fuzzy rules are calculated. Next, inference of the each fuzzy if-then rule are calculated and single conclusion is obtained after combining all inferred fuzzy if-then rules. Finally; fuzzy conclusion is defuzzified to the crisp output by using one of the defuzzification methods. As it was mentioned; central of area method is used as a defuzzification method in this thesis.

Hypothetical problem is considered below as an example for the fuzzy logic system which is explained above.

Inputs and Output

There are two inputs (A and B) and one output (C) of the hypothetical problem.

Linguistic Variables and Membership Functions

Linguistic variables and membership functions of the inputs and output are defined as in the Figure 14. For the simplicity, same linguistic variables and membership functions are used for the inputs and output in this problem.

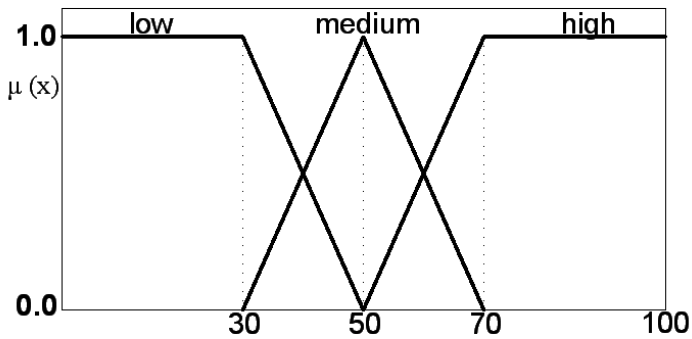

Figure 14: Linguistic Variables and Membership Functions of the A, B and C

Fuzzification

Two fuzzy sets (A and B) created by using linguistic variables and fuzzy theory. Consider two crisp input values which are a = 55 and b = 65 for the problem. By using predefined linguistic variables and membership functions; fuzzified values can be calculated for the given crisp input values. Results of the fuzzification process are given in Figure 15, below.

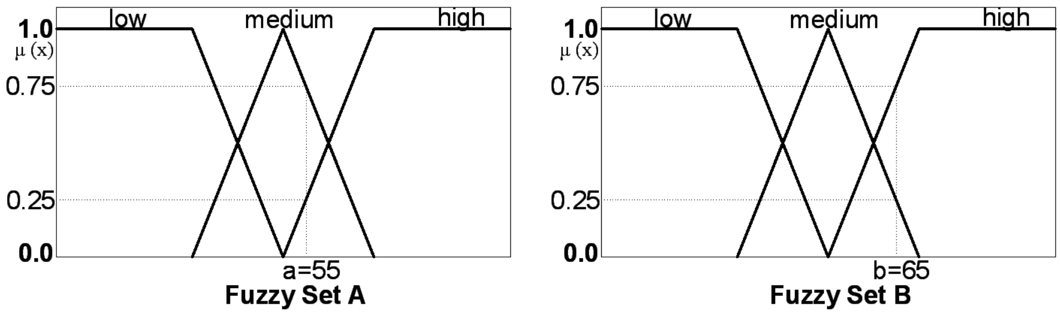

Figure 15: Fuzzified Value of the Crisp Input Values

Fuzzy If-Then Rules

In this problem, three rules are constructed and degree of importance of each rule is considered as same. In other words; weight of the each rule is same. Constructed rules are given in the following equations;

If A is low AND B is low THEN C is low (Equation 30)

If A is medium OR B is medium THEN C is medium (Equation 31)

If A is high AND B is high THEN C is high (Equation 32)

Fuzzy Matching and Inference

In this process; AND (min) and OR (max) operator is used in order to determine the degree to which the input data match the condition of the fuzzy rules. Results of this process for the given input values can be seen in the Figure 16, Figure 17 and Figure 18, below.

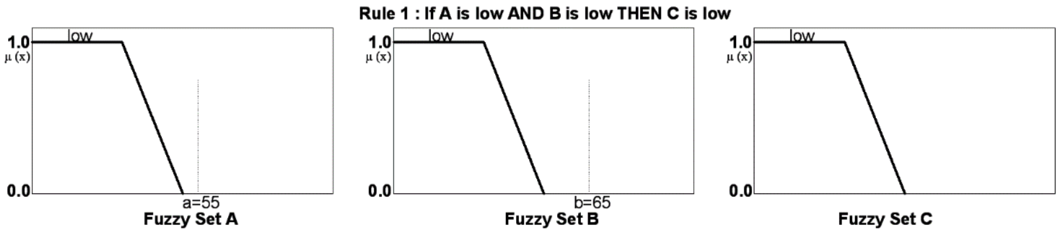

Figure 16: Evaluation of the Rule 1

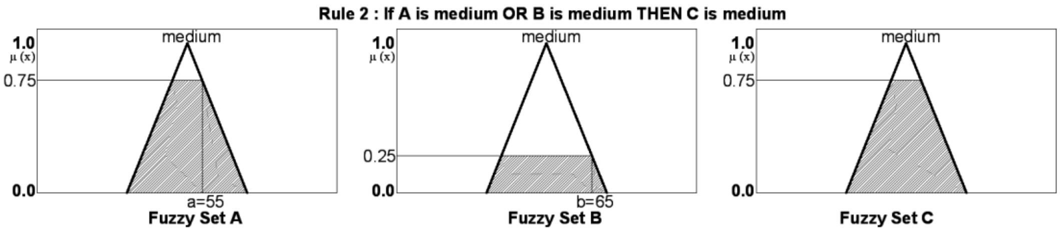

Figure 17: Evaluation of the Rule 2

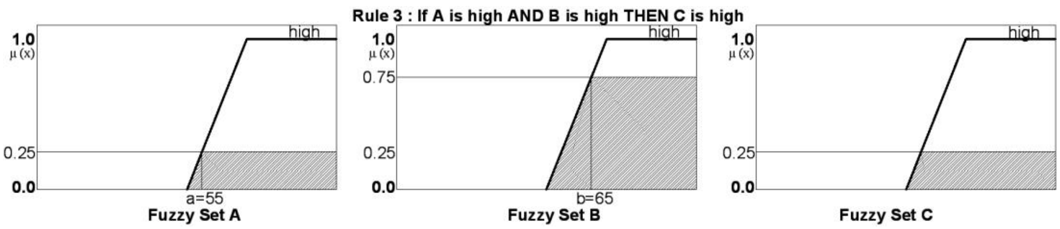

Figure 18: Evaluation of the Rule 3

In Figure 16, the rule is not active because both of the input values have zero membership degree for the linguistic values A and B respectively. In Figure 17, since the OR (max) operator is used; the maximum fuzzified value, which is 0.75, is selected. On the other hand, AND (min) operator is used in the Figure 18; therefore, minimum fuzzified value, which is 0.25 is selected.

Combination of the Results and Defuzzification

Final conclusion is obtained by combining the results of the rule 2 and rule 3. Then, central area method with using Equation 29 is used as a defuzzification method and final crisp output is found. The schematic representation of these processes is given in the Figure 19, below.

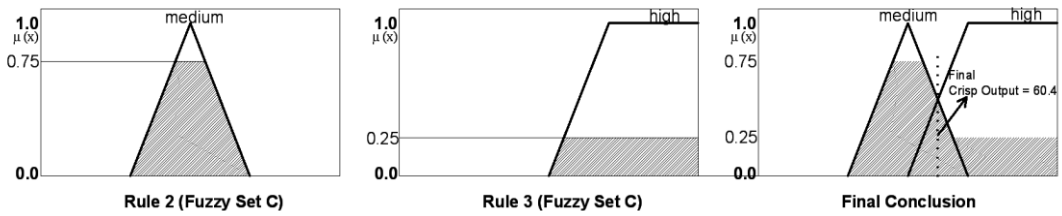

Figure 19: Combination of the Rules and Final Crisp Output

4.3 Advantages of Fuzzy Logic

General advantages of fuzzy logic are summarized below (Fuzzy Logic Toolbox^{TM} User's Guide (2013), MATLAB, the MathWorks, Inc.);

- Being is easy to understand.
- Providing flexible and simple solution to the complex problems.
- Using natural language.
- Tolerance to imprecise data.
- Easily takes into account experts' opinions by using fuzzy logic.

Besides the general advantages; fuzzy logic is convenient for the construction projects to deal with the factors which are out of control such as site, labor, equipment, climate, unforeseen circumstances, time dependence situations and regulations (Malek, 2000). Also, activities' characteristics, activities' interdependencies and project characteristics which are required in order to calculate the optimum size of time buffer for the each activity on the construction schedule, can be taken into consideration by using fuzzy logic.

4.4 Fuzzy Logic Studies on Construction Projects

Fuzzy logic is used in a number of fields in today's world such as social science, psychology, economics and management etc.. In this thesis; since our concern is calculation of optimum size of the time buffer with using fuzzy logic in order to deal with uncertainties, variations and delays occurred on construction projects, some examples of fuzzy logic application on construction projects in order to predict and evaluate the causes of delay and size of the buffers are given below.

Ghoddosi et al. (2008) used the fuzzy logic concept in order to identify and evaluate the causes of delay on Iran's dam construction projects. First, 39 causes of delay were found on Iran's dam construction projects by making literature review and questionnaire and those causes of delay were classified into 5 groups in this study. Then, by using expert's opinion, importance of the causes of delay and groups were calculated by using triangular and trapezoidal fuzzy sets (membership functions).

Farag (2010) developed a "fuzzy logic buffering model" in order to calculate the size of the time buffer more definitely to capture the actual variation in the project. According to the proposed model; time buffer size was calculated for the each activity in the project. Inputs for the fuzzy logic system were degree of confidence of the activity, duration of the activity, degree of uncertainty and degree of influence of the activity. Output of the system was size of the time buffer. Membership functions and rules were determined by using the experts' opinion from the literature and conducted survey. Highway construction project in Egypt was used as a real case study for the proposed model in the study and Matlab was used in order to simulate the model. According to the results; reliability of the schedule was increased from 70% to 94% by calculated the size of the time buffer more accurately with using fuzzy logic.

Uncertainty and impreciseness in the schedule of the construction projects can also be handled by using the fuzzy logic concepts. Project managers can give the smoothness to the schedules of the construction projects by using the fuzzy times. Fuzzy times can be generated by imposing fuzzy boundaries to the durations of the activities (Lorterapong and Moselhi, 1996). In the literature; Fuzzy Network Analysis (FNA), which uses the fuzzy times, has been developed in order to predict the durations of the activities. Fuzzy early and late times of each activity constitute the outputs of the FNA and they can be found by making backward and forward pass calculations (Ghaziani, 2012).

Ghaziani (2012) developed a software model in order to predict and evaluate the delays encountered on construction projects. By considering the potential delays on construction projects, estimated project scheduling was created with using fuzzy scheduling by conducting fuzzy logic concept which allows linguistic and subjective assessments. In this model; first, potential causes of delay were determined for each relevant activity in the project by the experts. Then, frequency of occurrence and impact of the relevant causes of delay to the relevant activity were determined by the experts. After that, fuzzy logic was applied to a construction's network scheduling and fuzzy early and late times are found by making fuzzy forward and backward calculations. Hypothetical project was considered in this study in order to show the serviceability of the model. At the end of the study, comparison table of the original durations and estimated (fuzzy) durations were given for the hypothetical project.

Ko and Chen (2012) developed a Time Buffer Evaluation Model (TBEM) in order to deliver precast products to the site on time and without increasing the inventory capacity. According to the paper; fabricators start to produce precast products as soon as possible after receiving relevant design information from the site; however, delivery dates and design information can be changed due to problems in the site. As a result of this; produced precast elements can cause overcrowded work area on the factory which is considered as waste. In order to reduce the waste of the inventory, it was suggested in the paper that production of the precast elements should be finished later than the required delivery date of the elements to the site. Fuzzy logic was used in this method in order to find the relevant delivery date by calculating the possible erection duration. Then time buffer was used as a contingency in order to be on the safe side. Mamdani Inference method is used in proposed fuzzy logic system. There were five inputs; namely, lifting speed, site layout, wind speed, rainfall and consecutive rainy days, and one output; namely, erection duration in the fuzzy logic system. Membership functions and rules were constructed by making interviews with the experts. Also, central area method was used as a defuzzification method.

In this thesis, fuzzy logic concept is used in order to find optimum size of the time buffer on the construction of concrete gravity dam and HEPP projects. Therefore, in the next part, detailed explanations of the model proposed in order to calculate the optimum size of the time buffer will be explained.

CHAPTER 5

BUFFER SIZING MODEL WITH FUZZY ASSESSMENT

The aim of this thesis is to find optimum size of the time buffers which can be used on concrete gravity dam and HEPP projects in order to create robust and stable schedule against possible uncertainties, variations and delays.

As it was mentioned, time equals money in today's world; therefore, completed the project with the desired time which is identified in the baseline schedule is crucial. Therefore, effective usage of time buffer against negative impact of uncertainties, variations and delays is essential in the scheduling. In order to calculate the size of the time buffers optimally, expert knowledge should be used. Also, project characteristic, activity characteristics and activity interdependencies in the project should be taken into account.

In accordance with this purpose; buffer sizing model with fuzzy assessment is proposed and defined in detail in this chapter. Also, hypothetical concrete gravity dam and HEPP project is given as an example application in order to demonstrate the capabilities of the proposed model. By following the methodology suggested in this model, robust and stable baseline schedule can be obtained by the project manager teams. Besides, which activities in concrete gravity dam and HEPP projects are inclined to greater delay can be understood by looking the size of the time buffers assigned to each activity; as a result of this, project manager teams can be prepared and additional precautions can be considered for those activities.

5.1 Dam and HEPP Projects

Encountering uncertainty, variation and delay in the dam and HEPP projects are highly probable due to complex nature and operation size of those projects. For instance; after making complete research of 99 projects, World Commission on Dams (WCD) reports that, only half of the projects were completed on time and 30% of the other half of the projects were delayed between 1 and 2 years and 15% of the projects were delayed between 3 and 6 years. Also, four projects were delayed more than 10 years (WCD, 2000).

Hydroelectric power is a major source of electricity in the world and this can be obtained from HEPP's. Furthermore; by constructing dams, water is supplied to the urban areas and floods can be prevented. There are also various other benefits of the dam and HEPP projects. As a result of these; dam and HEPP projects are crucial for the country that are constructed; therefore, timely completion of those projects are essential. In other words, if delay in the construction of the dam and HEPP projects occurs, it can lead to serious negative economic and political consequences over the country. Correspondingly; they should be prevented or minimized.

Detailed explanations of the methodology for the proposed buffer sizing model with fuzzy assessment for the concrete gravity dam and HEPP projects are given in the rest of this chapter.

5.2 Steps followed in the Buffer Sizing Model with Fuzzy Assessment

Following steps were followed in the Buffer Sizing Model with Fuzzy Assessment;

<u>Step 1</u>: Possible activities found on the schedule of the concrete gravity dam and HEPP projects were determined and listed.

Step 2: Cause of delays encountered on construction of the concrete gravity dam and HEPP projects for the each activity were found by making literature review and brainstorming.

Step 3: Frequency of occurrence and severity of the causes of delay for the each activity on concrete gravity dam and HEPP projects were determined by making survey with the experts.

Step 4: Linguistic variables, membership functions and fuzzy if-then rules were settled by consulting to the experts.

Step 5: Buffer sizing model with fuzzy assessment was constructed by using Fuzzy Logic Toolbox™ of the MATLAB Program Software.

Step 6: Hypothetical schedule of the construction of the concrete gravity dam and HEPP project was constructed in order to give an example and demonstrate the applicability of the model.

Detailed explanations and information of all steps were given in the following parts.

5.2.1 List of the Activities on the Schedule of the Concrete Gravity Dam and HEPP Projects

Several schedules of the real case concrete gravity dam and HEPP projects were examined and experts' opinions were taken into account in order to determine the possible activities on concrete gravity dam and HEPP projects. The list of the main activities considered in the proposed buffer sizing model with fuzzy assessment can be seen in the Table 3, below.

Table 3: List of the Main Activities on the Schedule of the Concrete Gravity Dam and HEPP Projects

#	Activity Name
1	Getting Necessary Permission from the Authorities
2	Expropriation Works of the Private Lands
3	Mobilization of the Site Facilities, Equipment & Materials and Construction of the Site & Access Roads
4	Construction of the Diversion Tunnel
5	Construction of the Cofferdam
6	Construction of the Dam Body
7	Construction of the Spillway
8	Construction of the Bottom Weir
9	Power Tunnel Works
10	Powerhouse and Switchyard Works
11	Test and Commissioning

5.2.2 Causes of Delays Encountered on Concrete Gravity Dam and HEPP Projects

As was mentioned above; due to complex nature of the dam and HEPP projects, several delays can be observed.

Causes of delay are needed in order to calculate the size of time buffers accurately in the proposed buffer sizing model with fuzzy assessment. As a result of this reason, detailed literature review was made in order to find causes of delay on dam and HEPP projects. Also, brainstorming sessions were made with two academician and two civil engineers who have the experience more than 15 years on dam and HEPP projects. Correspondingly, totally 89 causes of delay were found for the concrete gravity dam and HEPP projects.

In the detailed literature survey as given in Chapter 2, it was seen that causes of delay were classified according to their sources like client related, consulted related etc.. They were also identified for the whole projects. In other words, the studies did not consider activity specific conditions. On the other hand; in this thesis, causes of delay were obtained for each project activity listed in Table 3. Since causes of delay were given for each project activity, some of them are repeated; however, as their frequency of occurrence and severity vary depending on the activity type, including such variance is also important for this thesis. Also, considering cause of delays for each activity enables to calculate the required time buffer for each activity so to see the most problematic activities on the schedule by comparing the size of the time buffers used on each activity.

All causes of delay considered in this thesis for each project activity are listed in from Table 4 to Table 14.

Table 4: Causes of Delay for the Activity 1

Causes of Delay for the Activity "Getting Necessary Permission from the Authorities"
Poor knowledge of local regulations and laws by the client where the construction take place
Change in government policies such as environmental policies, legislations etc.
Bureaucratic delays in getting permits or approvals from the municipality or other authorities for the construction project

Table 5: Causes of Delay for the Activity 2

Causes of Delay for the Activity "Expropriation Works of the Private Lands"
Difficulty in site acquisition or failure to provide property due to problems with local residents
Effects of other organizations which protest construction of dam and HEPP due to environmental concerns (Greenpeace etc.)

Table 6: Causes of Delay for the Activity 3

Causes of Delay for the Activity "Mobilization of the Site Facilities, Equipment & Materials and Construction of the Site & Access Roads"
Unexpected geotechnical conditions encountered during site & access road construction (Ground subsidence etc.)
Breakdown of the equipment and idle time due to maintenance problem
Accidents during mobilization and construction of roads (Accidents can cause interruption of continued works and decrease in morale of the labourers)
Unavailability or late delivery of the required materials on site
Unavailability or late delivery of the required equipment & tools on site
Poor site lay-out due to improper planning of the contractor or project manager
Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)
Inclement weather effect during the construction (Hurricanes, storms etc.)

Table 7: Causes of Delay for the Activity 4

Causes of Delay for the Activity "Construction of the Diversion Tunnel"
Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site
Improper construction methods implemented by the contractor (Different methods should be used for the tunnel works depending on the geological properties)
Insufficient data collection and site investigation for the excavation works
Breakdown of the equipment and idle time due to maintenance problem
Unavailability or late delivery of the required materials on site (Shotcrete etc.)
Unavailability or late delivery of the required equipment & tools for tunnel excavation and concrete works
Accidents during diversion tunnel construction (Accidents can cause interruption of continued works and decrease in morale of the labourers)
Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)
Geological problems during construction of tunnel works (Earthquakes, landslides etc.)
Inclement weather effect during the construction (Hurricanes, storms etc.)

Table 8: Causes of Delay for the Activity 5

Causes of Delay for the Activity "Construction of the Cofferdam"
Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site
Improper construction methods implemented by the contractor
Insufficient data collection and site investigation for the excavation works (Excavation in order to prepare and straighten the soil for the cofferdam construction)
Breakdown of the equipment and idle time due to maintenance problem
Unavailability or late delivery of the required materials for the riprap operations which are required for the cofferdam construction
Problems related with type, quality and quantity of materials for riprap operations
Accidents during cofferdam construction (Accidents can cause interruption of continued works and decrease in morale of the labourers)
Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)
Geological problems during cofferdam construction (Earthquakes, landslides etc.)
Inclement weather effect during the construction (Hurricanes, storms etc.)

Table 9: Causes of Delay for the Activity 6

Causes of Delay for the Activity "Construction of the Dam Body"
Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site
Insufficient data collection and site investigation for the excavation works and foundation preparation works. (Which are done in order to construct dam body above the required quality of soil)
Breakdown of the equipment and idle time due to maintenance problem
Unavailability or late delivery of the required materials for the concrete works
Problems related with type, quality and quantity of materials for concrete works
Accidents during dam body construction (Accidents can cause interruption of continued works and decrease in morale of the labourers)
Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)
Geological problems during dam body construction (Earthquakes, landslides etc.)
Inclement weather effect during the construction (Hurricanes, storms etc.)

Table 9: Causes of Delay for the Activity 6 (Continued)

Lack of experience of the contractor on the Concrete Gravity Dam construction
Coordination problem between different working groups and engineer (Since construction of a dam body is complex and many different number of working groups can work on a site, difficulties in coordination can cause delay)
Overcrowded (Clustered) work area in the construction site
Poor inspection and testing procedure by the consultant (Time spent for the inspection and testing procedure can reach unexpected level)

Table 10: Causes of Delay for the Activity 7

Causes of Delay for the Activity "Construction of the Spillway"
Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site
Breakdown of the equipment and idle time due to maintenance problem
Unavailability or late delivery of the required materials for the construction of spillway
Problems related with type, quality and quantity of materials for concrete works
Accidents during construction of spillway (Accidents can cause interruption of continued works and decrease in morale of the labourers)
Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)
Geological problems during construction of a spillway (Earthquakes, landslides etc.)
Inclement weather effect during the construction (Hurricanes, storms etc.)
Delay due to coordination problems between the contractor and subcontractor
Overcrowded (Clustered) work area in the construction site
Poor inspection and testing procedure by the consultant (Time spent for the inspection and testing procedure can reach unexpected level)
Problems due to other works are on hold (Such as continued concrete works on the construction of a dam body can cause a delay on the concrete works on the construction of a spillway)
Delay in performing inspection and testing of the works by the consultant

Table 11: Causes of Delay for the Activity 8

Causes of Delay for the Activity "Construction of the Bottom Weir"
Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site
Breakdown of the equipment and idle time due to maintenance problem
Unavailability or late delivery of the required materials for the construction of bottom weir
Problems related with type, quality and quantity of materials for concrete and penstock works
Accidents during construction of bottom weir (Accidents can cause interruption of continued works and decrease in morale of the labourers)
Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)
Geological problems during construction of a bottom weir (Earthquakes, landslides etc.)
Inclement weather effect during the construction (Hurricanes, storms etc.)
Delay in performing inspection and testing of the works by the consultants

Table 12: Causes of Delay for the Activity 9

Causes of Delay for the Activity "Power Tunnel Works"
Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site
Improper construction methods implemented by the contractor (Different methods should be used for the tunnel works depending on the geological properties)
Insufficient data collection and site investigation for the excavation works
Breakdown of the equipment and idle time due to maintenance problem
Unavailability or late delivery of the required materials on site (Shotcrete etc.)
Unavailability or late delivery of the required equipment & tools for tunnel excavation and concrete works
Accidents during tunnel construction (Accidents can cause interruption of continued works and decrease in morale of the labourers)
Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)
Geological problems during construction of tunnel works (Earthquakes, landslides etc.)
Inclement weather effect during the construction (Hurricanes, storms etc.)
Lack of experience of the subcontractor and time spent to find appropriate subcontractors

Table 13: Causes of Delay for the Activity 10

Causes of Delay for the Activity "Powerhouse and Switchyard Works"
Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site
Breakdown of the equipment and idle time due to maintenance problem
Unavailability or late delivery of the required materials for the powerhouse and switchyard works
Problems related with type, quality and quantity of materials for concrete and penstock works
Accidents during powerhouse and switchyard works. (Accidents can cause interruption of continued wor decrease in morale of the labourers)
Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack o motivation or personnel issue etc.)
Excessive time spent to find appropriate subcontractors for Mechanical Electrical and Plumping (MEP) w
Geological problems during construction works (Earthquakes, landslides etc.)
Inclement weather effect during the construction (Hurricanes, storms etc.)

Table 14: Causes of Delay for the Activity 11

Causes of Delay for the Activity "Test and Commissioning"
Delay in final performing, inspection and testing

As it was understood while presenting causes of delay in from Table 4 to Table 14, delays due to financial problems were not considered. Financial causes of delay were ignored in the proposed buffer sizing model with fuzzy assessment because it was considered that delays due to financial problems certainly depend on the financial situation of the company carrying out the projects. Also, effects of the delay due to financial problems cannot be measured accurately. Besides, one of the aims of this thesis is to compare the size of the time buffers used in each activity on concrete gravity dam and HEPP projects in order to find the most problematic activities in the projects. On the other hand; if financial causes of delay are considered, frequency of occurrence and severity of the financial causes of delay, which are used in order to calculate the size of time buffer in the proposed buffer sizing model with fuzzy assessment, will be the same for the each activity; therefore, adding financial causes of delay is considered as unnecessary in the proposed model in this thesis.

5.2.3 Frequency of Occurrence and Severity of the Causes of Delay

Frequency of occurrence and severity of the causes of delay constitute input variables in the proposed buffer sizing model with fuzzy assessment. By using frequency values, it can be seen how recurrently causes of delay occurs and by using severity values, impact of the cause of delay like effects of the cause of delay in terms of duration, cost, resource allocation problems etc. can be measured.

In order to calculate the size of the time buffers accurately, activity characteristics of the project should be taken into account. For example, if inclement weather effect is considered as a cause of delay in the project, same size of the time buffer cannot be used for the indoor activities like tunnel works and outdoor activities like spillway works. As a result of this; as it was mentioned in the part 5.2.2, cause of delays were listed for each activity in the concrete gravity dam and HEPP projects and so that activity characteristics can be taken into account by considering the frequency of occurrence and severity values of the causes of delay under the each activity.

By determining frequency of occurrence and severity of the causes of delay for the each activity, besides the advantage of taking the property of activity characteristics into account; activity interdependencies, influence degree of activities with each other and uncertainty level of each activities, which are required to calculate the optimum size of time buffers, can be obtained on the concrete gravity dam and HEPP projects.

In this thesis, frequency of occurrence and severity values of the causes of delay were found by making an online survey. Before sending the online survey, pilot survey was made with the two academician and two civil engineers who have the more than 15 years of experience on the dam and HEPP projects in order to see the applicability and validity of the survey. Then, online survey was sent to the 20 civil engineers, who are the experts in the dam and HEPP projects, via email and 13 of them gave responds to the survey.

The data obtained from the survey was imported into MS Excel for analysis. According to the analysis, average experience period of the respondents is around 15 years; therefore, although sampling size was seen as small, data from the survey gave logical, trust worthy and credible results.

The survey is composed of three parts. In the first part, it was wanted from the participants of the survey to give general information about their education background, occupation, professional experience, professional experience in HEPP projects, size of the company that they are currently working or last worked and fields of expertise of the company that they are currently working or last worked. In the second part of the survey, it was asked to the participants of the survey to determine the frequency of occurrence and severity of the causes of delay that were listed in the survey for each activity. Values of the frequency of occurrence and severity of the causes of delay are given by the participants in the survey by using the given Likert Scale Chart. In this survey, five-point Likert Scale Chart ranged from 1 (very rarely) to 5 (always) for the frequency of occurrence of the causes of delay and five-point Likert Scale Chart ranged from 1 (very low) to 5 (very high) for the severity of the causes of delay were used. For example, if frequency of the cause of delay is considered as low and severity of it is considered as moderate then the point “2” is given for the frequency value and the point “3” is given for the severity value for the cause of delay. Finally; in the third part of the survey, recommended minimum and maximum size of the time buffer were asked to the participants of the survey based on the their own professional experience. Recommended buffer size was asked in order to compare the results of the proposed buffer sizing model with fuzzy assessment. Also, recommended buffer size can be graded by the participants by using five-point Likert Scale Chart, designed for grading of the time buffer size, ranged from 1 (very small) to 5 (very large). The sample survey form can be found in Table A.1 in Appendix A.

As it was mentioned, frequency of occurrence and severity values of the causes of delay are used as inputs for the proposed buffer sizing model with fuzzy assessment. These input values are taken as average of results obtained from survey answers conducted with 13 experts. Average frequency of occurrence and severity values of the causes of delay for each activity will be seen in the Table 15, below.

Table 15: Average Frequency and Severity Values of the Causes of Delay

Act. #	Causes of Delay	Frq.	Sev.
1	Poor knowledge of local regulations and laws by the client where the construction take place	1.77	2.62
	Change in government policies such as environmental policies, legislations etc.	1.62	2.92
	Bureaucratic delays in getting permits or approvals from the municipality or other authorities for the construction project	2.85	2.77
2	Difficulty in site acquisition or failure to provide property due to problems with local residents	3.08	3.31
	Effects of other organizations which protest construction of dam and HEPP due to environmental concerns (Greenpeace etc.)	1.69	2.23
3	Unexpected geotechnical conditions encountered during site & access road construction (Ground subsidence etc.)	1.62	1.92
	Breakdown of the equipment and idle time due to maintenance problem	1.62	1.62
	Accidents during mobilization and construction of roads (Accidents can cause interruption of continued works and decrease in morale of the labourers)	0.77	1.31
	Unavailability or late delivery of the required materials on site	1.08	1.23
	Unavailability or late delivery of the required equipment & tools on site	1.23	1.69
	Poor site lay-out due to improper planning of the contractor or project manager	1.77	2.46
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	1.62	2.08
	Inclement weather effect during the construction (Hurricanes, storms etc.)	0.92	2.00

Table 15: Average Frequency and Severity Values of the Causes of Delay (Continued)

4	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site	1.85	2.08
	Improper construction methods implemented by the contractor (Different methods should be used for the tunnel works depending on the geological properties)	1.08	2.46
	Insufficient data collection and site investigation for the excavation works	1.85	3.00
	Breakdown of the equipment and idle time due to maintenance problem	1.23	1.15
	Unavailability or late delivery of the required materials on site (Shotcrete etc.)	1.54	1.85
	Unavailability or late delivery of the required equipment & tools for tunnel excavation and concrete works	1.23	1.46
	Accidents during diversion tunnel construction (Accidents can cause interruption of continued works and decrease in morale of the labourers)	1.92	3.31
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	1.46	2.00
	Geological problems during construction of tunnel works (Earthquakes, landslides etc.)	1.54	3.77
	Inclement weather effect during the construction (Hurricanes, storms etc.)	0.77	1.46
5	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site	1.23	1.62
	Improper construction methods implemented by the contractor	0.85	1.31
	Insufficient data collection and site investigation for the excavation works (Excavation in order to prepare and straighten the soil for the cofferdam construction)	1.15	1.77
	Breakdown of the equipment and idle time due to maintenance problem	1.00	1.23
	Unavailability or late delivery of the required materials for the riprap operations which are required for the cofferdam construction	1.31	1.46
	Problems related with type, quality and quantity of materials for riprap operations	1.23	1.38
	Accidents during cofferdam construction (Accidents can cause interruption of continued works and decrease in morale of the labourers)	0.92	1.62
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	0.85	1.15
	Geological problems during cofferdam construction (Earthquakes, landslides etc.)	1.38	3.00
	Inclement weather effect during the construction (Hurricanes, storms etc.)	1.31	2.62
6	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site	1.69	2.08
	Insufficient data collection and site investigation for the excavation works and foundation preparation works. (Which are done in order to construct dam body above the required quality of soil)	2.00	2.77

Table 15: Average Frequency and Severity Values of the Causes of Delay (Continued)

6	Breakdown of the equipment and idle time due to maintenance problem	1.31	1.77
	Unavailability or late delivery of the required materials for the concrete works	1.62	1.62
	Problems related with type, quality and quantity of materials for concrete works	1.15	1.54
	Accidents during dam body construction (Accidents can cause interruption of continued works and decrease in morale of the labourers)	1.54	2.46
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	1.31	1.77
	Geological problems during dam body construction (Earthquakes, landslides etc.)	1.38	3.69
	Inclement weather effect during the construction (Hurricanes, storms etc.)	1.62	3.69
	Lack of experience of the contractor on the Concrete Gravity Dam construction	1.46	2.46
	Coordination problem between different working groups and engineer (Since construction of a dam body is complex and many different number of working groups can work on a site, difficulties in coordination can cause delay)	1.77	2.23
	Overcrowded (Clustered) work area in the construction site	0.77	0.77
	Poor inspection and testing procedure by the consultant (Time spent for the inspection and testing procedure can reach unexpected level)	1.77	2.00
7	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site	1.31	1.62
	Breakdown of the equipment and idle time due to maintenance problem	0.92	1.23
	Unavailability or late delivery of the required materials for the construction of spillway	1.31	1.77
	Problems related with type, quality and quantity of materials for concrete works	1.23	1.62
	Accidents during construction of spillway (Accidents can cause interruption of continued works and decrease in morale of the labourers)	1.46	2.62
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	1.00	1.38
	Geological problems during construction of a spillway (Earthquakes, landslides etc.)	1.38	3.08
	Inclement weather effect during the construction (Hurricanes, storms etc.)	1.62	3.15
	Delay due to coordination problems between the contractor and subcontractor	2.08	2.77
	Overcrowded (Clustered) work area in the construction site	0.46	0.69
	Poor inspection and testing procedure by the consultant (Time spent for the inspection and testing procedure can reach unexpected level)	1.31	1.69
	Problems due to other works are on hold (Such as continued concrete works on the construction of a dam body can cause a delay on the concrete works on the construction of a spillway)	1.92	2.23
	Delay in performing inspection and testing of the works by the consultant	1.23	1.46

Table 15: Average Frequency and Severity Values of the Causes of Delay (Continued)

8	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site	1.31	1.46
	Breakdown of the equipment and idle time due to maintenance problem	1.00	1.54
	Unavailability or late delivery of the required materials for the construction of bottom weir	1.23	1.46
	Problems related with type, quality and quantity of materials for concrete and penstock works	0.92	1.00
	Accidents during construction of bottom weir (Accidents can cause interruption of continued works and decrease in morale of the labourers)	0.92	1.69
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	0.92	1.31
	Geological problems during construction of a bottom weir (Earthquakes, landslides etc.)	1.15	2.85
	Inclement weather effect during the construction (Hurricanes, storms etc.)	0.92	1.62
	Delay in performing inspection and testing of the works by the consultants	1.00	0.92
9	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site	1.46	1.85
	Improper construction methods implemented by the contractor (Different methods should be used for the tunnel works depending on the geological properties)	1.31	2.00
	Insufficient data collection and site investigation for the excavation works	1.92	2.69
	Breakdown of the equipment and idle time due to maintenance problem	1.38	1.85
	Unavailability or late delivery of the required materials on site (Shotcrete etc.)	1.23	1.69
	Unavailability or late delivery of the required equipment & tools for tunnel excavation and concrete works	1.15	1.54
	Accidents during tunnel construction (Accidents can cause interruption of continued works and decrease in morale of the labourers)	1.62	2.62
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	1.46	2.00
	Geological problems during construction of tunnel works (Earthquakes, landslides etc.)	1.46	3.15
	Inclement weather effect during the construction (Hurricanes, storms etc.)	0.62	1.38
	Lack of experience of the subcontractor and time spent to find appropriate subcontractors	1.85	2.54
10	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site	1.46	1.46
	Breakdown of the equipment and idle time due to maintenance problem	1.00	1.23
	Unavailability or late delivery of the required materials for the powerhouse and switchyard works	1.15	1.38
	Problems related with type, quality and quantity of materials for concrete and penstock works	1.08	1.69

Table 15: Average Frequency and Severity Values of the Causes of Delay (Continued)

10	Accidents during powerhouse and switchyard works. (Accidents can cause interruption of continued works and decrease in morale of the labourers)	1.00	1.77
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	1.08	1.69
	Excessive time spent to find appropriate subcontractors for Mechanical Electrical and Plumping (MEP) works	1.23	1.62
	Geological problems during construction works (Earthquakes, landslides etc.)	0.92	2.31
	Inclement weather effect during the construction (Hurricanes, storms etc.)	1.15	2.38
11	Delay in final performing inspection and testing	2.54	3.00

5.2.4 Linguistic Variables, Membership Functions and Fuzzy If-Then Rules

Linguistic variables, membership functions and fuzzy if-then rules were found by making detailed literature review and consulting 2 academician and 2 experts who have the more than 15 years of experience on dam and HEPP projects. Also, generalized linguistic variables, membership functions and fuzzy if-then rules were tried to be constructed in order to globalize the proposed buffer sizing model with fuzzy assessment. In other words, proposed buffer sizing model with fuzzy assessment can be used universally with using constructed linguistic variables, membership functions and fuzzy if-then rules.

Since it is expected from the participants of the survey to determine the frequency of occurrence and severity of the causes of delay by using five-point Likert Scale Charts; membership functions were divided into five regions for the input variables of the buffer sizing model with fuzzy assessment.

Output variable of the proposed model is the size of the time buffer and expressed in terms of the percentage of the each activity duration located on the schedule of the concrete gravity dam and HEPP projects. Like input variables, membership function for the output variable is also divided into five regions between the minimum value of zero and maximum value of fifty percent of the activity durations. Also, piecewise linear functions were used for the membership functions of the both input variables and output variable because as it was mentioned in the Chapter 4, they are simple, changed easily with the corresponding changes in the related parameters and most widely used membership functions.

Linguistic variables and membership functions of the input variables and output variable, used in the proposed buffer sizing model with the fuzzy assessment, are given in the Figure 20, Figure 21 and Figure 22, below.

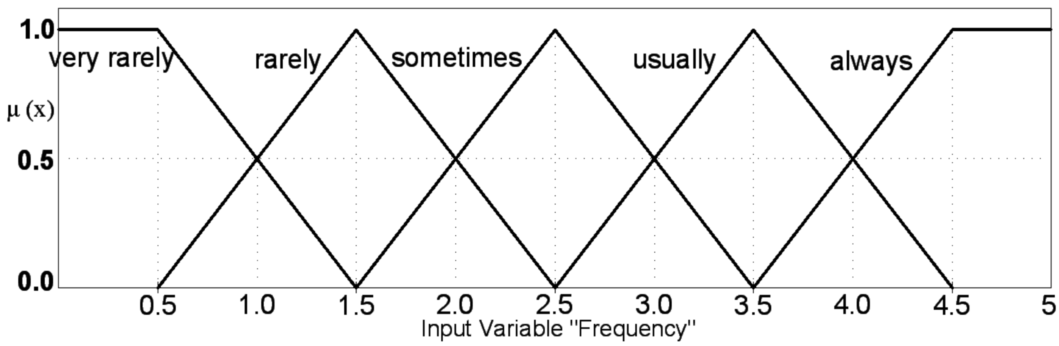

Figure 20: Linguistic Variables and Membership Functions for the Frequency

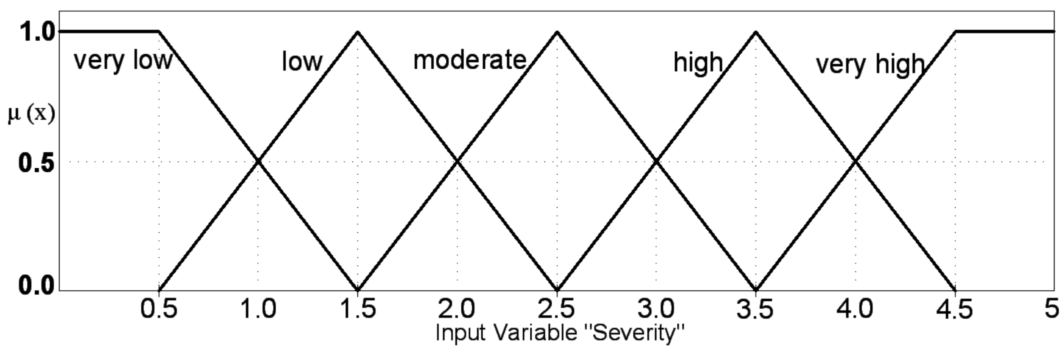

Figure 21: Linguistic Variables and Membership Functions for the Severity

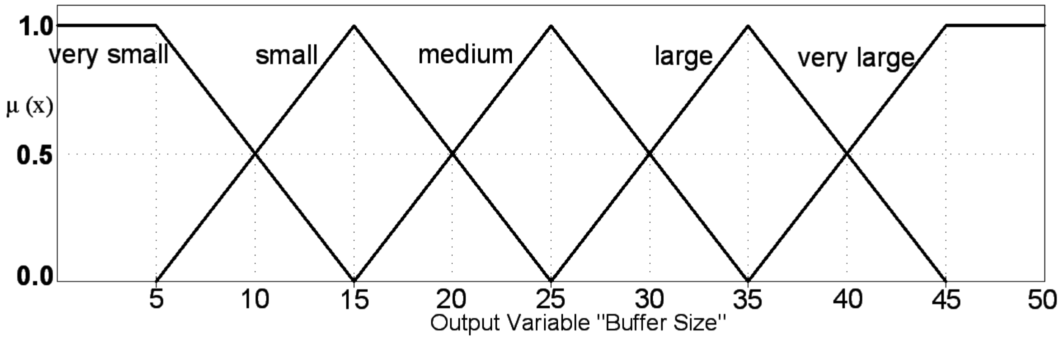

Figure 22: Linguistic Variables and Membership Functions for the Buffer Size

Fuzzy if-then rules, constructed for the model, can be seen in the Table 16, below.

