A PROBABILISTIC SCHEDULE DELAY ANALYSIS IN CONSTRUCTION PROJECTS BY USING FUZZY LOGIC INCORPORATED WITH RELATIVE IMPORTANCE INDEX (RII) METHOD

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A PROBABILISTIC SCHEDULE DELAY ANALYSIS IN CONSTRUCTION PROJECTS BY USING FUZZY LOGIC INCORPORATED WITH RELATIVE IMPORTANCE INDEX (RII) METHOD

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ABSTRACT

A PROBABILISTIC SCHEDULE DELAY ANALYSIS IN CONSTRUCTION PROJECTS BY USING FUZZY LOGIC INCORPORATED WITH RELATIVE IMPORTANCE INDEX (RII) METHOD

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The aim of this thesis is to propose a decision support tool for contractors before the bidding stage to quantify the probability of schedule delay in construction projects by using fuzzy logic incorporated with relative importance index (RII) method. Eighty three (83) different schedule delay factors were identified through detailed literature review and interview with experts from a leading Turkish construction company, then categorized into nine (9) groups and visualized by utilizing Ishikawa (Fish Bone) Diagrams. The relative importances of schedule delay factors were quantified by relative importance index (RII) method and the ranking of the factors and groups were demonstrated according to their importance level on schedule delay. A schedule delay assessment model was proposed by using Fuzzy Theory in order to determine a realistic time contingency by taking into account of delay factors characterized in construction projects. The assessment model was developed by using Fuzzy Logic Toolbox of the MATLAB Program Software. Proposed methodology was tested in a real case study and probability of schedule delay was evaluated by the assessment model after the required inputs were inserted to software. According to the case study results, the most contributing factors and groups (that need attention) to the probability of schedule delays were discussed. The assessment model results were found to be conceivably acceptable and adequate for the purpose of this thesis.

Keywords: Construction Projects, Fuzzy Theory, Probability, Relative Importance Index, Schedule Delay

ÖZ

İNŞAAT PROJELERİNDE BULANIK MANTIK İLE BİRLİKTE GÖRECELİ ÖNEM İNDEKSİ METODU BERABERLİĞİNDE BİR OLASILIKSAL SÜRE GECİKMESİ ANALİZİ

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Yüksek Lisans, İnşaat Mühendisliği Bölümü

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Bu tezin amacı, yüklenicilerin ihaleye teklif verme aşamasından önce, inşaat projelerindeki süresel gecikme ihtimalinin ölçülmesi için bulanık mantık ile birlikte göreceli önem indeksi metodu beraberliğinde bir karar destek aracı önerilmesidir. Ayrıntılı literatür taraması ve önde gelen bir Türk inşaat şirketi uzmanları ile yapılan görüşmeler ışığında birbirinden farklı seksen üç (83) adet süresel gecikme faktörü belirlenmiştir. Belirlenen faktörler, dokuz (9) grupta kategorize edilmiş ve Ishikawa (Balık Kılçığı) diyagramları kullanılarak görselleştirilmiştir. Bu gecikme faktörlerinin göreceli önem düzeyleri, göreceli önem indeksi metodu kullanılarak hesaplanmış, ve bu gecikme faktörleri ve grupları, göreceli önem düzeylerine göre sıralanmıştır. Gerçekçi bir süre kontenjanı belirlenebilmesi için, bulanık mantık teorisi kullanılarak ve inşaat projelerine has gecikme faktörleri göz önüne alınarak bir süresel gecikme ölçme modeli önerilmiştir. Bu ölçme modeli MATLAB Program Yazılımının Bulanık Mantık Araç Kutusu kullanılarak geliştirilmiştir. Önerilen metod, gerçek bir örnek durum incelemesinde test edilmiş ve gerekli girdilerin programa girilmesi neticesinde projenin süresel gecikme olasılığı hesaplanmıştır. Örnek durum incelemesi sonuçlarına gore, süresel gecikmelere neden olan en önemli farktörler ve gruplar

belirlenmiş ve tartışılmıştır. Önerilen modelin sonuçları makul ve kabul edilebilir bulunmuş ve bu tezin amacına uygun ve yeterli olduğu sonucuna varılmıştır.

Anahtar Kelimeler: İnşaat Projeleri, Bulanık Mantık Teorisi, Olasılık, Göreceli Önem İndeksi, Süre Gecikmesi

To My Family

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$\cap$	Intersection operator
$\cup$	Union operator
$\overline{}$	Complement operator
$\mu A(x)$	Membership of x into A
$\in$	Element
$\notin$	Not an element
℃	Degree Celsius
BOA	Bisector of Area
BOTAŞ	Petroleum Pipeline Corporation
COG	Center of Gravity
FIS	Fuzzy Inference System
LOM	Largest of Maxima
MOM	Mean of Maxima
RII	Relative Importance Index
SOM	Smallest of Maxima
U	Universe of discourse
USA	United States of America

ABBREVIATIONS

A	Absenteeism
ADC	Accidents during construction
CBC	Conflicts between consultant and design engineer
CBJ	Conflicts between joint-ownership
CIG	Changes in government regulations and laws
CIM	Changes in material types and specifications during construction
CO	Change orders
COP	Complexity of project design
COT	Complexity of the project
CRG1	Consultant Related Group
CRG2	Contractor Related Group
CWP	Conflict, war, and public enemy
DCB	Design changes by owner or his agent during construction
DEM	Design errors made by designers
DIA1	Delay in approving major changes in the scope of work by consultant
DIA2	Delay in approving design documents
DIM	Delay in manufacturing materials
DIO	Delay in obtaining permits from municipality
DIP	Delay in performing final inspection and certification by a third party
DIP1	Delay in performing inspection and testing
DIP2	Delay in providing services from utilities (such as water, electricity)
DIP3	Delay in progress payments

DIS	Delay in site delivery
DOS	Damage of sorted materials
DRG	Design Related Group
EAP	Equipment allocation problem
EOM	Escalation of material prices
ERG1	Equipment Related Group
ERG2	External Related Group
FEB	Frequent equipment breakdowns
FCO	Frequent change of subcontractors
GFC	Global financial crisis
H	High
ICE	Inadequate contractor experience
ICM	Inappropriate construction methods
IDC	Insufficient data collection and survey before design
IDO	Inadequate definition of substantial completion
IDP	Ineffective delay penalties
IE	Improper equipment
IME	Inadequate modern equipment
IPF	Improper project feasibility study
IPM	Inadequate project management assistance
IPP	Ineffective project planning and scheduling
IPT	Incompetent project team
ISI	Inaccurate site investigation
L	Low
LDB	Legal disputes between project participants
LDO	Late delivery of materials
LEO	Low efficiency of equipment

LIR	Late in reviewing and approving design documents
LMA	Low motivation and morale of labor
LOC	Lack of capable representative
LOE1	Lack of experience of consultant in construction projects
LOE2	Lack of experience of design team in construction projects
LOE3	Lack of experience of owner in construction projects
LOI	Lack of incentives for contractor to finish ahead of schedule
LOT	Loss of time by traffic control and restriction at job site
LRG	Labor Related Group
LPO	Low productivity of labor
M	Medium
MAD	Mistakes and delays in producing design documents
MOO	Misunderstanding of owner's requirements by design engineer
MRG	Materials Related Group
ND	Natural disasters (flood, hurricane, earthquake)
OCD	Original contract duration is short
ORG	Owner Related Group
OT	Obsolete technology
PCA	Personal conflicts among labor
PCC1	Poor communication and coordination with other parties
PCC2	Poor communication and coordination with other parties
PCC3	Poor communication and coordination with other parties
PF	Price fluctuations
PPO	Poor procurement of construction materials
PRG	Project Related Group
PQO	Poor quality of construction materials
PSM	Poor site management and supervision

PUO	Poor use of advanced engineering design software
PWN	Problem with neighbors
RDT	Rework due to errors
S	Strike
SDP	Schedule Delay Probability
SID	Slowness in decision making
SMO1	Slow mobilization of equipment
SMO2	Slow mobilization of labor
SOC	Shortage of construction materials
SOE	Shortage of equipment
SOL	Shortage of labor
SOW	Suspension of work by owner
SSC	Slow site clearance
UAI	Unclear and inadequate details in drawings
UCC	Unfavorable contract clauses
UEL	Unqualified / inadequate experienced labor
UWC	Unfavorable weather conditions
US	Unreliable subcontractors
US2	Unreliable suppliers
USS	Unexpected surface& subsurface conditions (such as soil, hw table)
VH	Very High
VL	Very low

CHAPTER 1

INTRODUCTION

1.1 Introduction

The construction industry is one of the largest if not the largest, major industries in any country in the world, whether developing or developed. In the USA, the construction industry and the food industry are the two largest industries. In Turkey, the construction industry, food industry and the petroleum industry are the tree largest industries (Duran, O. (2006)).

A construction project is commonly acknowledged as successful, when it is completed on time, within budget, in accordance with the specifications and to stakeholders' satisfaction (Majid, I. A. (2006))**.** Project success can be defined as meeting goals and objectives as prescribed in the project plan. A successful project means that the project has accomplished its technical performance, maintained its schedule, and remained within budgetary costs (Frimpong, et al. (2003)).

In construction industry, contractors want to maximize their profit in order to grow in the market. To achieve this aim, it is crucial for contractors to carefully identify the factors that affect the success of project and estimate their impacts before the bidding stage.

Projects may differ in size, duration, objectives, uncertainty, complexity, pace, and some other dimensions. It does not matter how different or unique a project is; there is no doubt that every project contains some degree of uncertainty. It is required to be aware of these uncertainties and to develop the necessary responses to get the desired level of project success (Tüysüz, F., Kahraman, C. (2006)).