Table 16: Fuzzy If-Then Rules with Verbal Representation

#	IF-THEN RULES											
1	If	frequency	is	very rarely	and	severity	is	very low	then	buffer percentage	is	very small
2	If	frequency	is	very rarely	and	severity	is	low	then	buffer percentage	is	very small
3	If	frequency	is	very rarely	and	severity	is	moderate	then	buffer percentage	is	small
4	If	frequency	is	very rarely	and	severity	is	high	then	buffer percentage	is	small
5	If	frequency	is	very rarely	and	severity	is	very high	then	buffer percentage	is	small
6	If	frequency	is	rarely	and	severity	is	very low	then	buffer percentage	is	very small
7	If	frequency	is	rarely	and	severity	is	low	then	buffer percentage	is	small
8	If	frequency	is	rarely	and	severity	is	moderate	then	buffer percentage	is	medium
9	If	frequency	is	rarely	and	severity	is	high	then	buffer percentage	is	medium
10	If	frequency	is	rarely	and	severity	is	very high	then	buffer percentage	is	medium
11	If	frequency	is	sometimes	and	severity	is	very low	then	buffer percentage	is	small
12	If	frequency	is	sometimes	and	severity	is	low	then	buffer percentage	is	medium
13	If	frequency	is	sometimes	and	severity	is	moderate	then	buffer percentage	is	medium
14	If	frequency	is	sometimes	and	severity	is	high	then	buffer percentage	is	large
15	If	frequency	is	sometimes	and	severity	is	very high	then	buffer percentage	is	large
16	If	frequency	is	usually	and	severity	is	very low	then	buffer percentage	is	small
17	If	frequency	is	usually	and	severity	is	low	then	buffer percentage	is	medium
18	If	frequency	is	usually	and	severity	is	moderate	then	buffer percentage	is	large
19	If	frequency	is	usually	and	severity	is	high	then	buffer percentage	is	large
20	If	frequency	is	usually	and	severity	is	very high	then	buffer percentage	is	very large
21	If	frequency	is	always	and	severity	is	very low	then	buffer percentage	is	small
22	If	frequency	is	always	and	severity	is	low	then	buffer percentage	is	medium
23	If	frequency	is	always	and	severity	is	moderate	then	buffer percentage	is	large
24	If	frequency	is	always	and	severity	is	high	then	buffer percentage	is	very large
25	If	frequency	is	always	and	severity	is	very high	then	buffer percentage	is	very large

As it can be seen in the Table 16, totally 25 fuzzy if-then rules were constructed in order to describe the interrelationships between the input variables "frequency" and "severity" and the output variable "time buffer size" in the buffer sizing model with fuzzy assessment. Besides, Mamdani-Style type of fuzzy if-then rules were considered while constructing fuzzy-if then rules because as it was mentioned in the Chapter 4, it is the most commonly used method in the literature.

Besides the Table 16 where the verbal representation of the fuzzy if-then rules used in the buffer sizing model with fuzzy assessment is listed, index representation of the fuzzy if-then rules also can be seen in the Table 17, below.

Table 17: Fuzzy If-Then Rules with Index Representation

#	IF-THEN RULES											
1	If	frequency	is	1	and	severity	is	1	then	buffer percentage	is	1
2	If	frequency	is	1	and	severity	is	2	then	buffer percentage	is	1
3	If	frequency	is	1	and	severity	is	3	then	buffer percentage	is	2
4	If	frequency	is	1	and	severity	is	4	then	buffer percentage	is	2
5	If	frequency	is	1	and	severity	is	5	then	buffer percentage	is	2
6	If	frequency	is	2	and	severity	is	1	then	buffer percentage	is	1
7	If	frequency	is	2	and	severity	is	2	then	buffer percentage	is	2
8	If	frequency	is	2	and	severity	is	3	then	buffer percentage	is	3
9	If	frequency	is	2	and	severity	is	4	then	buffer percentage	is	3
10	If	frequency	is	2	and	severity	is	5	then	buffer percentage	is	3
11	If	frequency	is	3	and	severity	is	1	then	buffer percentage	is	2
12	If	frequency	is	3	and	severity	is	2	then	buffer percentage	is	3
13	If	frequency	is	3	and	severity	is	3	then	buffer percentage	is	3
14	If	frequency	is	3	and	severity	is	4	then	buffer percentage	is	4
15	If	frequency	is	3	and	severity	is	5	then	buffer percentage	is	4
16	If	frequency	is	4	and	severity	is	1	then	buffer percentage	is	2
17	If	frequency	is	4	and	severity	is	2	then	buffer percentage	is	3
18	If	frequency	is	4	and	severity	is	3	then	buffer percentage	is	4
19	If	frequency	is	4	and	severity	is	4	then	buffer percentage	is	4
20	If	frequency	is	4	and	severity	is	5	then	buffer percentage	is	5
21	If	frequency	is	5	and	severity	is	1	then	buffer percentage	is	2
22	If	frequency	is	5	and	severity	is	2	then	buffer percentage	is	3
23	If	frequency	is	5	and	severity	is	3	then	buffer percentage	is	4
24	If	frequency	is	5	and	severity	is	4	then	buffer percentage	is	5
25	If	frequency	is	5	and	severity	is	5	then	buffer percentage	is	5

5.2.5 Buffer Sizing Model with Fuzzy Assessment

Fuzzy Logic Toolbox^{TM} is used in order to construct the proposed buffer sizing model with fuzzy assessment.

5.2.5.1 Fuzzy Logic Toolbox

Fuzzy Logic Toolbox^{TM} provides functions, applications and a Simulink block for analyzing, designing, and simulating systems based on fuzzy logic. It is built on the MATLAB, language of the technical computing, and it can be used as a stand-alone fuzzy inference engine (Fuzzy Logic Toolbox^{TM} User's Guide (2013), MATLAB, the MathWorks, Inc.).

Five fundamental graphical user interface tools are available in the Fuzzy Logic Toolbox^{TM} in order to perform fuzzy inference systems. These graphical user interface tools are;

- Fuzzy Inference System (FIS) Editor
- Membership Function Editor
- Rule Editor
- Rule Viewer
- Surface Viewer

The proposed buffer sizing model with fuzzy assessment was constituted with using aforementioned graphical user interface tools. Therefore, detailed explanations of these tools with the demonstration of the proposed buffer sizing model with fuzzy assessment can be seen below.

5.2.5.1.1 Fuzzy Inference System (FIS) Editor

Input and output variables can be defined in this editor. Besides, aggregation and defuzzification methods and the norms used in order to determine the degree to which the input data match the condition of the fuzzy rules can be described by using this editor. Fuzzy Inference System (FIS) Editor for the buffer sizing model with fuzzy assessment can be seen in the Figure 23, below.

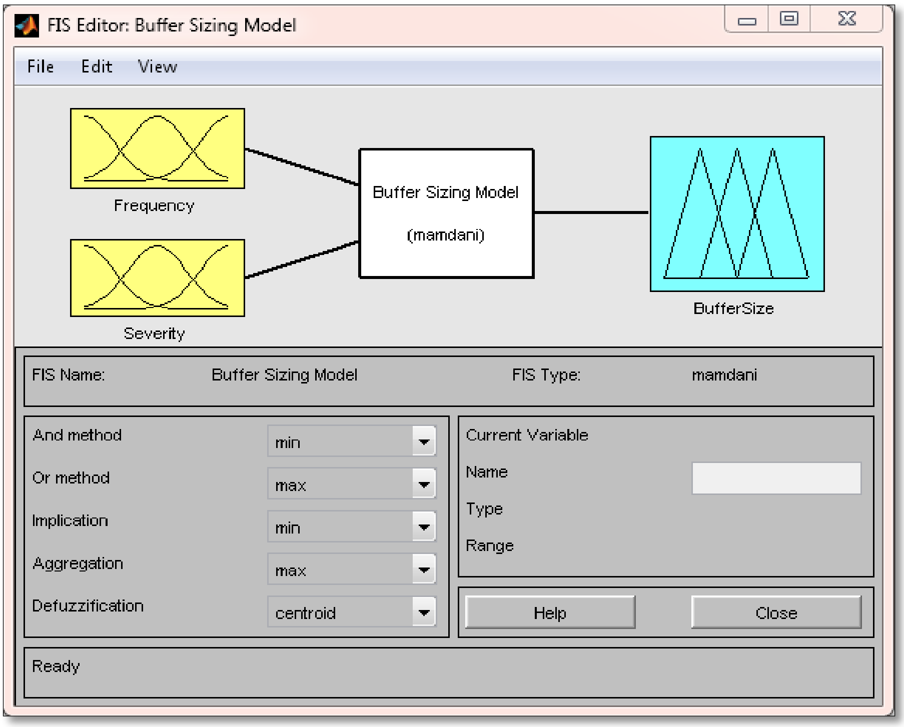

Figure 23: FIS Editor for Buffer Sizing Model with Fuzzy Assessment

In the proposed buffer sizing model with fuzzy assessment; as it can be seen in the Figure 23, frequency of occurrence and severity of the causes of delay for each activity, listed in the Table 3, were considered as input variables. Time buffer size was considered as an output variable which was expressed in terms of percentage of activity duration. Also, minimum and maximum operators were used in order to determine the degree to which the input data match the condition of the fuzzy rules.

Moreover; maximum operator was used for the aggregation process and central area technique was used for the defuzzication.

5.2.5.1.2 Membership Function Editor

Linguistic variables and membership functions for both input variables and output variable can be defined in this editor. In Part 5.2.4; linguistic variables and membership functions for input variables and output variable of the buffer sizing model with fuzzy assessment were decided; therefore, information of these predefined linguistic variables and membership functions were entered to the membership function editor. Linguistic variables and membership functions for the input variables and output variable after entering necessary information to the Membership Function Editor can be seen in the Figure 24, Figure 25 and Figure 26, below.

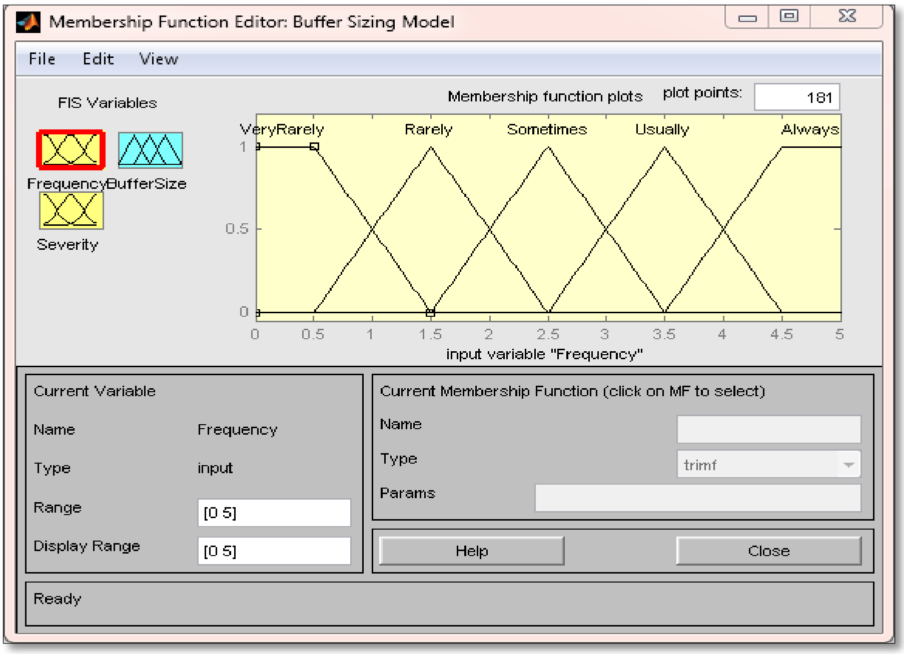

Figure 24: Membership Function Editor for the Frequency

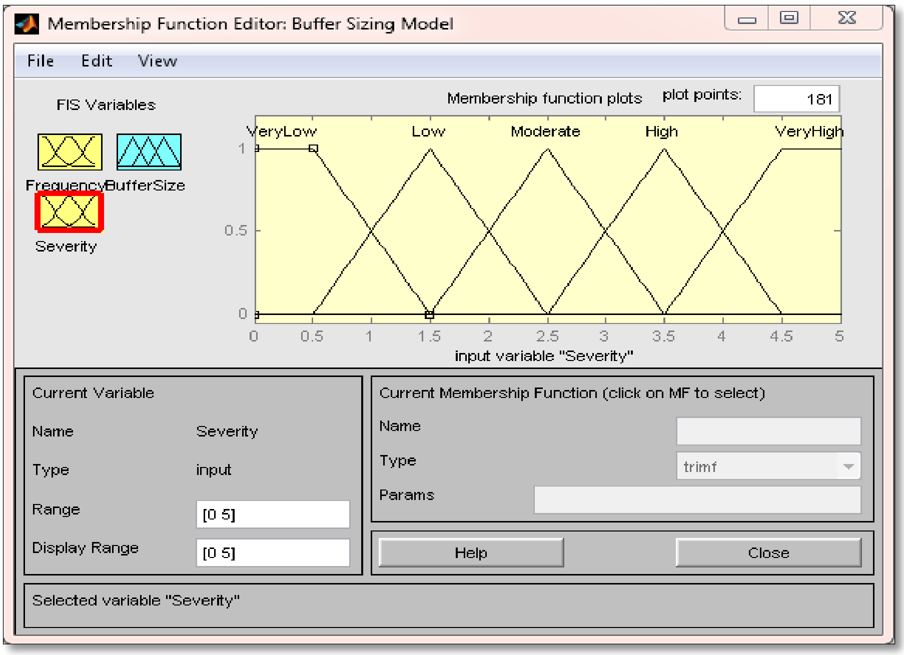

Figure 25: Membership Function Editor for the Severity

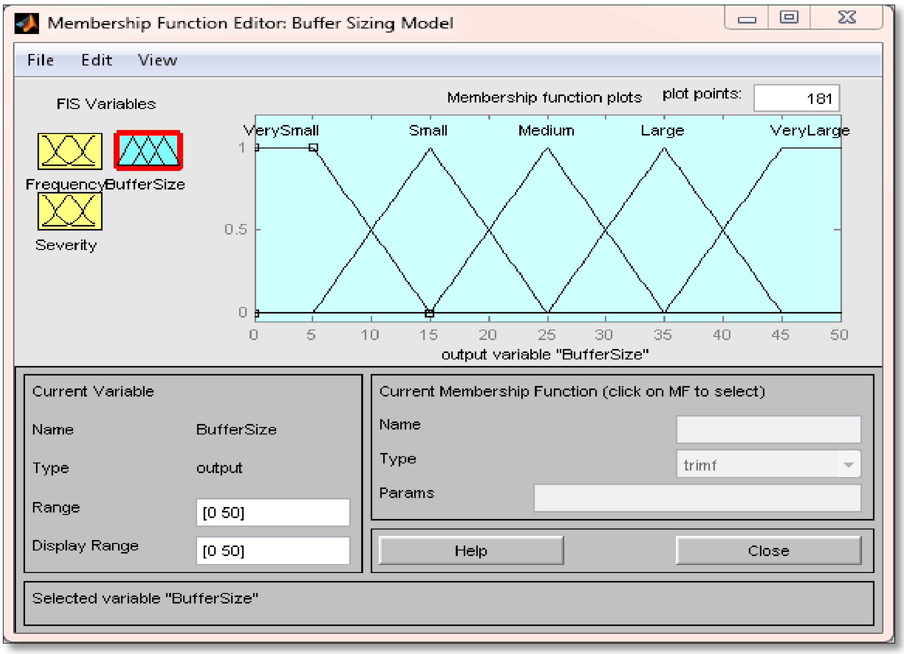

Figure 26: Membership Function Editor for the Buffer Size

5.2.5.1.3 Rule Editor

Fuzzy if-then rules can be defined in the Fuzzy Logic Toolbox™ by using Rule Editor. In Rule Editor; verbal, symbolic and index representations of the fuzzy if-then rules can be displayed. Fuzzy if-then rules defined in the Rule Editor with verbal representation is given in Figure 27, below.

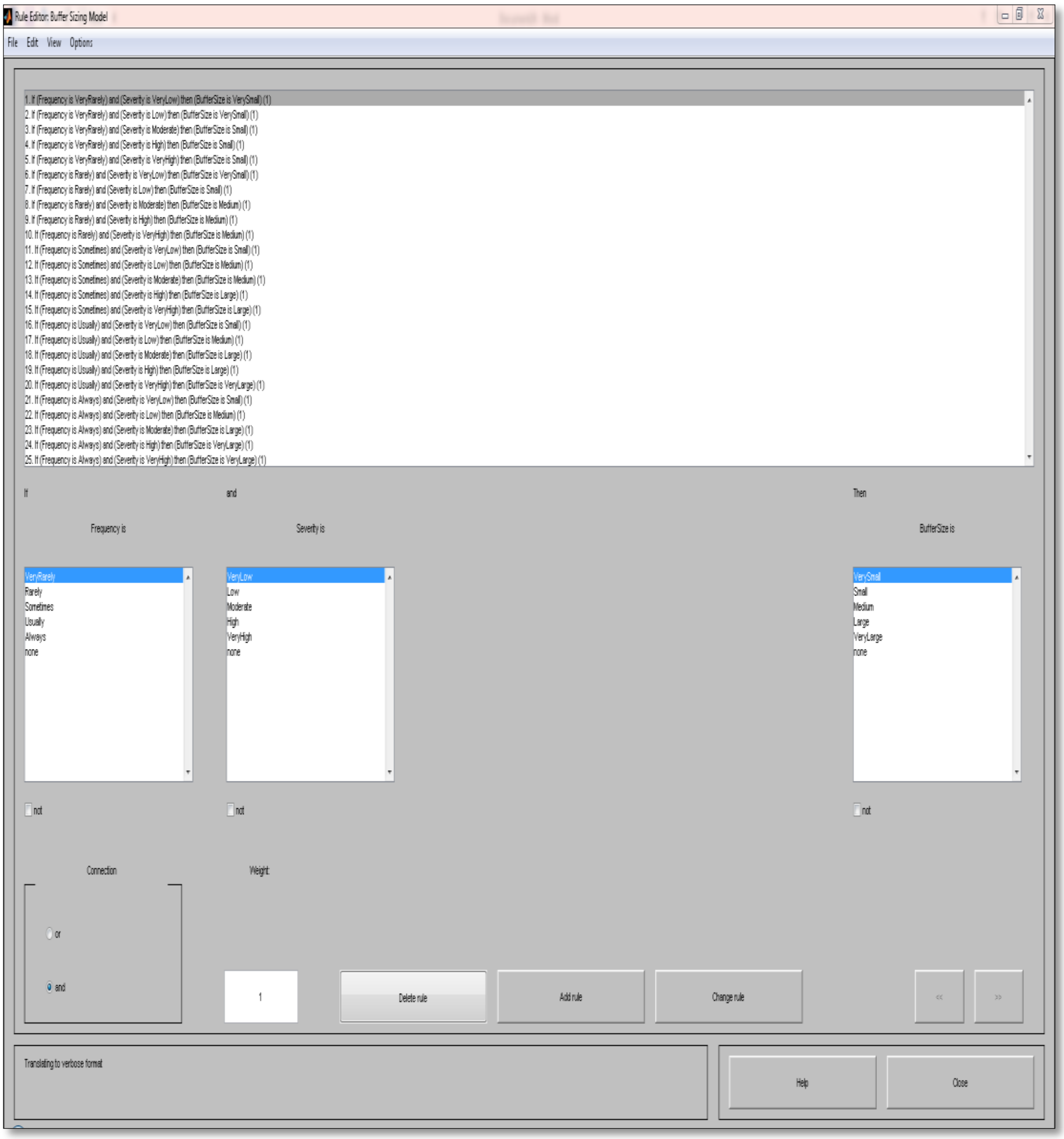

Figure 27: Fuzzy If-Then Rules in the Rule Editor

The value “1” in the parentheses near the each fuzzy if-then rules was assigned in order to represent the weight of the rules. This property in the Rule Editor can be used in the situation where it is desired to give relative importance value to each rules. Since each fuzzy if-then rule is considered having the same importance level, the value “1” was assigned to each fuzzy if-then rule as a weight of the rules.

5.2.5.1.4 Rule Viewer

In Rule Viewer; it can be seen which fuzzy if-then rule is active or how individual membership function shapes effect the results. By changing input values in the Rule Viewer; various output values can be obtained.

In the proposed buffer sizing model with fuzzy assessment, the intended output variable is the time buffer size for the each activity listed in the Table 3; therefore, by changing frequency of occurrence and severity values of the causes of delay, which are the input values in the model, time buffer size can be obtained.

Firstly, time buffer size for the each causes of delay in the dam and HEPP projects were analyzed in the buffer sizing model with fuzzy assessment because frequency of occurrence and severity values were found for the each causes of delay. Then, by using the importance weight of the causes of delay which were grouped under each relevant activity, as it can be seen in from Table 4 and Table 14; time buffer size for the each activity can be calculated.

As it was mentioned above; totally 89 causes of delay were found for the concrete gravity dam and HEPP projects; therefore, 89 different input values were entered in the Rule Viewer in order to obtain the buffer size for the each cause of delay.

Results which were found in the Rule Viewer for the all input values can be seen in the Appendix B. However; as an example, results of the causes of delay for the first activity in the schedule of the concrete gravity dam and HEPP projects were given in Figure 28, Figure 29 and Figure 30 below. Summary table for the first activity in the schedule which shows related causes of delay with frequency and severity values can also be seen in Table 18, below.

Table 18: Summary Table for the First Activity

Activity	Causes of Delay	Frq.	Sev.
Getting Necessary Permission from the Authorities	Poor knowledge of local regulations and laws by the client where the construction take place	1.77	2.62
	Change in government policies such as environmental policies, legislations etc.	1.62	2.92
	Bureaucratic delays in getting permits or approvals from the municipality or other authorities for the construction project	2.85	2.77

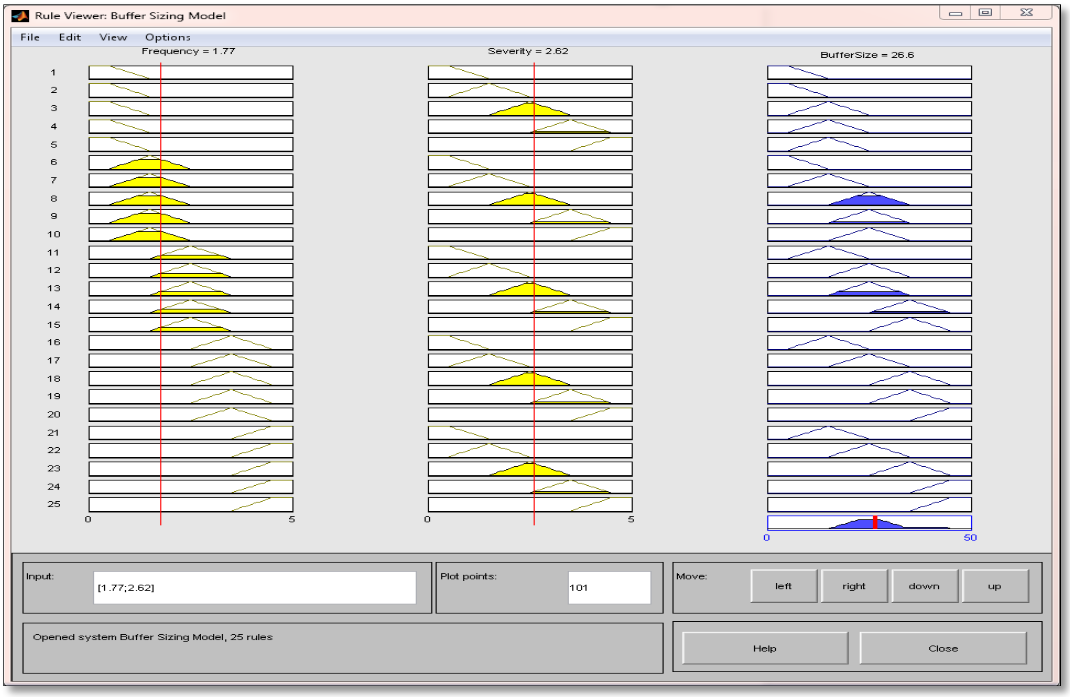

Figure 28: Results in the Rule Viewer for the Input Values “1.77, 2.62”

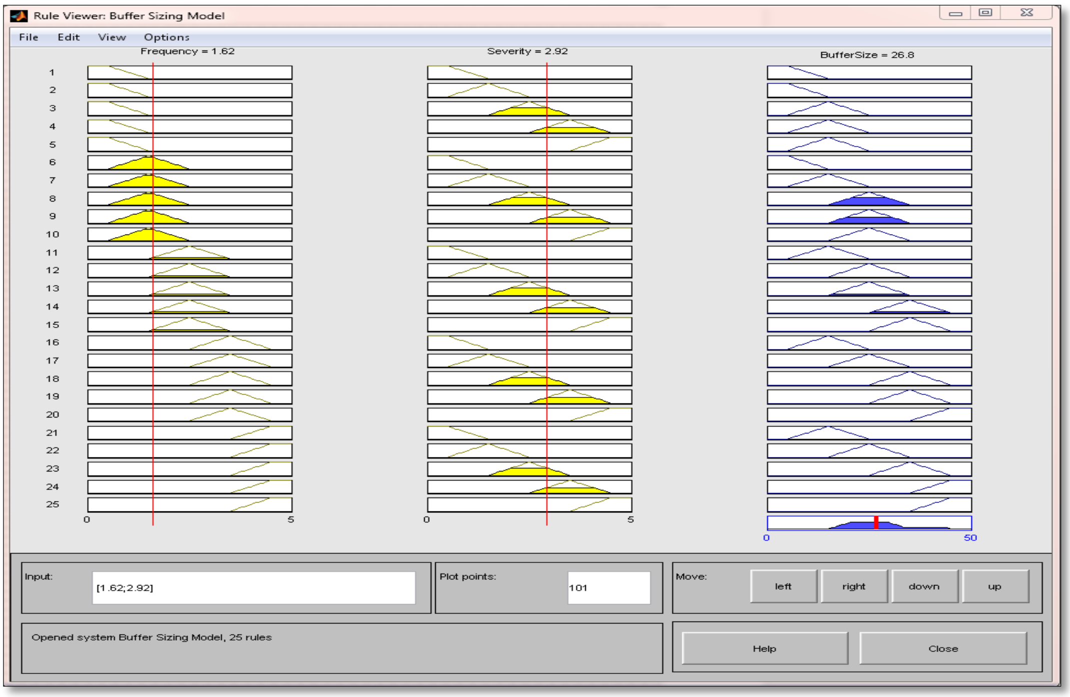

Figure 29: Results in the Rule Viewer for the Input Values "1.62, 2.92"

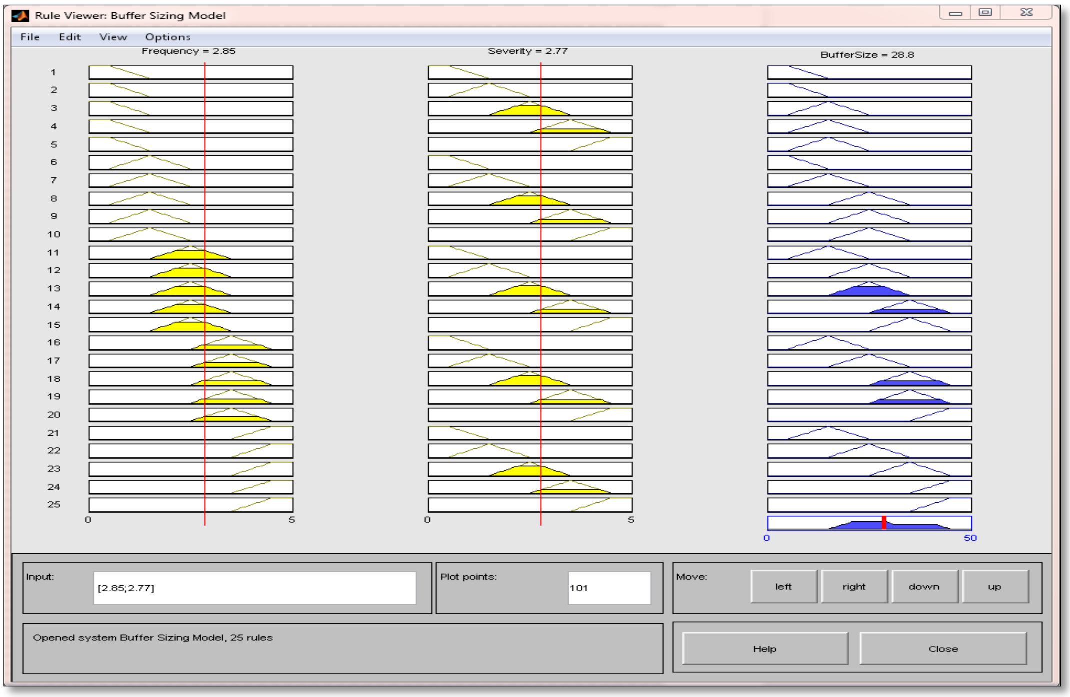

Figure 30: Results in the Rule Viewer for the Input Values "2.85, 2.77"

As it was mentioned; after calculated the time buffer sizes for each cause of delay, time buffer sizes for each activity were found by using importance weight of the causes of delay. Using importance weight of the causes of delay enables to see the relative effect of each causes of delay on the selected activity. Importance weight of the causes of delay were calculated by using the Equation 32, Equation 33 and Equation 34, below.

$$I_k = F_k \times S_k \qquad \text{(Equation 32)}$$

$$\mathrm{TI} = \mathrm{F_1} \times \mathrm{S_1} + \mathrm{F_2} \times \mathrm{S_2} \ldots . \mathrm{F_n} \times \mathrm{S_n} \qquad \text{(Equation 33)}$$

$$IW_k = \frac{I_k}{TI} \qquad \text{(Equation 34)}$$

In Equation 32, I_k represents the importance value of the arbitrary cause of delay and calculated by multiplying F_k and S_k where F_k is the frequency of occurrence and S_k is the severity of the arbitrary cause of delay. In Equation 33, TI is the total importance of the all causes of delay grouped under the relevant activity and n is the total number of causes of delay for the relevant activity. In Equation 34, IW_k means the importance weight of the arbitrary cause of delay and found by dividing I_k to the TI.

Time buffer sizes of each activity, listed in Table 3, were calculated by finding weighted buffer percentages of each cause of delay, which is obtained by multiplying buffer size and importance weight values of the causes of delay, and adding them up to represent the activity buffer percentage.

Time buffer size and importance weight of the each 89 causes of delay can be seen in the Table 19, below.

Table 19: Buffer Size and Importance Weight Values of the Causes of Delay

Act. #	Causes of Delay	Buffer Size (%)	Importance Weight
1	Poor knowledge of local regulations and laws by the client where the construction take place	26.6	0.26854
	Change in government policies such as environmental policies, legislations etc.	26.8	0.27404
	Bureaucratic delays in getting permits or approvals from the municipality or other authorities for the construction project	28.8	0.45742
2	Difficulty in site acquisition or failure to provide property due to problems with local residents	32.4	0.72943
	Effects of other organizations which protest construction of dam and HEPP due to environmental concerns (Greenpeace etc.)	21.9	0.27057
3	Unexpected geotechnical conditions encountered during site & access road construction (Ground subsidence etc.)	19.4	0.15780
	Breakdown of the equipment and idle time due to maintenance problem	16.6	0.13255
	Accidents during mobilization and construction of roads (Accidents can cause interruption of continued works and decrease in morale of the labourers)	8.86	0.05110
	Unavailability or late delivery of the required materials on site	11.9	0.06733
	Unavailability or late delivery of the required equipment & tools on site	15.4	0.10580
	Poor site lay-out due to improper planning of the contractor or project manager	24.4	0.22122
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	20.6	0.17042
	Inclement weather effect during the construction (Hurricanes, storms etc.)	15.7	0.09378
4	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site	20.6	0.11182
	Improper construction methods implemented by the contractor (Different methods should be used for the tunnel works depending on the geological properties)	20.3	0.07731
	Insufficient data collection and site investigation for the excavation works	29.2	0.16152
	Breakdown of the equipment and idle time due to maintenance problem	12.5	0.04142
	Unavailability or late delivery of the required materials on site (Shotcrete etc.)	18.8	0.08283
	Unavailability or late delivery of the required equipment & tools for tunnel excavation and concrete works	13.1	0.05246
	Accidents during diversion tunnel construction (Accidents can cause interruption of continued works and decrease in morale of the labourers)	29.4	0.18550
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	19.7	0.08525
	Geological problems during construction of tunnel works (Earthquakes, landslides etc.)	25.6	0.16911
	Inclement weather effect during the construction (Hurricanes, storms etc.)	8.86	0.03279

Table 19: Buffer Size and Importance Weight Values of the Causes of Delay (Continued)

5	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site	14.7	0.09929
	Improper construction methods implemented by the contractor	9.72	0.05526
	Insufficient data collection and site investigation for the excavation works (Excavation in order to prepare and straighten the soil for the cofferdam construction)	15.6	0.10195
	Breakdown of the equipment and idle time due to maintenance problem	11.2	0.06147
	Unavailability or late delivery of the required materials for the riprap operations which are required for the cofferdam construction	13.7	0.09545
	Problems related with type, quality and quantity of materials for riprap operations	13.1	0.08511
	Accidents during cofferdam construction (Accidents can cause interruption of continued works and decrease in morale of the labourers)	12.2	0.07447
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	9.72	0.04876
	Geological problems during cofferdam construction (Earthquakes, landslides etc.)	23	0.20745
	Inclement weather effect during the construction (Hurricanes, storms etc.)	22.7	0.17080
6	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site	20.6	0.07880
	Insufficient data collection and site investigation for the excavation works and foundation preparation works. (Which are done in order to construct dam body above the required quality of soil)	28.6	0.12417
	Breakdown of the equipment and idle time due to maintenance problem	16.7	0.05187
	Unavailability or late delivery of the required materials for the concrete works	16.6	0.05850
	Problems related with type, quality and quantity of materials for concrete works	13	0.03980
	Accidents during dam body construction (Accidents can cause interruption of continued works and decrease in morale of the labourers)	24.4	0.08490
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	16.7	0.05187
	Geological problems during dam body construction (Earthquakes, landslides etc.)	23.4	0.11462
	Inclement weather effect during the construction (Hurricanes, storms etc.)	26.6	0.13372
	Lack of experience of the contractor on the Concrete Gravity Dam construction	24	0.08066
	Coordination problem between different working groups and engineer (Since construction of a dam body is complex and many different number of working groups can work on a site, difficulties in coordination can cause delay)	21.9	0.08849
	Overcrowded (Clustered) work area in the construction site	8.86	0.01327
	Poor inspection and testing procedure by the consultant (Time spent for the inspection and testing procedure can reach unexpected level)	20	0.07933

Table 19: Buffer Size and Importance Weight Values of the Causes of Delay (Continued)

7	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site	15.2	0.05790
	Breakdown of the equipment and idle time due to maintenance problem	10.4	0.03114
	Unavailability or late delivery of the required materials for the construction of spillway	16.7	0.06341
	Problems related with type, quality and quantity of materials for concrete works	14.7	0.05449
	Accidents during construction of spillway (Accidents can cause interruption of continued works and decrease in morale of the labourers)	24.4	0.10477
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	11.2	0.03795
	Geological problems during construction of a spillway (Earthquakes, landslides etc.)	23.2	0.11677
	Inclement weather effect during the construction (Hurricanes, storms etc.)	26.7	0.13964
	Delay due to coordination problems between the contractor and subcontractor	28.4	0.15764
	Overcrowded (Clustered) work area in the construction site	5.59	0.00876
	Poor inspection and testing procedure by the consultant (Time spent for the inspection and testing procedure can reach unexpected level)	16	0.06066
	Problems due to other works are on hold (Such as continued concrete works on the construction of a dam body can cause a delay on the concrete works on the construction of a spillway)	21.6	0.11758
	Delay in performing inspection and testing of the works by the consultant	13.1	0.04930
8	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site	13.7	0.13056
	Breakdown of the equipment and idle time due to maintenance problem	11.8	0.10509
	Unavailability or late delivery of the required materials for the construction of bottom weir	13.1	0.12288
	Problems related with type, quality and quantity of materials for concrete and penstock works	10.8	0.06306
	Accidents during construction of bottom weir (Accidents can cause interruption of continued works and decrease in morale of the labourers)	13.1	0.10671
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	10.4	0.08246
	Geological problems during construction of a bottom weir (Earthquakes, landslides etc.)	21.2	0.22433
	Inclement weather effect during the construction (Hurricanes, storms etc.)	12.2	0.10186
	Delay in performing inspection and testing of the works by the consultants	10.8	0.06306

Table 19: Buffer Size and Importance Weight Values of the Causes of Delay (Continued)

9	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site	18.5	0.07889
	Improper construction methods implemented by the contractor (Different methods should be used for the tunnel works depending on the geological properties)	18.5	0.07647
	Insufficient data collection and site investigation for the excavation works	27.6	0.15138
	Breakdown of the equipment and idle time due to maintenance problem	17.9	0.07474
	Unavailability or late delivery of the required materials on site (Shotcrete etc.)	15.4	0.06090
	Unavailability or late delivery of the required equipment & tools for tunnel excavation and concrete works	13	0.05190
	Accidents during tunnel construction (Accidents can cause interruption of continued works and decrease in morale of the labourers)	26.6	0.12353
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	19.7	0.08547
	Geological problems during construction of tunnel works (Earthquakes, landslides etc.)	24.4	0.13478
	Inclement weather effect during the construction (Hurricanes, storms etc.)	7.02	0.02491
	Lack of experience of the subcontractor and time spent to find appropriate subcontractors	25.6	0.13702
10	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site	14.7	0.12384
	Breakdown of the equipment and idle time due to maintenance problem	11.2	0.07136
	Unavailability or late delivery of the required materials for the powerhouse and switchyard works	12.5	0.09262
	Problems related with type, quality and quantity of materials for concrete and penstock works	14.3	0.10566
	Accidents during powerhouse and switchyard works. (Accidents can cause interruption of continued works and decrease in morale of the labourers)	14.5	0.10257
	Unavailability or low productivity of the labourer (Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)	14.3	0.10566
	Excessive time spent to find appropriate subcontractors for Mechanical Electrical and Plumping (MEP) works	14.7	0.11527
	Geological problems during construction works (Earthquakes, landslides etc.)	17.9	0.12350
	Inclement weather effect during the construction (Hurricanes, storms etc.)	20.2	0.15952
11	Delay in final performing inspection and testing	30	1.00000

Buffer sizes for each activity, listed in Table 3, given as a percentage of the activity duration. Buffer Sizes for each activity can be seen in the Table 20, below.

Table 20: Buffer Sizes for each Activity

Activity Name	Buffer Size (%)
Getting Necessary Permission from the Authorities	27.66
Expropriation Works of the Private Lands	29.56
Mobilization of the Site Facilities, Equipment & Materials and Construction of the Site & Access Roads	18.53
Construction of the Diversion Tunnel	23.10
Construction of the Cofferdam	16.73
Construction of the Dam Body	22.28
Construction of the Spillway	21.16
Construction of the Bottom Weir	14.25
Power Tunnel Works	21.94
Powerhouse and Switchyard Works	15.41
Test and Commissioning	30.00

5.2.5.1.5 Surface Viewer

In Surface Viewer, dependency of one of the outputs on any one or two of the inputs can be viewed; therefore, in proposed buffer sizing model with fuzzy assessment; dependency of the time buffer size on the frequency of occurrence and severity values can be displayed in the Surface Viewer.

The relationship of the input values (frequency of occurrence and severity) and output value (time buffer size) can be seen in the Figure 31 and Figure 32, below.

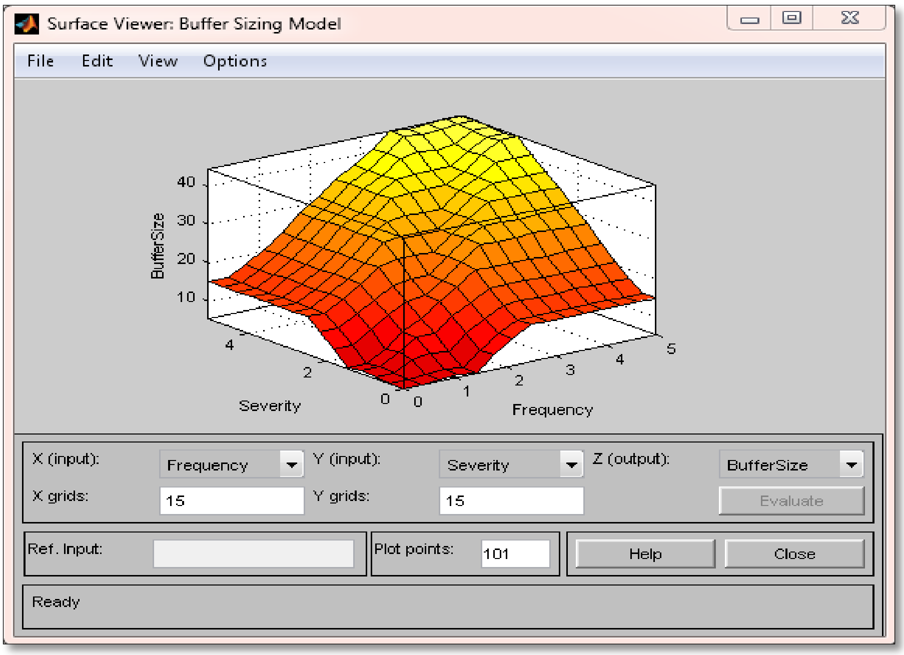

Figure 31: Surface View of the Input and Output Values

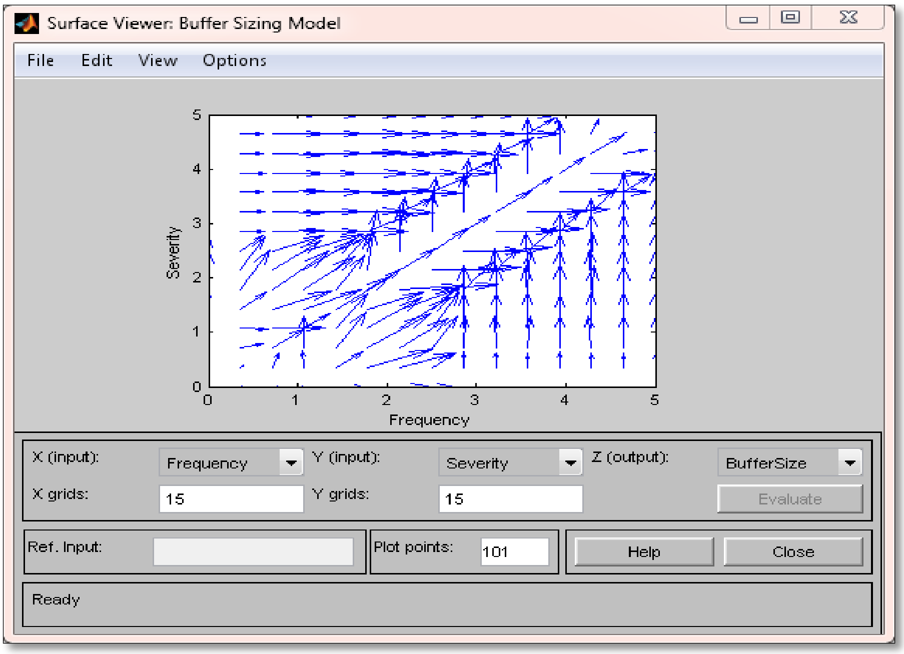

Figure 32: Quiver View of the Input and Output Values

5.2.6 Hypothetical Schedule and Validation of the Results

5.2.6.1 Hypothetical Project

Hypothetical project of the concrete gravity dam and HEPP project is given in this section in order to illustrate the concepts given in the previous steps.