1.2 Problem Statement

Construction projects are one-off endeavors with many unique features such as long period, complicated processes, abominable environment, financial intensity and dynamic organization structures (Zou, et al. (2007)).

The construction industry has a very poor reputation for coping with delays. Delay analysis is either ignored or done subjectively by simply adding a contingency. As a result many major projects fail to meet schedule deadlines. In a construction project where time truly equals money, the management of time is critical (Duran, O. (2006)), thus predicting the likelihood of schedule delay may play a key role towards project success (Luu, et al. (2009). Schedule delay means non-completion of the project within the specified duration agreed on contract. According to Kaming, et al. (1997a) and Trigunarsyah, B. (2004), schedule delay is the extension of time beyond planned completion dates traceable to the contractors. Elinwa and Joshua (2001) defined it as the lapse between the agreed estimation or completion data and the actual data of completion. In Indonesia, Trigunarsyah, B. (2004) identified that only 47% of the projects were completed within the schedule, 15% ahead of schedule, and 38% were behind schedule.

Schedule delays are common in various construction projects and cause considerable losses to project parties. It is widely accepted that construction project schedule plays a key role in project management due to its influence on project success (Luu, et al. (2009). The common results of schedule delays are: Late completion of project, increased cost, disruption of work, loss of productivity, third party claims, disputes and abandonment or termination of contracts. Therefore schedule delays in construction projects give rise to dissatisfaction to all the parties involved (Majid, I. A. (2006)).

It is clear that predicting the probability of schedule delay plays a key role towards project success and the contractor should carefully quantify it to determine a reliable time contingency before the bidding stage in order to achieve project success. Thus, there exists a need to develop a probabilistic schedule delay analysis model as a decision support tool for contractors before the bidding stage.

1.3 Aim of the Study

This research aimed to propose a decision support tool for contractors before the bidding stage to quantify the probability of schedule delay in construction projects by using fuzzy logic incorporated with relative importance index (RII) method.

To achieve the above aim, the following objectives have been identified:

1) To identify the schedule delay factors in construction projects.

2) To categorize the schedule delay factors in construction projects by utilizing Ishikawa (Fish Bone) Diagrams.

3) To quantify relative importances of schedule delay factors and demonstrate the ranking of the factors and groups according to their importance level on schedule delay.

4) ***a)*** To determine the linguistic variables & fuzzy membership functions, ***b)*** to construct fuzzy rules (if-then, if-and-then rules), ***c)*** to determine the rules' weight by using Relative Importance Index (RII) method findings, and ***d)*** carry out aggregation & defuzzification operations to construct "the fuzzy assessment model to estimate the probability of schedule delay".

5) To propose a delay analysis model by using Fuzzy Theory in order to determine a realistic time contingency by taking into account of delay factors characterized in construction projects.

6) To test the proposed methodology in a real case study and to evaluate the probability of schedule delay.

7) To address the most contributing factors and groups to cause schedule delays (i.e., to discuss the probability of the factors and groups that need attention).

1.4 Thesis Organization

In Chapter 2, the revision of the literature which provided a key role in the development of this thesis will be presented.

In Chapter 3, the schedule delays in a construction project will be briefly explained. The causes of schedule delays will be identified, categorized and demonstrated by utilizing Ishikawa (Fishbone) Diagrams.

In Chapter 4, the basics of fuzzy set theory, fuzzy inference and fuzzy modeling will be presented. Based upon this theory, the proposed fuzzy probability assessment model will be constructed.

In Chapter 5, the relative importances of schedule delay factors will be quantified by using relative importance index (RII) method. The findings of this chapter will also serve to determine the fuzzy rules' weights to develop the fuzzy probability assessment model in the following chapter.

In Chapter 6, the proposed fuzzy probability assessment model will be developed in order to quantify the probability of schedule delay in construction projects by using Fuzzy Logic Toolbox of the MATLAB Program Software. A real case study will be presented as an application of the proposed tool.

In Chapter 7, conclusions of the study and recommendations of the future work will be discussed.

CHAPTER 2

LITERATURE REVIEW

The revision of the literature which provided a key role in the development of this thesis was presented in this chapter.

2.1 Previous Studies in the Field of the Causes of Schedule Delays in Construction Projects

As the process of construction project is very complicated with combination of various parties' endeavors, many stages of work and carrying a long period till the completion, (Puspasari, T. R. (2006)) there are many factors that contributed to causes of schedule delays in construction projects. Various researchers have examined and identified the causes of schedule delays in construction projects. Some of the previous studies were presented below.

Baldwin, J. and Manthei, J. (1971) researched into the reasons for schedule delays in building projects in the United States of America. They cited seventeen (17) delay factors: weather, labor supply, subcontractors, design changes, shop drawings, foundation conditions, material shortage, manufactured items, sample approvals, jurisdictional disputes, equipment failure, contracts, construction mistakes, inspections, finances, permits and building codes. Other factors which were not in their original list but were mentioned by the respondents included labor management relations, strike, poor organization, scheduling, coordination, deteriorating quality of workmanship, productivity, lack of skills in craftsmen, quality of training, delivery delays and the high cost of financing. Their findings concluded with weather, labor supply and the sub-contractors as the three major causes of construction delays.

Arditi R.D., et al. (1985) researched into the reasons of schedule delays in publicly funded construction projects for the period 1970-1980 in Turkey. They identified twenty three (23) reasons for the construction delays. Their findings concluded that the delays were due to shortage of materials (e.g., steel and cement), difficulty in receiving payments from agencies (e.g., payment not made on time; no advance payment; expensive surety bonds; insufficient public agency budget), contractor's difficulties (e.g., shortage of liquid funds; hard to get loans; hard to get credit purchase), organizational characteristics of contracting companies and public agencies (e.g., ill defined duties and responsibilities; site manager lacks authority; inadequate and slow decision-making mechanism; multitude of bureaucratic obstacles; high turnover in technical personnel).

Ubaid A.G. (1991) discussed the performance of contractors as one of the major causes of schedule delay. Thirteen (13) major factors were considered. These factors were related to contractor resources and capabilities.

Mansfield, N. R. et al. (1994) studied the causes of schedule delay and cost overrun in construction projects in Nigeria. They identified sixteen (16) major factors. According to their findings the most important factors were financing and payment for completed works, poor contract management, changes in site conditions, shortage of materials, and improper planning.

Assaf, S. A. et al. (1995) studied the causes of schedule delays in large building construction projects in Saudi Arabia. In their study, they identified that fifty six (56) causes of schedule delay exist in Saudi construction projects. They found that the most important causes of schedule delay included were the approval of shop drawings, delays in payment to contractors and the resulting cash problems during construction, design changes, conflicts in work schedules of subcontractors, slow decision making and executive bureaucracy in owner’s organizations, design errors, labor shortage and inadequate labor skills. Schedule delay factors were grouped into nine (9) major categories with different levels of importance to different parties. These categories were changes, contractual relationship, environment, equipment, financing, government relations, material, manpower, scheduling and controlling group. It was also shown that the financing group of delay factors was ranked the highest and that environment was ranked the lowest.

Al-Ghafly, M.A. (1995) studied the schedule delay in public water and sewage projects. Sixty (60) causes of schedule delay were identified and classified. Al- Ghafly identified that, the schedule delay occurred frequently in medium and large size projects, and considered severe in small projects. There were many important causes of schedule delay related to owner involvement, contractor performance, and the early planning and design of the project. The most important causes were financial problems, changes in the design and scope, delay in making decisions and approvals by owner, difficulties in obtaining work permit, and coordination and communication problems.

Ogunlana, S.O. et al. (1996) studied the delays in building project in Thailand, as an example of developing economies. They concluded that the problems of the construction industry in developing economies can be nested in three layers: problem of shortages or inadequacies in industry infrastructure, mainly supply of resources; problems caused by clients and consultants; and problems caused by incompetence of contractors. They were classified source and causes of delays into six groups: Owners related delay factors, designers related delay factors, inspector related delay factors, contractors related delay factors, resources suppliers related delay factors, and other factors.

Chan, D.W. and Kumaraswamy, M.M. (1997) conducted a survey to evaluate the relative importance of eighty-three (83) potential schedule delay factors which were grouped into eight (8) major categories in Hong Kong construction projects. These categories were project related, client related, design team related, contractor related, materials, labor, plant/equipment and external factors. They analyzed and ranked main reasons for schedule delays and classified them into two groups: (a) the role of the parties in the local construction industry (i.e. whether client, consultants or contractors) and (b) the type of projects. The results of their research indicated that the five (5) principal and common causes of schedule delays were: poor site management and supervision; unforeseen ground condition; low speed of decision making involving all projects team; client initiated variations; and necessary variation of works.

Odeyinka, H.A. and Yusif, A. (1997) studied the causes of schedule delays in building projects in Nigeria. They categorized the causes of schedule delay as client-related, contractor-related and extraneous factors. Client-related causes of schedule delays included variation in orders, slow decision-making and cash flow problems. Contractor-related schedule delays identified were: financial difficulties, material management problems, planning and scheduling problems, inadequate site inspection, equipment management problems and shortage of manpower. Extraneous causes of schedule delays identified were: inclement weather, acts of nature, labor disputes and strikes.

Kaming, P. F. et al. (1997) examined thirty one (31) high-rise projects in Indonesian construction projects. They identified eleven (11) variables of schedule delays. They pointed out that the most important factors causing schedule delays were design changes, poor labor productivity, inadequate planning, and resource shortages. They identified that 54. 5 % of project managers completed more than 90% of their projects that they handled on time, 15. 2% of completed only between 70 – 90% of their projects and 30. 3% completed less than 70%.