Hypothetical project was constructed by using the Microsoft Project which is a project manager software program, developed by Microsoft. Microsoft Project enables the users to create projects, track tasks and report results. The users can also control their resources and finance by assigning resources and budgets to the projects.

Hypothetical project, created in the scope of this thesis, is composed of the activities listed in the Table 3. Durations of the activities and logical relationships between the activities were created by analyzing the several schedules of the concrete gravity dam and HEPP projects found in the literature.

The project is given in the Figure 33, below. As it can be seen, total hypothetical project duration is 965 days and it was assumed that project was started in 01.01.2015. Also, critical path was shown with the red boxes and red lines in the figure.

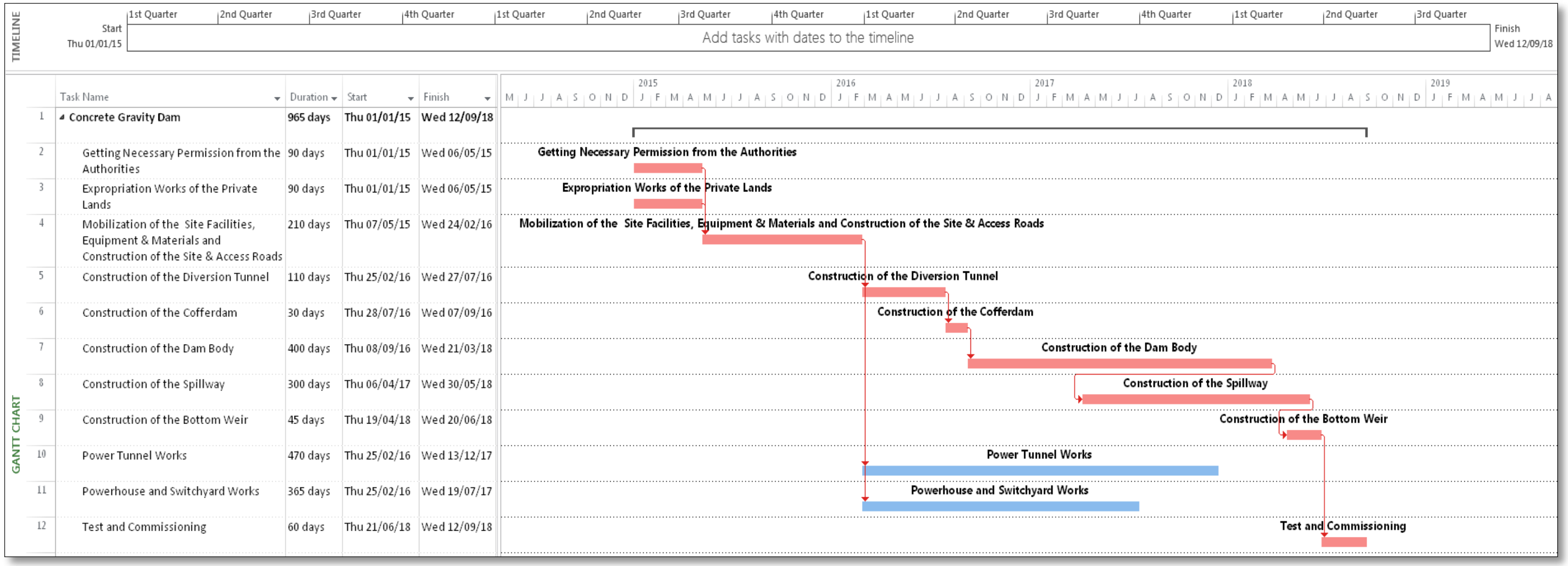

Figure 33: Baseline Schedule for the Hypothetical Project

Final time buffer sizes calculated for the each activity in the schedule of the concrete gravity dam and HEPP projects were given in the Table 20. After adding the time buffers to the each relevant activity in the hypothetical schedule, total project duration is calculated as 1237 days. It means that total project duration lengthens as 272 days which is equal to 28.19 % of the total baseline duration of the project.

Proposed time buffered schedule with the baseline schedule for the hypothetical project can be seen in the Figure 34, below. As it can be seen, critical path remains the same.

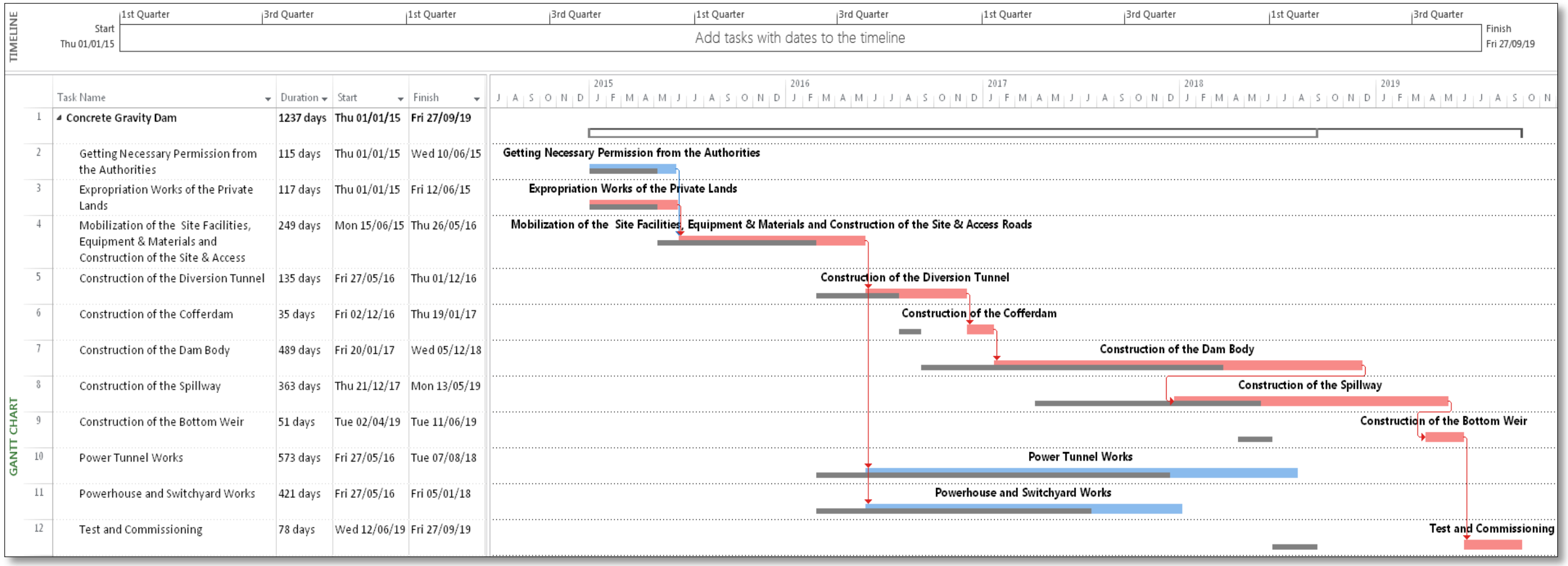

Figure 34: Proposed Time Buffered Schedule for the Hypothetical Project

Several projects in the literature were examined and it was concluded that using 28.19 % of the time buffer in terms of the percentage of the total project duration is the logical result.

Time buffer size of the hypothetical project was also calculated by using the Goldratt Method. Goldratt Method gave around 311 days as an entire project buffer. Since hypothetical project duration lengthens with 272 days (1237 days-965 days) in the proposed model, the closeness of the results also demonstrated the reliability of the buffer sizing model with fuzzy assessment in this thesis. At this point it should be kept in mind that although these methods gave almost similar results; the major difference of them is related with the distribution of the time buffers. In Goldratt Method; size of the time buffer is also primarily depend on the span of the durations and size of the time buffer increase linearly with the length of the Critical Chain and Non-Critical Chain without considering whether there are high level of uncertainties and variations exist on the construction project or not. Therefore; usage of Goldratt Method can cause overestimated results for some projects. On the other hand; unlike the Goldratt Method, time buffers are found for the each activity in the proposed model; which enables to take activities' durations, activities' characteristics, activities' interdependencies and projects characteristics into account, which are required in order to calculate the sizes of the time buffers more accurately.

Finally; as it was mentioned, the online survey, which was made in the scope of this thesis, is composed of three parts and recommended time buffer sizes were asked to the experts as a scope of the third part of the survey.

13 experts, who have the experience more than 15 years in the dam and HEPP projects, filled out this part of the survey by giving recommended minimum and maximum time buffer size values as a percent of the activity durations. After getting

the results from the experts; data's were evaluated in the MS Excel and average values of the information given by the 13 experts were calculated.

The average results of the recommended minimum and maximum time buffer sizes, obtained from the online survey, given in the Table 21, below.

Table 21: Recommended Time Buffer Sizes

Activity Name	Recommended Buffer (%)	
	Minimum	Maximum
Getting Necessary Permission from the Authorities	11.50	28.00
Expropriation Works of the Private Lands	13.50	30.50
Mobilization of the Site Facilities, Equipment & Materials and Construction of the Site & Access Roads	8.30	24.50
Construction of the Diversion Tunnel	13.00	30.50
Construction of the Cofferdam	10.30	25.00
Construction of the Dam Body	15.70	34.00
Construction of the Spillway	11.50	25.50
Construction of the Bottom Weir	8.00	21.50
Power Tunnel Works	14.50	29.50
Powerhouse and Switchyard Works	11.50	25.50
Test and Commissioning	11.70	24.50

At this point, recommended time buffer sizes, given in the Table 21, were added to durations of the related activities in the hypothetical project, given in the Figure 33, by using the Microsoft Project. Total project duration was increased from 965 days to 1120 days and 1321 days corresponding with the usage of recommended minimum and maximum time buffer sizes, respectively. It means that sizes of the time buffers were estimated by the experts a range from %16.10 and %36.90 of the total baseline duration of the project. According to the results; since sizes of the time buffers and distributions of them found in the Fuzzy Logic Toolbox^{TM} in the scope of the proposed buffer sizing model with fuzzy assessment are almost similar with the subjective judgment of the experts, it can be interpreted that results found from the proposed model are reliable and logical.

5.3 Discussion of the Results

Buffer sizing model with fuzzy assessment was developed in this chapter. By following the methodology given in the proposed model; deficiencies encountered on the traditional time buffer sizing methods can be solved and time buffer sizes can be calculated optimally.

In the buffer sizing model with fuzzy assessment; sizes of the time buffers are calculated on the basis of the activities, located on the schedule of the concrete gravity dam and HEPP projects, with using the frequency of occurrence and severity values of the causes of delay. In other words, sizes of the time buffers are expressed in terms of the percentage of the activities' durations. Distribution of the time buffers to the activities with using the frequency of occurrence and severity values of the causes of delay of the each activity brings several advantages. One of the advantages is that activities' durations, activities' characteristics, activities' interdependencies and project characteristics are easily taken into account which enables to calculate the sizes of the time buffers more accurately. The other advantage is that problematic activities can be distinguished by the project managers or engineers by only interpreted the sizes of the time buffers because activities, which have larger time buffers, are more inclined to the uncertainties, variations and delays. As a result of this; additional precautions can be taken in order to protect the problematic activities.

As it was mentioned, each construction project is unique; therefore, it can be difficult and sometimes impossible to find statistical data. As a result of this; using experts' opinions become more important for the construction projects. The other benefit of the buffer sizing model with fuzzy assessment is addressed at this point. Since fuzzy logic concepts are used in the proposed model, experts' opinions are taken into account easily.

The other contribution of the buffer sizing model with fuzzy assessment is that imprecise or incorrect data can be tolerated in the model. It means that if underestimated or overestimated values for the frequency of occurrence and severity of the causes of delay are entered in the model by the experts or some of the data are missed; the model will still continue to give almost the reliable results. This substantial feature comes from the property of the fuzzy logic concepts used in the proposed model and cannot be encountered on the traditional time buffer sizing methods.

Although; project managers and engineers can estimate the frequency of occurrence and severity values of the causes of delay encountered on the construction projects; they sometimes have difficulties to estimate the required size of the time buffer used in order to create robust and stable schedule against uncertainties, variations and delay. At this point; proposed model and methodology have significant contribution to this problem because by only estimating the frequency of occurrence and severity values as inputs of the proposed model; reliable sizes of the time buffers can be calculated easily.

The results were found by getting the experts' opinions from the online survey. Therefore; if different experts give opinions, different results can be obtained. As a result of this; the proposed model only shows a methodology. Sizes of the time buffers can be found for different projects by following the methodology given in this thesis.

Interpretations of the sizes of the time buffers found for the concrete gravity dam and HEPP projects were given below.

Interpretations of the Time Buffers Found in the Proposed Model

It can be seen from the Table 20 that sizes of the time buffers for the activities "Getting Necessary Permission from the Authorities", "Expropriation Works of the Private Lands" and "Test and Commissioning" are larger than the sizes of the time buffers calculated for the other activities. As a result of this; besides the usage of time buffers, special importance should be given to them by the project managers and engineers in order to reduce or eliminate the negative impacts of the uncertainties, variations and delays. The aforementioned activities are not directly related with the main construction process. In other words; these activities constitute the preliminary and final steps of the construction of the dam and HEPP projects. Therefore; required care are not given to them and durations of these activities are sometimes underestimated or disregarded by the project managers and engineers during creating a baseline schedule. Despite being considered as trivial by the project managers and engineers; these activities are located on the critical path on the schedule of the concrete gravity dam and HEPP projects and the other activities are directly affected from them thus severity values for the causes of delay encountered on these activities are high. Also, according to the experience of the experts; encountering uncertainties, variations and delays for these activities are inevitable. In other words, frequency of occurrence of the causes of delay for these activities is tremendous. As a result of these reasons; usage of large time buffers is logical and recommended for these activities in order to remain in the border of the durations of the activities.

Again it can be seen from the Table 20 that sizes of the time buffers calculated for the activities "Construction of the Cofferdam", "Construction of the Bottom Weir" and "Powerhouse & Switchyard Works" are smaller than the sizes of the time buffers calculated for the other activities. It is logical to use smaller time buffers for these activities on the concrete gravity dam and HEPP projects because construction methods used for these activities are simple. In addition; cofferdam and bottom weir are small scaled structures. Also, the construction works for the powerhouse and switchyard can be carried out independently from the other activities such as construction of the dam body or power tunnel works. Therefore; this activity is almost located on the non-critical path on the schedule. As a result of these; frequency of occurrence and severity values of the causes of delay encountered on these activities are very low.

When the activities in the proposed model are further compared, it is seen that larger size of the time buffer is calculated for the activity "Construction of the Diversion Tunnel" when compared with the activities "Construction of the Dam Body" and "Construction of the Spillway". It is normal because possibility of occurrence and effects of the delays are high on the tunnel works which are directly related with geology in which many unknowns exist.

Causes of delay and frequency of occurrence of them are similar for the activities "Power Tunnel Works" and "Construction of the Diversion Tunnel". On the other hand; sizes of the time buffers, calculated in the proposed model, are different with each other for these activities. The reason is that severity values of the causes of delay are different for these activities. In other words; the activity "Power Tunnel Works" can be carried out independently from the other activities, like the activity "Powerhouse and Switchyard Works"; therefore, this activity is almost not located on the critical path. As a result of this; delays, occurred in this activity, do not affect the other activities as much as the activity "Construction of the Diversion Tunnel" so usage of smaller time buffer size is logical for the activity "Power Tunnel Works" when compared the "Construction of the Diversion Tunnel".

Finally; as it was mentioned above, results of the model were compared with the previous projects found in the literature, Goldratt Method and time buffers recommended by the experts on the third part of the online survey. According to the results; outcomes found in the Fuzzy Logic Toolbox™ in the scope of the proposed buffer sizing model with fuzzy assessment are reliable and logical in terms of the sizes of the time buffers. In detail; sizes of the time buffers calculated in the proposed model are within the boundaries of the minimum and maximum values of the sizes of the time buffers recommended by the experts in the survey. Also; sizes of the time buffers, found in the proposed model, are similar with the delays encountered on the schedule of the previous dam and HEPP projects.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Encountering uncertainties, variations and delays are inevitable on construction projects. Especially; construction of dam and HEPP projects can be subjected to various uncertainties, variations and delays due to complex nature of them. Since diverse negative effects can be occurred on dam and HEPP projects due to uncertainties, variations and delays such as negotiations and lawsuits between parties, loss of money, interruption of works, damage to the company's reputation, economical and political consequences over the country etc., all project participants try to minimize the negative effects of them and try to complete the project on planned time.

Robust planning and scheduling is required in order to minimize or eliminate the negative effects of uncertainties, variations and delays. In the literature; using time buffers on the schedule of construction projects is considered as the most effective methods in order to create a robust planning and scheduling thus calculation of sizes of the time buffers accurately and distribution of them to construction schedule optimally are essential. However; traditional time buffer sizing methods have several deficiencies; therefore, there existed a need to develop an improved time buffer sizing method.

As a result of this; the main aim of this thesis was develop a model in order to calculate the sizes of the time buffers accurately and distribute them optimally on the schedule of the construction of the concrete gravity dam and HEPP projects.

For this purpose; a buffer sizing model with fuzzy assessment were developed in this thesis. In the scope of this study; firstly, detailed literature review was made about the uncertainties, variations and delays. Further investigations were also made about the buffers, fuzzy logic and applications of them which are used on construction projects in order to calculate the sizes of the time buffers. Then, activities located on the schedule of the concrete gravity dam and HEPP projects were determined by consulting the experienced civil engineers and using the information found in the literature.

The third stage of the study was finding the potential causes of delay encountered on concrete gravity dam and HEPP projects by making literature review and brainstorming with the two experts who have the experience more than 15 years on dam and HEPP projects. Totally, 89 causes of delay were found for the activities on the schedule of the concrete gravity dam and HEPP projects.

In the following parts of the research; firstly, frequency of occurrence and severity values of the causes of delay for each relevant activity were found by making online survey. In the online survey; respondents used five-point Likert Scale Chart in order to determine the frequency of occurrence and severity values of the causes of delay. In addition to the online survey; pilot survey had also been conducted to two academician and two experts in order to see the applicability and validity of the survey. After finding frequency of occurrence and severity values of the causes of delay; the fuzzy membership functions & linguistic variables, fuzzy rules and aggregation & defuzzification methods were determined by examining the literature and consulting to the experts.

In the last stage of the study; buffer sizing model with fuzzy assessment was constructed by using Fuzzy Logic Toolbox™ which is built on the MATLAB. Required time buffer sizes for each activity were computed in the model. Then, applicability of the model was tested with a hypothetical concrete gravity dam and HEPP project. For the hypothetical project with a total duration of 965 day; the model calculated the total time buffer size as 272 days. In other words; total project duration lengthens as 272 days which is equal to 28.19 % of the total baseline duration of the hypothetical project. The results were also compared with the previous projects in the literature, Goldratt Method and time buffers recommended by the experts on the third part of the online survey. According to the results; outcomes found in the Fuzzy Logic Toolbox™ in the scope of the proposed buffer sizing model with fuzzy assessment are reliable and logical.

In this research; the proposed buffer sizing model with fuzzy assessment showed that how fuzzy logic concepts and Fuzzy Logic Toolbox™ should be used for the calculation of the size of the time buffer. Major contribution of the usage of fuzzy logic concepts on the proposed model is that experts' opinions can be captured easily. This is indispensable because it can be difficult and sometimes impossible to find statistical data for the construction projects. Moreover; multiple inputs can be easily handled and classical problems can be quantified more realistically. Also, fuzzy logic concepts give tolerance to imprecise data. It means that if underestimated or overestimated values for the frequency of occurrence and severity of the causes of delay are entered in the model by the experts or some of the data are missed; the model will still continue to give almost the reliable results.

The proposed buffer sizing model with fuzzy assessment has made several contributions to construction projects. The main contribution is that time buffers found in the model are expressed in terms of the activities' durations by considering the frequency of occurrence and severity values of the causes of delay of the each activity. As a result of this; activities' durations, activities' characteristics, activities' interdependencies and project characteristics are easily taken into account which enables to calculate the sizes of the time buffers more accurately.

Besides the calculation of the sizes of the time buffers optimally; expression of the time buffers on the basis of each activity gives another contribution to the project participants. By looking the time buffer sizes calculated for the each activity, it can be interpreted that which activity is more inclined to the uncertainties, variations and delays; therefore, required precautions can be taken by the project managers or engineers. For example; according to the results found in the proposed model for the concrete gravity dam and HEPP projects; the activities "Getting Necessary Permission from the Authorities", "Expropriation Works of the Private Lands" and "Test and Commissioning" require larger buffer sizes for the robust and stable scheduling when compared with the other activities. Therefore, additional care should be given to those activities. Also, sizes of the time buffer for the activities "Construction of the Cofferdam", "Construction of the Bottom Weir" and "Powerhouse & Switchyard Works" are smaller than the sizes of the time buffers should be used for the other activities.

Another contribution of this study is that although the model was proposed for the construction of the concrete gravity dam and HEPP projects; optimum sizes of the time buffers can be calculated for the other types of the projects by following the methodology given in the proposed model. In other words; methodology proposed in this study assist the project managers and engineers to create robust and stable schedule for any construction project by showing the required steps to calculate the sizes of the time buffers optimally.

6.2 Limitations of the Research and Recommendations for Future Studies

The major limitation in the proposed buffer sizing model with fuzzy assessment is that the frequency of occurrence and severity values of the causes of delay must be determined by the estimators. Therefore; experienced estimators are needed in order to find reliable and accurate results.

The other shortcoming of the research is that applicability and reliability of the proposed model and methodology are only trialed in a single hypothetical project. Therefore; in the future studies, the proposed model can be tested on the real case examples in order to recognize the deficiencies or other missing parameters that should have been considered in the model. Moreover; methodology given in the proposed model can be used for the other types of construction projects in order to test and validate it.

For the future studies; the proposed model can also be improved and more powerful, user friendly software can be constructed by using the methodology given in this thesis.

REFERENCES

Asmuni, H.B. (2008), *Fuzzy Methodologies for Automated University Timetabling Solution Construction and Evaluation.* PH. D. Dissertation, University of Nottingham, UK.

Assaf, S.A. and Al-Hejji, S. (2006), "Causes of Delay in Large Construction Projects." *International Journal of Project Management*, **24**(4), pp. 349-357.

Ballard, G. and Howell, G. (1995), Toward Construction JIT. *Proceedings of the 1995 ARCOM Conference*, Association of Researchers in Construction Management, Sheffield, England.

Chua, D.K.H. and Shen, L.J. (2001), Constraint Modeling and Buffer Management with Integrated Production Scheduler. *Proceedings of IGLC-9: Ninth Annual Conference of the International Group for Lean Construction*, Singapore.

El Razek, M.E., Bassioni, H.A. and Mobarak, A.M. (2008), "Causes of Delay in Building Construction Projects in Egypt." *ASCE Journal of Construction Engineering and Management*, **134**(11), pp. 831-841.

Farag, M.A.M. (2010), *An Integration of a Buffering Assessment Model Using Fuzzy Logic with Lean Management for Improving Highway Construction Process*. PH.D. Dissertation, Karlsruhe Institute of Technology, Germany.

Flanagan, R. and Norman, G. (2000), *Risk Management and Construction*. Blackwell Scientific Publications, Oxford, UK.

Frimpong, Y., Oluwoye, J. and Crawford, L. (2003), "Causes of Delay and Cost Overruns in Construction of Groundwater Projects in a Developing Countries; Ghana as a Case Study." *International Journal of Project Management*, **21**, pp. 321-326.

Fugar, F.D.K. and Agyakwah-Baah, A.B. (2010), "Delays in Building Construction Projects in Ghana." *Australasian Journal of Construction Economics and Building,* **10**(1/2), pp. 103-116.

Fuzzy Logic Toolbox™ (2013), MATLAB, The MathWorks, Inc.

Fuzzy Logic Toolbox™ User's Guide (2013), MATLAB, The MathWorks, Inc.

Ghaziani, A. (2012), *A Fuzzy Delay Assessment Tool for Construction Projects.* Master Thesis, Middle East Technical University, Ankara.

Ghoddosi, P., Hosseinalipour, M. and Jalal, M.P. (2008), "Fuzzy Assessment of Causes of Time Overrun (Delays) in Iran's Dam Construction Projects." *Journal of Applied Sciences*, **8**(19), pp. 3423-3430.

Goldratt, E.M. (1997), *Critical Chain*. The North River Press, New York, USA.

Gonzalez, V., Rischmoller, L. and Alarcon, L.F. (2004), Design of Buffers in Repetitive Projects: Using Production Management Theory and IT Tools. *Proceedings of the 4th International Postgraduate Research Conference*, University of Salford, Manchester,, UK.

Gündüz, M., Nielsen, Y. and Özdemir, M. (2013), "Quantification of Delay Factors Using the Relative Importance Index Method for Construction Projects in Turkey." *ASCE Journal of Management in Engineering*, **29**(2), pp. 133-139.

Haseeb, M., Lu, X., Bibi, A., Dyian, M.U. and Rabbani, W. (2011), "Problems of Projects and Effects of Delays in the Construction Industry of Pakistan." *Australian Journal of Business and Management Research*, **1**(5), pp. 41-50.

Hopp, W.J. and Spearman, M.L. (2008), *Factory Physics*. McGraw-Hill, New York, USA.

Horman, M.J. and Thomas, H.R. (2005), "Role of Inventory Buffers in Construction Labor Performance." *ASCE Journal of Construction Engineering and Management*, **131**(7), pp.834-843.

Howell, G. and Ballard, G. (1994), Implementing Lean Construction: Reducing Inflow Variation. *Proceedings of 2nd Annual Conference on Lean Construction, Catholic University of Chile,* Chile.

Jaskowski, P. and Biruk, S. (2010), *"*Buffer Sizing Method for Constructing Stable Schedules with Duration Constraints.*" Journal of Civil Engineering and Architecture,* **4**(10), pp. 24-30.

Kazaz, A., Ulubeyli, S. and Tuncbilekli, N.A. (2012), "Causes of Delays in Construction Projects in Turkey." *Journal of Civil Engineering and Management,* **18**(3), pp. 426-435.

Kim., J., Lee, H., Park, M. and Ryu, H. (2006), Assignment Buffer Control for Construction Projects. *Proceedings of the 23rd ISARC,* Tokyo, Japan, pp. 872-877.

Ko, C.H. and Chen, Y.C. (2012), "Evaluating Production Time Buffer for Precast Fabrication." *Journal of Engineering, Project, and Production Management,* **2**(2), pp. 101-111.

Leach, L.P. (2005), *Critical Chain Project Management*. Artech House Inc., London, UK.

Leach, L.P. (2005), *Lean Project Management: Eight Principles for Success*. Advanced Projects, Inc. Idaho, USA.

Lorterapong, P. and Moselhi, O. (1996), "Project-Network Analysis using Fuzzy Set Theory Analysis." *Journal of Construction Engineering and Management*, **122**(4), pp. 308-318.

Majid, I. A. (2006), *Causes and Effect of Delays in Aceh Construction Industry*. Master Thesis, University Technology Malaysia, Malaysia.

Malek, M. (2000), An Application of Fuzzy Modeling in Construction Engineering. *Proceedings of the 36th Annual International Conference of the Associated Schools of Construction (ASC)*, Purdue University, Indiana, USA, pp. 287-300.

Mansfield, N.R., Ugwu, O.O. and Daran, T. (1994), "Causes of Delay and Cost Overruns in Nigerian Construction Projects." *International Journal of Project Management*, **12**(4), pp. 254-260

Meyer, A. D., Loch, C. and Pich, M. (2001), "Uncertainty and Project Management: Beyond the Critical Path Mentality." INSEAD Working Paper Series.

Mubarak, S. (2005), *Construction Project Scheduling and Control*. Pearson Prentice Hall, USA.

Mukaidono, M. (2001), *Fuzzy Logic for Beginners. World Scientific, Singapore.*

Newbold, R.C. (1998), *Project Management in the Fast Lane: Applying the Theory of Constraints*. St. Lucie Press, New York, USA

Odeh, A.M. and Battaineh, H.T. (2002), “Causes of Construction Delay: Traditional Contracts.” *International Journal of Project Management*, **20**, pp. 67-73.

Oxford English Dictionary (2014), Oxford University Press, Oxford.

Perminova, O., Magnus, G. and Wikström, K. (2008), “Defining Uncertainty in Projects – A New Perspective.” *International Journal of Project Management,* **26**, pp. 73-79.

Ribeiro, J.A., Pereira, P.J. and Brandao, E. (2013), “Volume Uncertainty in Construction Projects: A Real Options Approach.” Working Paper Series.

Rwelamila, P.D. and Hall K.A. (1995), “Total Systems Intervention: An Integrated Approach to Time, Cost and Quality Management.” Construction Management and Economics, **13**(3), pp. 235-241.

Sakamoto, M., Horman, M., and Randolph, T. (2002), A study of the relationship between buffers and performance in construction. *Proceedings of International Group of Lean Construction, 10th Annual Conference*, Brazil.

Sambasivan, M. and Soon, Y.W. (2007), "Causes and Effects of Delays in Malaysian Construction Industry." *International Journal of Project Management*, **25**, pp. 517-526.

Shou, Y. and Yeo, K.T. (2000), Estimation of Project Buffers in Critical Chain Project Management. *Proceedings of the 2000 IEEE International Conference*, Management of Innovation and Technology, pp. 162-167.

Shu-Hui, J. and Ping, H.S. (2006), Construction Project Buffer Management in Scheduling Planning and Control. *Proceedings of the 23rd ISARC*, Tokyo, Japan, pp. 858-863.

Tukel, O.I., Rom, W.O. and Eksioglu, S.D. (2006), "An Investigation of Buffer Sizing Techniques in Critical Chain Scheduling." *European Journal of Operational Research*, **172**, pp. 401-416.

Tumi, S.A.H., Omran, A. and Pakir, A.H.K (2009), Causes of Delay in Construction Industry in Libya. *Proceedings of the International Conference on Economics and Administration, Faculty of Administration and Business*, University of Bucharest, Romania.

Ward, S. and Chapman, C. (2003), “Transforming Project Risk Management into Project Uncertainty Management.” *International Journal of Project Management*, **21**, pp. 97-105.

World Commission on Dams (WCD) (2000), *Dams and Development, A New Framework for Decision Making.* Earthscan Publications, Ltd., London, UK.

Yen, J. and Langari, R. (1999), *Fuzzy Logic: Intelligence, Control, and Information.* Prentice Hall, Upper Saddle River, New Jersey, USA.

Yusof, M.A.B., Mohammad, N.B. and Derus, Z.B.M (2007), “Excusable and Compensable Delays in the Construction of Building Project-A Study in the States of Selangor and Wilayah Persekutuan Kuala Lumpur, Malaysia.” *Journal-The Institution of Engineers, Malaysia*, **68**(4), pp.21-26.

Zack, J.G. (2003), Schedule Delay Analysis; Is There Agreement? *Proceedings of PMI-CPM College of Performance Spring Conference, Project Management Institute*, New Orleans, USA.

Zadeh, L.A. (1965), “Fuzzy Sets.” *Information and Control*, **8**, pp. 338-353.

APPENDIX A

SAMPLE QUESTIONNAIRE FORM

Table A. 1: Sample Questionnaire Form

Part 1

1. **Name, Surname**

2. **Education** *(Please thick (X) to the relevant space)*
   - PhD
   - MSc
   - BSc
   - Other

3. **Occupation** *(Please thick (X) to the relevant space)*
   - Civil Engineer
   - Mechanical Engineer
   - Electric & Electronic Engineer
   - Other

4. **Professional experience** *(Please thick (X) to the relevant space)*
   0-1 1-5 5-10 15 or more

5. **Professional experience in HEPP projects** *(Please thick (X) to the relevant space)*
   0-1 1-5 5-10 15 or more

6. **Size of the company that you are currently working or last worked**
   (Please thick (X) to the relevant space)
   Small Medium Large

7. **Fields of expertise of the company that you are currently working or last worked**
   (Please thick (X) to the relevant space(s). You can thick more than ones!)
   - Dams and Hydroelectric Power Stations
   - Highways, Roads and Bridges
   - Industrial Facilities and Plants
   - Residential Buildings and Housings
   - Other

Table A. 2: Sample Questionnaire Form (Continued)

<u>**List of the Causes of Delay for the Activities in Dam and HEPP Project**</u> *(Please fill the relevant spaces)*

*(Causes of delay due to <u>financial problems</u> are out of scope of this study; therefore, they are neglected)

#	Activity Name	Activity Duration	Causes of Delay for the Relevant Activity	Rel. (Y/N)	Frequency (1-5)	Severity (1-5)	Buffer Size (1-5)	Recommended Buffer (%T)	
								Min.	**Max.**
1	**Getting Necessary Permission from the Authorities** *(in order to start the construction).*	**T1**	Poor knowledge of local regulations and laws by the client where the construction take place.						
			Change in government policies such as environmental policies, legislations etc.						
			Bureaucratic delays in getting permits or approvals from the municipality or other authorities for the construction project.						
			Other *(Please add any other cause(s) of delay for this activity, if required)*						
2	**Expropriation Works of the Private Lands** *(Lands which should be expropriate for the construction facilities or will be under the water due to dam reservoir).*	**T2**	Difficulty in site acquisition or failure to provide property due to problems with local residents.						
			Effects of other organizations which protest construction of dam and HEPP due to environmental concerns (Greenpeace etc.)						
			Other*(Please add any other cause(s) of delay for this activity, if required)*						

Table A. 3: Sample Questionnaire Form (Continued)

#	Activity Name	Activity Duration	Causes of Delay for the Relevant Activity	Rel. (Y/N)	Frequency (1-5)	Severity (1-5)	Buffer Size (1-5)	Recommended Buffer (%T)	
								Min.	Max.
3	**Mobilization of the Site Facilities, Equipment & Materials and Construction of the Site & Access Roads** *(Site Roads should be constructed in order to reach the construction site area from the villages and access roads should be constructed in order to transport within construction area safely and timely).*	T3	Unexpected geotechnical conditions encountered during site & access road construction *(Ground subsidence etc.).*						
			Breakdown of the equipment and idle time due to maintenance problem.						
			Accidents during mobilization and construction of roads *(Accidents can cause interruption of continued works and decrease in morale of the labors).*						
			Unavailability or late delivery of the required materials on site.						
			Unavailability or late delivery of the required equipment & tools on site.						
			Poor site lay-out due to improper planning of the contractor or project manager.						
			Unavailability or low productivity of the labor *(Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)*						
			Inclement weather effect during the construction *(Hurricanes, storms etc.)*						
			Other*(Please add any other cause(s) of delay for this activity, if required)*						

Table A. 4: Sample Questionnaire Form (Continued)

#	Activity Name	Activity Duration	Causes of Delay for the Relevant Activity	Rel. (Y/N)	Frequency (1-5)	Severity (1-5)	Buffer Size (1-5)	Recommended Buffer (%T)	
								Min.	Max.
4	**Construction of the Diversion Tunnel** *(Build in order to bypass the dam construction site)*	**T4**	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site.						
			Improper construction methods implemented by the contractor *(Different methods should be used for the tunnel works depending on the geological properties)*						
			Insufficient data collection and site investigation for the excavation works.						
			Breakdown of the equipment and idle time due to maintenance problem.						
			Unavailability or late delivery of the required materials on site (Shotcrete etc.).						
			Unavailability or late delivery of the required equipment & tools for tunnel excavation and concrete works.						
			Accidents during diversion tunnel construction *(Accidents can cause interruption of continued works and decrease in morale of the labors).*						
			Unavailability or low productivity of the labor *(Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)*						
			Geological problems during construction of tunnel works (Earthquakes, landslides etc.)						
			Inclement weather effect during the construction *(Hurricanes, storms etc.)*						
			Other*(Please add any other cause(s) of delay for this activity, if required)*						

Table A. 5: Sample Questionnaire Form (Continued)

#	Activity Name	Activity Duration	Causes of Delay for the Relevant Activity	Rel. (Y/N)	Frequency (1-5)	Severity (1-5)	Buffer Size (1-5)	Recommended Buffer (%T) Min.	Recommended Buffer (%T) Max.
5	**Construction of the Cofferdam** *(A Temporary watertight structure that encloses an area under the water ,pumped dry to enable construction work to be carried out)*	T5	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site.						
			Improper construction methods implemented by the contractor.						
			Insufficient data collection and site investigation for the excavation works *(Excavation in order to prepare and straighten the soil for the cofferdam construction).*						
			Breakdown of the equipment and idle time due to maintenance problem.						
			Unavailability or late delivery of the required materials for the riprap operations which are required for the cofferdam construction.						
			Problems related with type, quality and quantity of materials for riprap operations.						
			Accidents during cofferdam construction *(Accidents can cause interruption of continued works and decrease in morale of the labors).*						
			Unavailability or low productivity of the labor *(Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)*						
			Geological problems during cofferdam construction (Earthquakes, landslides etc.)						
			Inclement weather effect during the construction *(Hurricanes, storms etc.)*						
			Other*(Please add any other cause(s) of delay for this activity, if required)*						

Table A. 6: Sample Questionnaire Form (Continued)

#	Activity Name	Activity Duration	Causes of Delay for the Relevant Activity	Rel. (Y/N)	Frequency (1-5)	Severity (1-5)	Buffer Size (1-5)	Recommended Buffer (%T)	
								Min.	Max.
6	**Construction of the Dam Body** *(Concrete Gravity Dam was considered as a type of a dam).*	T6	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site.						
			Insufficient data collection and site investigation for the excavation works and foundation preparation works. *(Which are done in order to construct dam body above the required quality of soil).*						
			Breakdown of the equipment and idle time due to maintenance problem.						
			Unavailability or late delivery of the required materials for the concrete works.						
			Problems related with type, quality and quantity of materials for concrete works.						
			Accidents during dam body construction *(Accidents can cause interruption of continued works and decrease in morale of the labors).*						
			Unavailability or low productivity of the labor *(Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)*						
			Geological problems during dam body construction (Earthquakes, landslides etc.)						
			Inclement weather effect during the construction *(Hurricanes, storms etc.)*						
			Lack of experience of the contractor on the Concrete Gravity Dam construction.						
			Coordination problem between different working groups and engineer *(Since construction of a dam body is complex and many different number of working groups can work on a site, difficulties in coordination can cause delay).*						

Table A. 7: Sample Questionnaire Form (Continued)

#	Activity Name	Activity Duration	Causes of Delay for the Relevant Activity	Rel. (Y/N)	Frequency (1-5)	Severity (1-5)	Buffer Size (1-5)	Recommended Buffer (%T)	
								Min.	Max.
6	**Construction of the Dam Body** (*Continued*)	**T6**	Overcrowded (Clustered) work area in the construction site.						
			Poor inspection and testing procedure by the consultant (Time spent for the inspection and testing procedure can reach unexpected level).						
			Other*(Please add any other cause(s) of delay for this activity, if required)*						
7	**Construction of the Spillway** *(Spillway is a structure used to provide the controlled release of flows from a dam)*	**T7**	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site.						
			Breakdown of the equipment and idle time due to maintenance problem.						
			Unavailability or late delivery of the required materials for the construction of spillway.						
			Problems related with type, quality and quantity of materials for concrete works.						
			Accidents during construction of spillway *(Accidents can cause interruption of continued works and decrease in morale of the labors).*						

Table A. 8: Sample Questionnaire Form (Continued)

#	Activity Name	Activity Duration	Causes of Delay for the Relevant Activity	Rel. (Y/N)	Frequency (1-5)	Severity (1-5)	Buffer Size (1-5)	Recommended Buffer (%T)	
								Min.	Max.
7	**Construction of the Spillway** *(Continued)*	**T7**	Unavailability or low productivity of the labors *(Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)*						
			Geological problems during construction of a spillway (Earthquakes, landslides etc.)						
			Inclement weather effect during the construction *(Hurricanes, storms etc.)*						
			Delay due to coordination problems between the contractor and subcontractor.						
			Overcrowded (Clustered) work area in the construction site.						
			Poor inspection and testing procedure by the consultant (Time spent for the inspection and testing procedure can reach unexpected level).						
			Problems due to other works are on hold *(Such as continued concrete works on the construction of a dam body can cause a delay on the concrete works on the construction of a spillway).*						
			Delay in performing inspection and testing of the works by the consultant.						
			Other*(Please add any other cause(s) of delay for this activity, if required)*						

Table A. 9: Sample Questionnaire Form (Continued)

#	Activity Name	Activity Duration	Causes of Delay for the Relevant Activity	Rel. (Y/N)	Frequency (1-5)	Severity (1-5)	Buffer Size (1-5)	Recommended Buffer (%T)	
								Min.	Max.
8	**Construction of the Bottom Weir**	**T8**	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site.						
			Breakdown of the equipment and idle time due to maintenance problem.						
			Unavailability or late delivery of the required materials for the construction of bottom weir.						
			Problems related with type, quality and quantity of materials for concrete and penstock works.						
			Accidents during construction of bottom weir *(Accidents can cause interruption of continued works and decrease in morale of the labors).*						
			Unavailability or low productivity of the labor *(Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)*						
			Geological problems during construction of a bottom weir (Earthquakes, landslides etc.)						
			Inclement weather effect during the construction *(Hurricanes, storms etc.)*						
			Delay in performing inspection and testing of the works by the consultants.						
			Other *(Please add any other cause(s) of delay for this activity, if required)*						

Table A. 10: Sample Questionnaire Form (Continued)

#	Activity Name	Activity Duration	Causes of Delay for the Relevant Activity	Rel. (Y/N)	Frequency (1-5)	Severity (1-5)	Buffer Size (1-5)	Recommended Buffer (%T)	
								Min.	Max.
9	**Power Tunnel Works**	**T9**	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site.						
			Improper construction methods implemented by the contractor *(Different methods should be used for the tunnel works depending on the geological properties).*						
			Insufficient data collection and site investigation for the excavation works.						
			Breakdown of the equipment and idle time due to maintenance problem.						
			Unavailability or late delivery of the required materials on site (Shotcrete etc.).						
			Unavailability or late delivery of the required equipment & tools for tunnel excavation and concrete works.						
			Accidents during tunnel construction *(Accidents can cause interruption of continued works and decrease in morale of the labors).*						
			Unavailability or low productivity of the labor *(Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)*						
			Geological problems during construction of tunnel works (Earthquakes, landslides etc.)						
			Inclement weather effect during the construction *(Hurricanes, storms etc.)*						
			Lack of experience of the subcontractor and time spent to find appropriate subcontractors.						
			Other *(Please add any other cause(s) of delay for this activity, if required)*						

Table A. 11: Sample Questionnaire Form (Continued)

#	Activity Name	Activity Duration	Causes of Delay for the Relevant Activity	Rel. (Y/N)	Frequency (1-5)	Severity (1-5)	Buffer Size (1-5)	Recommended Buffer (%T)	
								Min.	Max.
10	**Powerhouse and Switchyard Works**	T10	Unclear, inadequate details in drawings' projects and delays in preparation and delivery of them to the construction site.						
			Breakdown of the equipment and idle time due to maintenance problem.						
			Unavailability or late delivery of the required materials for the powerhouse and switchyard works.						
			Problems related with type, quality and quantity of materials for concrete and penstock works.						
			Accidents during powerhouse and switchyard works. *(Accidents can cause interruption of continued works and decrease in morale of the labors).*						
			Unavailability or low productivity of the labor *(Low level of productivity can be occurred due to lack of motivation or personnel issue etc.)*						
			Excessive time spent to find appropriate subcontractors for Mechanical Electrical and Plumping (MEP) works.						
			Geological problems during construction works (Earthquakes, landslides etc.)						
			Inclement weather effect during the construction *(Hurricanes, storms etc.)*						
			Other*(Please add any other cause(s) of delay for this activity, if required)*						

Table A. 12: Sample Questionnaire Form (Continued)

#	Activity Name	Activity Duration	Causes of Delay for the Relevant Activity	Rel. (Y/N)	Frequency (1-5)	Severity (1-5)	Buffer Size (1-5)	Recommended Buffer (%T)	
								Min.	Max.
11	Test and Commissioning	T11	Delay in final performing, inspection and testing						
			Other *(Please add any other cause(s) of delay for this activity, if required)*						

APPENDIX B

RESULTS FOUND IN THE RULE VIEWER

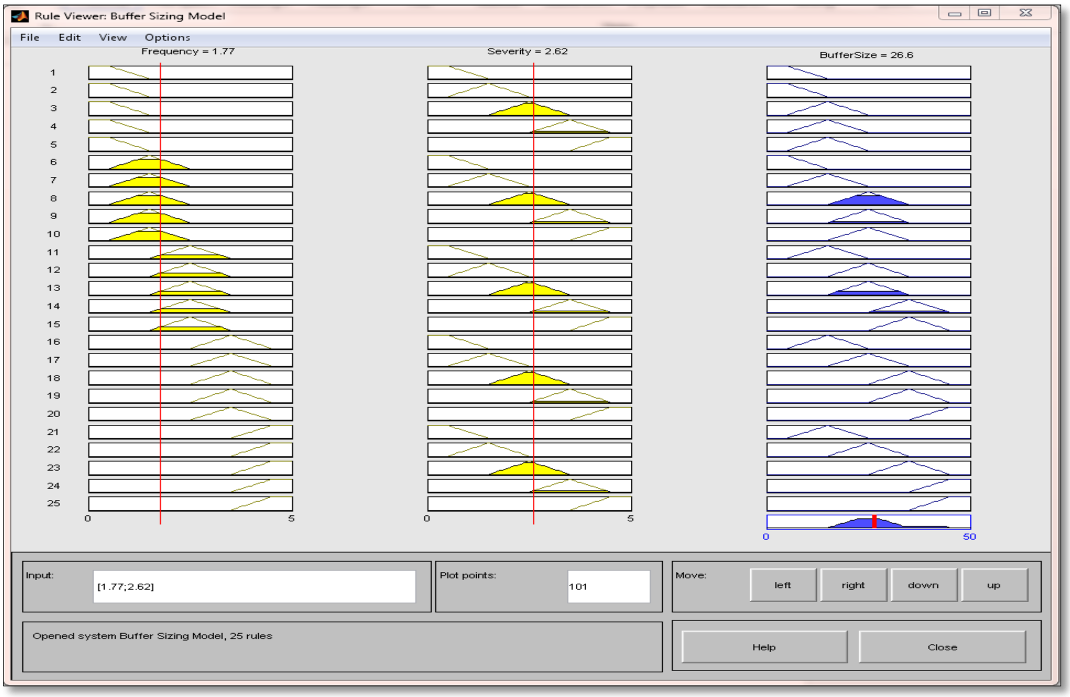

Figure B. 1: Results in the Rule Viewer for the Input Values "1.77, 2.62"

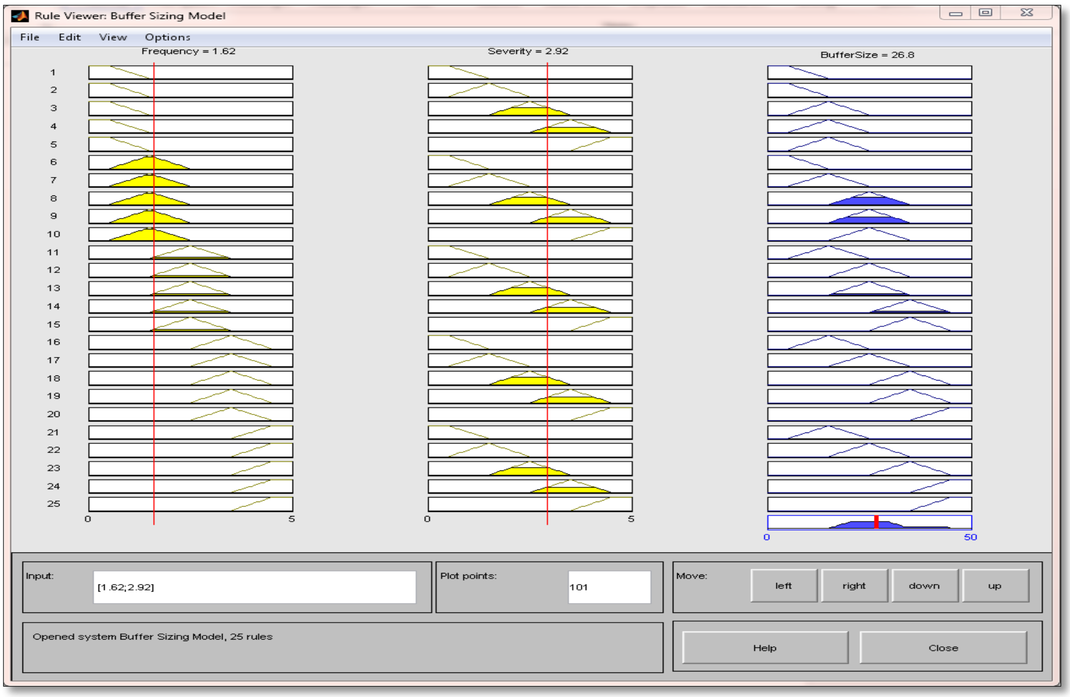

Figure B. 2: Results in the Rule Viewer for the Input Values "1.62, 2.92"

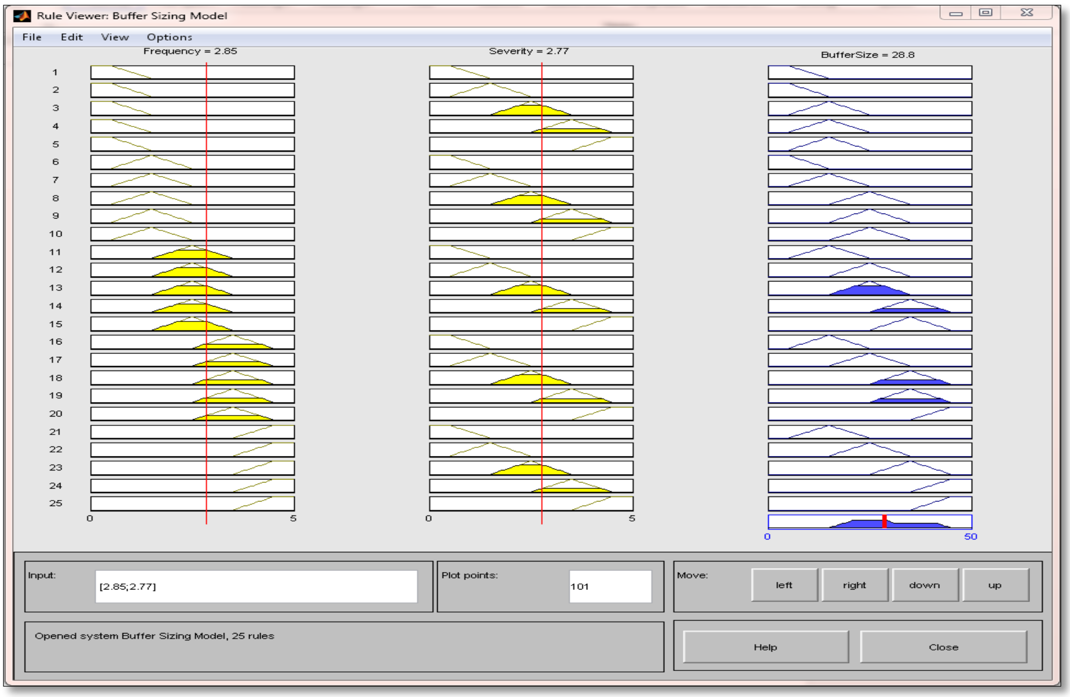

Figure B. 3: Results in the Rule Viewer for the Input Values "2.85, 2.77"

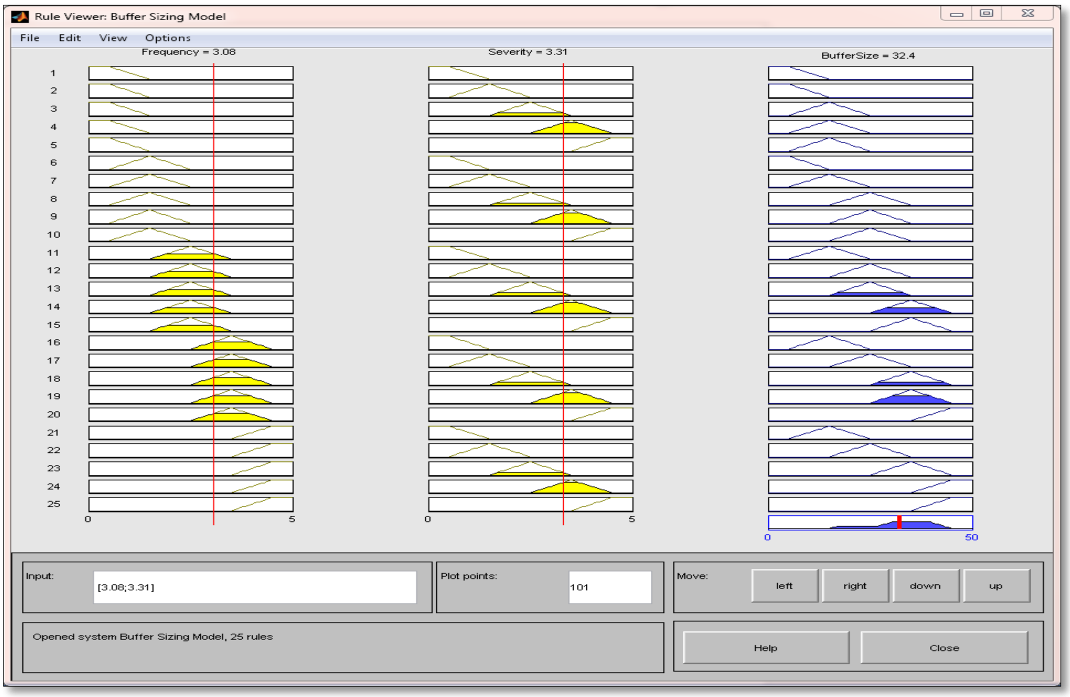

Figure B. 4: Results in the Rule Viewer for the Input Values “3.08, 3.31”

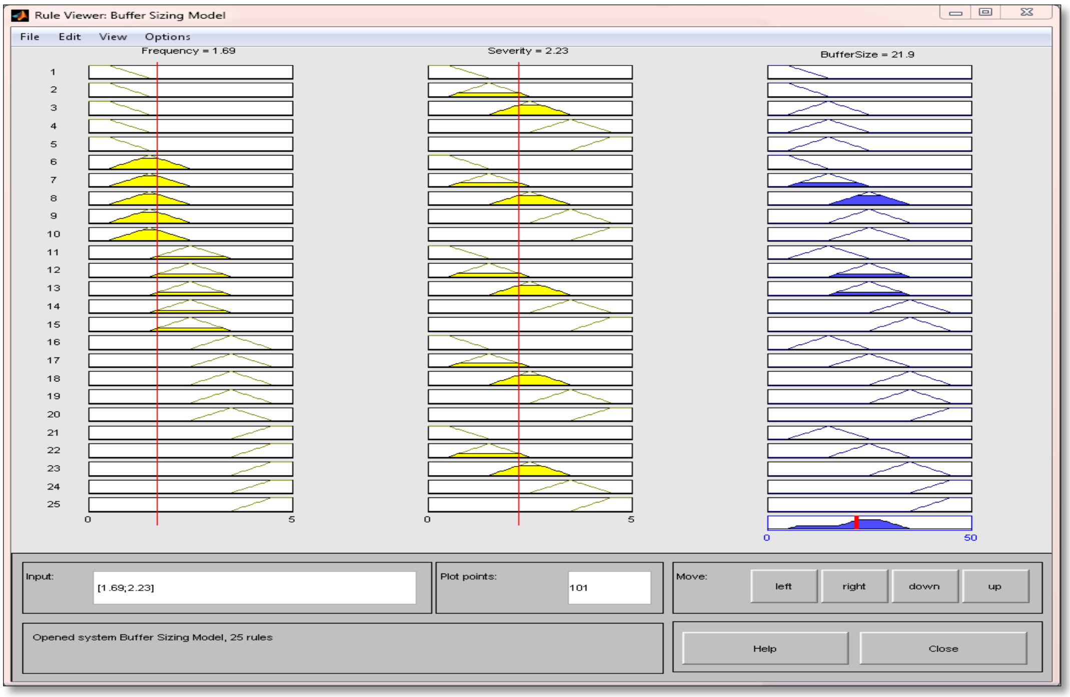

Figure B. 5: Results in the Rule Viewer for the Input Values “1.69, 2.23”

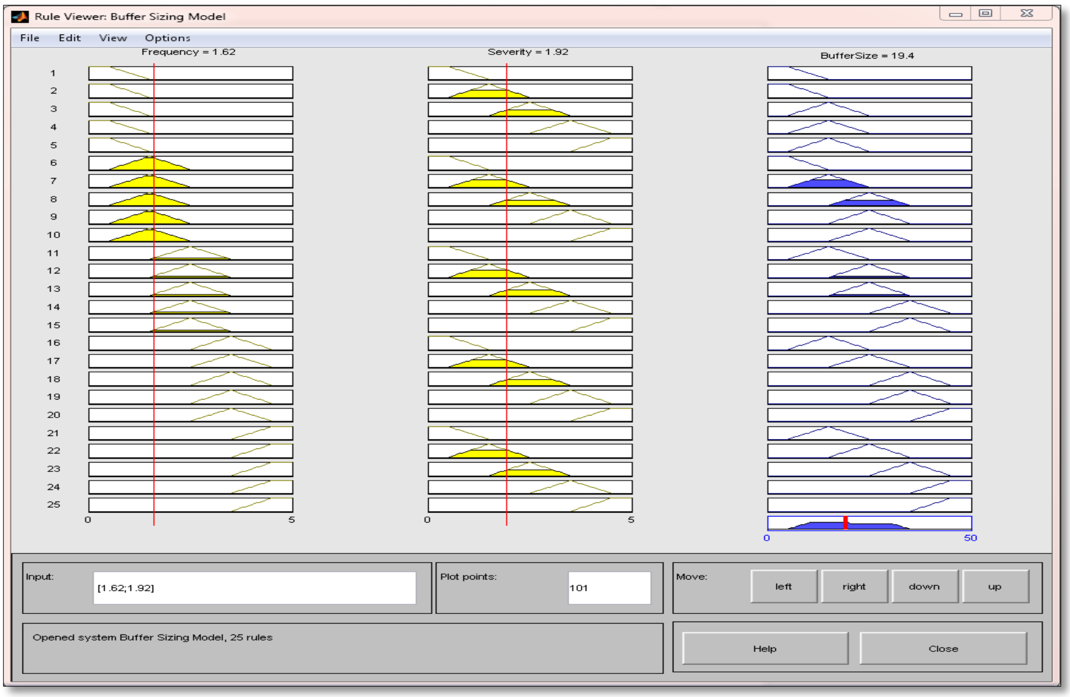

Figure B. 6: Results in the Rule Viewer for the Input Values “1.62, 1.92”

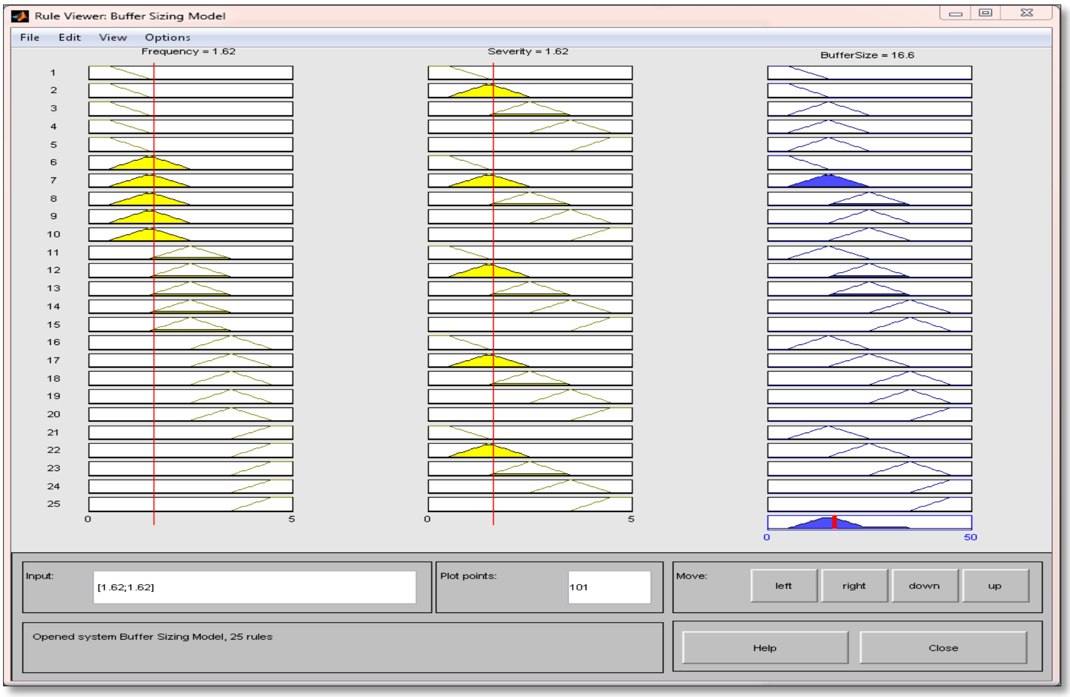

Figure B. 7: Results in the Rule Viewer for the Input Values “1.62, 1.62”

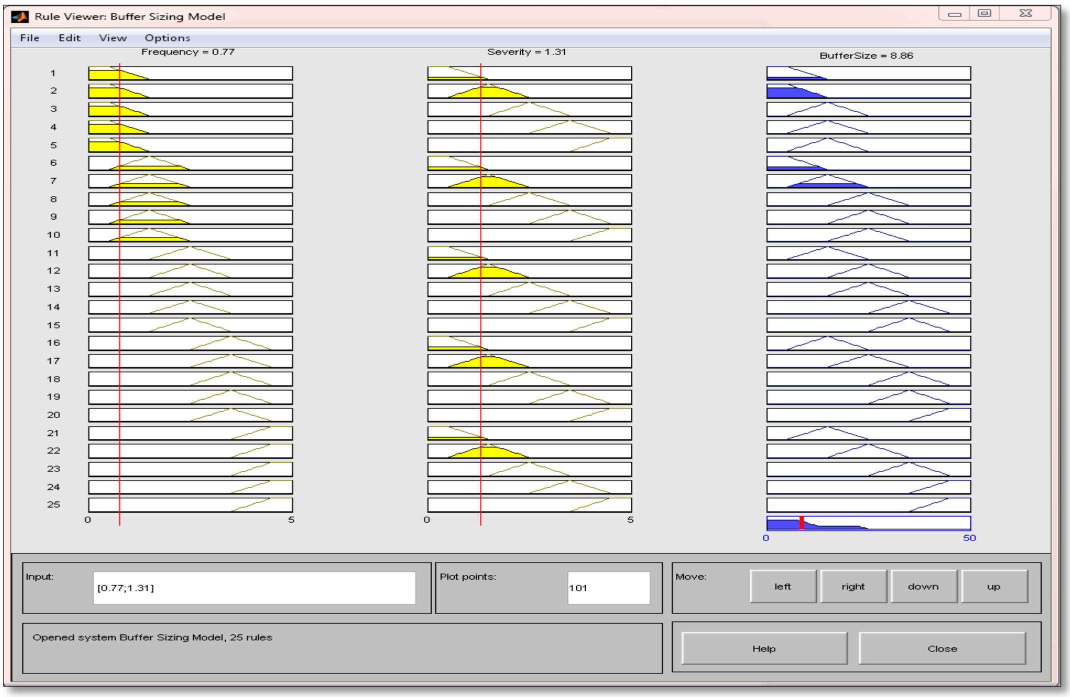

Figure B. 8: Results in the Rule Viewer for the Input Values "0.77, 1.31"

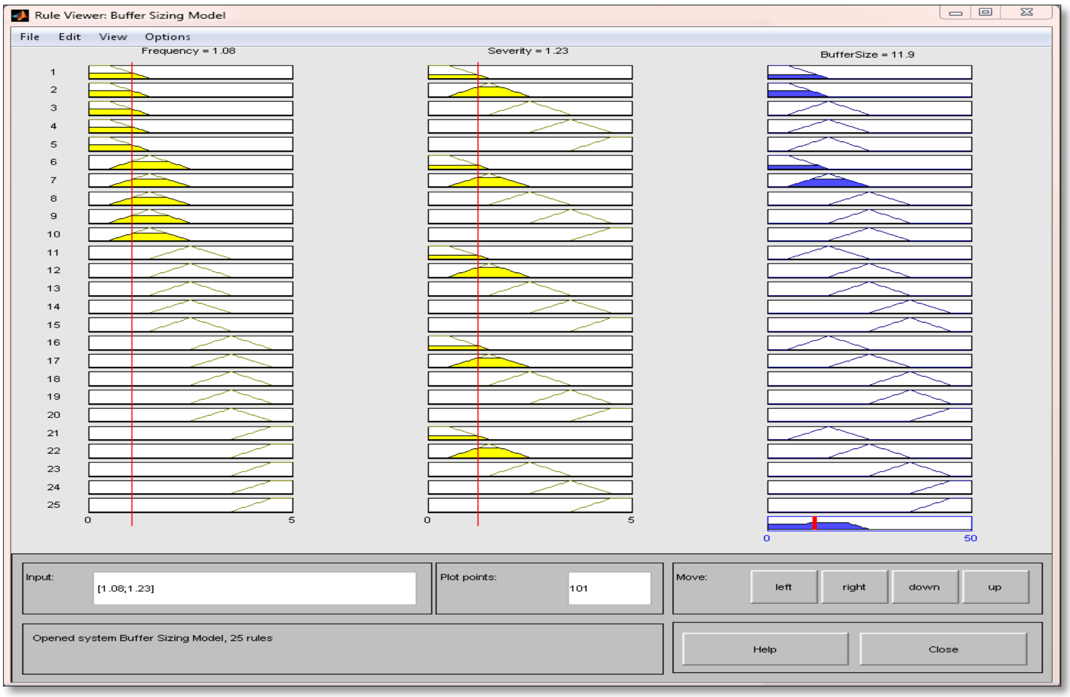

Figure B. 9: Results in the Rule Viewer for the Input Values "1.08, 1.23"

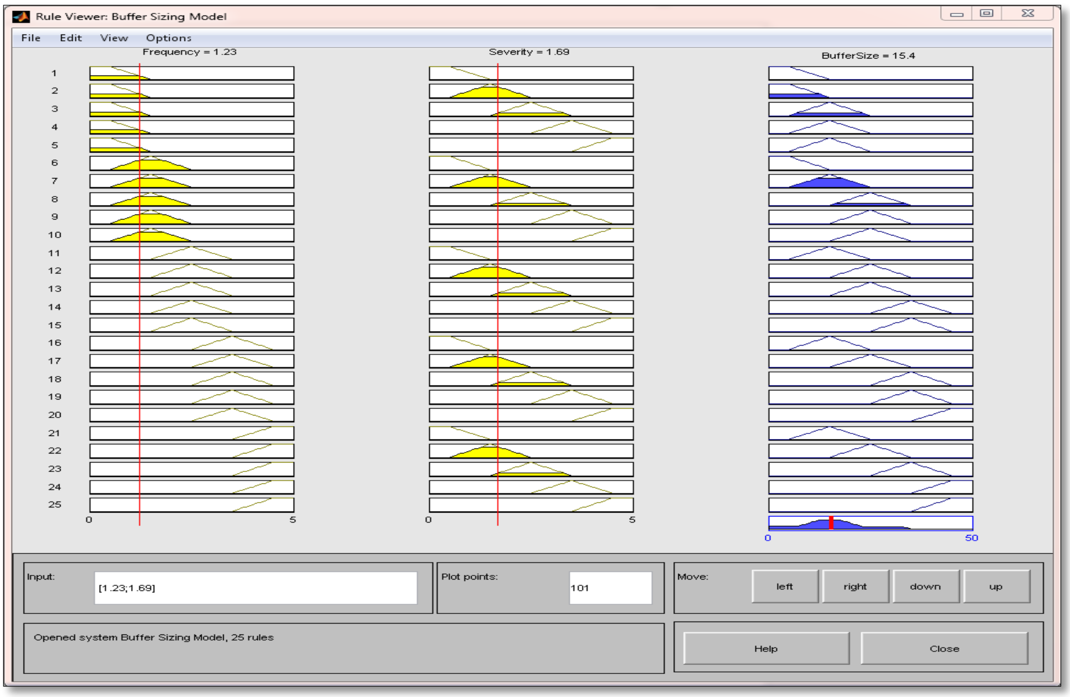

Figure B. 10: Results in the Rule Viewer for the Input Values “1.23, 1.69”

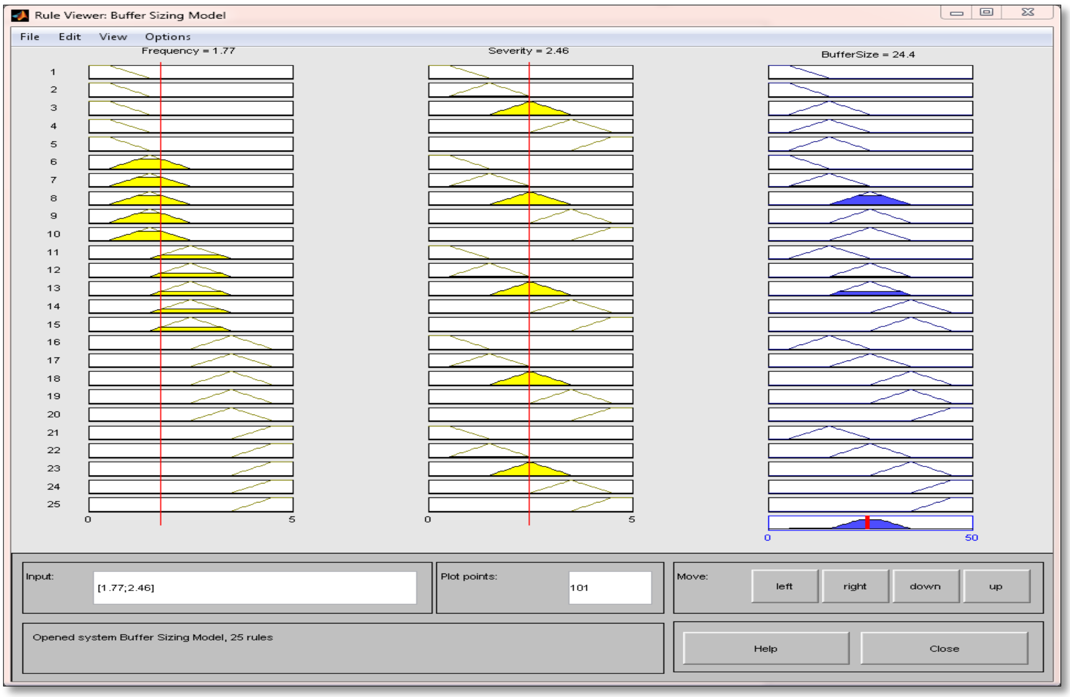

Figure B. 11: Results in the Rule Viewer for the Input Values “1.77, 2.46”

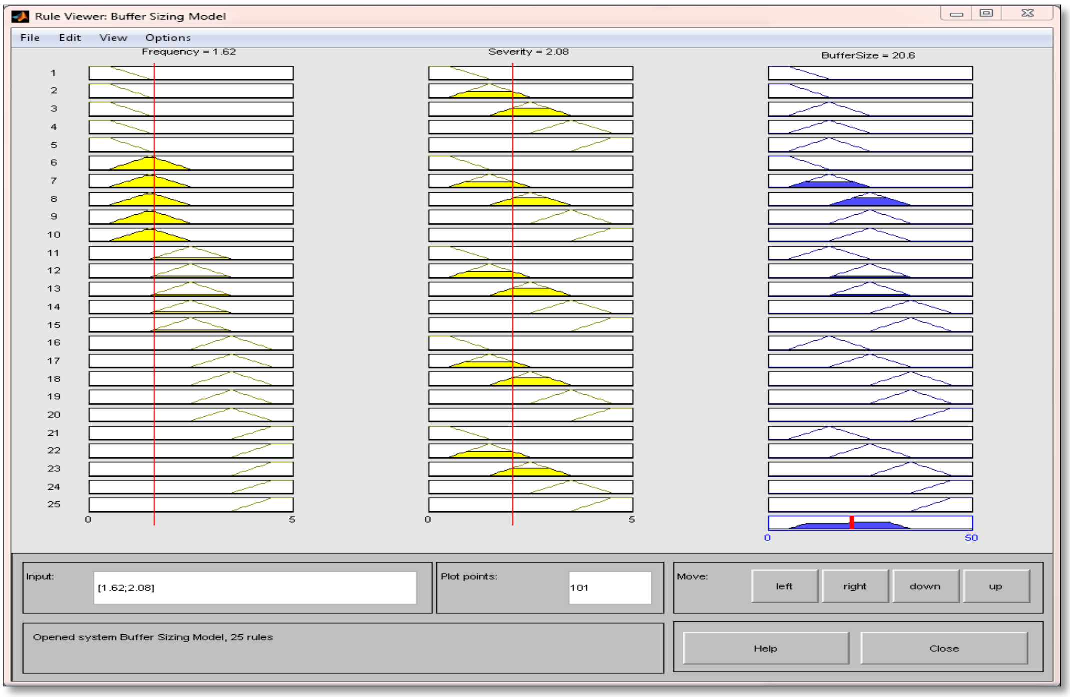

Figure B. 12: Results in the Rule Viewer for the Input Values "1.62, 2.08"

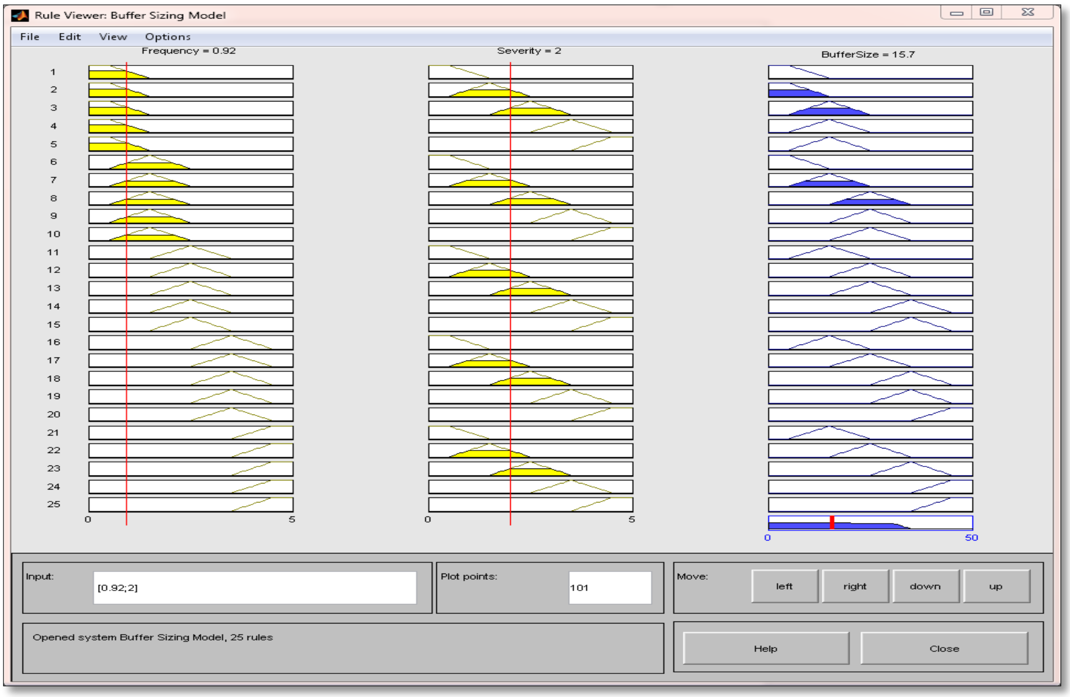

Figure B. 13: Results in the Rule Viewer for the Input Values "0.92, 2.00"

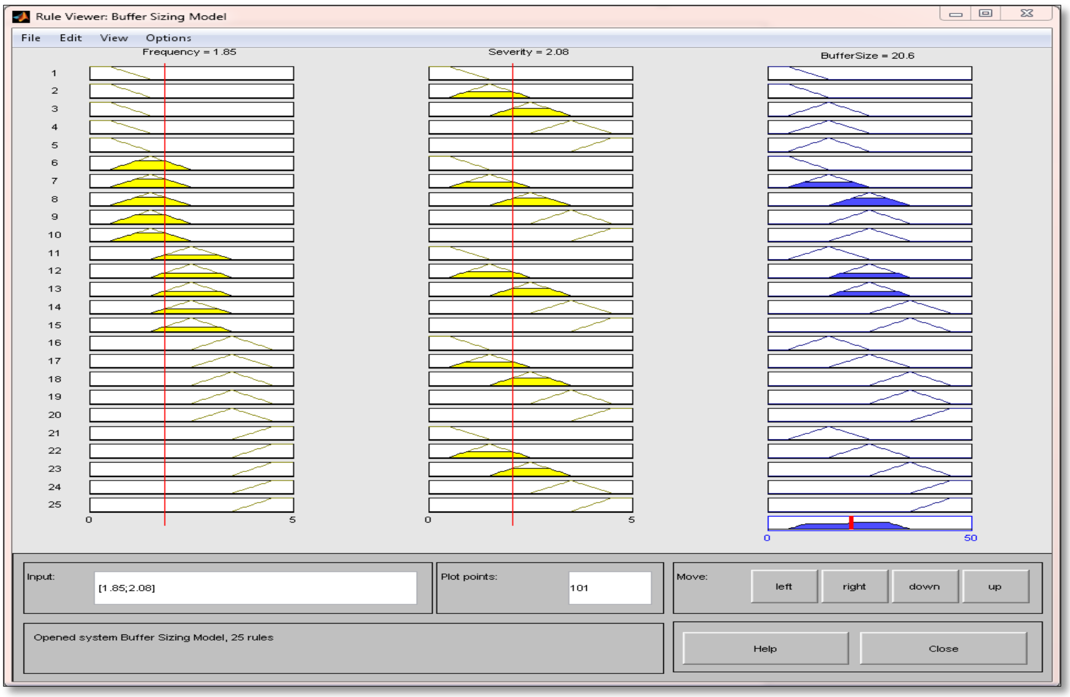

Figure B. 14: Results in the Rule Viewer for the Input Values "1.85, 2.08"

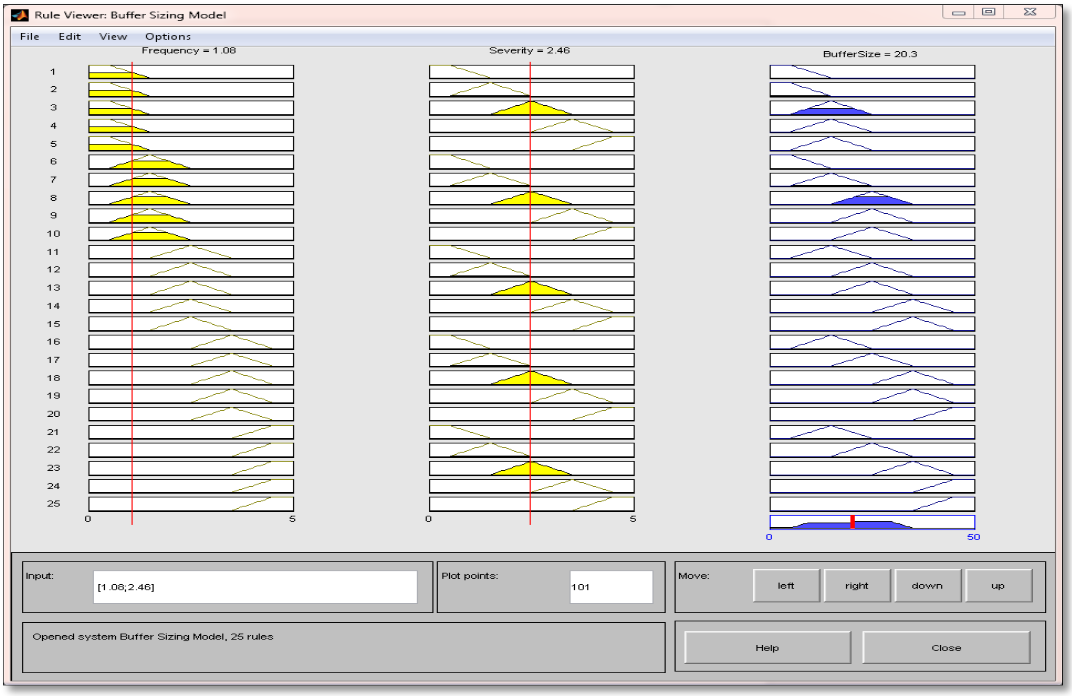

Figure B. 15: Results in the Rule Viewer for the Input Values "1.08, 2.46"

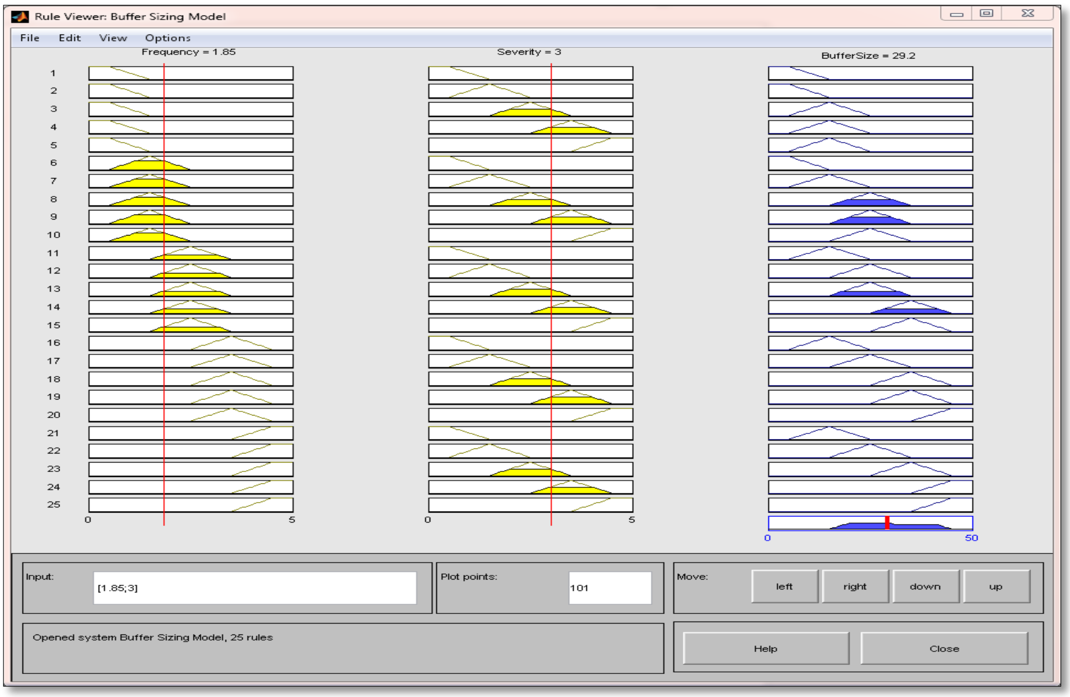

Figure B. 16: Results in the Rule Viewer for the Input Values "1.85, 3.00"