Mezher, T.M. and Tawil, W. (1998) carried out a survey of the causes of schedule delays in the construction industry in Lebanon. The survey included sixty four (64) causes of delay, grouped into ten (10) major groups. According to their findings, financial issues, contractors regarded contractual relationship, and project management issues were the most important causes of schedule delays.

Noulmanee, A. et al. (1999) investigated causes of schedule delays in highway construction in Thailand. According to their findings, schedule delays might be caused by all parties involved in projects. They identified that the main causes come from inadequacy of subcontractors, organization that lacks of sufficient resources, incomplete and unclear drawings and deficiencies between consultants and contractors. They suggested that schedule delay can be minimized by discussions that lead to understanding.

Al-Momani, A. (2000) carried out a quantitative analysis of construction schedule delays in a hundred and thirty (130) public building projects constructed in Jordan. The researcher found that the main causes of schedule delays in construction projects relate to designers, user changes, weather, site conditions, late deliveries, economic conditions, and increase in quantities.

Odeh, A.M., Battaineh, H.T. (2002) carried out a survey to identify the most important causes of schedule delays in construction projects with traditional type of contracts. They classified the causes of delays into the following eight (8) major groups: Client related, contractor related, consultant related, material related, labor and equipment related, contract related, external related delay factors. Results of the survey indicated that interference, inadequate contractor experience, financing and payments, labor productivity, slow decision making, improper planning, and subcontractors were among the top ten most important factors.

Frimpong, Y. et al. (2003) conducted a survey to identify the factors contributing to schedule delay and cost overruns in Ghana groundwater construction projects. They listed and ranked twenty six (26) factors responsible for project schedule delays and cost overruns. The results of the study indicated that the main causes of schedule delay and cost overruns in construction of groundwater projects includes: monthly payment difficulties from agencies; poor contractor management; material procurement; poor technical performances; and escalation of material prices.

Koushki, P.A. et al. (2005) conducted a survey of the schedule delay associated with the construction of private residential projects in the state of Kuwait. They identified three (3) main causes of schedule delays include: changing orders; owners' financial constraints; and owners' lack of experience in the construction business.

Wiguna, I.P.A. and Scott, S. (2005) studied the risks affecting construction schedule delays in building projects in Surabaya and Denpasar, Indonesia. They identified the most critical factors were: high inflation/increased material price; design change by client; defective design; weather conditions; delayed payment on contracts and defective construction work.

Assaf, S.A. and Al-Hejji, S. (2006) studied the causes of schedule delays in large construction projects in Saudi Arabia. In their study, they identified that seventy three (73) causes of schedule delay exist in Saudi construction projects. Schedule delay factors were grouped into nine (9) major categories with different levels of importance to different parties. These groups were owner related, consultant related, design team related, materials related, labor related, contractor related, project related, external related, and plan/equipment related delay factors. According to survey results, 76% of the contractors and 56% of the consultants indicated that average of schedule delay is between 10% and 30% of the original duration. The most common cause of delay identified by all the three parties was ‘‘change order’’. Surveys concluded that 70% of projects experienced schedule delay and found that 45 out of 76 projects considered were delayed. They found that the most important causes of schedule delay as seen by contractors were: delay in progress payments by owner, late in reviewing and approving design documents by owner, change orders by owner during construction, delays in producing design documents, late in reviewing and approving design documents by consultant, difficulties in financing project by contractor, mistakes and discrepancies in design documents, late procurement of materials, inflexibility (rigidity) of consultant, slowness in decision making process by owner.

El Razek, M.E. et al. (2008) conducted a survey to identify the main causes of delay in construction projects in Egypt from the point of view of contractors, consultants, and owners. They identified thirty two (32) causes of schedule delay which were grouped into nine (9) groups to fit the Egyptian construction industry. These groups were: Financing, materials, contractual relationships, changes, rules & regulations, manpower, scheduling & control, equipment, environment related causes. Their findings indicated that the most important causes are: financing by contractor during construction, delays in contractor’s payment by owner, design changes by owner or his agent during construction, partial payments during construction, and non-utilization of professional construction/contractual management.

2.2 Previous Studies in the Field of Fuzzy Set Theory and Fuzzy Logic

Numerous researchers have utilized fuzzy set theory in their studies. Some of the previous studies were presented below.

Ayyub, B. M. and Haldar, A. (1984) applied fuzzy set concepts to construction project scheduling.

Koehn, E. (1984) studied on the utilization of fuzzy sets to the complex problems of building or facility satisfaction and productivity on a construction site. The researcher aimed to provide a basic framework for the utilization of the theory in construction risk evaluation.

Nguyen, V. U. (1985) applied the fuzzy set theory to a decision model for selecting bid contracts.

Kangari, R. (1988) presented an integrated knowledge-based system for construction risk management by using fuzzy sets. The system, called Expert- Risk, performed risk analysis in two situations: before construction, and during construction. Risk levels were described using linguistic variables implemented as fuzzy sets.

Kangari, R. and Riggs, L. S. (1989) described a system to test the concept of construction risk assessment using linguistic variables. A limited number of risks were covered to allow for greater detail in the assessment, and the problems and benefits of linguistic variables were discussed.

Chun, M. and Ahn, K. (1992) proposed the use of fuzzy set theory to quantify the imprecision and judgmental uncertainties of accident progression event trees.

Peak, J.H. et al. (1993) proposed the use of fuzzy sets for the assessment of bidding prices for construction projects. They analyzed risks which could result in a loss of money in construction contracts, and suggested a risk pricing method emphasizing the uncertainty, represented by fuzzy sets, associated with construction projects.

Tah, J.H.M. et al. (1993) presented a linguistic approach to risk management using fuzzy sets. The work was designed for risk assessment during the tender stage for contingency allocation, and utilized linguistic descriptions of risk probability and severity for assessment and analysis.

Tah, J.H.M. and V. Carr (2000) used a hierarchical risk breakdown structure representation to develop a formal model for qualitative risk assessment. They presented a common language for describing risks. The relationships between risk factors, risks and their consequences were represented on cause and effect diagrams. These diagrams and the concepts of fuzzy association and fuzzy composition were applied to identify relationships between risk sources and the consequences for project performance measures. A methodology for evaluating the risk exposure, regarding the consequences in terms of time, cost, quality, and safety performance measures of a project based on fuzzy estimates of the risk components was presented.

Leu, S. S. et al. (2001) developed a new optimal construction time-cost trade-off method by using fuzzy set theory in order to provide an insight into the optimal balance of time and cost under different risk levels.

Han, S. (2005), and Dikmen, I. et al. (2007) proposed a fuzzy risk assessment methodology to quantify cost delay risk in construction projects and developed a tool to implement the proposed methodology. They assumed that a total number of twenty three (23) risk factors stemming from project and country levels lead to cost overrun risk. According to their risk model, nine (9) factors were affecting country risk, and fourteen (14) factors were causing project risk. A computer program was developed for an international construction company and applicability of this system during risk assessment at the bidding stage was tested by using real company and project information.

2.3 Contributions of the Current Study to Existing Literature

The very limited previous research into fuzzy techniques in schedule delay analysis problems encouraged the author to investigate employing fuzzy techniques to assist in estimating the probability of schedule delay in construction projects. It is the author's belief that the power of fuzzy techniques may be very useful in the schedule delay problem environment, in which key decisions are influenced by many subjective factors. The ability to represent the problem in natural language may provide the tool (mechanism) to investigate how human experts (decision makers) estimate the necessary time contingency in the real world construction projects.

According to literature survey findings, the studies were mainly focused on finding causes of schedule delays. Some of these studies identified very limited (lacking) factors as mentioned in previous part. In this thesis, through comprehensive literature review and interview with experts from a leading Turkish Construction Company, the author identified eighty three (83) schedule delay factors and categorized in nine (9) groups. Another observation made by the author was that, various studies focused on the estimation of cost and budget related issues of construction projects (Peak, et al. (1993), Han Sedat (2005), Dikmen, et al. (2007)). To complete the project within budget is an important factor for success of the project. However, according to literature survey findings, there are two other important factors for the success of the project: To complete the project on scheduled time, and in accordance with the specifications and to stakeholders' satisfaction (Majid, I. A. (2006), Frimpong, et al. (2003)). When companies fail to complete the project on scheduled time, it will result in schedule delays which are common in various construction projects and cause considerable losses to project parties such as late completion of project, increased cost, disruption of work, loss of productivity, third party claims, disputes and abandonment or termination of contracts.

Therefore, in this research, the author took an integrated approach and attempted to link the fuzzy logic techniques incorporated with relative importance index (RII) method to the quantification of the probability of schedule delay in construction projects which will be presented in the following chapters.

CHAPTER 3

CAUSES OF SCHEDULE DELAYS IN CONSTRUCTION PROJECTS

3.1 Introduction

Completing projects on time is an indicator of an efficient construction industry (NEDO (1988)). Also, Rwelamila and Hall (1995) found that the timely completion of a project was frequently seen as a major criterion of project success.

In fact, a construction project is commonly acknowledged as successful, when it is completed on time, within budget, in accordance with the specifications and to stakeholders' satisfaction (Majid, I. A. (2006)).

Schedule delays in a construction project can be defined as the late completion of works as compared to the planned schedule or contract schedule. It could be possibly be interpreted as a loss of time. "Time" refers to the duration for completing the construction project. Time in a construction project is the construction period or in contract administration is the contract period. When the project period is delayed, it means the project cannot be completed within original schedule. Delays in construction project will lead to either: extension of time; non-completion; termination of contract; or a combination of two or more than the factors mentioned above (Majid, I. A. (2006)).