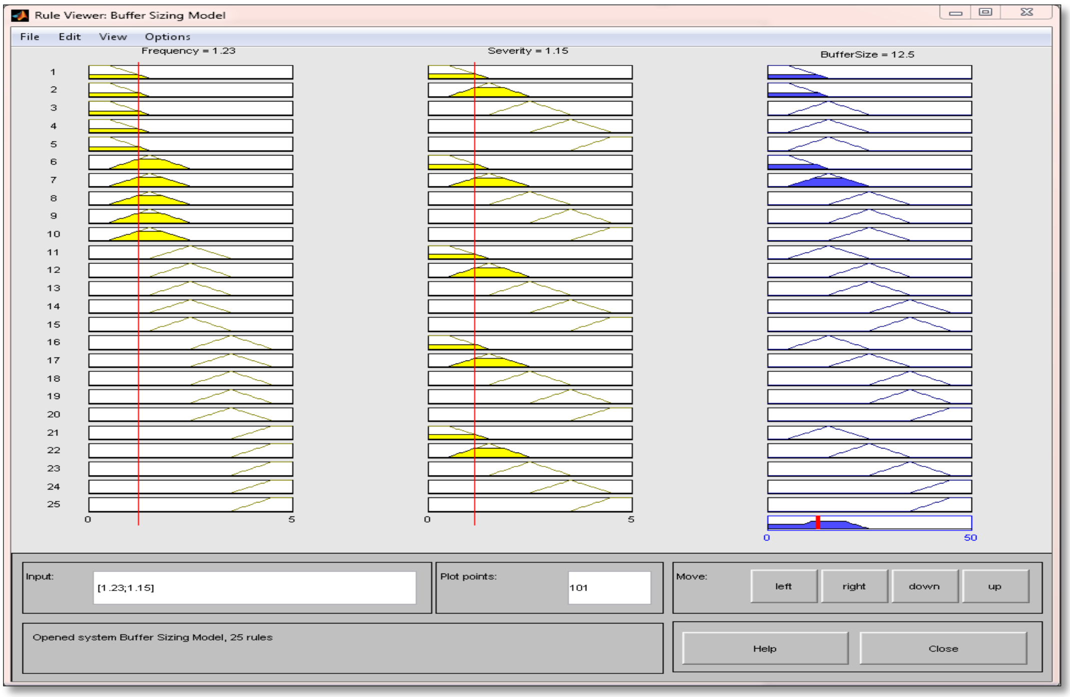

Figure B. 17: Results in the Rule Viewer for the Input Values "1.23, 1.15"

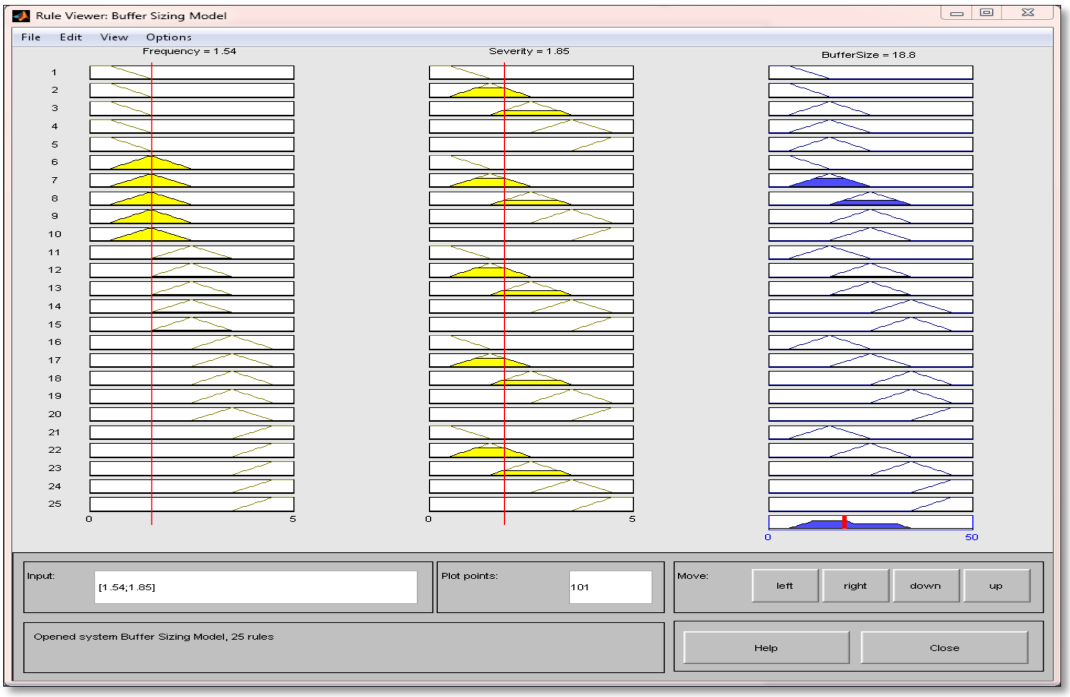

Figure B. 18: Results in the Rule Viewer for the Input Values "1.54, 1.85"

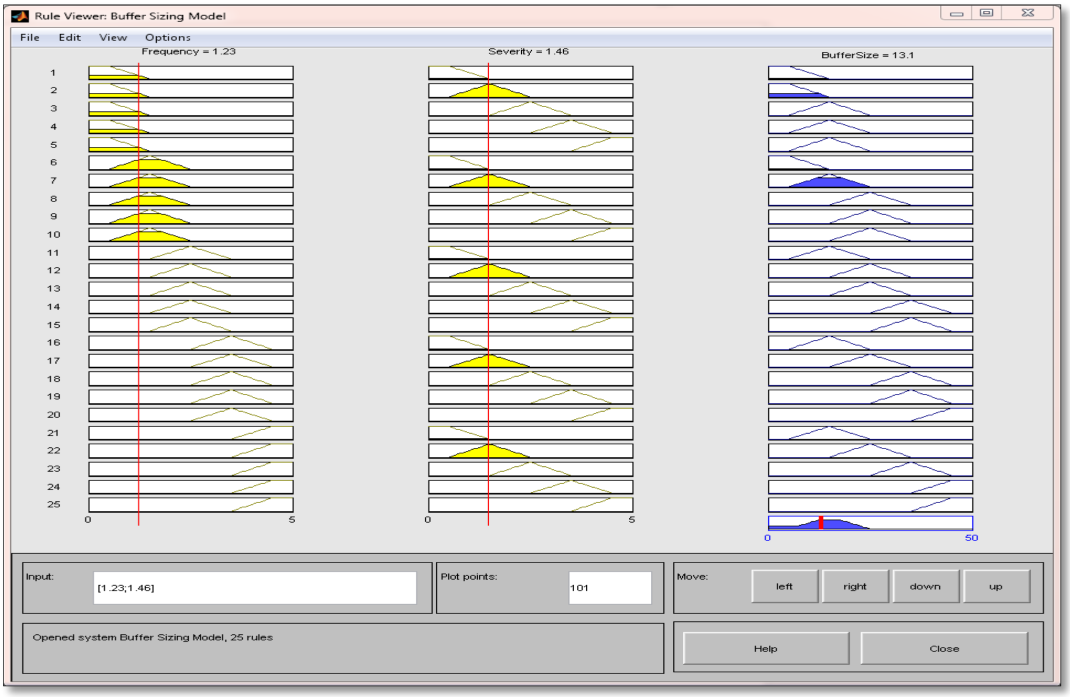

Figure B. 19: Results in the Rule Viewer for the Input Values "1.23, 1.46"

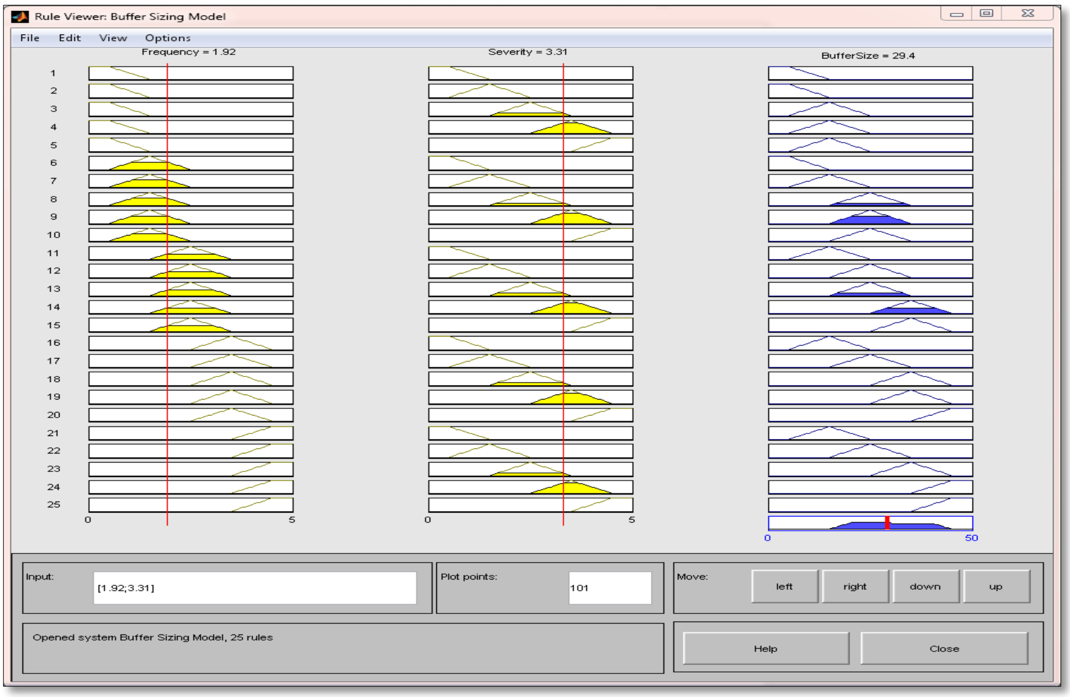

Figure B. 20: Results in the Rule Viewer for the Input Values “1.92, 3.31”

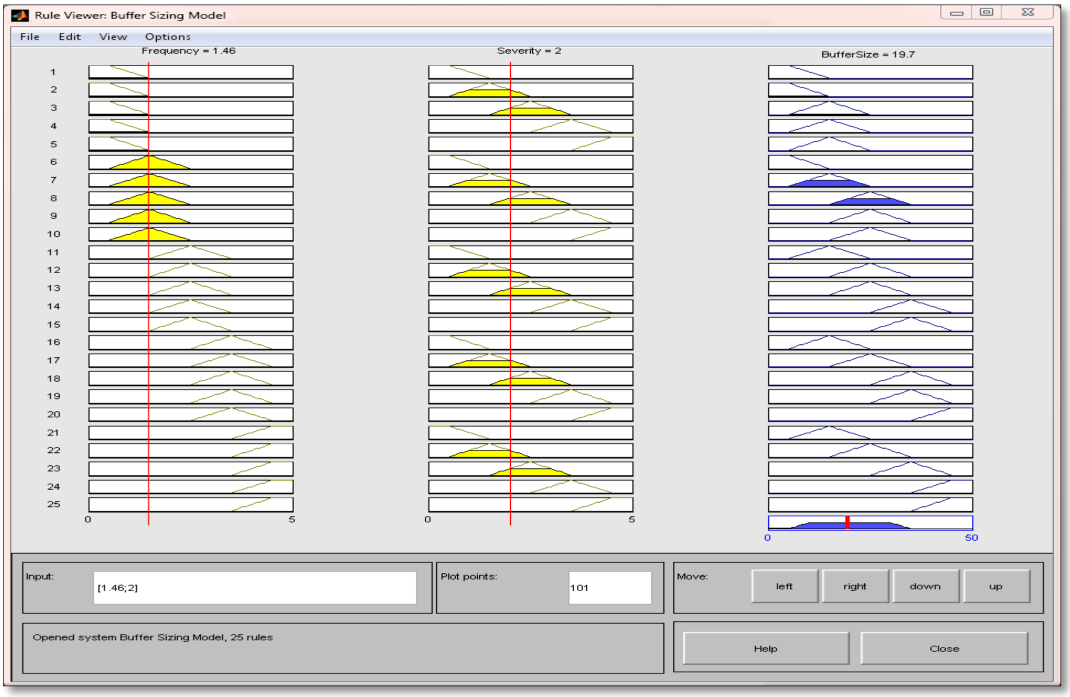

Figure B. 21: Results in the Rule Viewer for the Input Values “1.46, 2.00”

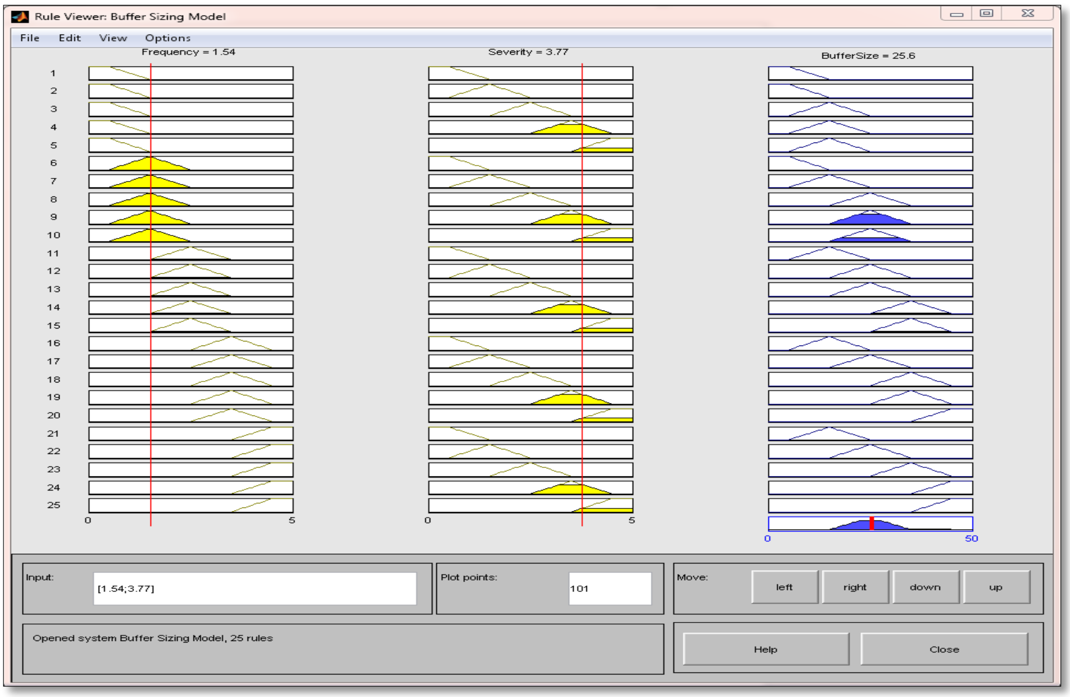

Figure B. 22: Results in the Rule Viewer for the Input Values "1.54, 3.77"

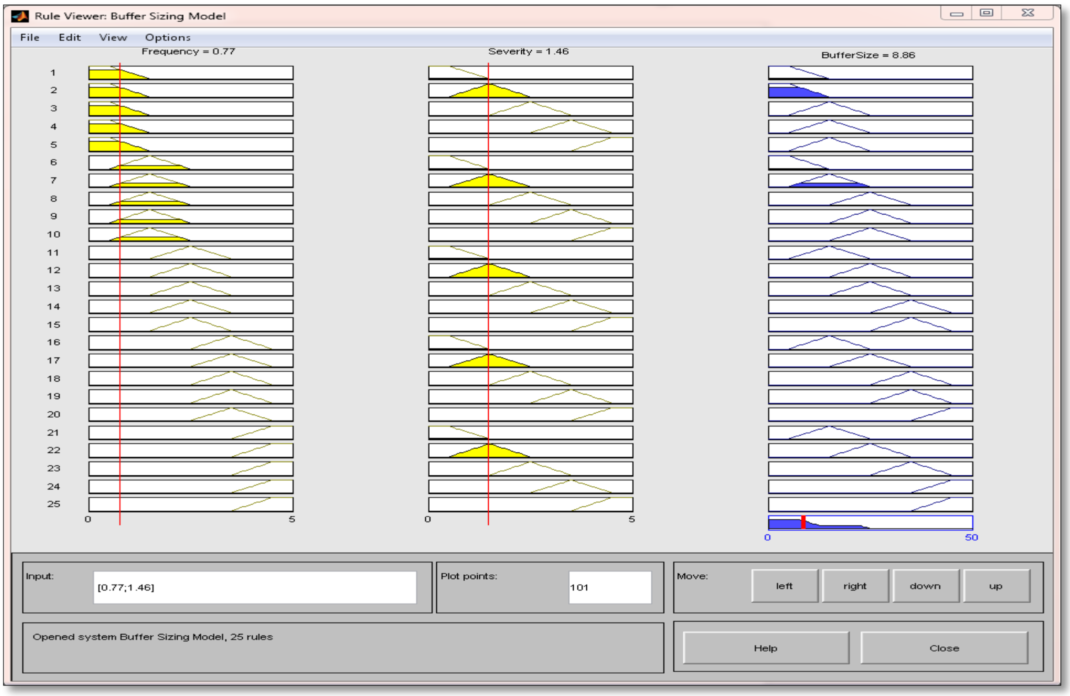

Figure B. 23: Results in the Rule Viewer for the Input Values "0.77, 1.46"

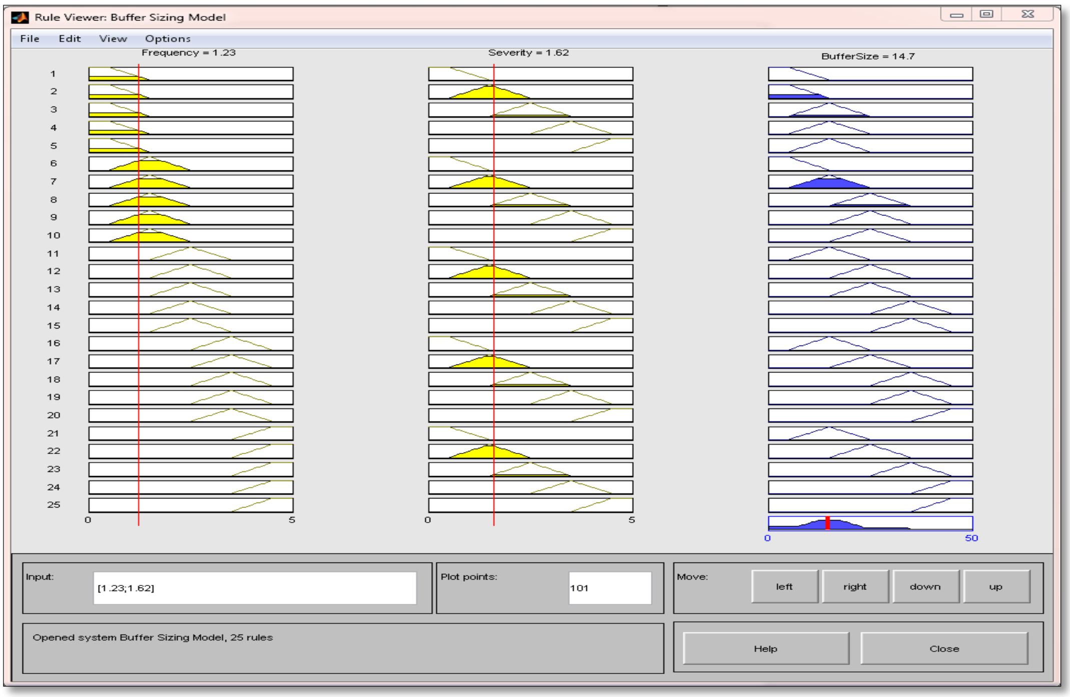

Figure B. 24: Results in the Rule Viewer for the Input Values "1.23, 1.62"

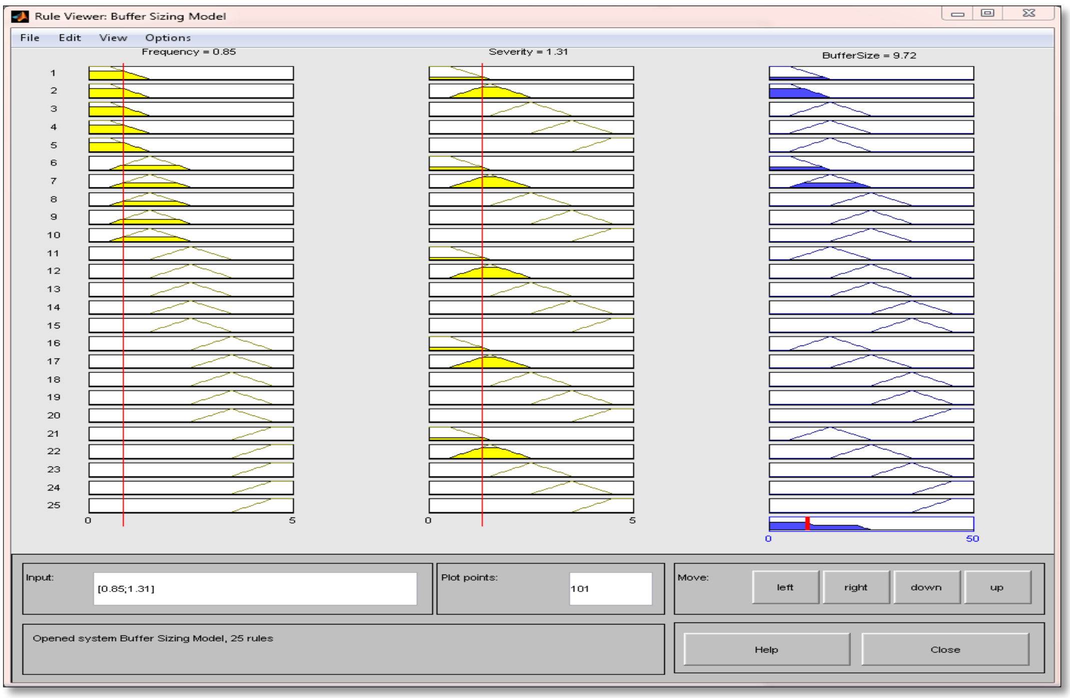

Figure B. 25: Results in the Rule Viewer for the Input Values "0.85, 1.31"

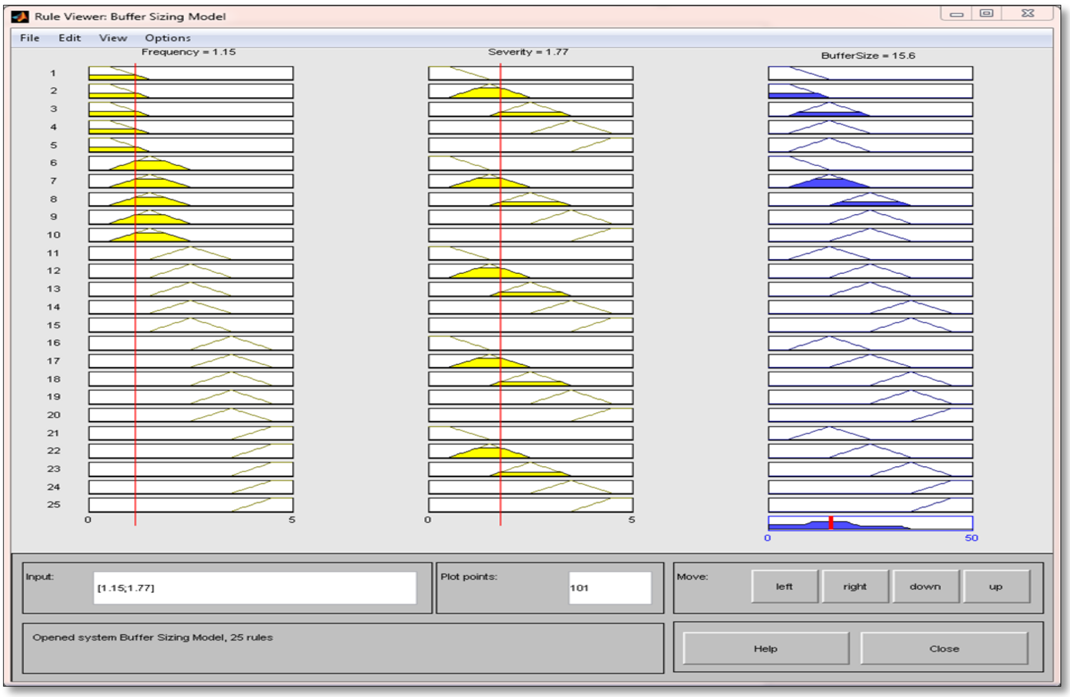

Figure B. 26: Results in the Rule Viewer for the Input Values “1.15, 1.77”

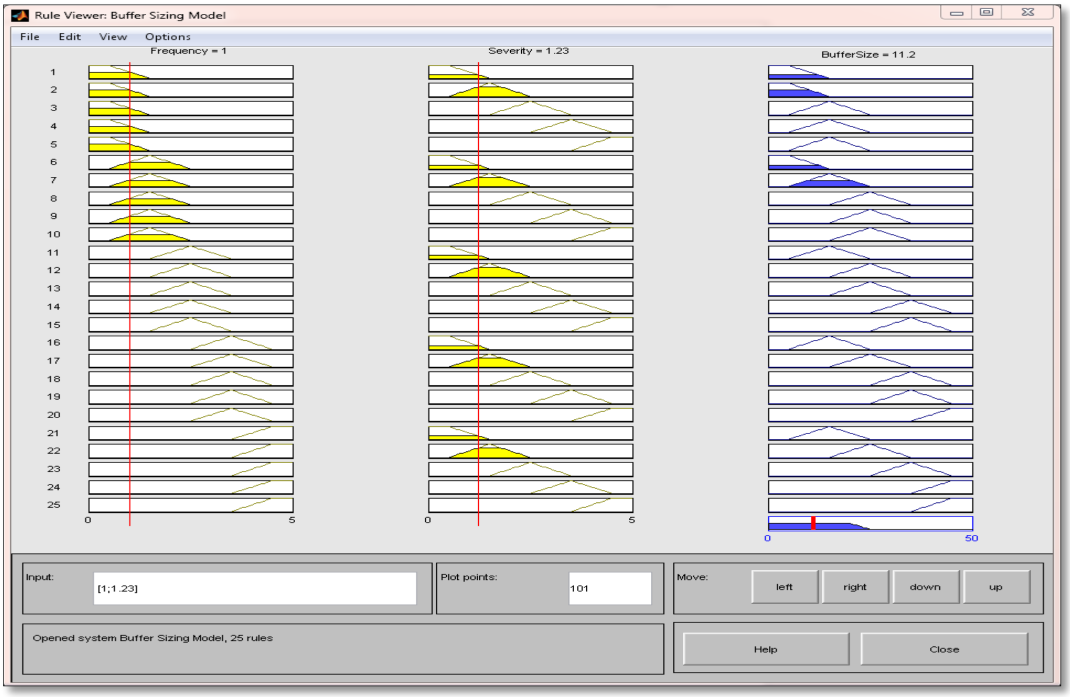

Figure B. 27: Results in the Rule Viewer for the Input Values “1.00, 1.23”

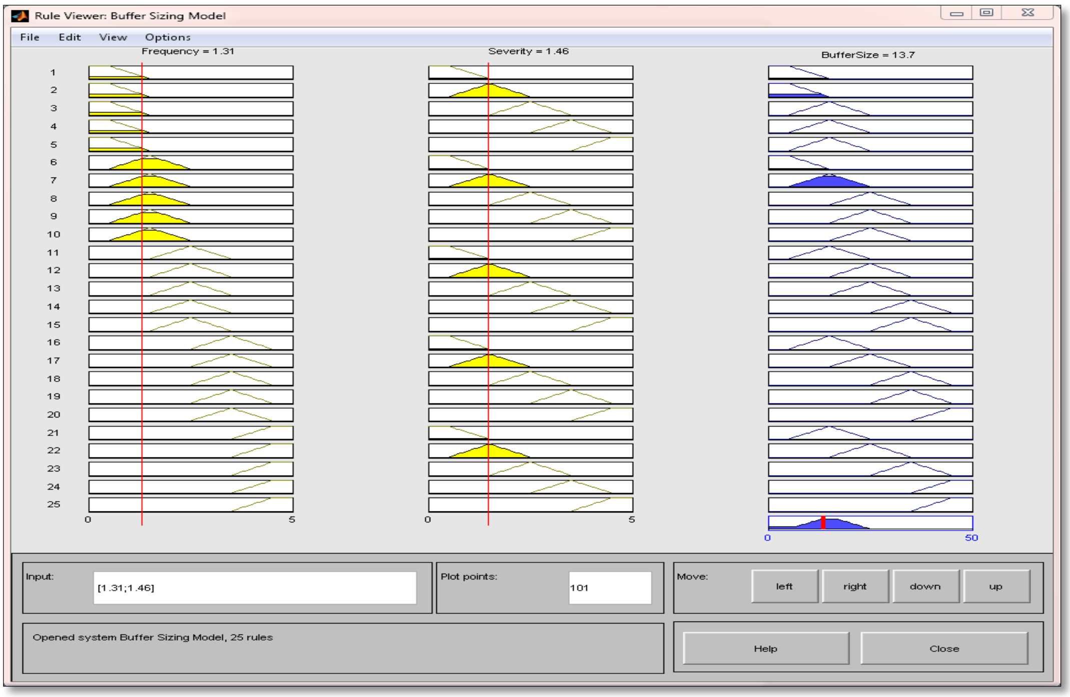

Figure B. 28: Results in the Rule Viewer for the Input Values "1.31, 1.46"

Figure B. 29: Results in the Rule Viewer for the Input Values "1.23, 1.38"

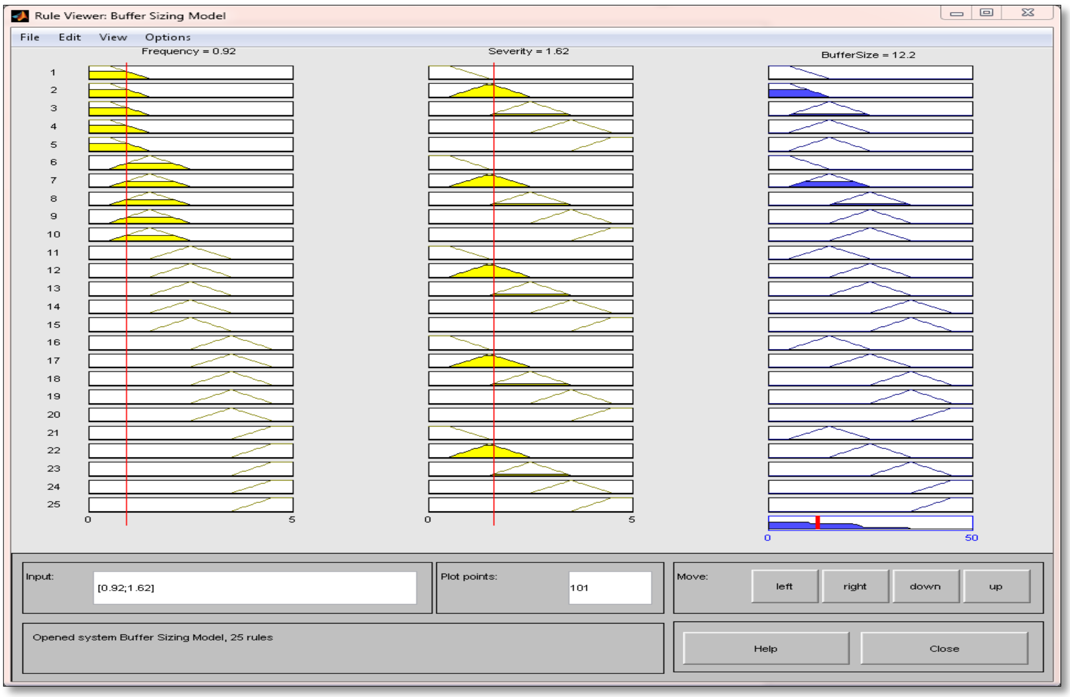

Figure B. 30: Results in the Rule Viewer for the Input Values "0.92, 1.62"

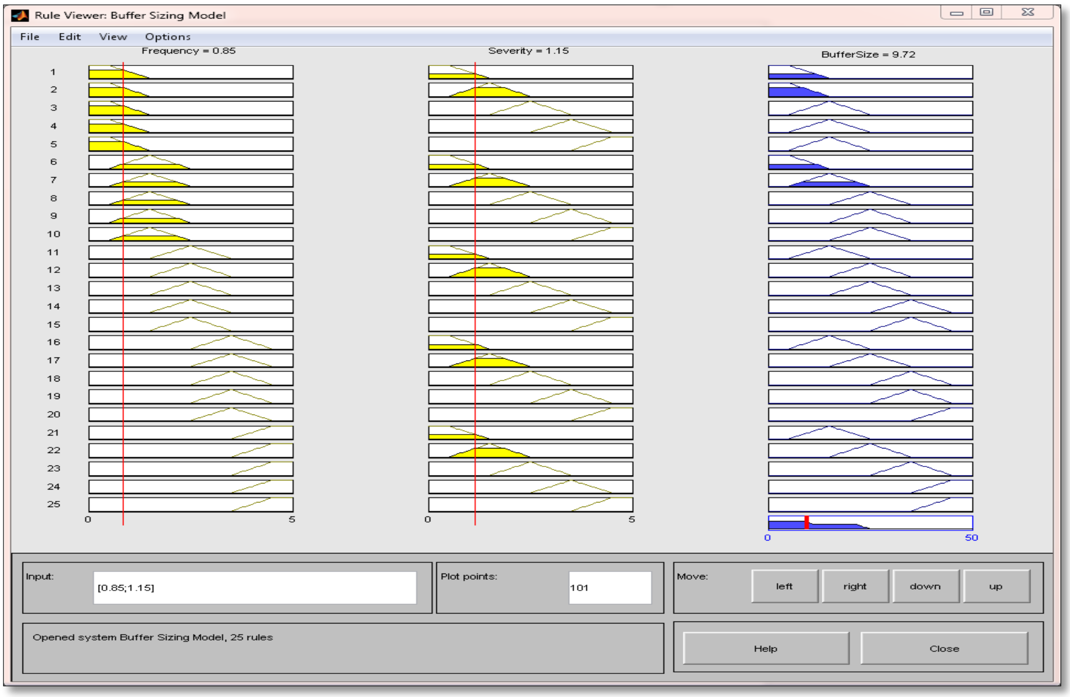

Figure B. 31: Results in the Rule Viewer for the Input Values "0.85, 1.15"

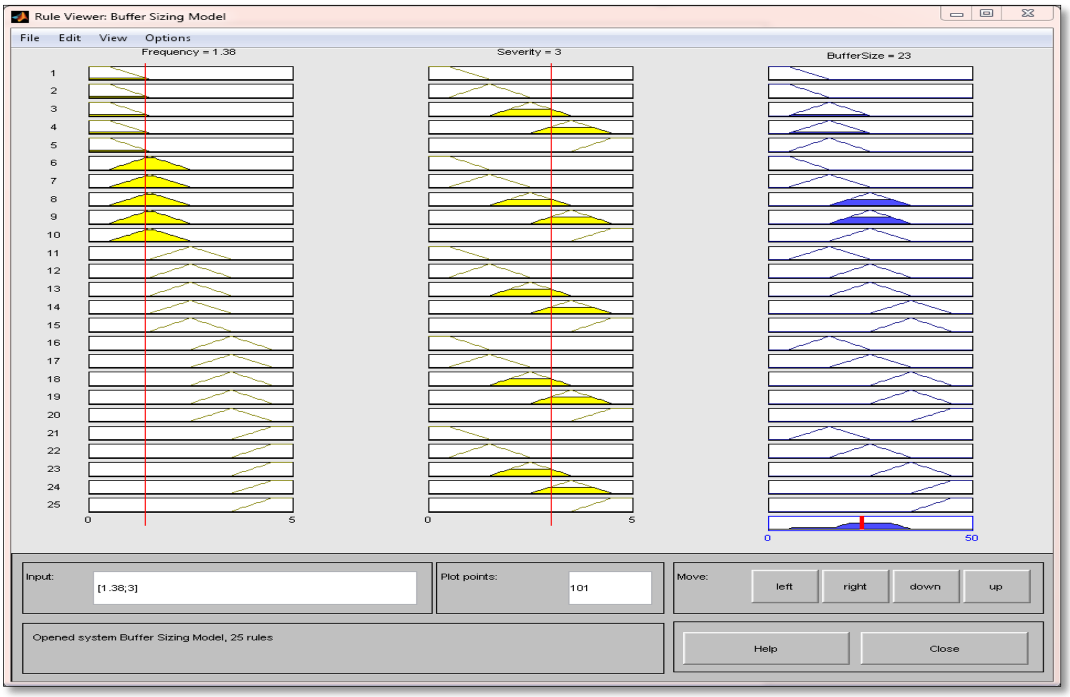

Figure B. 32: Results in the Rule Viewer for the Input Values "1.38, 3.00"

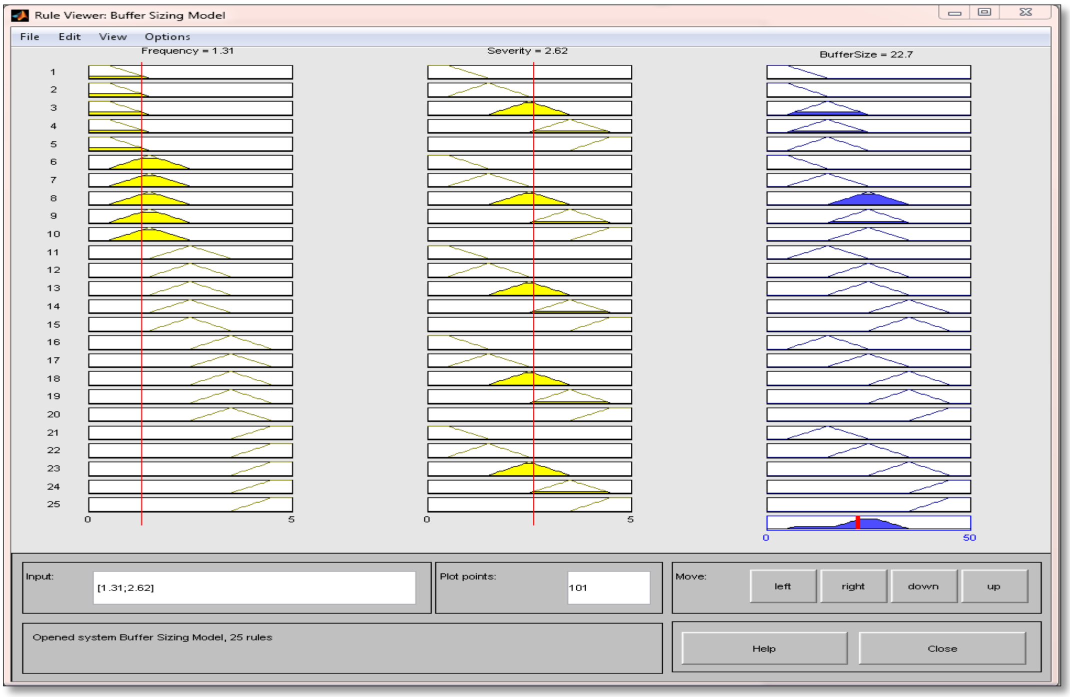

Figure B. 33: Results in the Rule Viewer for the Input Values "1.31, 2.62"

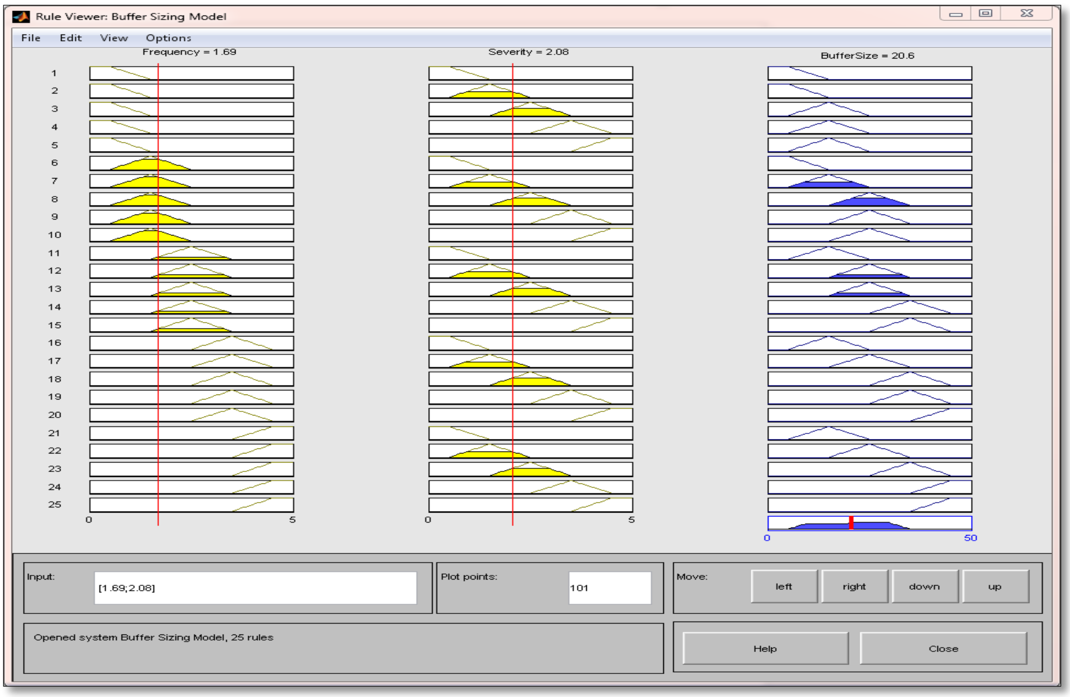

Figure B. 34: Results in the Rule Viewer for the Input Values “1.69, 2.08”

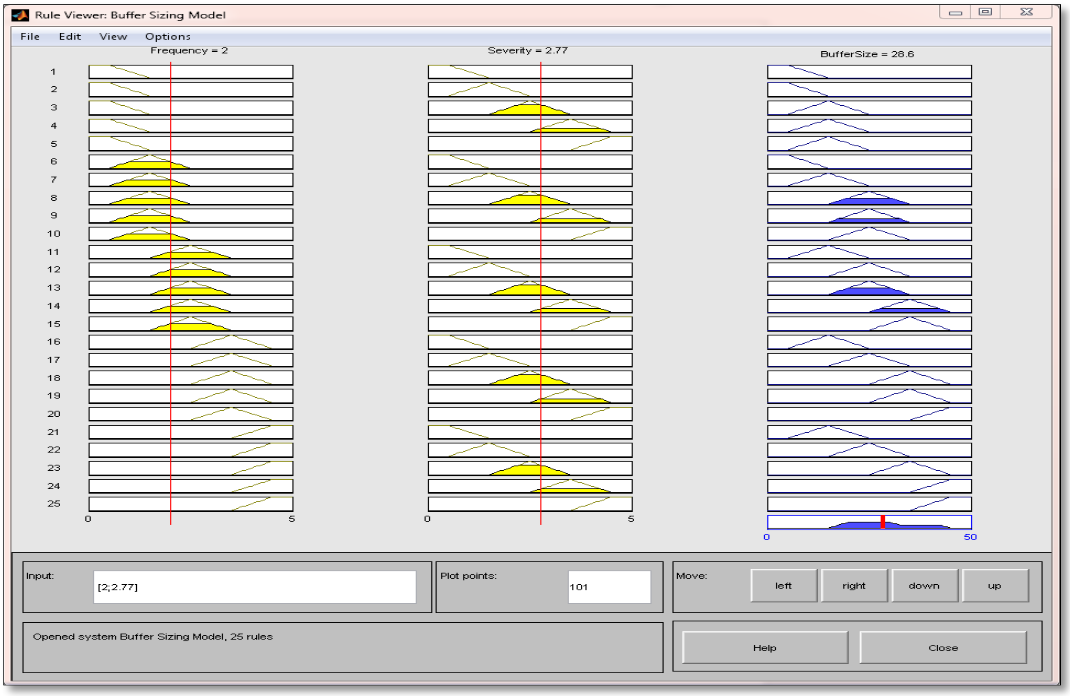

Figure B. 35: Results in the Rule Viewer for the Input Values “2.00, 2.77”

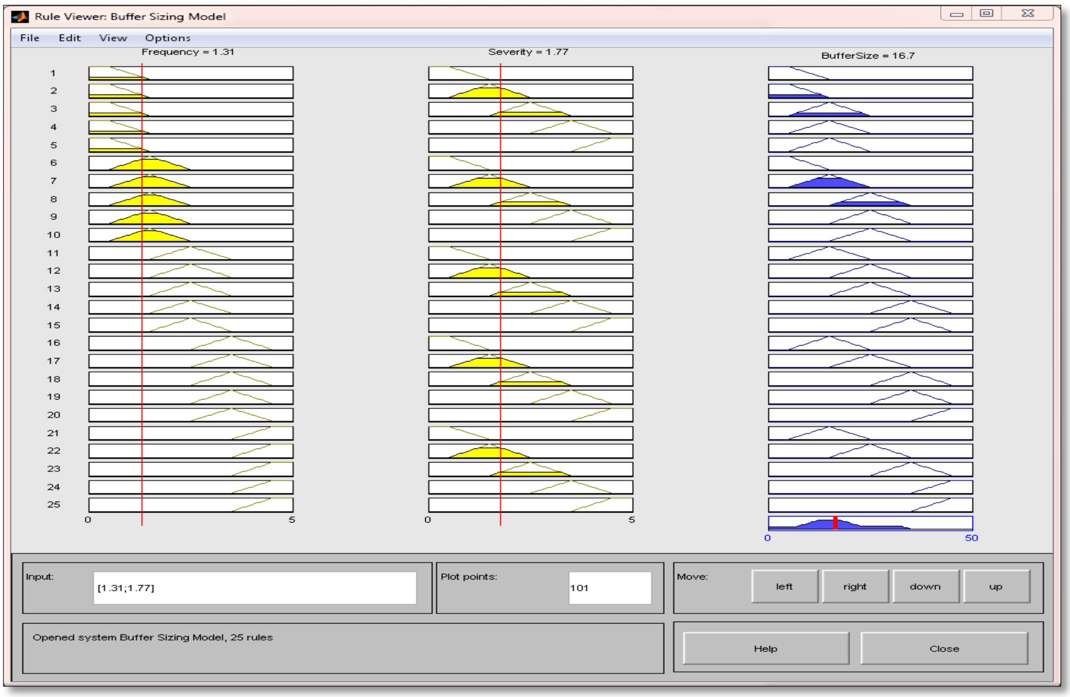

Figure B. 36: Results in the Rule Viewer for the Input Values "1.31, 1.77"

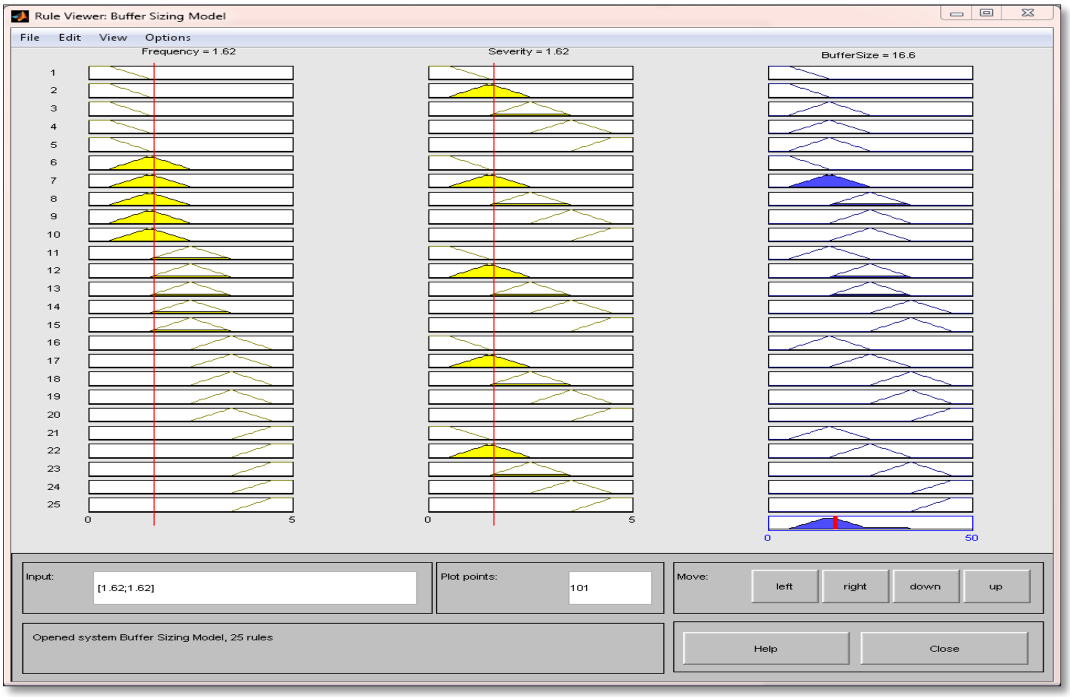

Figure B. 37: Results in the Rule Viewer for the Input Values "1.62, 1.62"

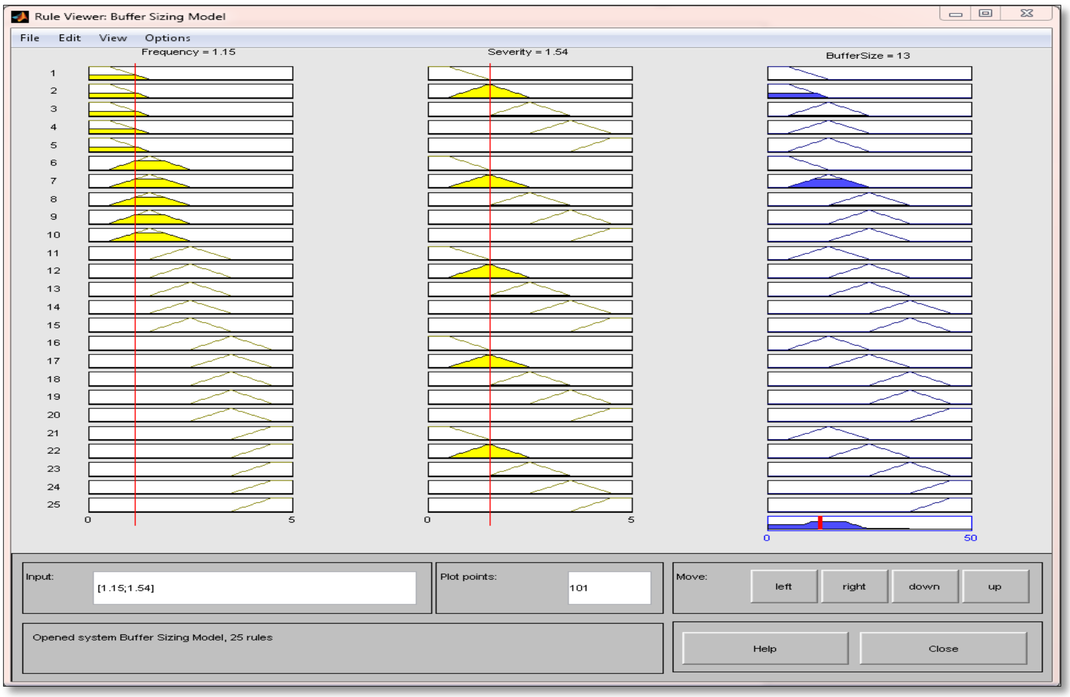

Figure B. 38: Results in the Rule Viewer for the Input Values "1.15, 1.54"

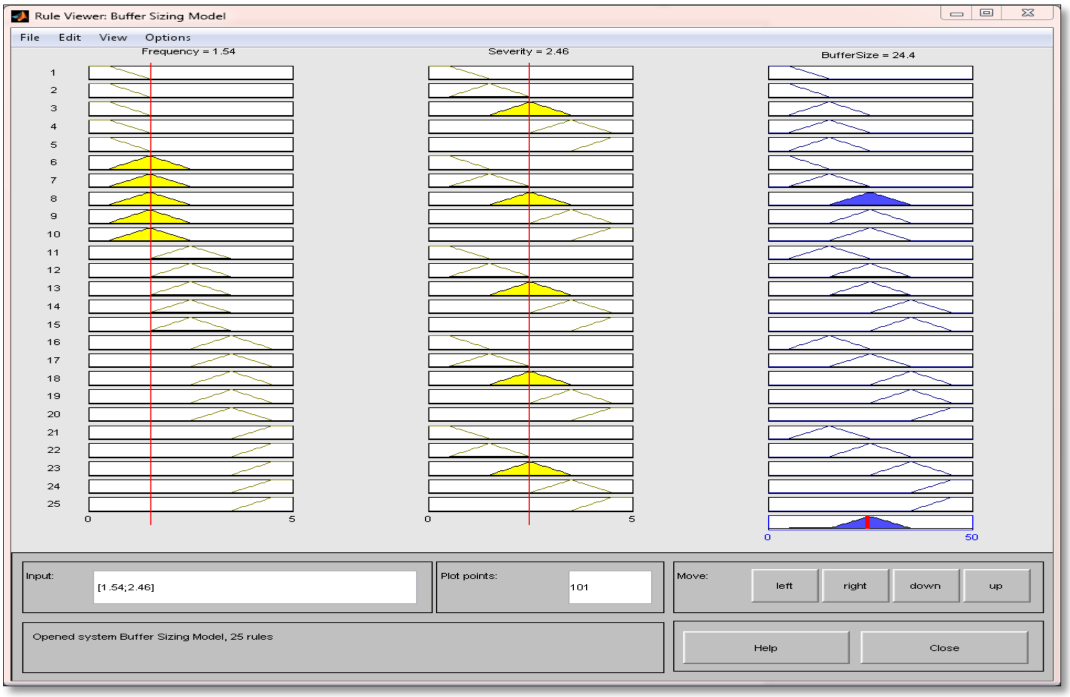

Figure B. 39: Results in the Rule Viewer for the Input Values "1.54, 2.46"

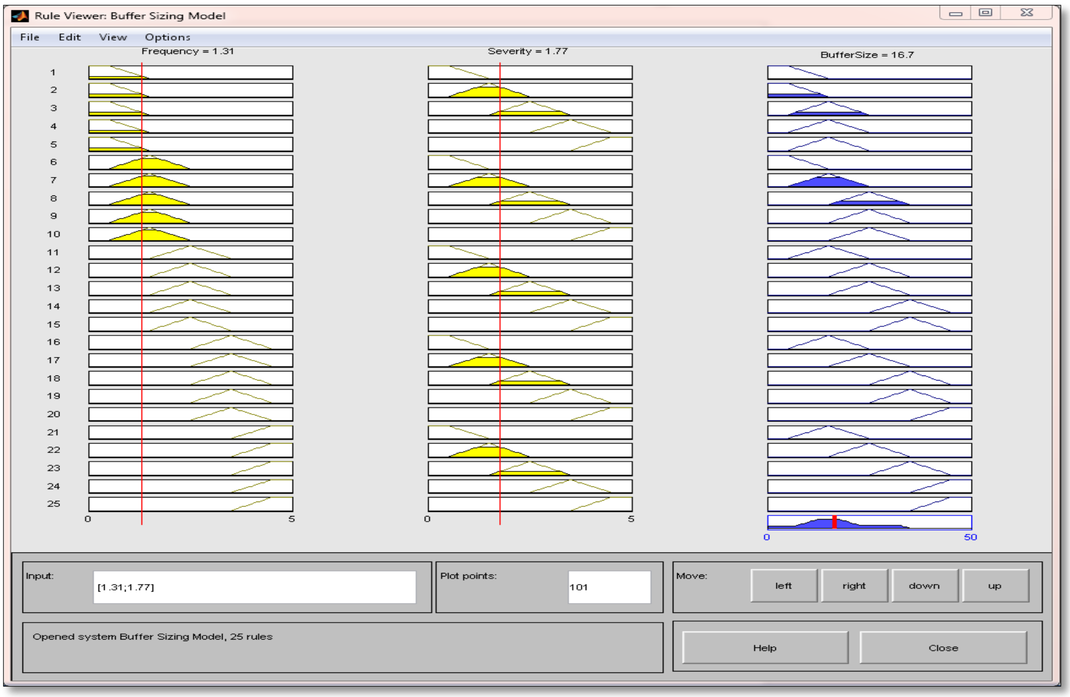

Figure B. 40: Results in the Rule Viewer for the Input Values “1.31, 1.77”

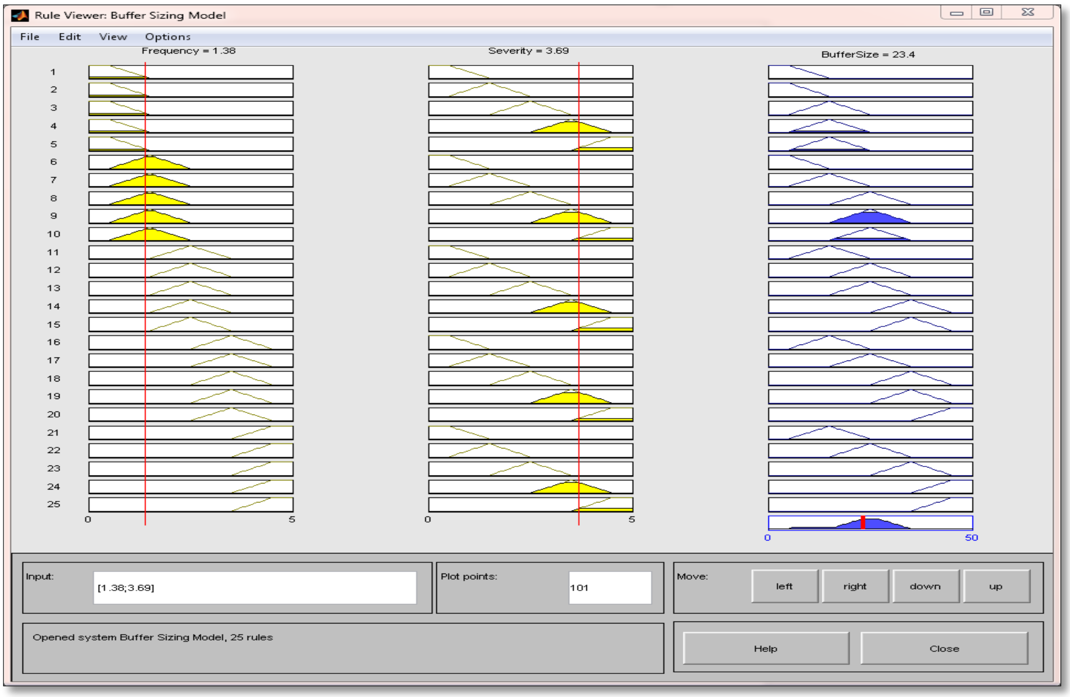

Figure B. 41: Results in the Rule Viewer for the Input Values “1.38, 3.69”

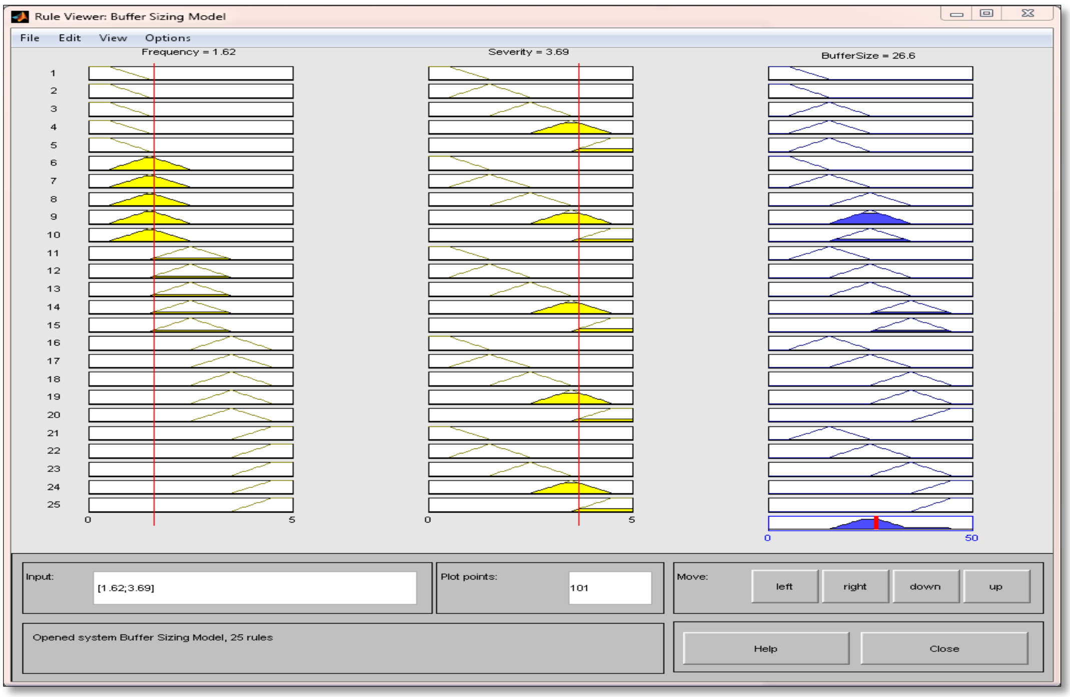

Figure B. 42: Results in the Rule Viewer for the Input Values “1.62, 3.69”

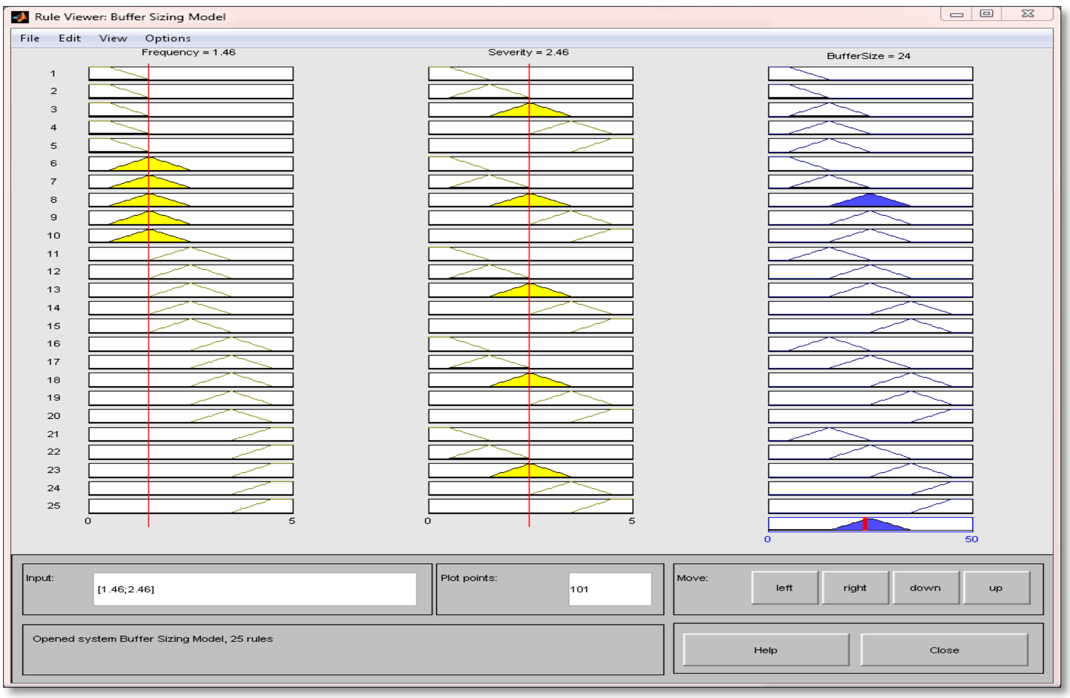

Figure B. 43: Results in the Rule Viewer for the Input Values “1.46, 2.46”

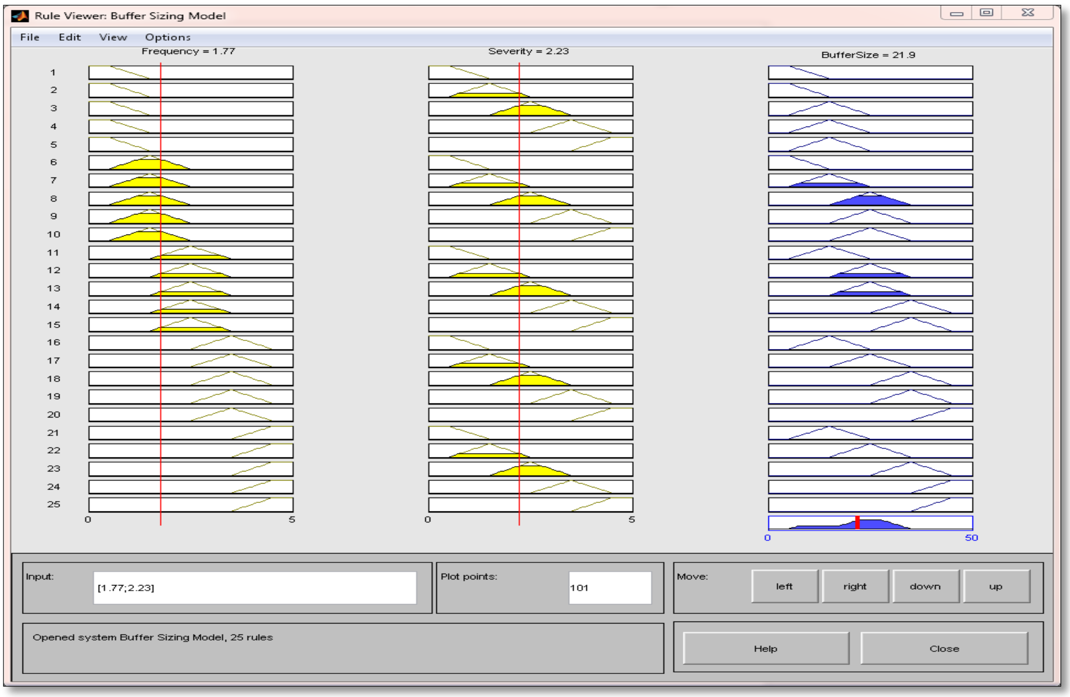

Figure B. 44: Results in the Rule Viewer for the Input Values “1.77, 2.23”

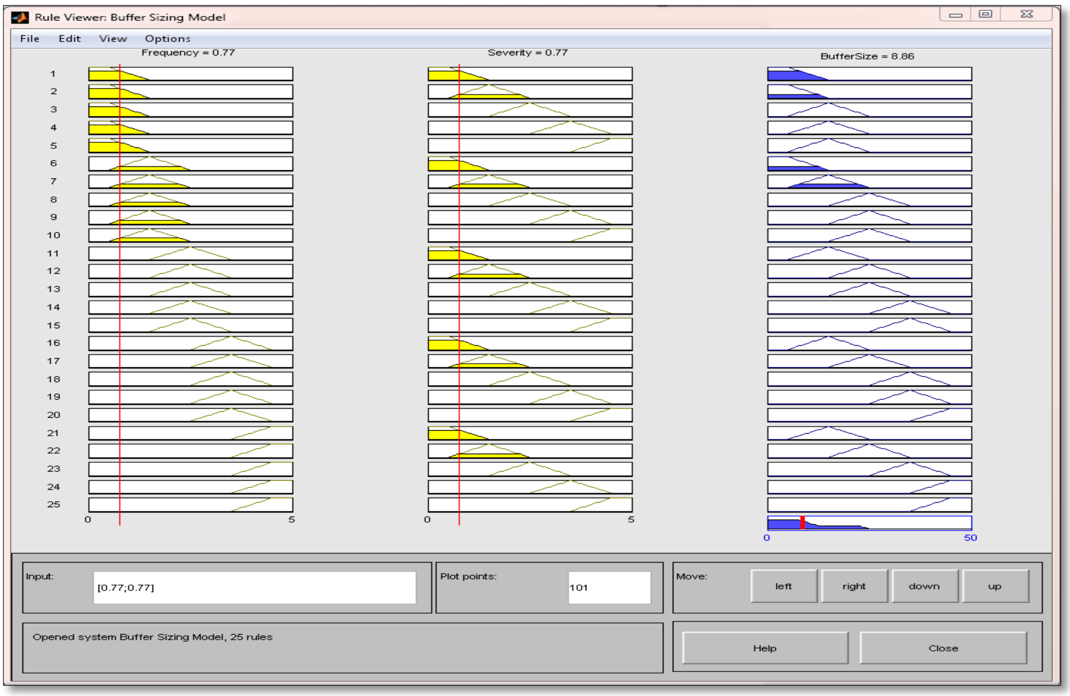

Figure B. 45: Results in the Rule Viewer for the Input Values “0.77, 0.77”

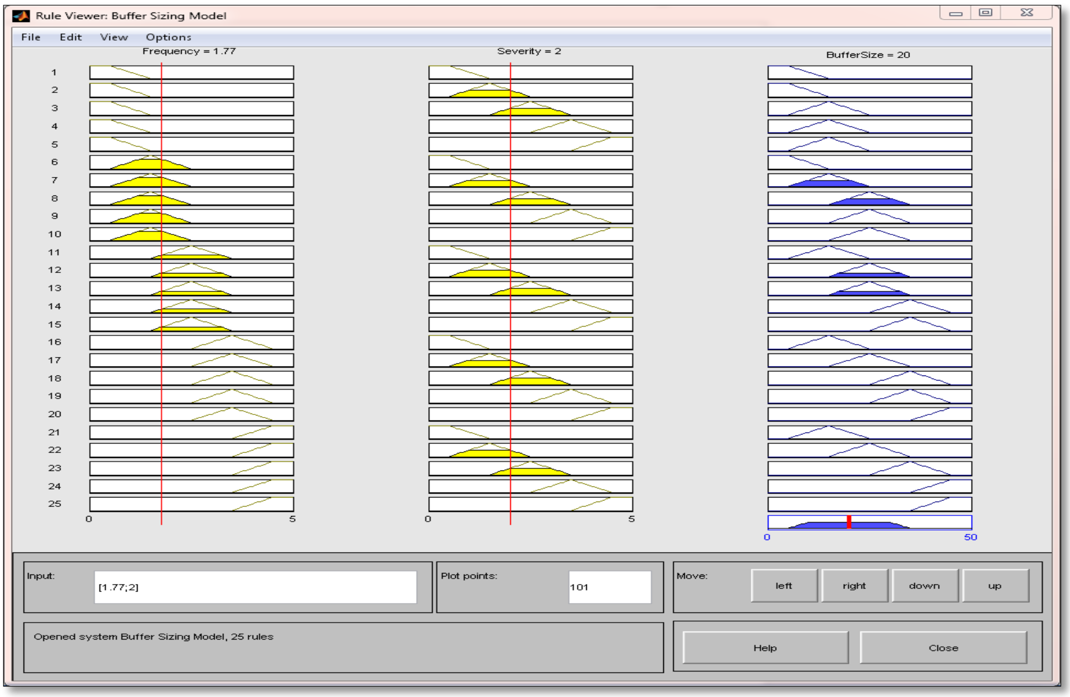

Figure B. 46: Results in the Rule Viewer for the Input Values “1.77, 2.00”

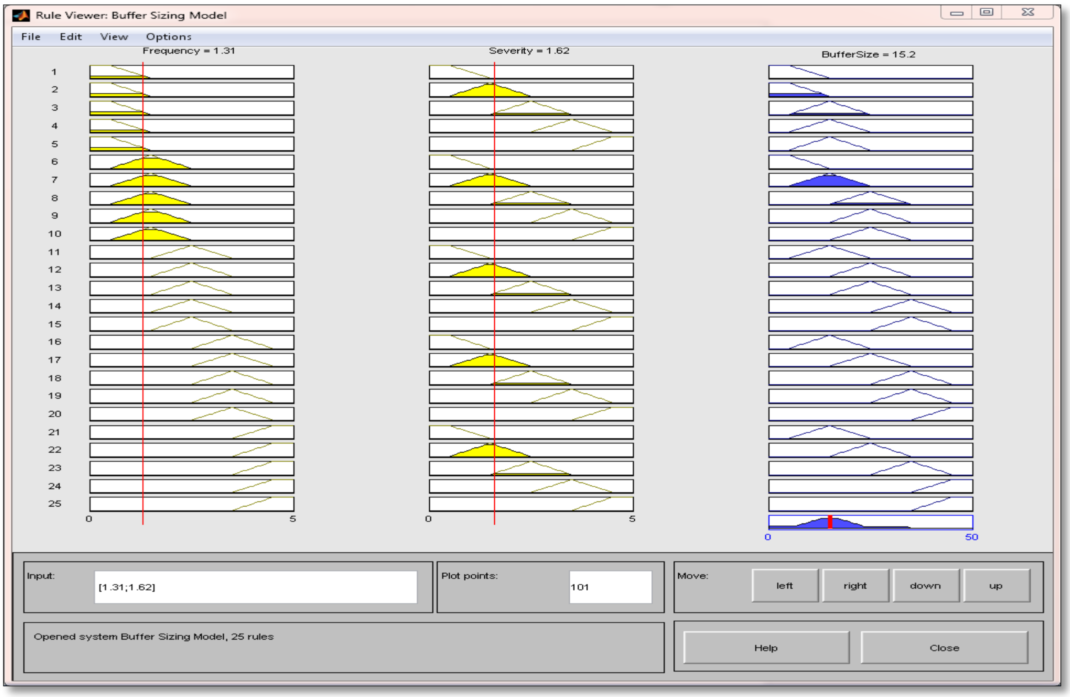

Figure B. 47: Results in the Rule Viewer for the Input Values “1.31, 1.62”

Figure B. 48: Results in the Rule Viewer for the Input Values "0.92, 1.23"

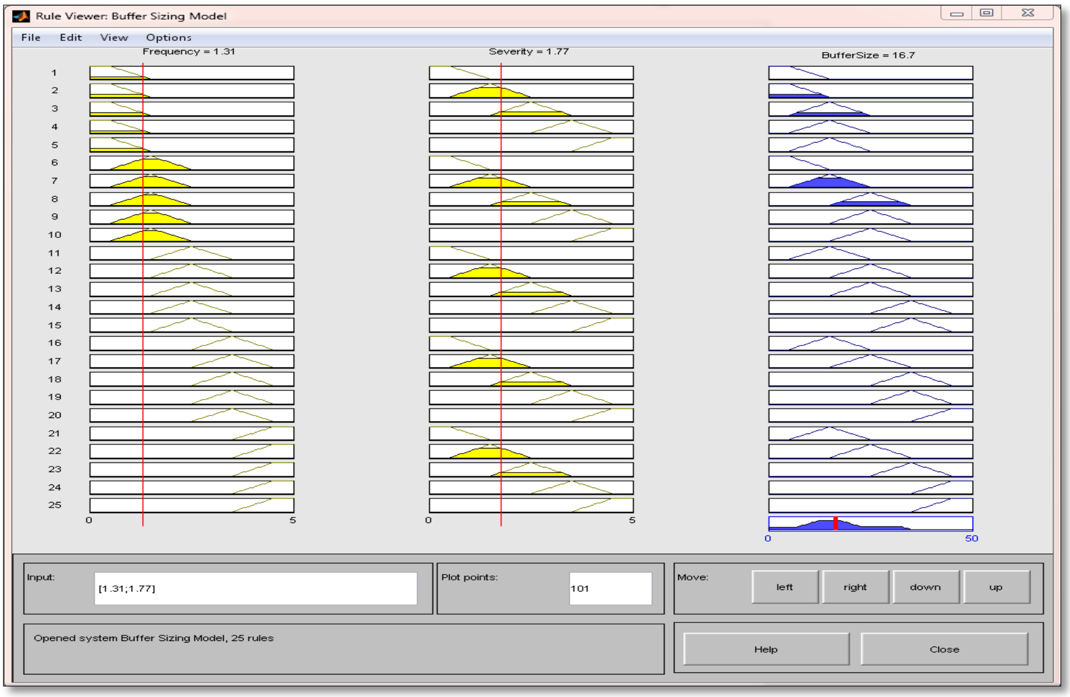

Figure B. 49: Results in the Rule Viewer for the Input Values "1.31, 1.77"

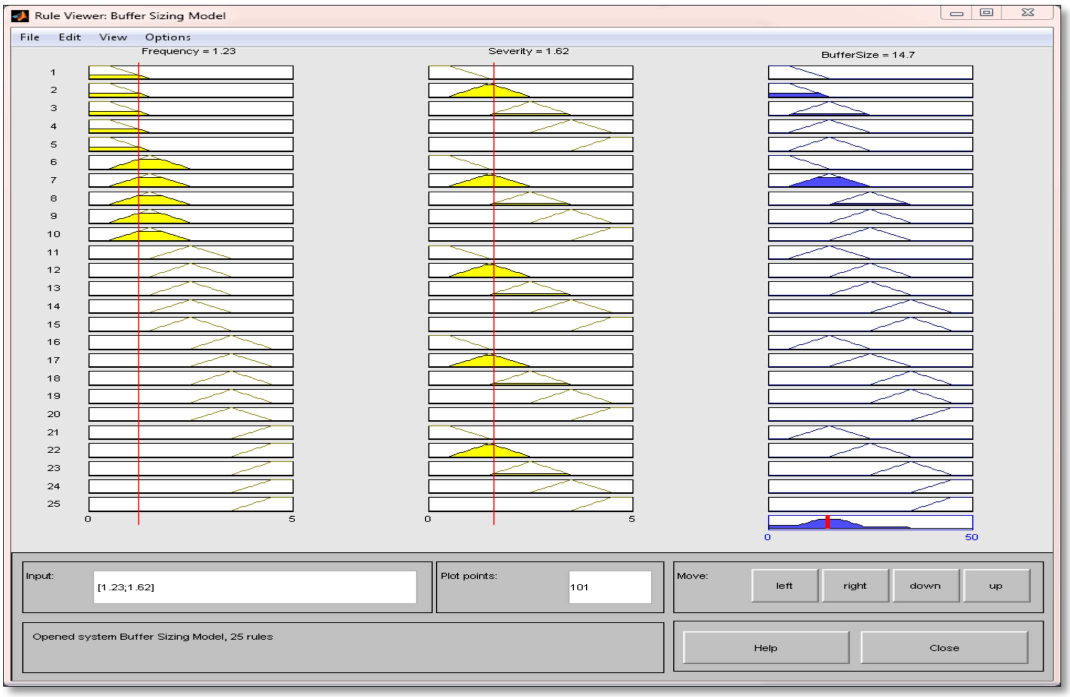

Figure B. 50: Results in the Rule Viewer for the Input Values “1.23, 1.62”

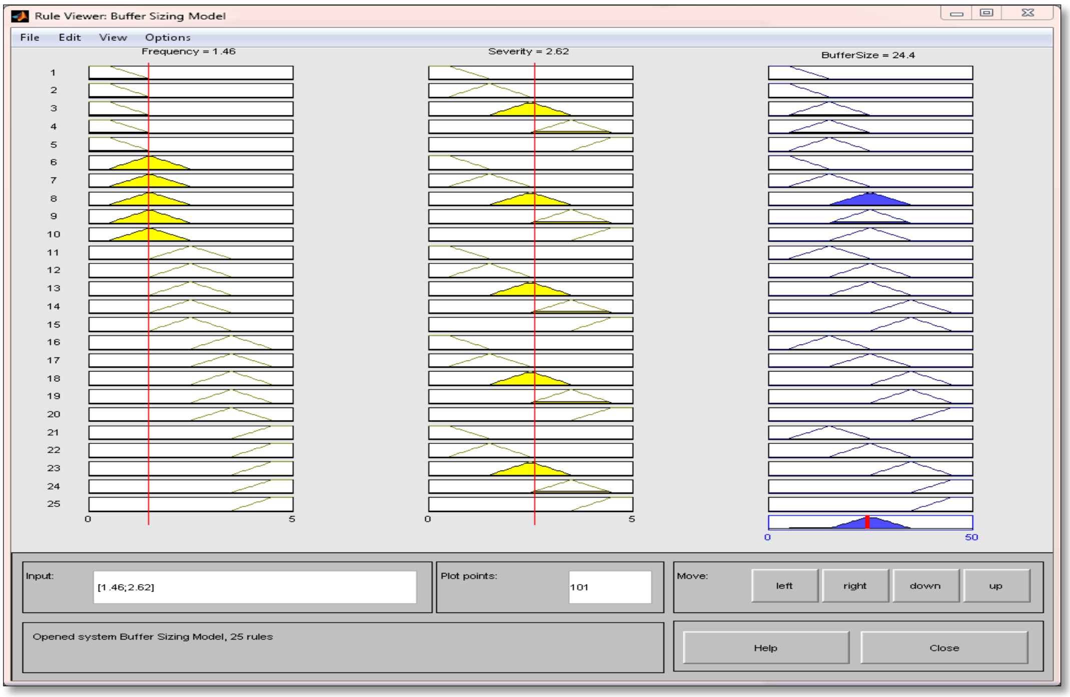

Figure B. 51: Results in the Rule Viewer for the Input Values “1.46, 2.62”

Figure B. 52: Results in the Rule Viewer for the Input Values “1.00, 1.38”

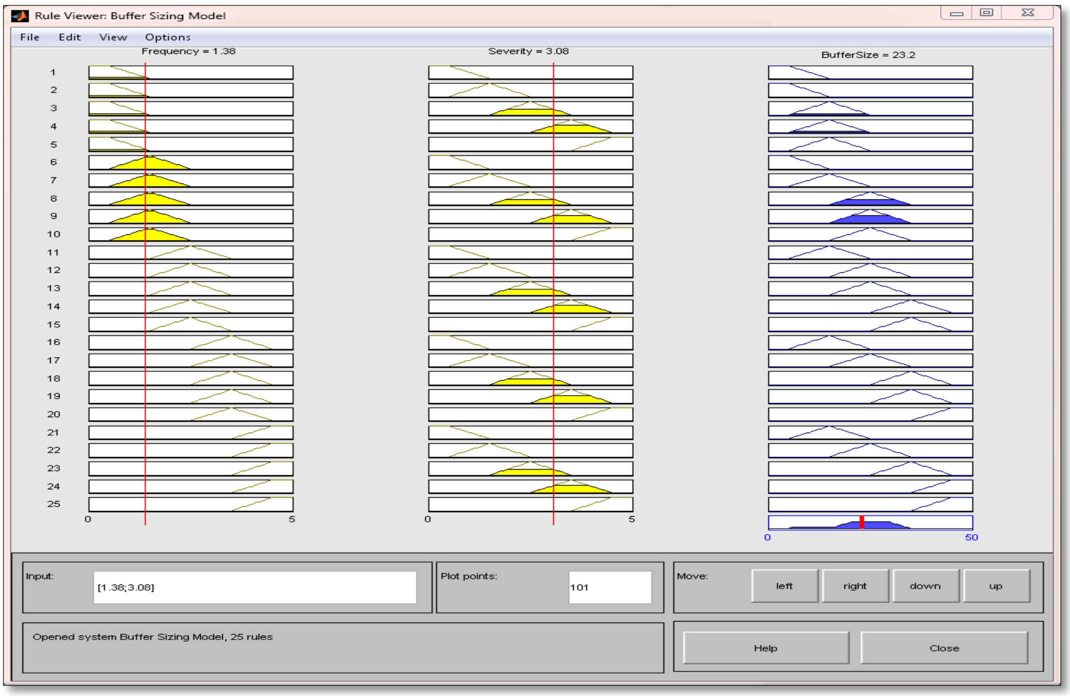

Figure B. 53: Results in the Rule Viewer for the Input Values “1.38, 3.08”

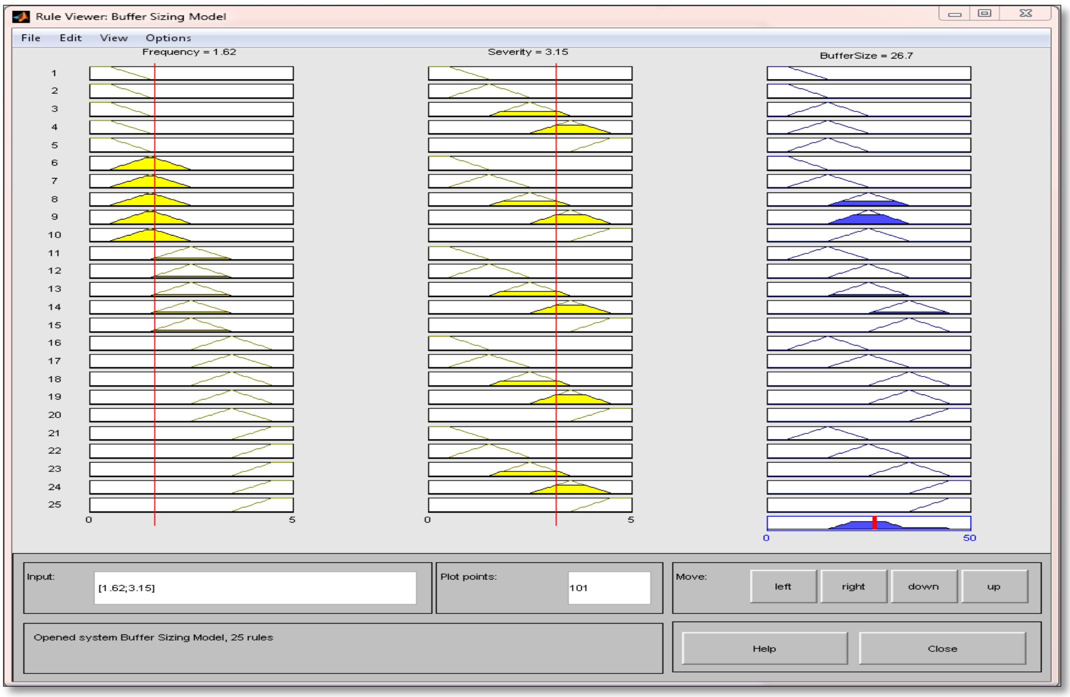

Figure B. 54: Results in the Rule Viewer for the Input Values “1.62, 3.15”