The duration of a construction project is an important factor to set forth when entering into a construction agreement. If a contractor works with a planned parameter, he or she should be able to finish the construction project in a timely manner. However, compared to other industries, it is difficult to complete a construction project in which many construction trades participate and numerous unknown variables exist. When such difficulties arise, construction schedules are delayed, and consequently delay claim occur (Majid, I. A. (2006)).

Delay is a situation when the contractor, consultant, and client jointly or severally contributed to the non-completion of the project within the original or the stipulated or agreed contract period. Delays can be avoided or minimized when their causes are clearly identified. Identification of the factors that contributed to the causes of delays has been studied by numerous researchers in several countries (Majid, I. A. (2006)).

3.2 Types of Delays

Abd. Majid, M.Z. and McCaffer, R. (1998) revealed that there were three ways to classify delays:

1. Excusable delays with compensation,

2. Excusable delays without compensation,

3. Non-excusable delays.

3.2.1 Excusable Delays

Excusable delays are those not attributable to the contractor's actions or inactions, and typically include unforeseen events. These events are beyond the contractor's control and are without fault or negligence on his/her part. Excusable delays, when founded, entitle the contractor to a time extension if the completion date is affected. This type of delay can also have an impact on non-critical activities which need a more detailed analysis to determine whether additional time extension is warranted, or if the reduction of float time can be justified. Excusable delays can be further classified into excusable with compensation and excusable without compensation. ***Excusable with compensation*** are caused by the client's actions or inactions. When contractors encounter this type of delay, they are entitled to time extension as well as monetary compensation due to the delays. An example of an excusable delay with compensation would be when an owner denies access to the site once the notice to proceed is given. ***Excusable without compensation*** are delays where neither the client nor the contractor is deemed responsible. When this type of delay is encountered, only a time extension will be warranted since there are no grounds for damages. Some examples of excusable without compensation delays are unprovoked strikes, or any ‘act of God’ (Majid, I. A. (2006)).

3.2.2 Non-excusable Delays

Non-excusable delays are delays which result from the contractors’ or subcontractors’ actions or inactions. These delays might be the results of underestimates of productivity, improper project planning and scheduling, poor site management and supervision, wrong construction methods, equipment breakdowns, unreliable subcontractors or suppliers. Consequently, this type of delay presents no entitlement to a time extension or delay damages for the contractor if the delay can be proved to have affected the whole project. The client, however, could be entitled to liquidated damages. An example of a non-excusable delay would be when a contractor fails to provide sufficient manpower to complete the job on time (Majid, I. A. (2006)).

3.2.3 Concurrent Delays

Concurrent delays refer to delay situations when two or more delays occur at the same time or overlap to some degree either of which, had the delays occurred alone, would have affected the ultimate completion date. Normally concurrent delays which involve any two or more excusable delays result in a time extension. When excusable with compensation and non-excusable delays are concurrent, a time extension can be issued or the delay can be apportioned between the owner and the contractor (Majid, I. A. (2006)).

3.3 Identification of Schedule Delay Factors & Categories

The literature review was done through books, engineering journals, conference papers, master theses, the internet, and interview with experts from a leading Turkish Construction Company. The causes for schedule delays that may be encountered in a construction project were identified and categorized through a detailed review of literature and demonstrated by using Ishikawa diagrams presented below.

The Ishikawa Diagram, also known as the Fishbone Diagram or the Cause-and-Effect Diagram, is a tool used for systematically identifying and presenting all the possible causes of a particular problem in graphical format. The possible causes are presented at various levels of detail in connected branches, with the level of detail increasing as the branch goes outward, i.e., an outer branch is a cause of the inner branch it is attached to. Thus, the outermost branches usually indicate the root causes of the problem. The Ishikawa Diagram resembles a fishbone (hence the alternative name "Fishbone Diagram"), it has a box (the 'fish head') that contains the statement of the problem at one end of the diagram. From this box originates the main branch (the 'fish spine') of the diagram. Sticking out of this main branch are major branches that categorize the causes according to their nature. (Web site: http://www.siliconfareast.com/ishikawa.htm).

A sample Ishikawa diagram is shown in Figure 3.1.

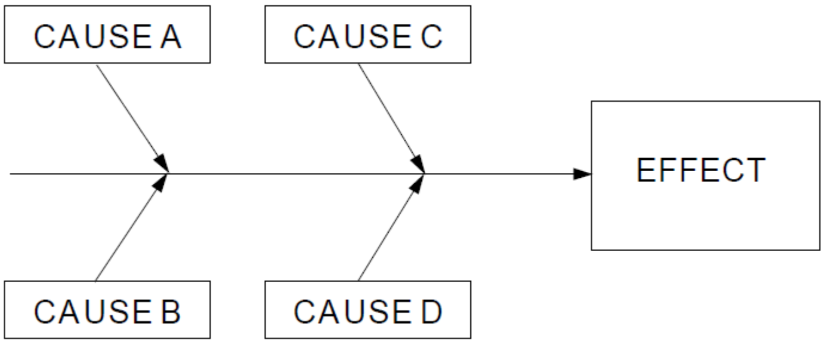


Figure 3.1: A sample of Ishikawa (Fish Bone) Diagram

3.3.1 Consultant Related Delay Factors

Consultant Related Delay Factors category was identified as one of the groups of causes of schedule delays in construction projects. Several studies have identified consultant related factors to cause schedule delays. Ogunlana, S.O. et al. (1996) identified the factors of poor design and delay in design, slow response and poor inspection, and incomplete drawing and detail design that contribute to causes of delays in construction project. Odeh, A.M. and Battaineh, H.T. (2002) identified the factors of slow response and poor inspection as factors of consultant related delays. Long, et al. (2004) identified the factors of inadequate consultant experience, inadequate project management assistance, incomplete drawing and detail design, and inaccurate site investigation as contributors to causes of delays. Assaf and Hejji (2006) identified the consultant related delay factors as; delay in performing inspection and testing by consultant, delay in approving major changes in the scope of work by consultant, inflexibility (rigidity) of consultant, poor communication/coordination between consultant and other parties, late in reviewing and approving design documents by consultant, conflicts between consultant and design engineer, inadequate experience of consultant.

Based on this previous literature review, the author identified eight (8) factors of consultant related delays as shown in Table 3.1.

Table 3.1: Consultant Related Delay Factors

1. Lack of experience of consultant in construction projects
2. Conflicts between consultant and design engineer
3. Delay in approving major changes in the scope of work by consultant
4. Delay in performing inspection and testing
5. Inaccurate site investigation
6. Inadequate project management assistance
7. Late in reviewing and approving design documents
8. Poor communication and coordination with other parties

The Ishikawa Diagram as shown in Figure 3.2 was employed to assist in identifying consultant related delay factors.

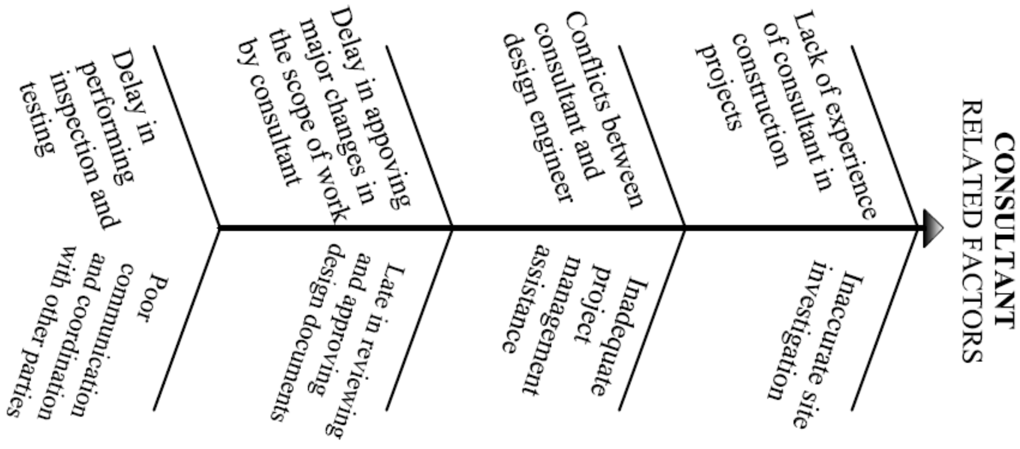


Figure 3.2: The Ishikawa diagram of Consultant Related Delay Factors

3.3.2 Contractor Related Delay Factors

Contractor Related Delay Factors category was identified as one of the groups of causes of schedule delays in construction projects. Several studies have identified contractor related delay factors to cause schedule delays. Chan, D.W. and Kumaraswamy, M.M. (1997) identified the factors of poor site management and supervision and improper project planning and scheduling that contribute to causes of delays. Ogunlana, S.O. et al. (1996) identified the factor of improper project planning and scheduling as factors of contractor related delays. Abd. Majid, M.Z. and McCaffer, R. (1998) identified the factors of inadequate contractor experience, inappropriate construction methods, and improper project planning and scheduling, and unreliable subcontractor as contributors to causes of delays. Odeh, A.M. and Battaineh, H.T. (2002) identified the factors of inadequate contractor experience, inappropriate construction methods, poor site management and supervision, and unreliable subcontractor as contributors to causes of delays. Long, D. N., et al. (2004) identified the factors of inadequate contractor experience, inappropriate construction methods, inaccurate time estimating, inaccurate cost estimating, improper project planning and scheduling, incompetent project team, unreliable subcontractor, and obsolete technology that contribute to causes of delays in construction project. Assaf, S.A. and Al-Hejji, S. (2006)identified the contractor related delay factors as; difficulties in financing project by contractor, conflicts in sub-contractors schedule in execution of project, rework due to errors during construction, conflicts b/w contractor and other parties (consultant and owner), poor site management and supervision by contractor, poor communication and coordination by contractor with other parties, ineffective planning and scheduling of project by contractor, improper construction methods implemented by contractor, delays in sub-contractors work, inadequate contractor's work, frequent change of sub-contractors because of their inefficient work, poor qualification of the contractor's technical staff, delay in site mobilization.