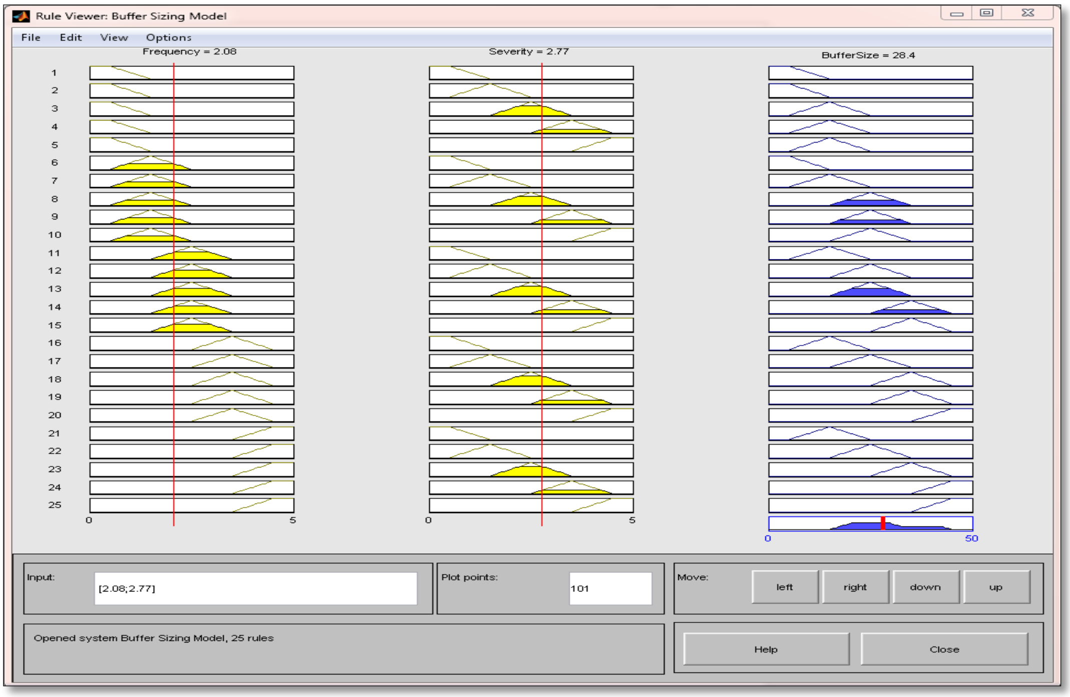

Figure B. 55: Results in the Rule Viewer for the Input Values “2.08, 2.77”

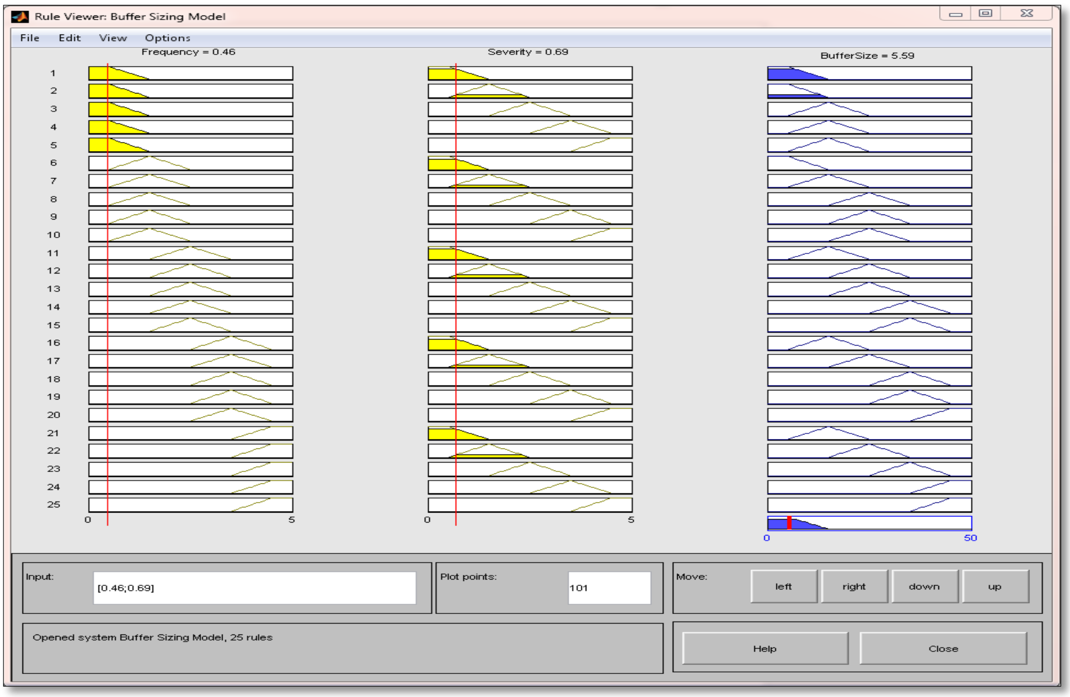

Figure B. 56: Results in the Rule Viewer for the Input Values "0.46, 0.69"

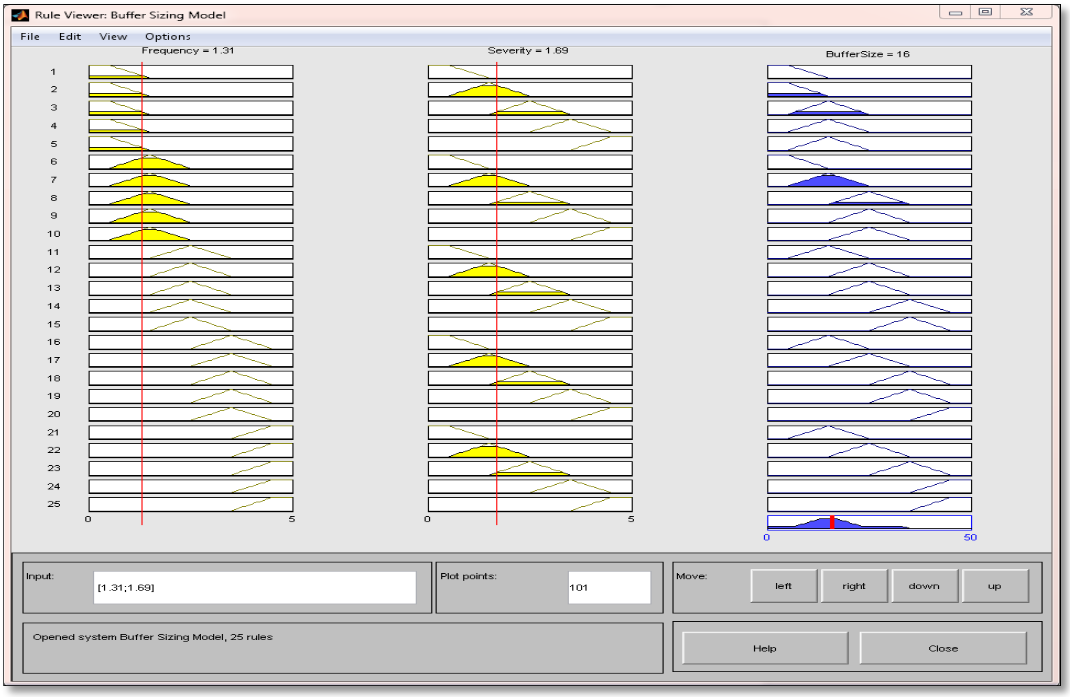

Figure B. 57: Results in the Rule Viewer for the Input Values "1.31, 1.69"

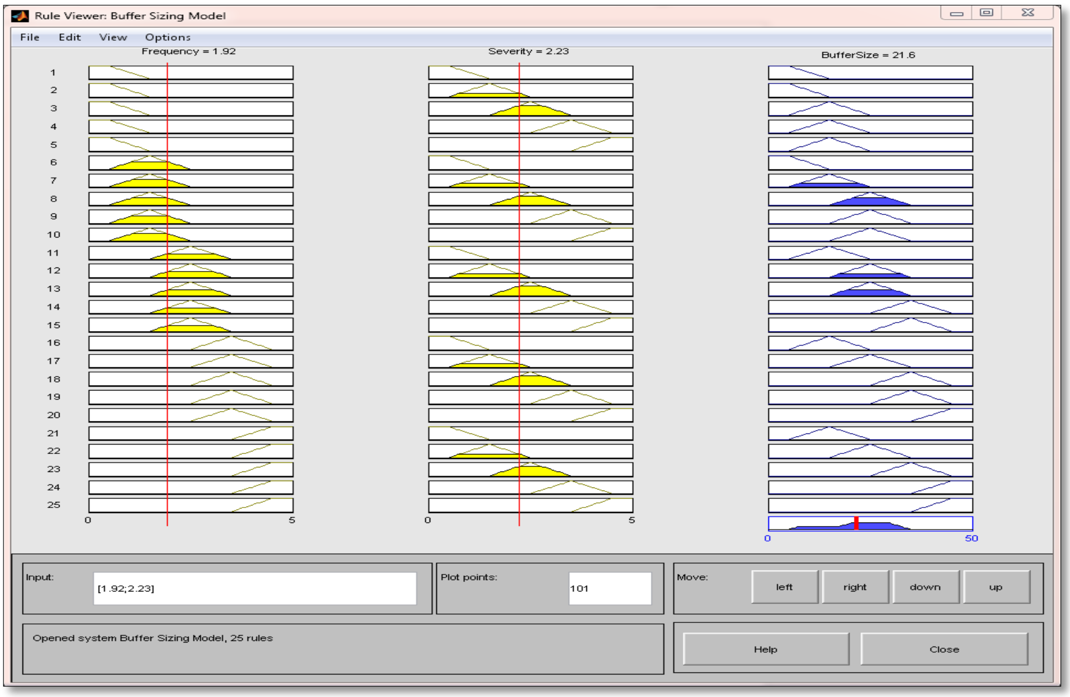

Figure B. 58: Results in the Rule Viewer for the Input Values “1.92, 2.23”

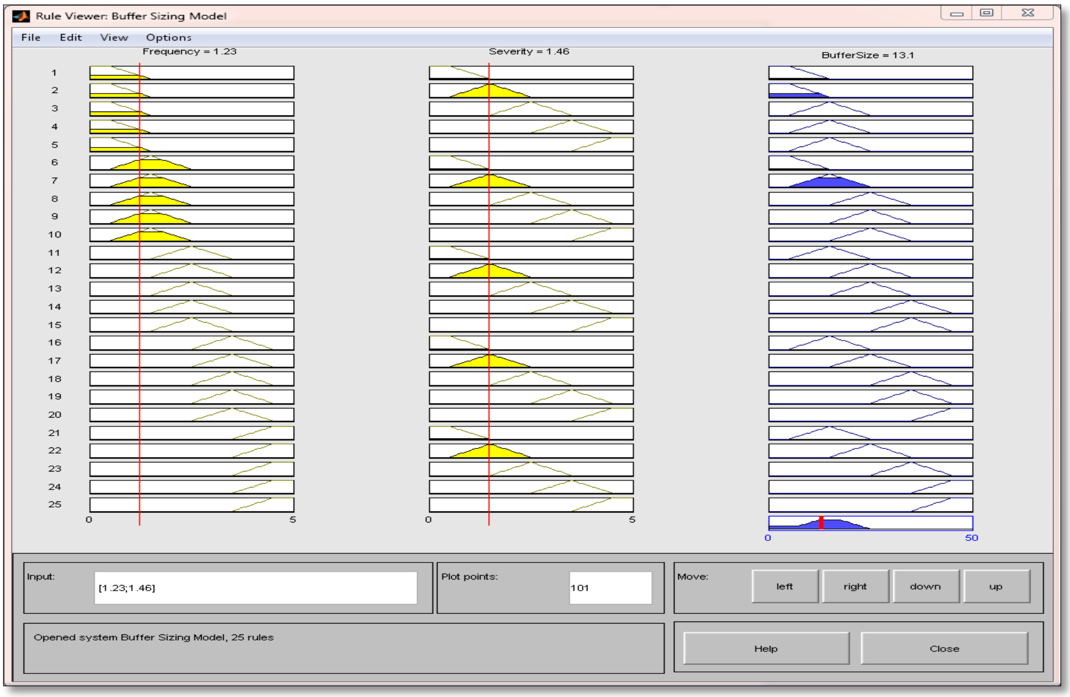

Figure B. 59: Results in the Rule Viewer for the Input Values “1.23, 1.46”

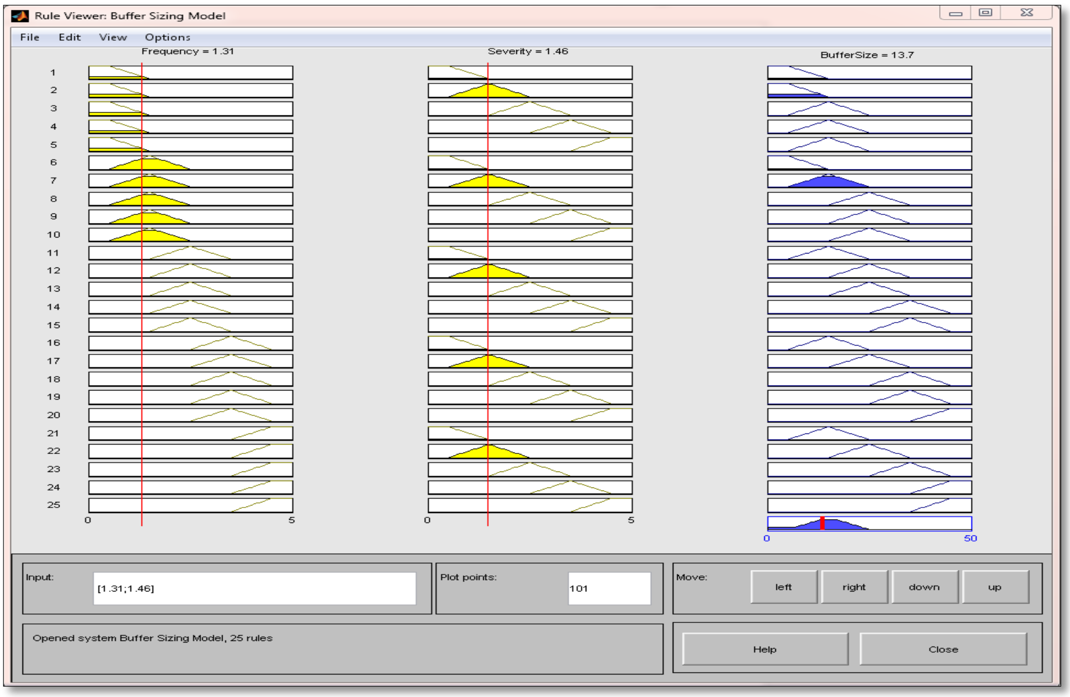

Figure B. 60: Results in the Rule Viewer for the Input Values “1.31, 1.46”

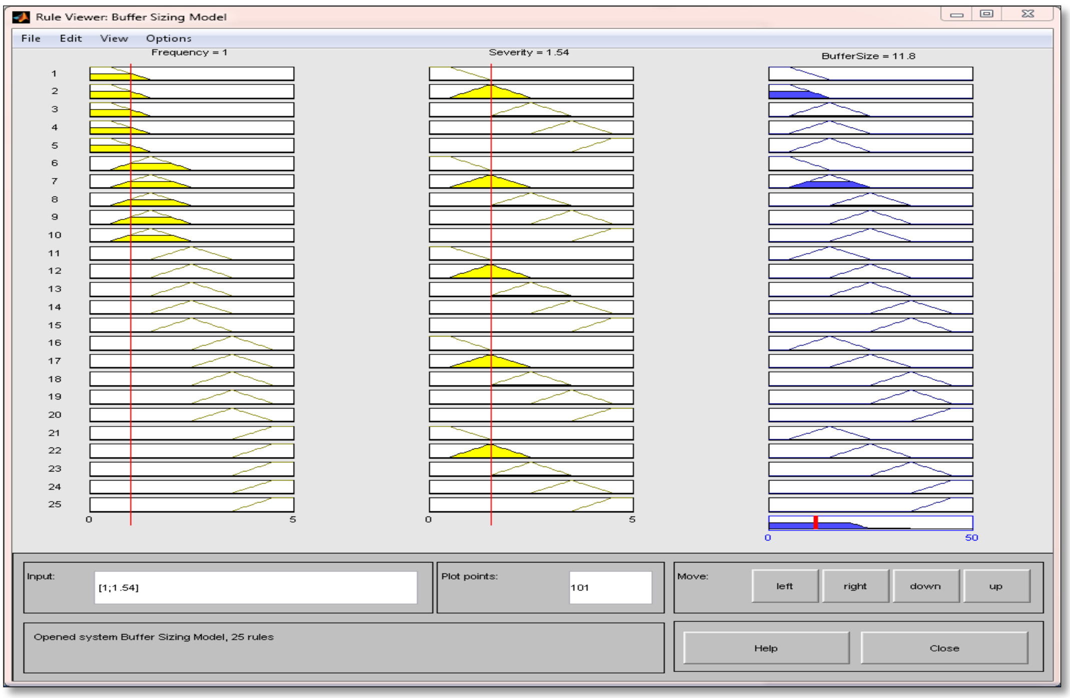

Figure B. 61: Results in the Rule Viewer for the Input Values “1.00, 1.54”

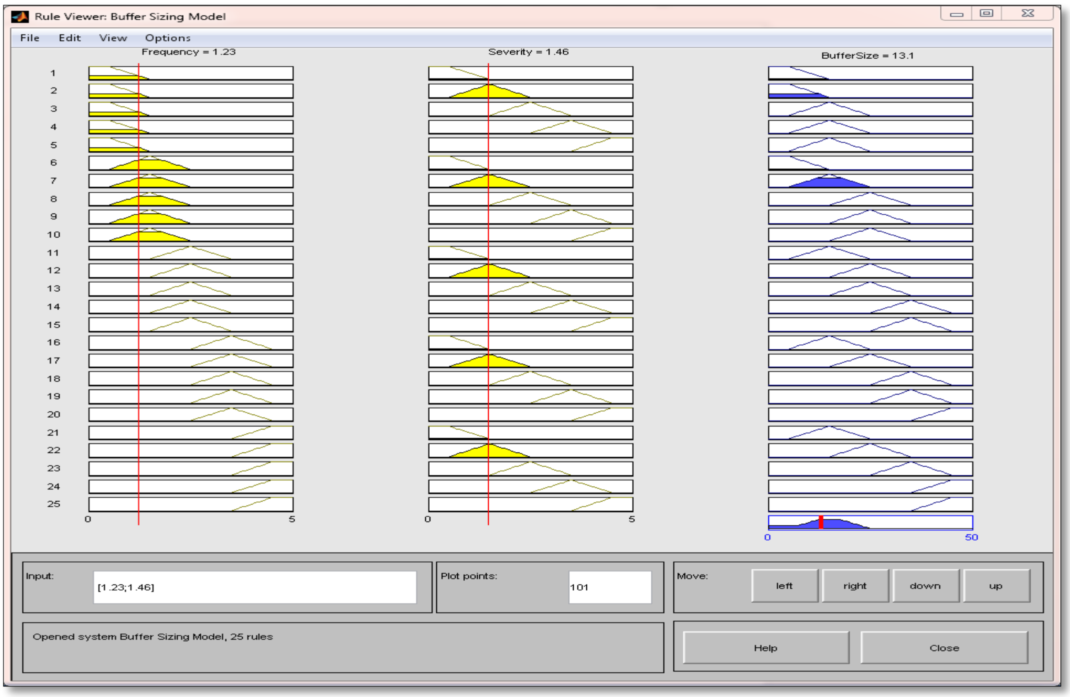

Figure B. 62: Results in the Rule Viewer for the Input Values "1.23, 1.46"

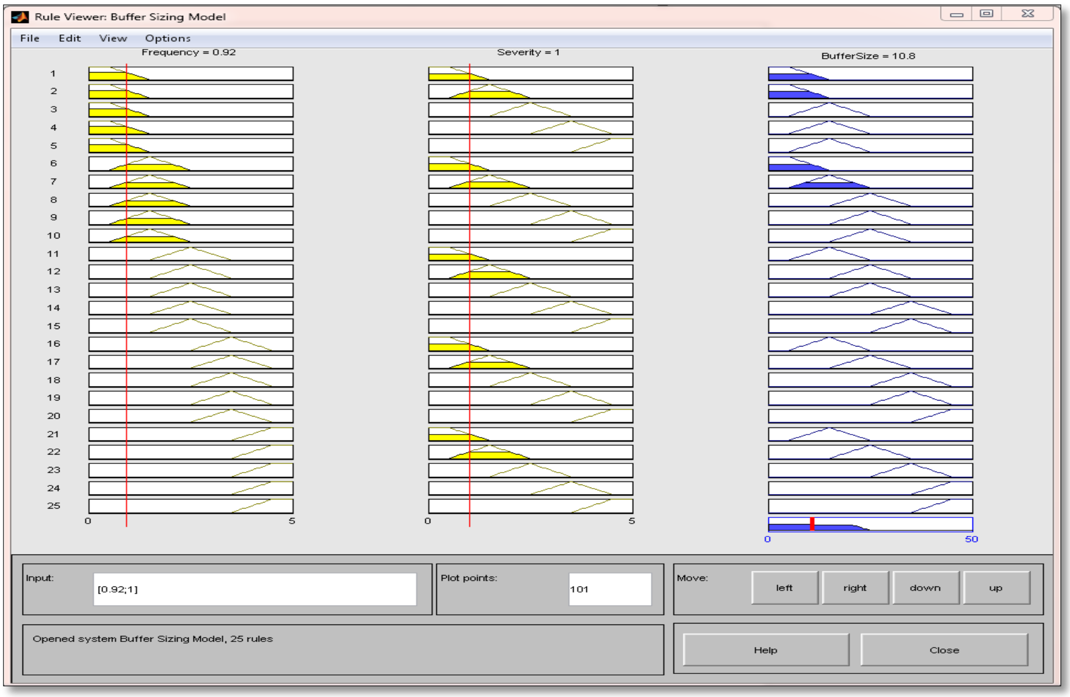

Figure B. 63: Results in the Rule Viewer for the Input Values "0.92, 1.00"

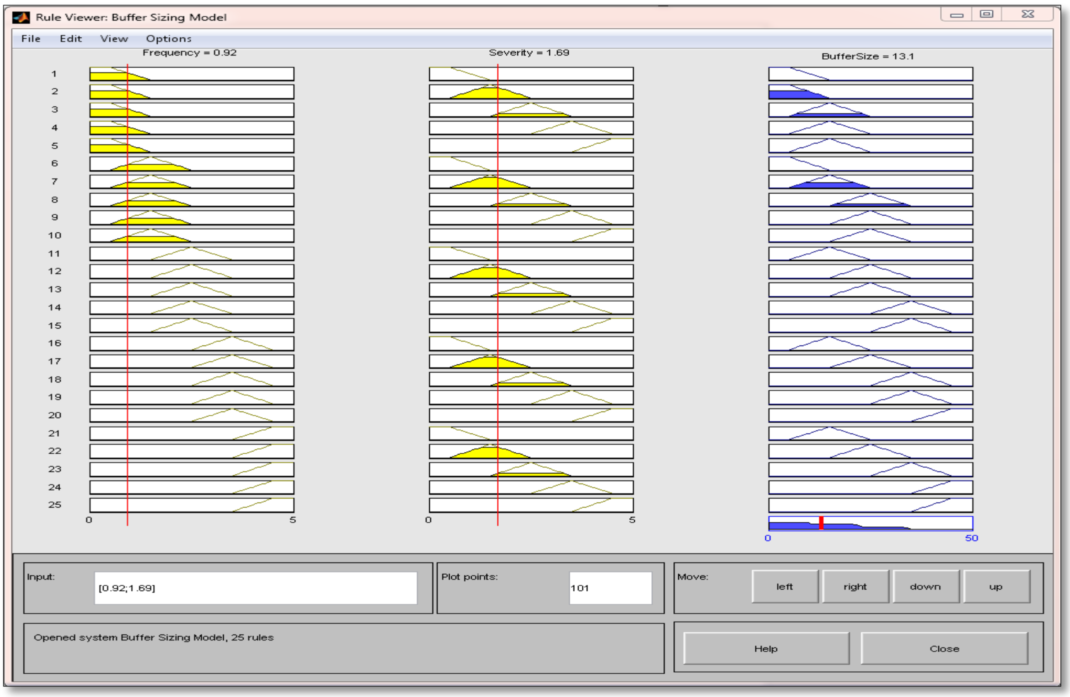

Figure B. 64: Results in the Rule Viewer for the Input Values "0.92, 1.69"

Figure B. 65: Results in the Rule Viewer for the Input Values "0.92, 1.31"

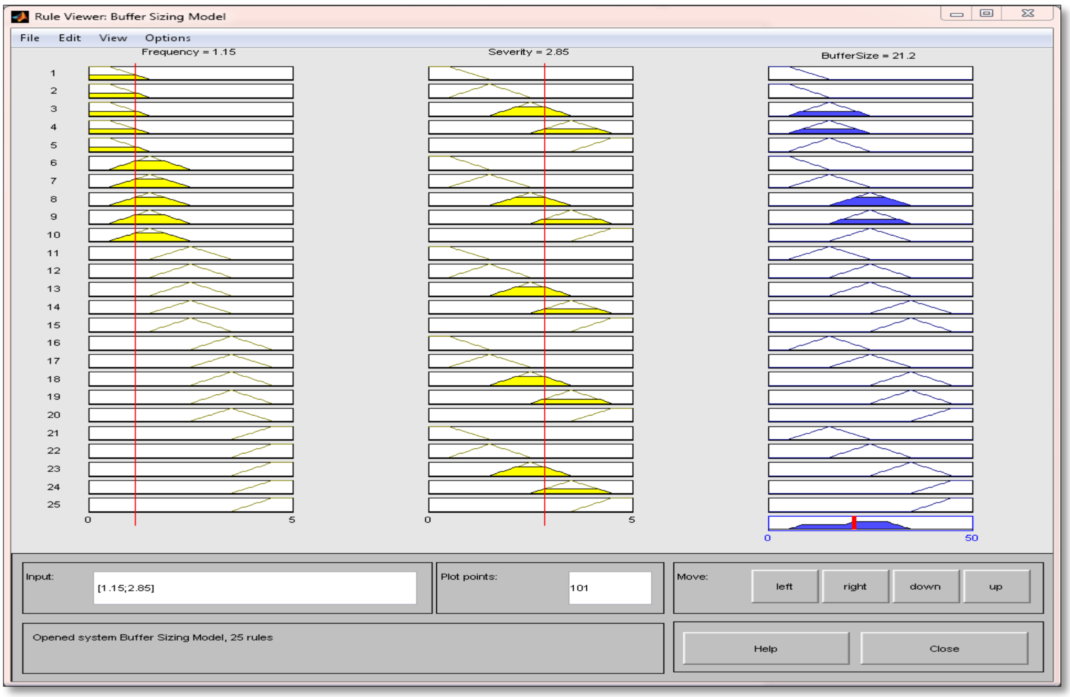

Figure B. 66: Results in the Rule Viewer for the Input Values "1.15, 2.85"

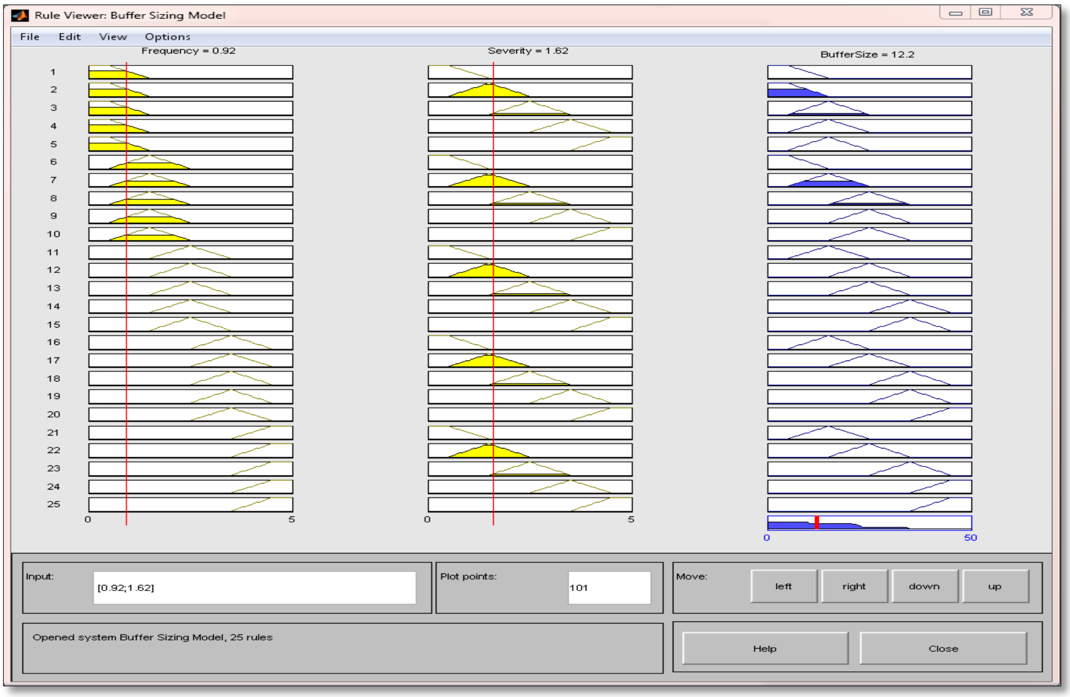

Figure B. 67: Results in the Rule Viewer for the Input Values "0.92, 1.62"

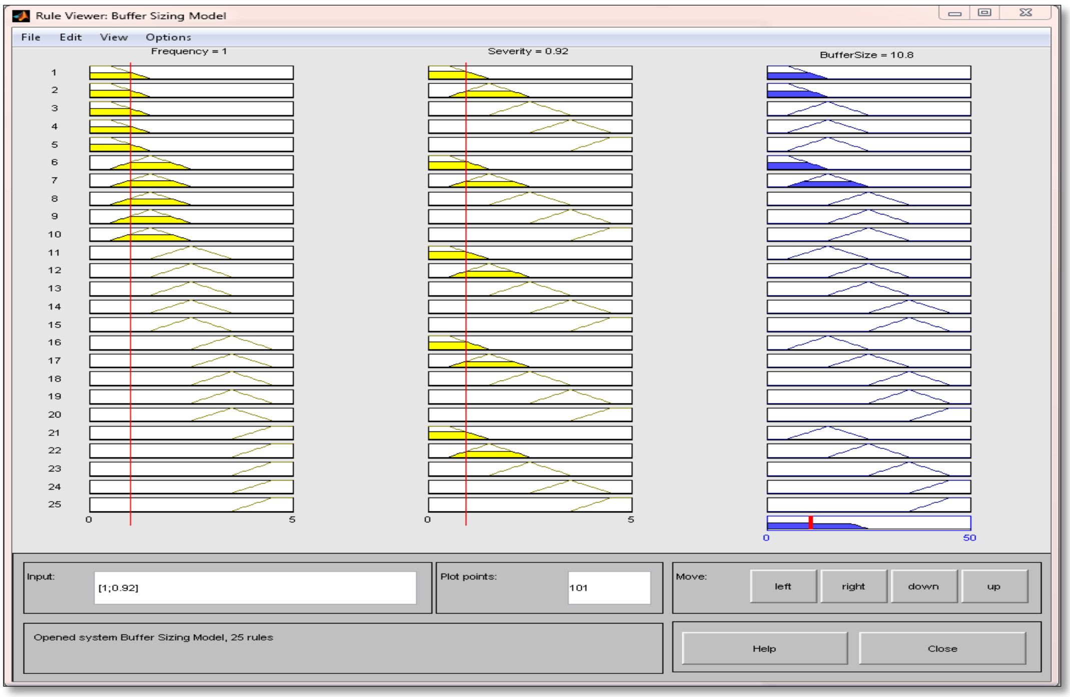

Figure B. 68: Results in the Rule Viewer for the Input Values “1.00, 0.92”

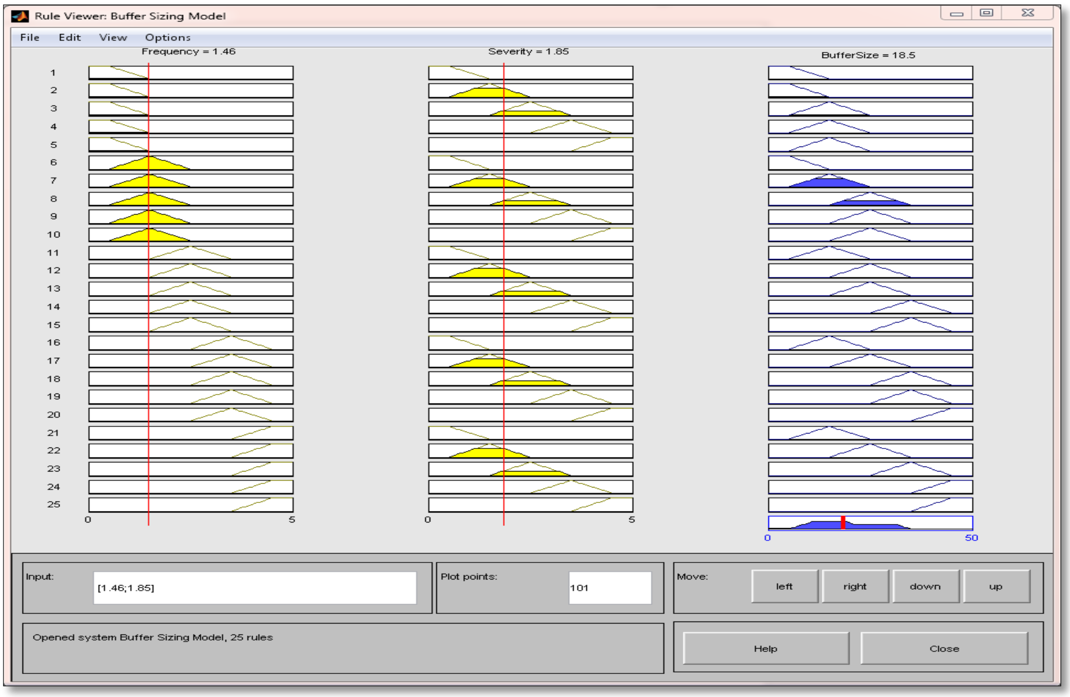

Figure B. 69: Results in the Rule Viewer for the Input Values “1.46, 1.85”

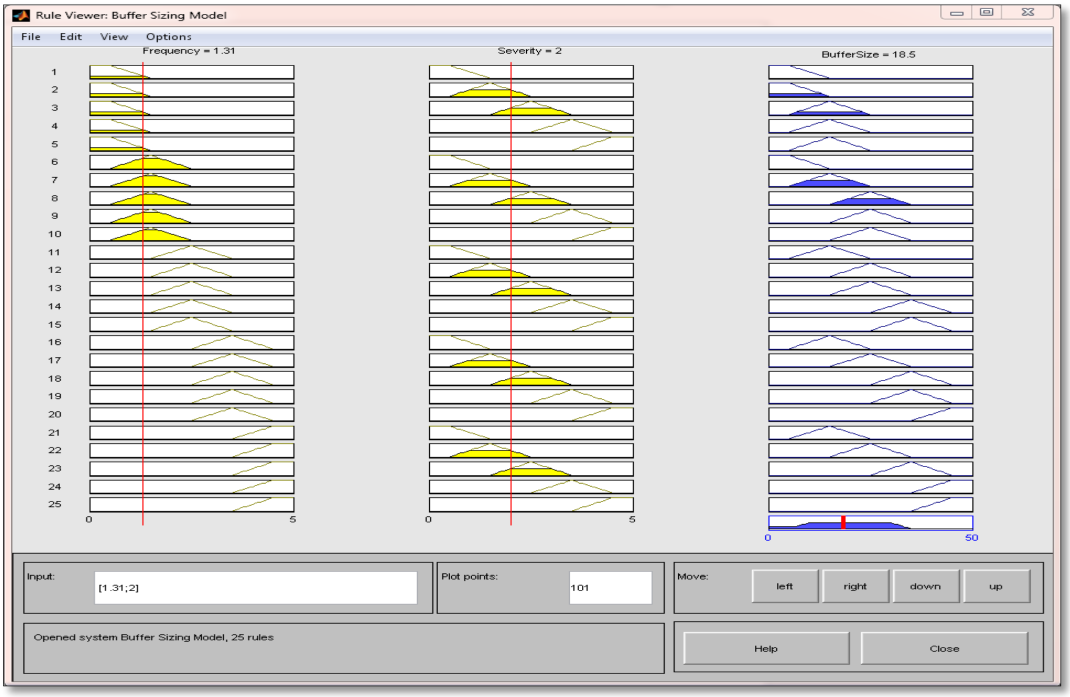

Figure B. 70: Results in the Rule Viewer for the Input Values “1.31, 2.00”

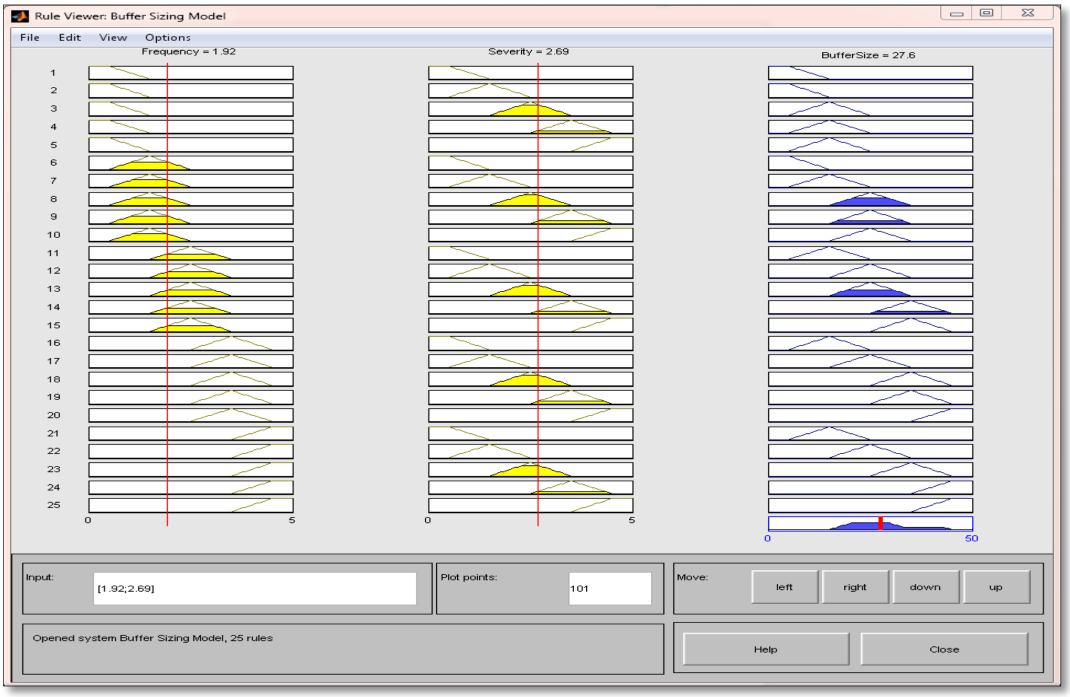

Figure B. 71: Results in the Rule Viewer for the Input Values “1.92, 2.69”

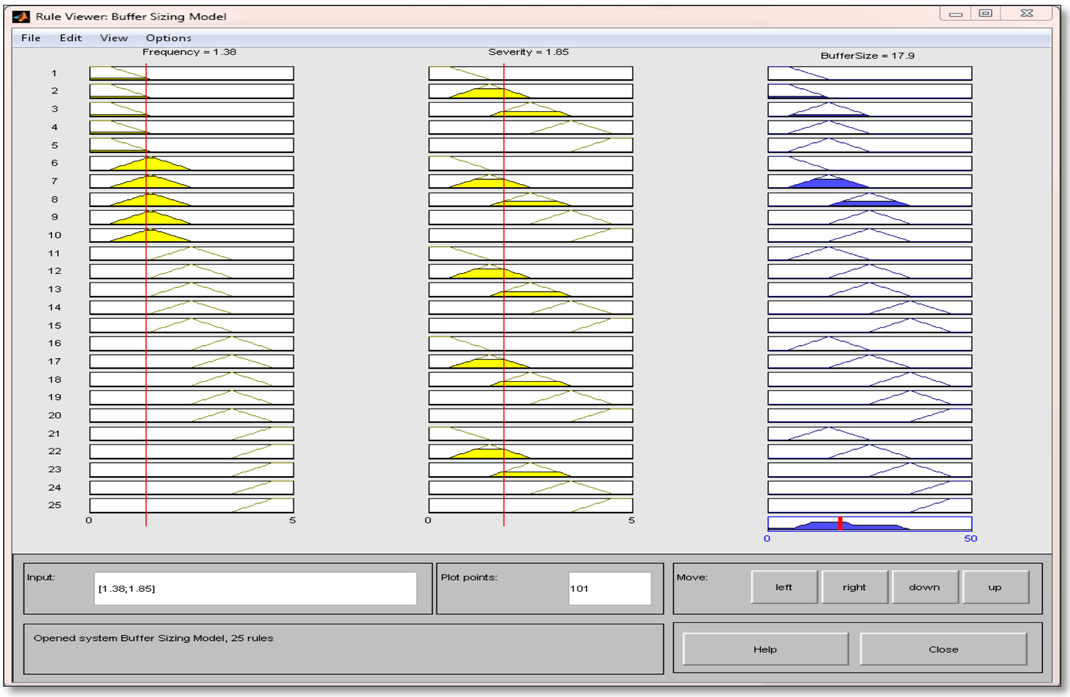

Figure B. 72: Results in the Rule Viewer for the Input Values “1.38, 1.85”