Based on this previous literature review, the author identified ten (10) factors of contractor related delays as shown in Table 3.2.

Table 3.2: Contractor Related Delay Factors

1. Frequent change of subcontractors
2. Inadequate contractor experience
3. Inappropriate construction methods
4. Incompetent project team
5. Ineffective project planning and scheduling
6. Obsolete technology
7. Poor communication and coordination with other parties
8. Poor site management and supervision
9. Rework due to errors
10. Unreliable subcontractors

The Ishikawa Diagram as shown in Figure 3.3 was employed to assist in identifying contractor related delay factors.

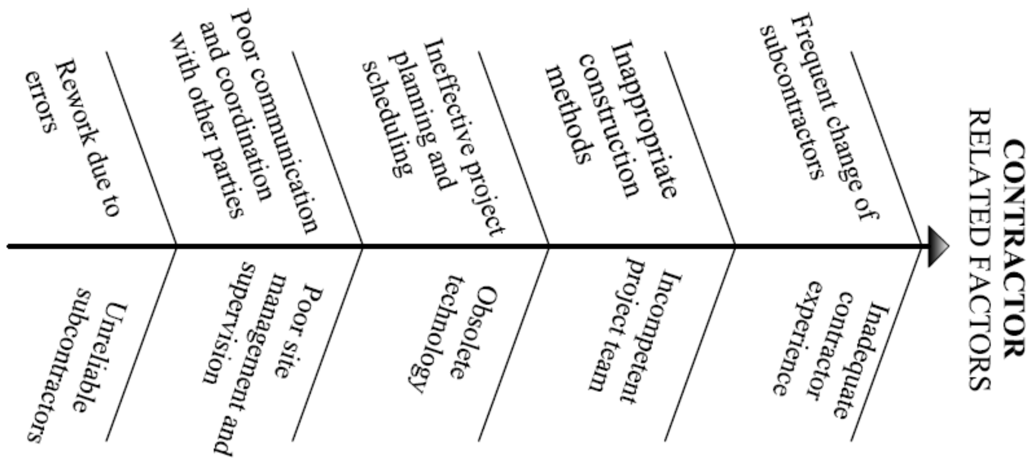


Figure 3.3: The Ishikawa diagram of Contractor Related Delay Factors

3.3.3 Design Related Delay Factors

Design Related Delay Factors category was identified as one of the groups of causes of schedule delays in construction projects. Several studies have identified design related delay factors to cause schedule delays. Chan, D.W., Kumaraswamy, M.M. (1997) identified the factors of design team experience, project design complexity, and mistakes and delays in producing design documents that contribute to causes of delays. Assaf, S.A., Al-Hejji, S.(2006) identified the external related delay factors as; mistakes and discrepancies in design documents, delays in producing design documents, unclear and inadequate details in drawings, complexity of project design, insufficient data collection and survey before design, misunderstanding of owner's requirements by design engineer, inadequate design-team experience, un-use of advanced engineering design software. El Razek, M.E. et al. (2008) identified the factors of design changes by owner or his agent during construction and design errors made by designers having high influence to causes of delays.

Based on this previous literature review, the author identified nine (9) factors of design related delays as shown in Table 3.3.

Table 3.3: Design Related Delay Factors

1. Complexity of project design
2. Design changes by owner or his agent during construction
3. Design errors made by designers
4. Insufficient data collection and survey before design
5. Lack of experience of design team in construction projects
6. Mistakes and delays in producing design documents
7. Misunderstanding of owner's requirements by design engineer
8. Poor use of advanced engineering design software
9. Unclear and inadequate details in drawings

The Ishikawa Diagram as shown in Figure 3.4 was employed to assist in identifying design related delay factors.

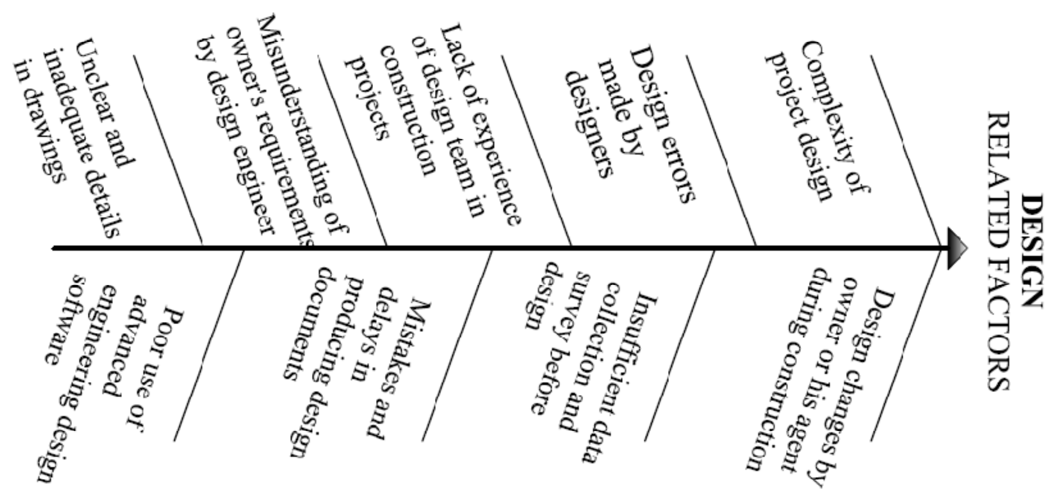


Figure 3.4: The Ishikawa diagram of Design Related Delay Factors

3.3.4 Equipment Related Delay Factors

Equipment Related Delay Factors category was identified as one of the groups of causes of schedule delays in construction projects. Several studies have identified equipment related delay factors to cause schedule delays. Chan, D.W., Kumaraswamy, M.M. (1997) identified the factor of shortage of equipment and improper equipment as factors that contribute to causes of delays. Ogunlana, S.O. et al. (1998) identified the factors of insufficient numbers of equipment; frequent equipment breakdown, and equipment allocation problem are the most significant factors that contribute to causes of delays. Abd. Majid, M.Z. and McCaffer, R. (1998) identified the factors of equipment breakdown, improper equipment, slow mobilization of equipment, and equipment allocation problem as contributors to causes of delays. Odeh, A.M. and Battaineh, H.T. (2002) identified the factor of equipment allocation problem having high occurrence to causes of construction delays. Long, D. N., et al. (2004) identified the factor of inadequate modern equipment as factors of equipment related delays. Assaf, S.A. and Al-Hejji, S. (2006) identified the equipment related delay factors as; equipment breakdowns, shortage of equipment, low level of equipment-operator's skill, low productivity and efficiency of equipment, lack of high-technology mechanical equipment.

Based on this previous literature review, the author identified seven (7) factors of equipment related delays as shown in Table 3.4.

Table 3.4: Equipment Related Delay Factors

1. Equipment allocation problem
2. Frequent equipment breakdowns
3. Improper equipment
4. Inadequate modern equipment
5. Low efficiency of equipment
6. Shortage of equipment
7. Slow mobilization of equipment

The Ishikawa Diagram as shown in Figure 3.5 was employed to assist in identifying equipment related delay factors.

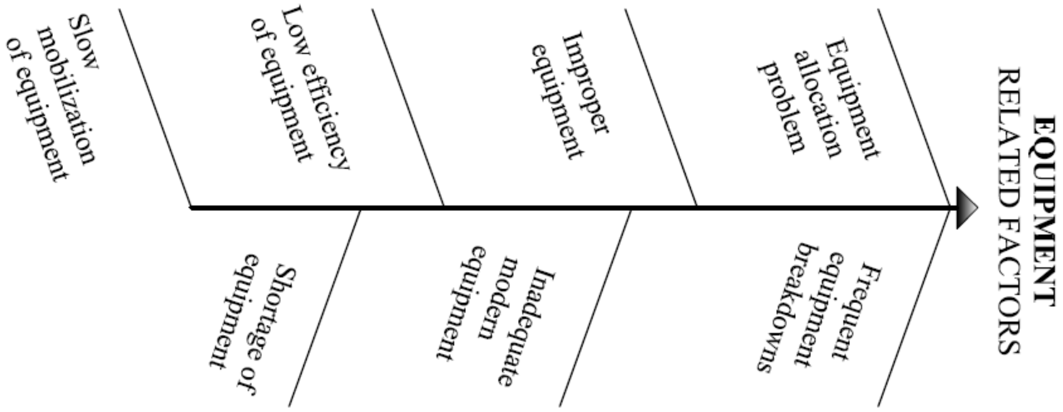


Figure 3.5: The Ishikawa diagram of Equipment Related Delay Factors

3.3.5 External Related Delay Factors

External Related Delay Factors category was identified as one of the groups of causes of schedule delays in construction projects. Several studies have identified external related delay factors to cause schedule delays. Ogunlana, S.O. et al. (1996) identified the factors of problem with neighbors that contribute to causes of delays. Al-Momani, A. (2000) identified the factor of weather condition as contributors to causes of delays in construction projects. Odeh, A.M. and Battaineh, H.T. (2002) identified the factors of unforeseen ground condition, problem with neighbors, and weather condition as contributors to causes of delays. Long, D. N., et al. (2004) identified factors unforeseen ground condition, inflation/price fluctuation, slow site clearance, and weather condition as factors of external related delays. Wiguna, I.P.A. and Scott, S. (2005) identified the factor of inflation/prices fluctuation having high influence to causes of delays. Assaf, S.A. and Al-Hejji, S. (2006) identified the external related delay factors as; effects of subsurface conditions (e.g., soil, high water table, etc.), delay in obtaining permits from municipality, hot weather effect on construction activities, rain effect on construction activities, unavailability of utilities in site (such as, water, electricity, telephone, etc.), effect of social and cultural factors, traffic control and restriction at job site, accident during construction, differing site (ground) conditions, changes in government regulations and laws, delay in providing services from utilities (such as water, electricity), delay in performing final inspection and certification by a third party.

Based on this previous literature review, the author identified fourteen (14) factors of external related delays as shown in Table 3.5.

Table 3.5: External Related Delay Factors

1. Accidents during construction
2. Changes in government regulations and laws
3. Conflict, war, and public enemy
4. Delay in obtaining permits from municipality
5. Delay in performing final inspection and certification by a third party
6. Delay in providing services from utilities (such as water, electricity)
7. Global financial crisis
8. Loss of time by traffic control and restriction at job site
9. Natural disasters (flood, hurricane, earthquake)
10. Price fluctuations
11. Problem with neighbors
12. Slow site clearance
13. Unexpected surface& subsurface conditions (such as soil, high water table)
14. Unfavorable weather conditions

The Ishikawa Diagram as shown in Figure 3.6 was employed to assist in identifying external related delay factors.

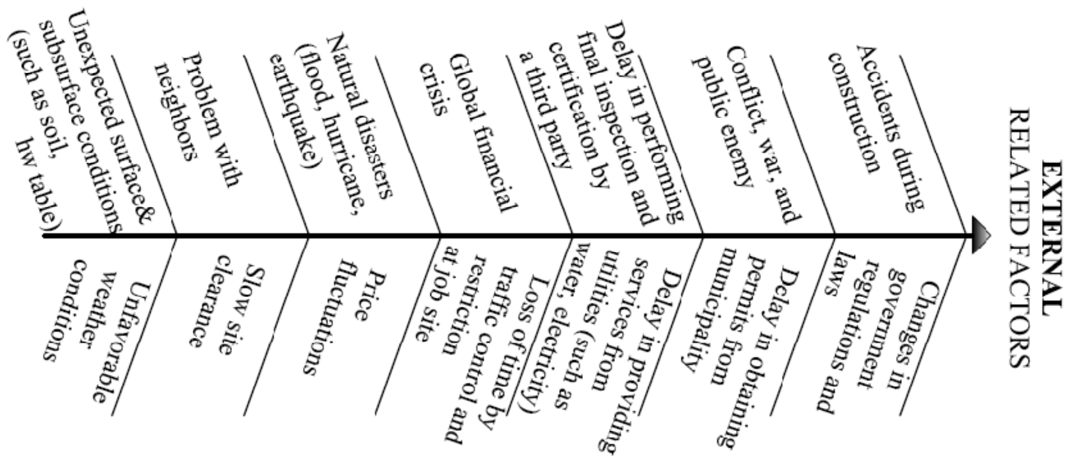


Figure 3.6: The Ishikawa diagram of External Related Delay Factors

3.3.6 Labor Related Delay Factors

Labor Related Delay Factors category was identified as one of the groups of causes of schedule delays in construction projects. Several studies have identified labor related delay factors to cause schedule delays. Chan, D.W. and Kumaraswamy, M.M. (1997) identified the factor of shortage of skill labor is the most important factor that contributed to causes of delays. Ogunlana, S.O. et al. (1996) identified the factor of shortage of skill labor and labor productivity having high influence to causes of delays. Abd. Majid, M.Z. and McCaffer, R. (1998) identified the factors of slow mobilization of labor, labor supply, absenteeism, strike, and low motivation and morale are the critical factors that contribute to causes of delays. Odeh, A.M. and Battaineh, H.T. (2002) in their research identified the factors of labor of productivity and labor supply as contributors to causes of delays. Assaf, S.A. and Al-Hejji, S. (2006) identified the labor related delay factors as; shortage of labors, unqualified workforce, nationality of labors, low productivity level of labors, personal conflicts among labors.

Based on this previous literature review, the author identified eight (8) factors of labor related delays as shown in Table 3.6.

Table 3.6: Labor Related Delay Factors

1. Absenteeism
2. Low motivation and morale of labor
3. Low productivity of labor
4. Personal conflicts among labor
5. Shortage of labor
6. Slow mobilization of labor
7. Strike
8. Unqualified / inadequate experienced labor

The Ishikawa Diagram as shown in Figure 3.7 was employed to assist in identifying labor related delay factors.

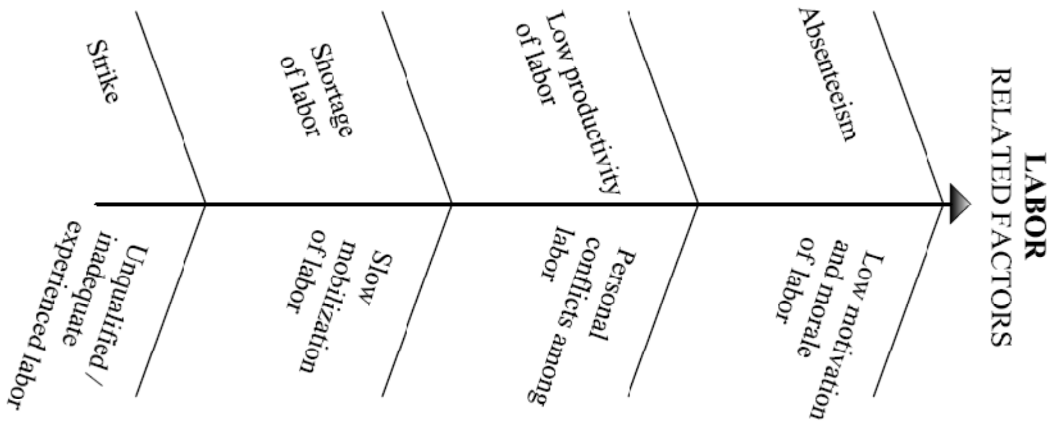


Figure 3.7: The Ishikawa diagram of Labor Related Delay Factors

3.3.7 Material Related Delay Factors

Material Related Delay Factors category was identified as one of the groups of causes of schedule delays in construction projects. Several studies have identified material related delay factors to cause schedule delays. Chan, D.W. And Kumaraswamy, M.M. (1997) concluded that factors shortage of material and poor procurement of material as contributors that contribute to causes of delays. Ogunlana, S.O. et al. (1996) found that factor shortage of material, poor quality of material, escalation of material prices and late delivery were identified as factors to causes of delays in construction project. Abd. Majid, M.Z. and McCaffer, R. (1998) identified the factor of shortage of material, poor quality of material, poor procurement of material, late delivery of material, and unreliable suppliers that contribute to causes of delays. Odeh, A.M. and Battaineh, H.T. (2002) identified the factor of poor quality of materials having high influence to causes of delays. Frimpong, Y. et al. (2003) identified the factor of poor procurement of materials that contributed to causes of delays. Koushki, P.A. et al. (2005) revealed that factor shortage of construction material, poor quality of material, and poor procurement of material that contribute to causes of delays. Wiguna, I.P.A. and Scott, S. (2005) identified the factor of escalation of material prices was one factor that contribute to causes of delays. Assaf, S.A. and Al-Hejji, S. (2006) identified the material related delay factors as; shortage of construction materials in market, changes in material types and specifications during construction, delay in material delivery, damage of sorted material while they are needed urgently, delay in manufacturing special building materials, late procurement of materials, late in selection of finishing materials due to availability of many types in market.

Based on this previous literature review, the author identified nine (9) factors of material related delays as shown in Table 3.7.

Table 3.7: Material Related Delay Factors

1. Changes in material types and specifications during construction
2. Damage of sorted materials
3. Delay in manufacturing materials
4. Escalation of material prices
5. Late delivery of materials
6. Poor procurement of construction materials
7. Poor quality of construction materials
8. Shortage of construction materials
9. Unreliable suppliers

The Ishikawa Diagram as shown in Figure 3.8 was employed to assist in identifying material related delay factors.