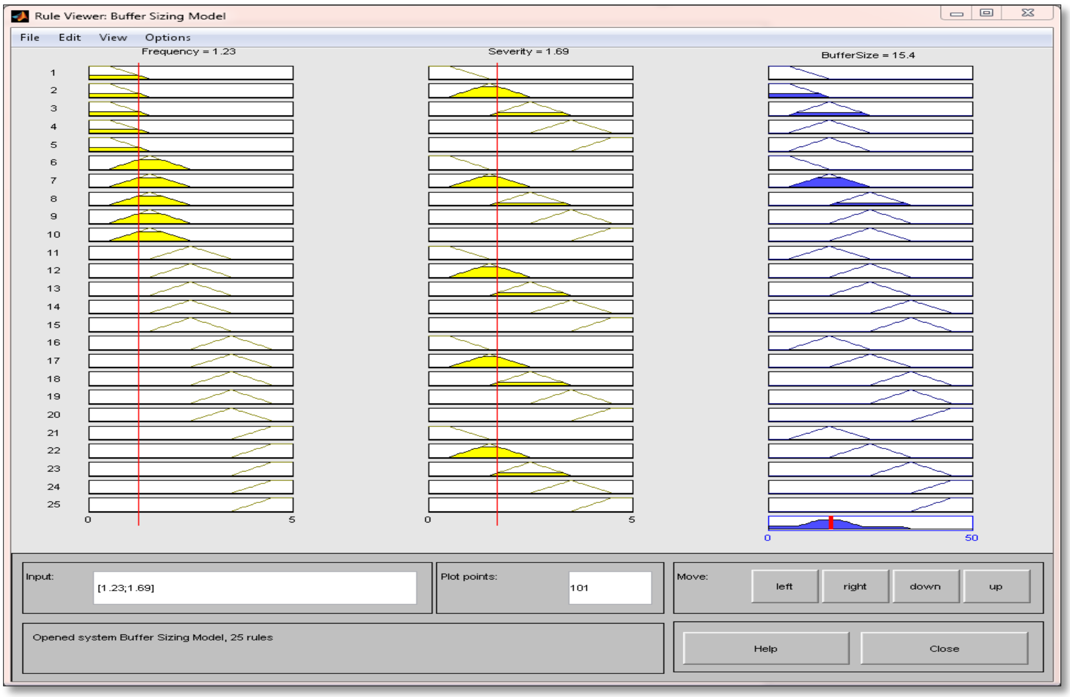

Figure B. 73: Results in the Rule Viewer for the Input Values “1.23, 1.69”

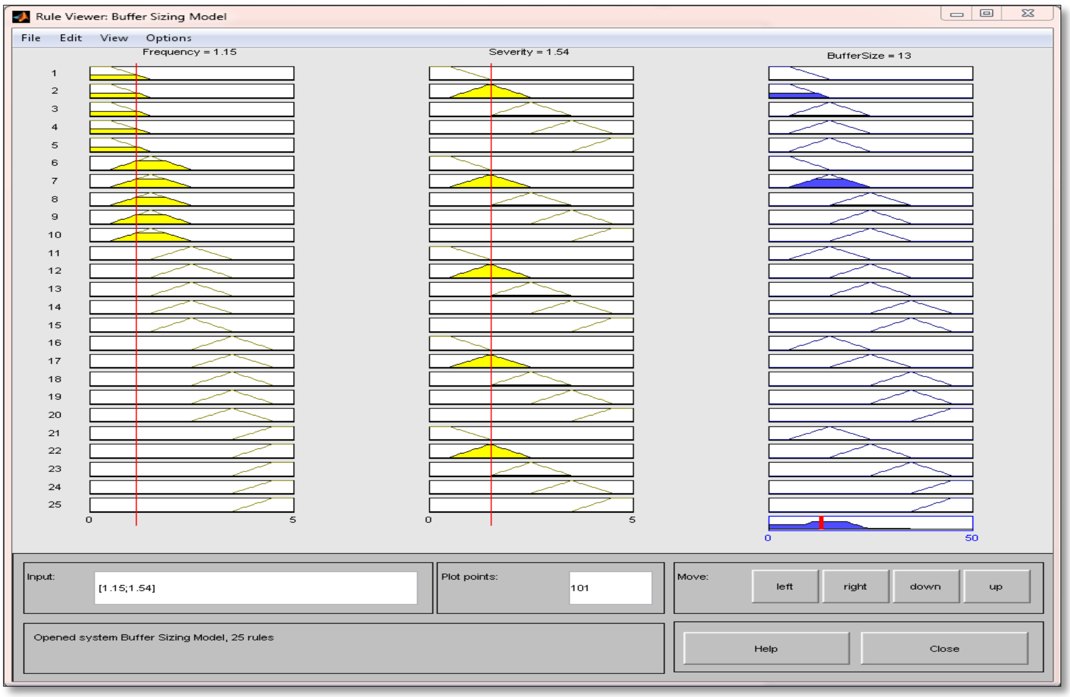

Figure B. 74: Results in the Rule Viewer for the Input Values “1.15, 1.54”

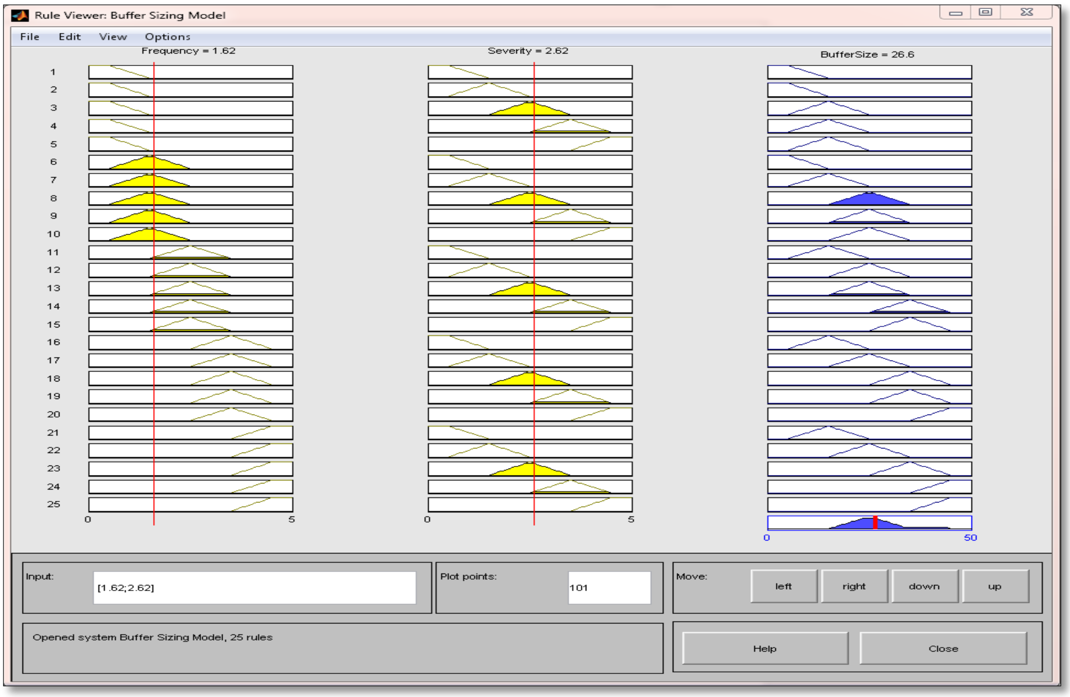

Figure B. 75: Results in the Rule Viewer for the Input Values “1.62, 2.62”

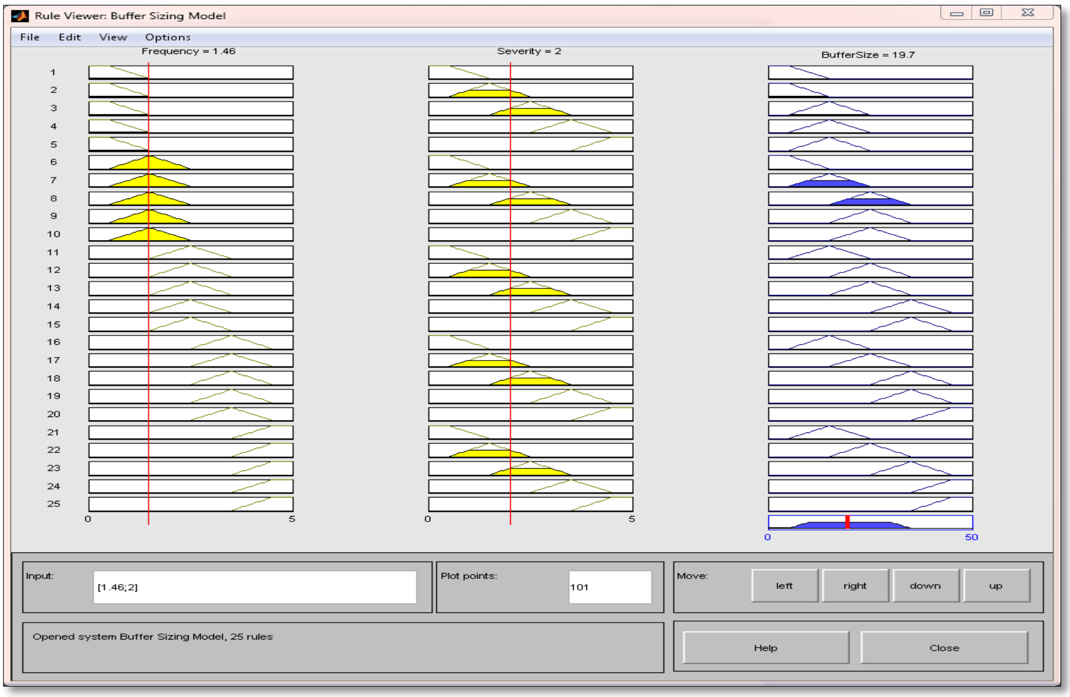

Figure B. 76: Results in the Rule Viewer for the Input Values "1.46, 2.00"

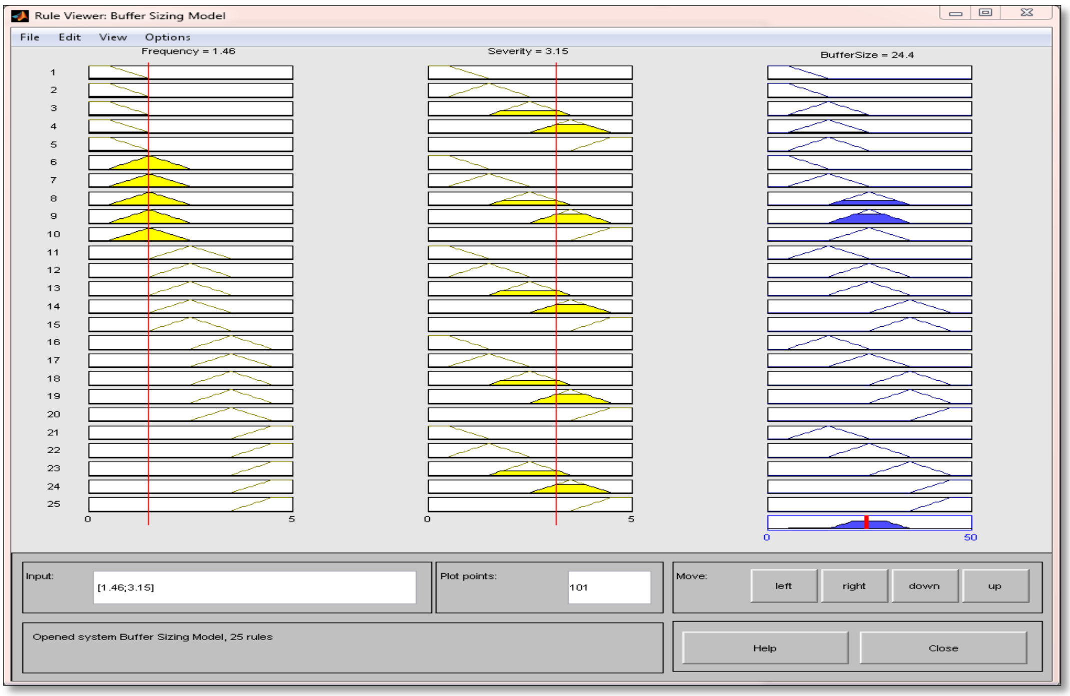

Figure B. 77: Results in the Rule Viewer for the Input Values "1.46, 3.15"

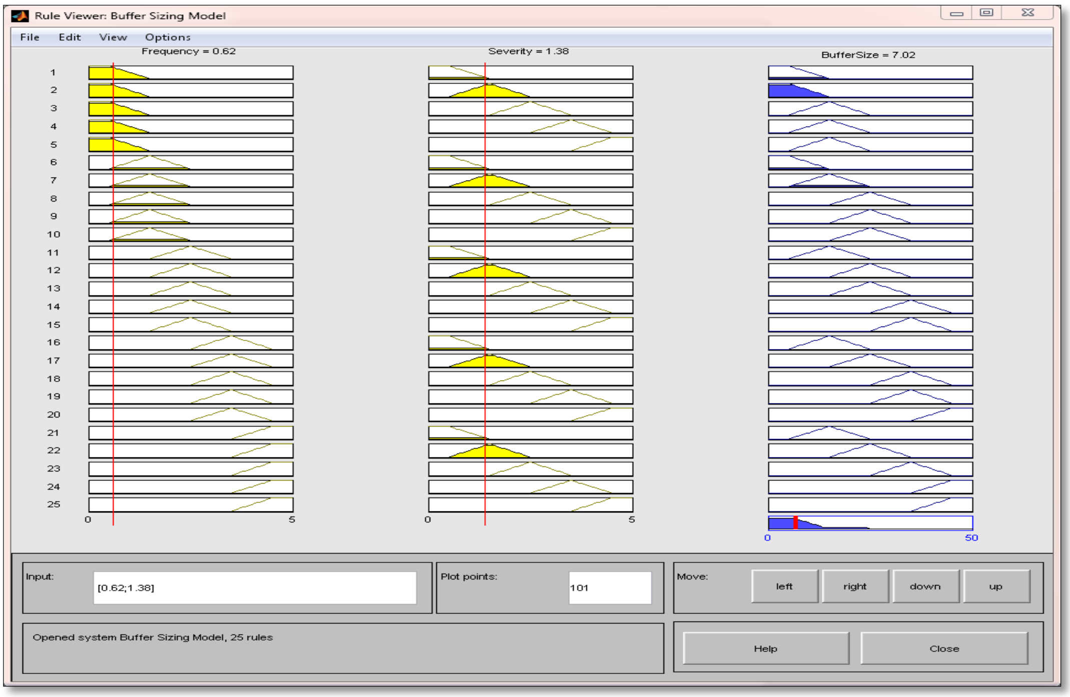

Figure B. 78: Results in the Rule Viewer for the Input Values “0.62, 1.38”

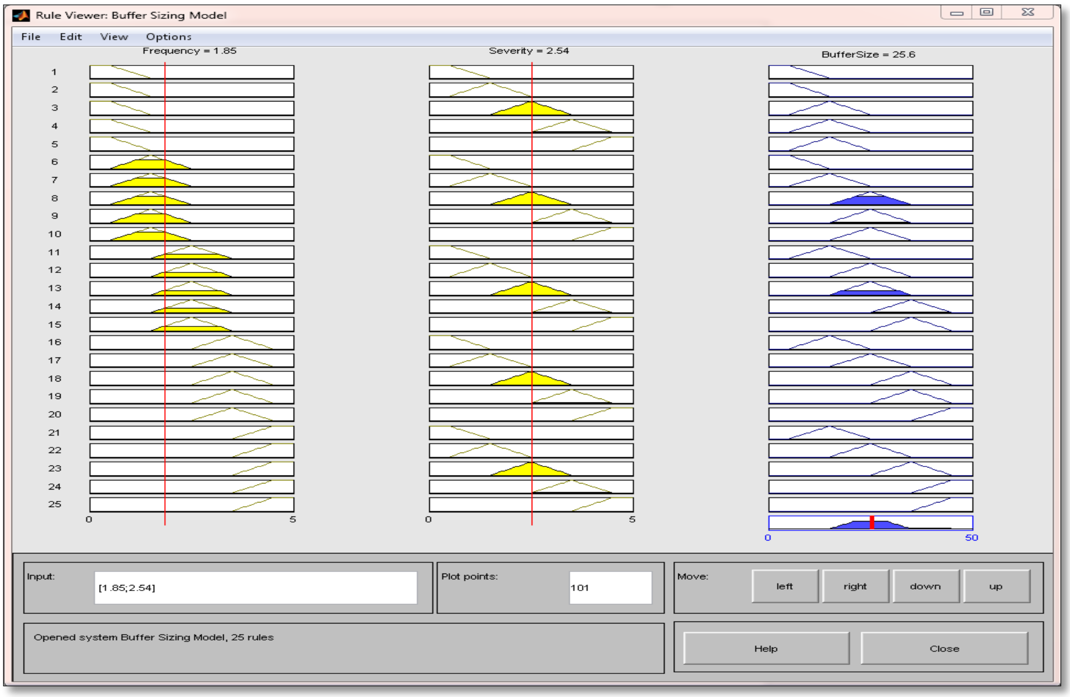

Figure B. 79: Results in the Rule Viewer for the Input Values “1.85, 2.54”

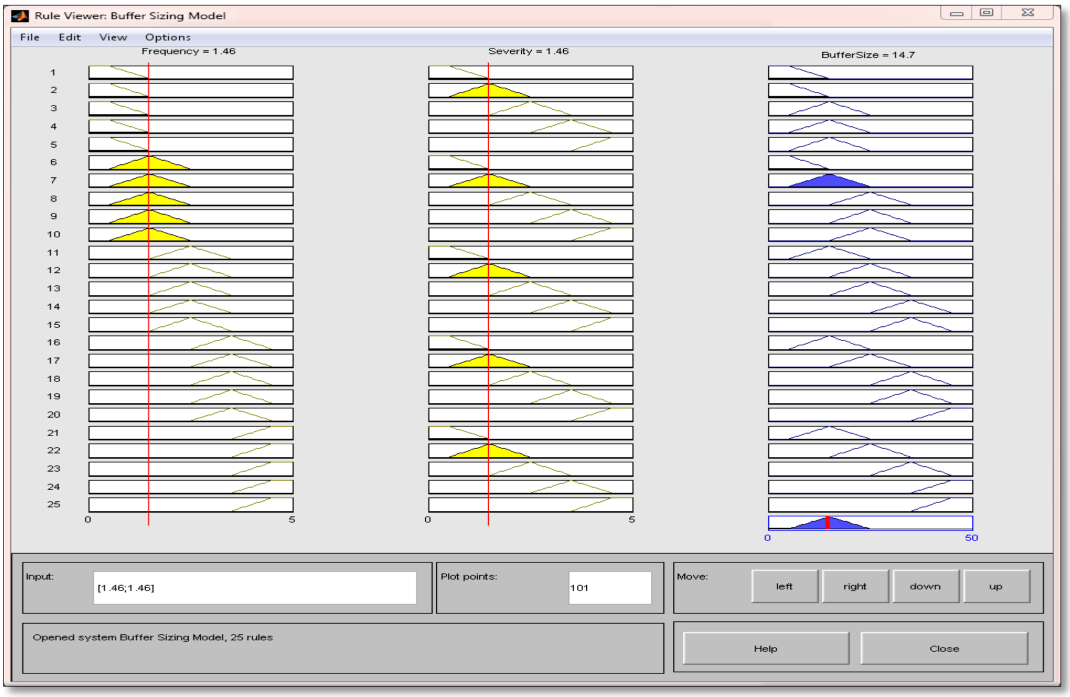

Figure B. 80: Results in the Rule Viewer for the Input Values “146, 1.46”

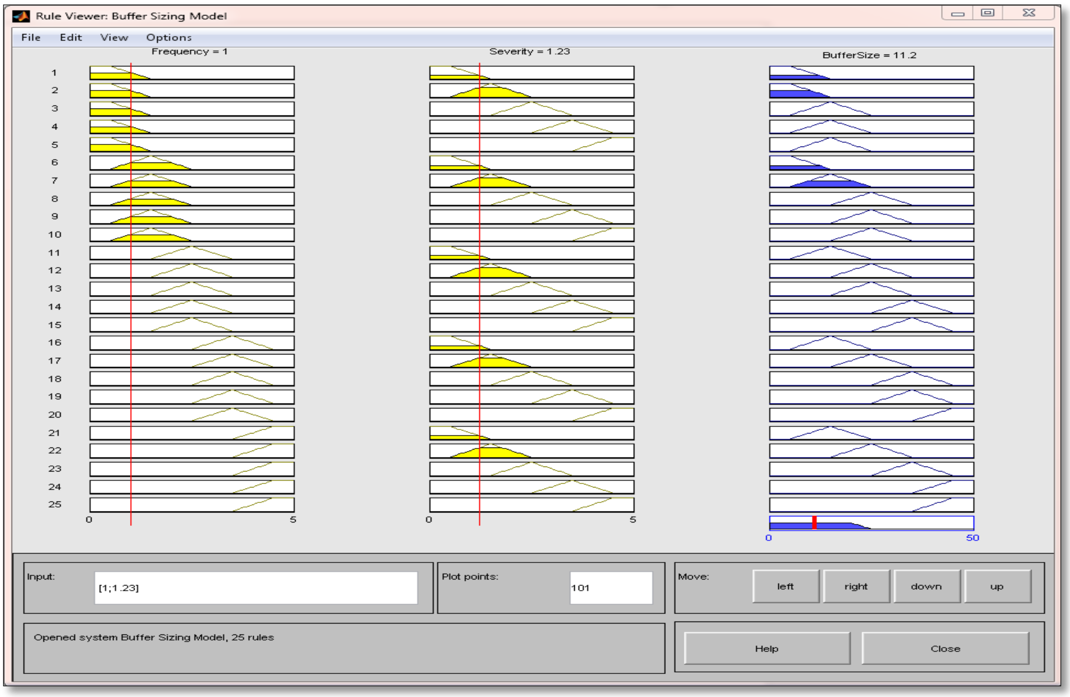

Figure B. 81: Results in the Rule Viewer for the Input Values “1.00, 1.23”

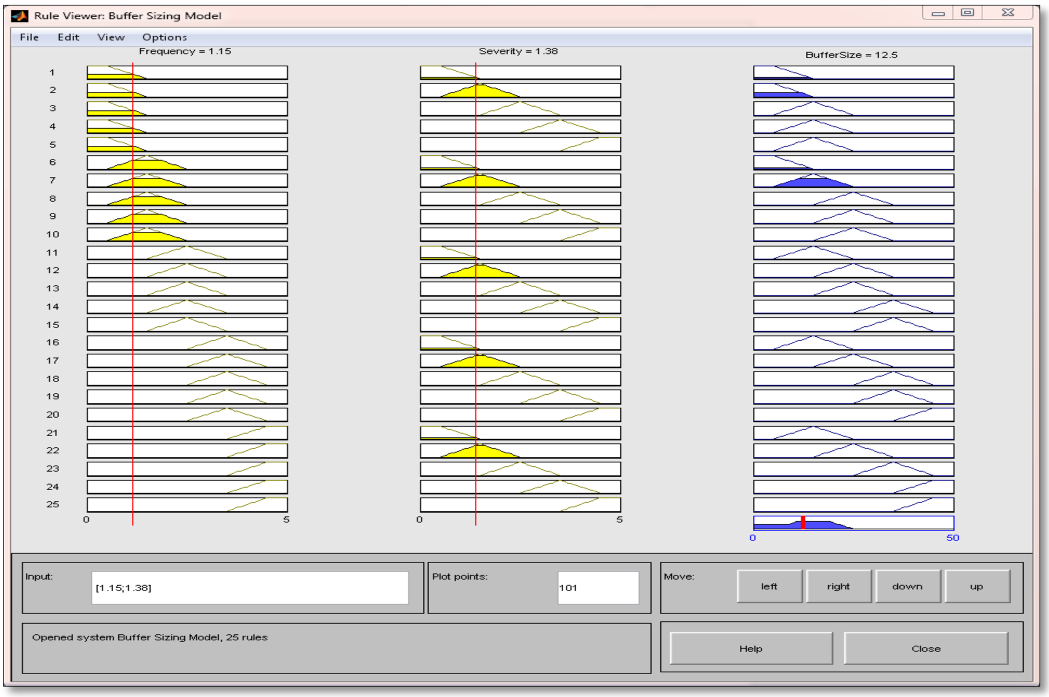

Figure B. 82: Results in the Rule Viewer for the Input Values "1.15, 1.38"

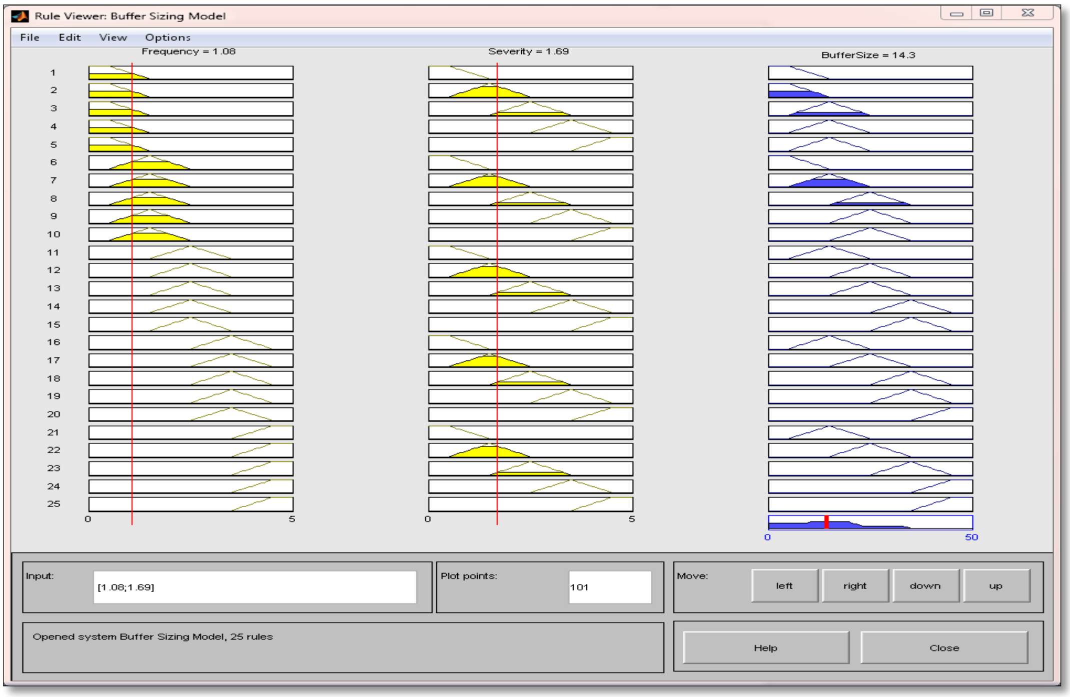

Figure B. 83: Results in the Rule Viewer for the Input Values "1.08, 1.69"

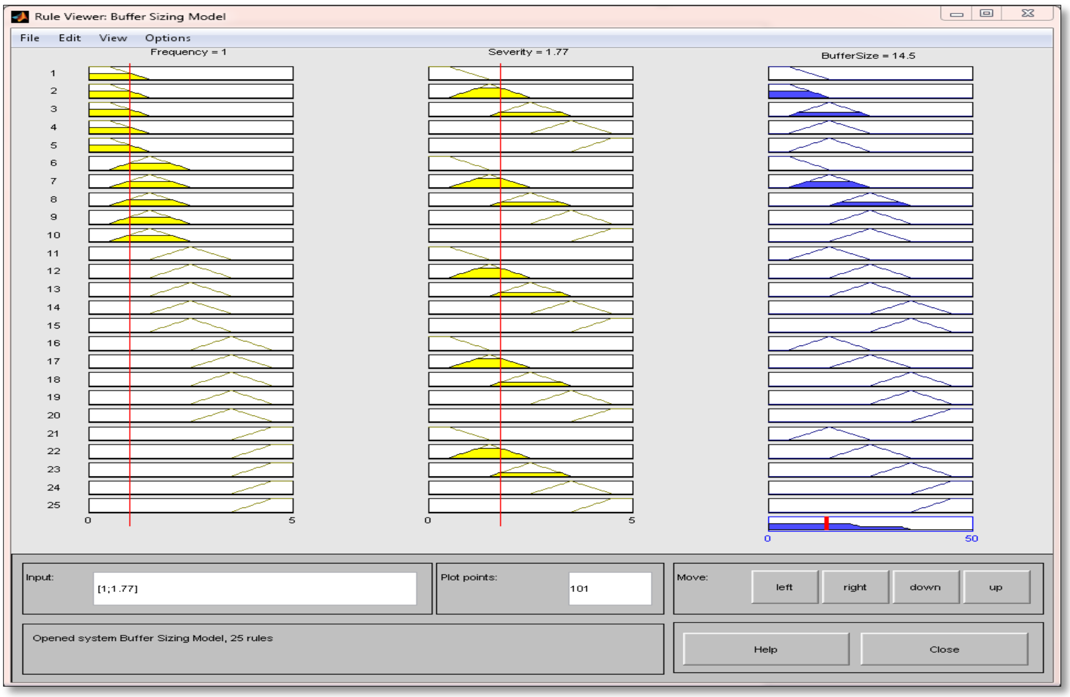

Figure B. 84: Results in the Rule Viewer for the Input Values “1.00, 1.77”

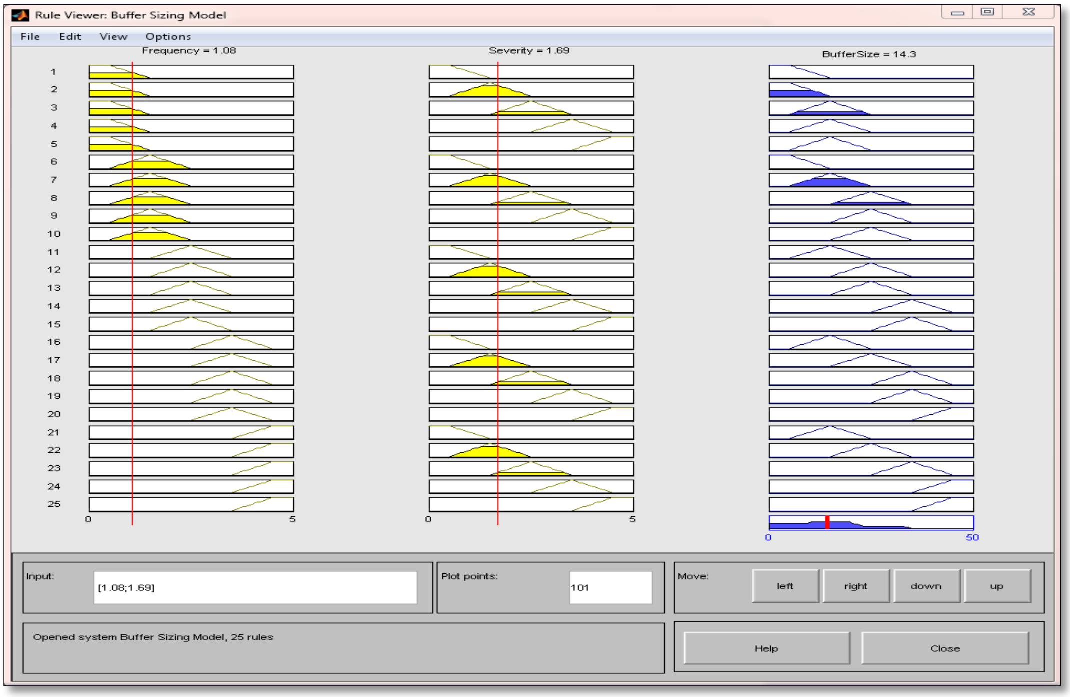

Figure B. 85: Results in the Rule Viewer for the Input Values “1.08, 1.69”

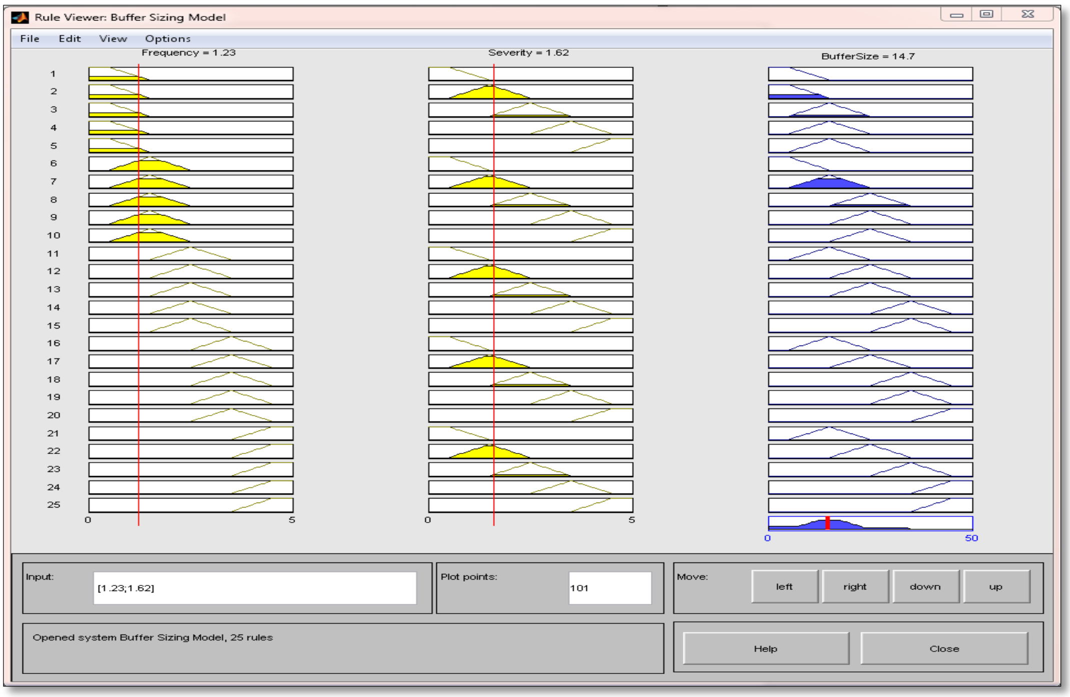

Figure B. 86: Results in the Rule Viewer for the Input Values “1.23, 1.62”

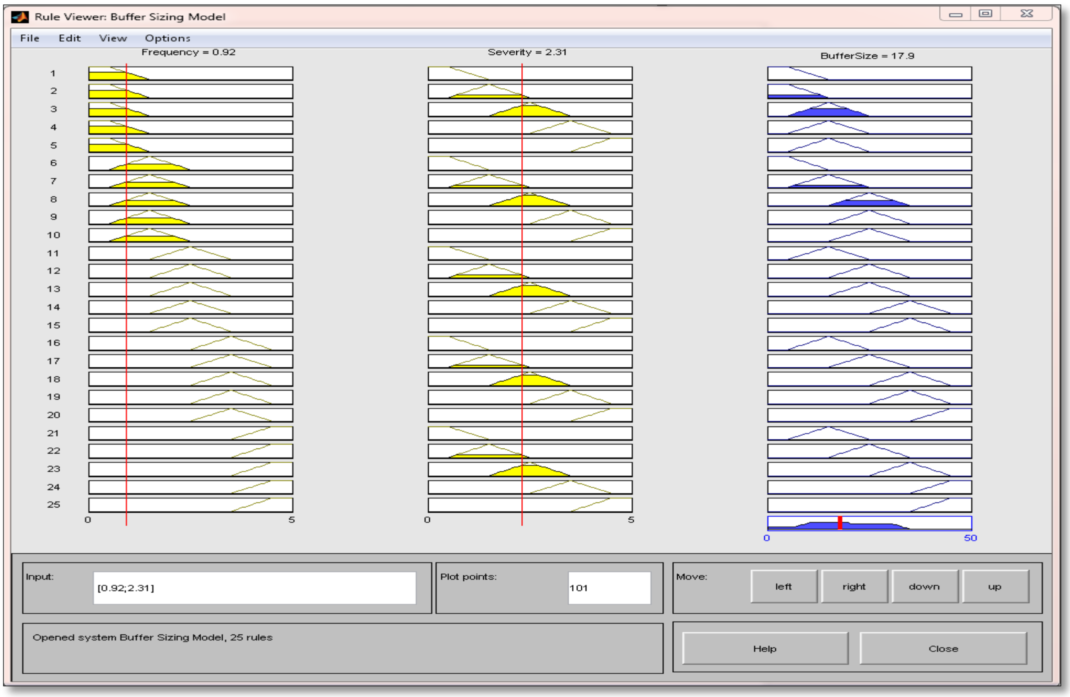

Figure B. 87: Results in the Rule Viewer for the Input Values “0.92, 2.31”

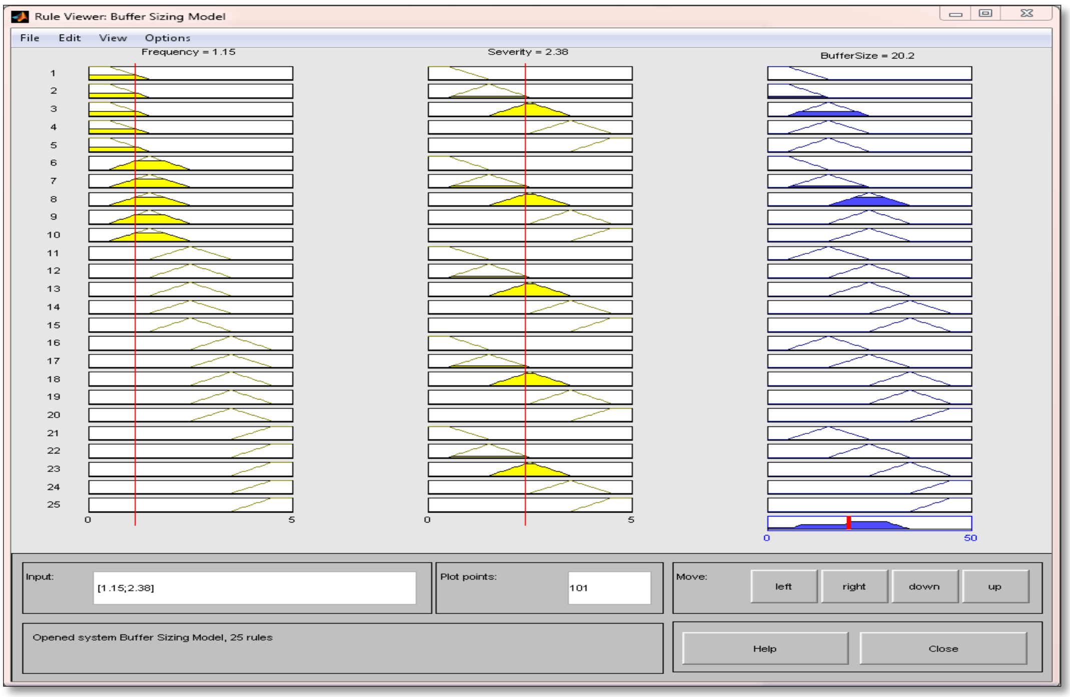

Figure B. 88: Results in the Rule Viewer for the Input Values “1.15, 2.38”

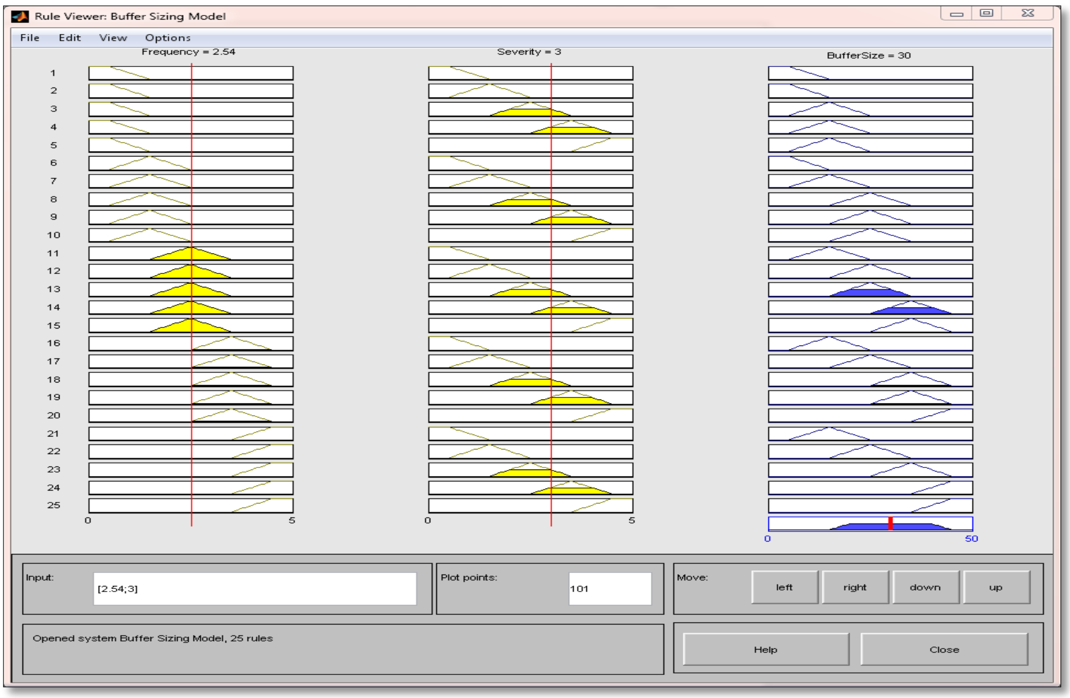

Figure B. 89: Results in the Rule Viewer for the Input Values “2.54, 3.00”