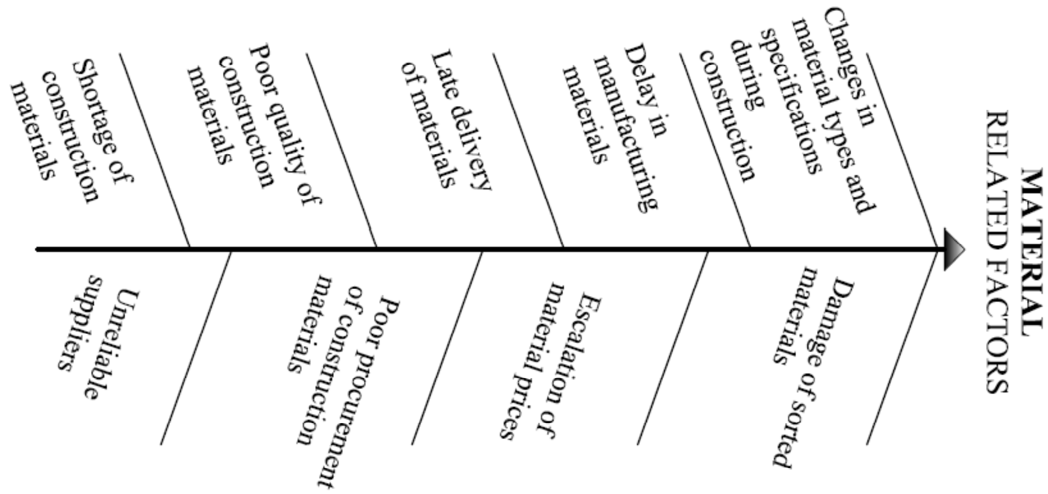


Figure 3.8: The Ishikawa diagram of Material Related Delay Factors

3.3.8 Owner Related Delay Factors

Owner Related Delay Factors category was identified as one of the groups of causes of schedule delays in construction projects. Several studies have identified owner related delay factors to cause schedule delays. Ogunlana, S.O. et al. (1996) and Odeh, A.M. and Battaineh, H.T. (2002) identified the factors of change orders, and slow decision making by owner that contribute to causes of delays. Long, D. N., et al. (2004) identified the factors owner interference, lack of capable representative, lack of communication and coordination, and improper project feasibility study that contribute to causes of delays in construction project. Koushki, P.A. et al. (2005) identified factors of change orders and lack of experience of owner in construction projects have high affect to the causes of delays. Assaf, S.A. and Al-Hejji, S. (2006) identified the owner related delay factors as; delay in progress payments by owner, delay to furnish and deliver the site to the contractor by the owner, change orders by owner during construction, late in revising and approving design documents by owner, delay in approving shop drawings and sample materials, poor communication and coordination by owner and other parties, slowness in decision making process by owner, conflicts between joint-ownership of the project, unavailability of incentives for contractor for finishing ahead of schedule, suspension of work by owner.

Based on this previous literature review, the author identified twelve (12) factors of owner related delays as shown in Table 3.8.

Table 3.8: Owner Related Delay Factors

1. Change orders
2. Conflicts between joint-ownership
3. Delay in approving design documents
4. Delay in progress payments
5. Delay in site delivery
6. Improper project feasibility study
7. Lack of capable representative
8. Lack of experience of owner in construction projects
9. Lack of incentives for contractor to finish ahead of schedule
10. Poor communication and coordination with other parties
11. Slowness in decision making
12. Suspension of work by owner

The Ishikawa Diagram as shown in Figure 3.9 was employed to assist in identifying owner related delay factors.

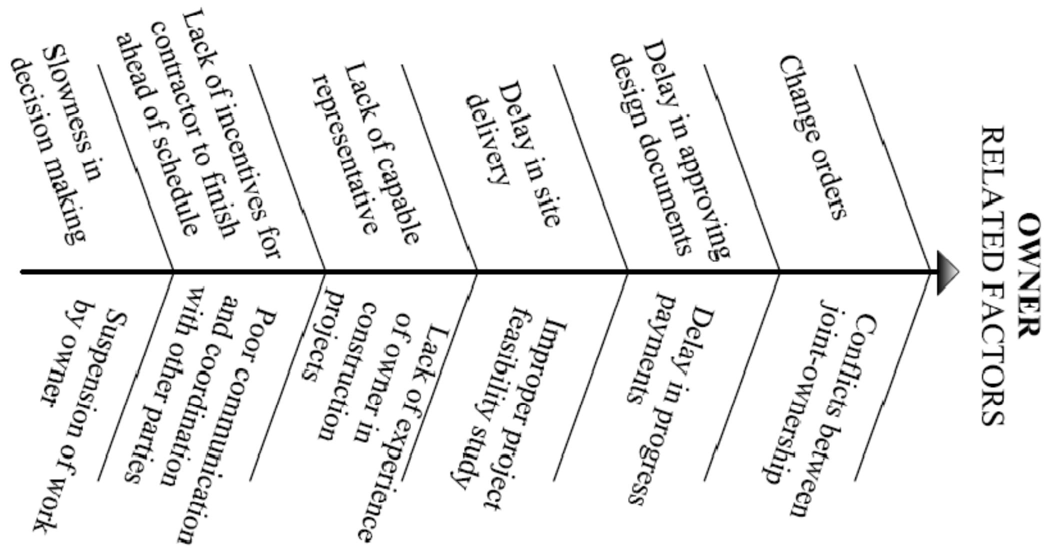


Figure 3.9: The Ishikawa diagram of Owner Related Delay Factors

3.3.9 Project Related Delay Factors

Project Related Delay Factors category was identified as one of the groups of causes of schedule delays in construction projects. Several studies have identified project related delay factors to cause schedule delays. Chan, D.W. And Kumaraswamy, M.M.(1997) identified the factors of project characteristics, necessary variations, communication among the various parties, speed of decision making involving all project teams and ground conditions that contribute to causes of delays. Assaf, S.A. and Al-Hejji, S.(2006) identified the project related delay factors as; original contract duration is too short, legal disputes b/w various parts, inadequate definition of substantial completion, ineffective delay penalties, type of construction contract (turnkey, construction only), type of project bidding and award (negotiation, lowest bidder)

Based on this previous literature review, the author identified six (6) factors of project related delays as shown in Table 3.9.

Table 3.9: Project Related Delay Factors

1. Complexity of the project
2. Inadequate definition of substantial completion
3. Ineffective delay penalties
4. Legal disputes between project participants
5. Original contract duration is short
6. Unfavorable contract clauses

The Ishikawa Diagram as shown in Figure 3.10 was employed to assist in identifying project related delay factors.

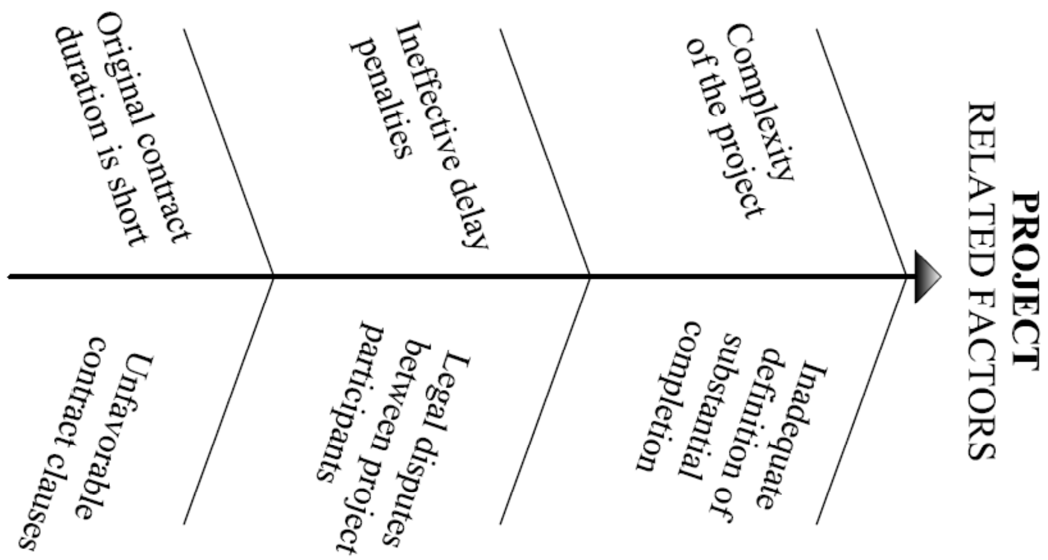


Figure 3.10: The Ishikawa diagram of Project Related Delay Factors

3.4. Chapter Summary

A total of eighty three (83) factors in nine (9) groups of causes of schedule delays in construction projects were identified through detailed literature review. The Ishikawa diagram (Fish Bone diagram) was utilized to demonstrate the factors that may cause schedule delays in construction projects as shown in Figure 3.11.

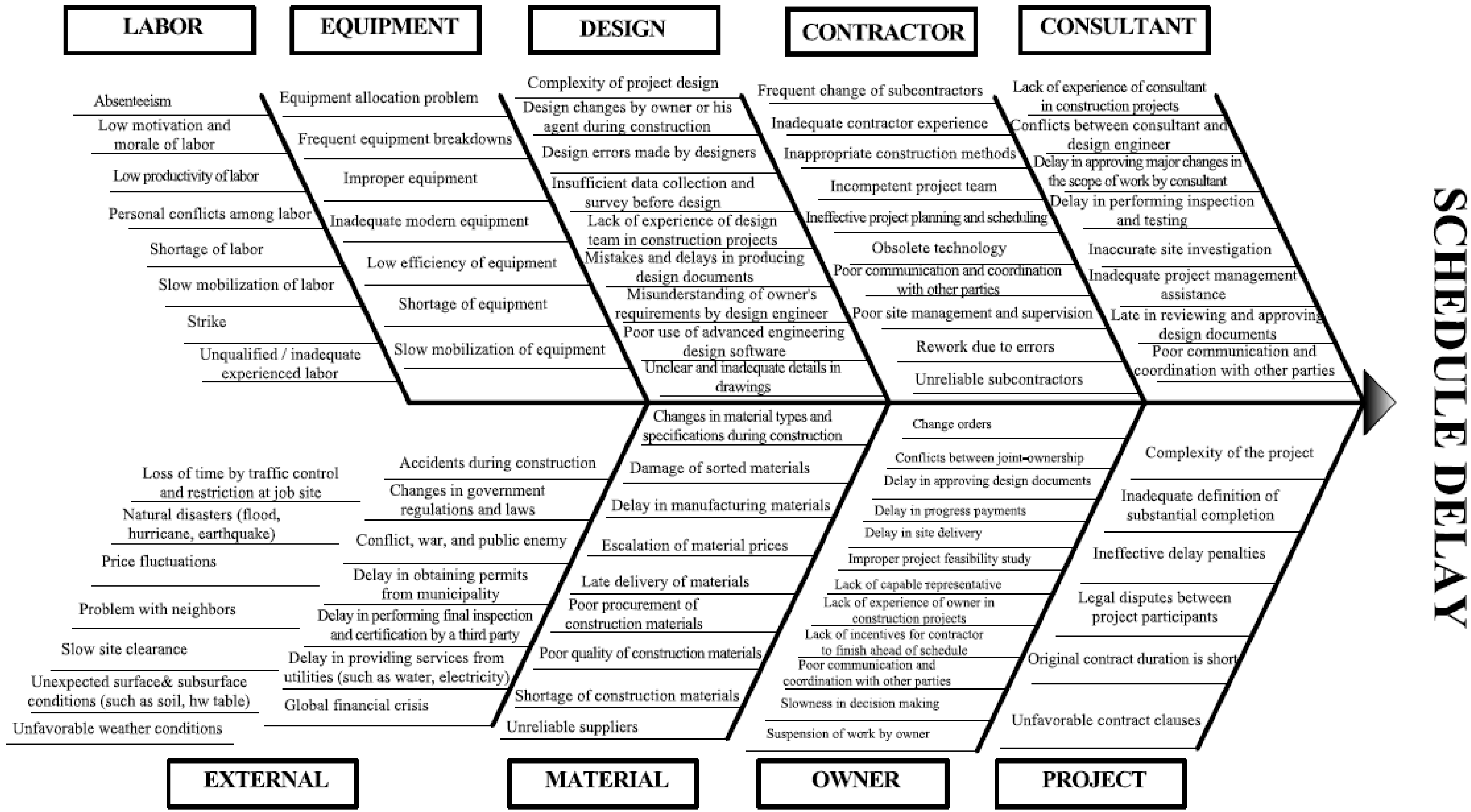


Figure 3.11: The Ishikawa diagram of categories and factors that cause schedule delays

CHAPTER 4

THE BASICS OF FUZZY SET THEORY, FUZZY INFERENCE AND FUZZY MODELING

4.1 Introduction

In many decision making environments, it is often the case that several factors need to be taken into account simultaneously. Often, it is not known which factor(s) need to be emphasized more in order to generate a better decision. Somehow, a trade off between the various (potentially conflicting) factors must be made. The general framework of fuzzy reasoning facilitates the handling of such uncertainty. Fuzzy systems are used for representing and employing knowledge that is imprecise, uncertain, or unreliable. This chapter will describe the basics of fuzzy set theory, fuzzy inference and fuzzy modeling.

The concept of fuzzy logic was first introduced in 1965 by Zadeh in his seminal paper on fuzzy sets (Zadeh, (1965)). Since then, research on fuzzy set has expanded to cover a wide range of disciplines and applications. (Hishammuddin, A. (2008)).

In this thesis, the use of fuzzy techniques was focused only on its use in rule-based systems. Therefore, this chapter will present a general background of the fuzzy set theory and fuzzy methodologies that were utilized within the research work. The contents were selected to be sufficient to explain how these fuzzy techniques work. A fully detailed description of the logical framework based on fuzzy set theory was not included, as it was not utilized here.

4.2 Fuzzy Sets and Membership Functions

Fuzzy sets can be considered as an extension of classical or 'crisp' set theory. In classical set theory, an element x is either a member or non-member of set A. Thus, the membership μA(x) of x into A is given by:

$$\mu_A(x) = \begin{cases} 1, & \text{if } x \in A \\ 0, & \text{if } x \notin A \end{cases}$$

Consider room temperature as an example. One might say that "a temperature less than 10°C is cold". This statement can be represented in the form of classical set as cold = {x|x ≤ 10} and the membership function characterizing this set is shown in Figure 4.1.

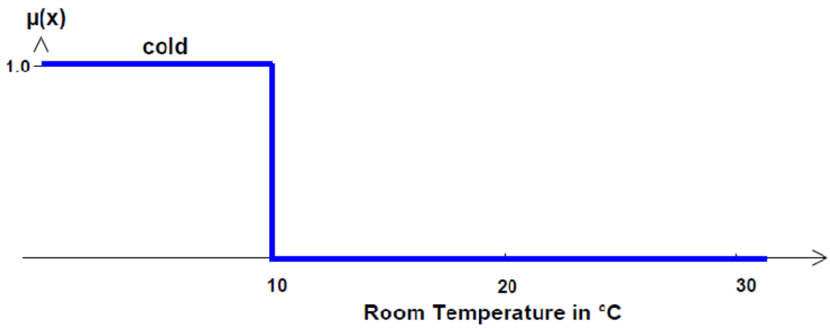


Figure 4.1: Membership function for the set of cold temperatures, defined as cold = {x|x ≤ 10}

In contrast to classical set theory, the fuzzy set methodology introduced the concept of degree to the notion of membership. More formally, a fuzzy set A of a universe of discourse X (the range over which the variable spans) is characterized by a membership function μA(x): X → [0, 1] which associates with each element x of X a number μA(x) in the interval [0, 1], with μA(x) representing the grade of membership of x in A. The precise meaning of the membership grade is not rigidly defined, but is supposed to capture the 'compatibility' of an element to the notion of the set.

Returning to the example above, an everyday statement like "a temperature below about 10°C is considered cold" can be represented in the form of the fuzzy set shown in Figure 4.2.

In comparison with classical set in which only sharp boundaries are permitted, the concept of membership degree in fuzzy sets allows fuzzy or blurred boundaries to be defined. In Figure 4.2, it can be seen that a temperature of 11°C can also be considered as cold but with a lesser degree of membership than for 10°C (i.e $\mu_{cold}(x = 11) = 0.85$); whereas in a classical set the degree of membership is zero (i.e. a temperature of 11°C does not belong to the set cold at all). Fuzzy sets provide the tools to represent problems in everyday language, and it is this property that provides a problem solving technique that mimics the characteristics of human reasoning and decision making (Hishammuddin, A. (2008)).

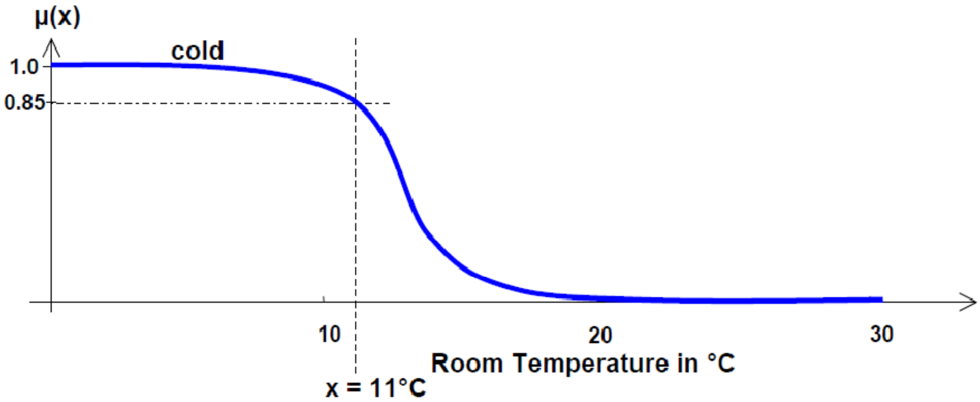


Figure 4.2: Membership function for the fuzzy set cold = {x | x is less than about 10}

4.3 Linguistic Variables, Values and Rules

The term 'linguistic variable' was introduced to refer to a variable whose values are in the form of "linguistic expressions" rather than numerical values. In the example shown in Figure 4.2, 'temperature' is a linguistic variable with a linguistic value 'cold'. Other possible linguistic values for the linguistic variable 'temperature' could include terms such as 'moderate', 'warm' and 'hot'. Each linguistic value is represented by a fuzzy set (membership function) in which the characteristic of each fuzzy set is dependent on the context of the particular problem. Although these linguistic terms are very subjective, they might be interpreted as (for example):

- 'cold' to be a temperature below about 10 °C
- 'moderate' to be a temperature around 15 °C
- 'warm' to be a temperature around 20 °C
- 'hot' to be a temperature above about 25 °C

In a universe of discourse U = [0, 50], these linguistic values would be associated with fuzzy sets whose membership functions are as follows:

$$\mu_{cold}(x) = \begin{cases} 1, & \text{if } x \leq 10 \\ 1 - (x - 10)/5, & \text{if } 10 < x < 15 \\ 0, & \text{otherwise} \end{cases}$$

$$\mu_{moderate}(x) = \begin{cases} 1 - |x - 15|/5, & \text{if } 10 < x < 20 \\ 0, & \text{otherwise} \end{cases}$$

$$\mu_{warm}(x) = \begin{cases} 1 - |x - 20|/5, & \text{if } 15 < x < 25 \\ 0, & \text{otherwise} \end{cases}$$

$$\mu_{hot}(x) = \begin{cases} 1, & \text{if } x \geq 25 \\ 1 - (x - 30)/5, & \text{if } 20 < x < 25 \\ 0, & \text{otherwise} \end{cases}$$

Graphical representations of these fuzzy sets are shown in Figure 4.3. Over the universe of discourse, the temperature T is partitioned into four fuzzy sets — cold, moderate, warm and hot. These fuzzy sets are partially overlapping. Hence, it can be seen that the room temperature of 18°C has partial membership in both the fuzzy set moderate and the fuzzy set warm, where;

$$\begin{aligned} \mu_{moderate}(x = 18) &= 0.25, \quad \text{and} \\ \mu_{warm}(x = 18) &= 0.75 \end{aligned}$$

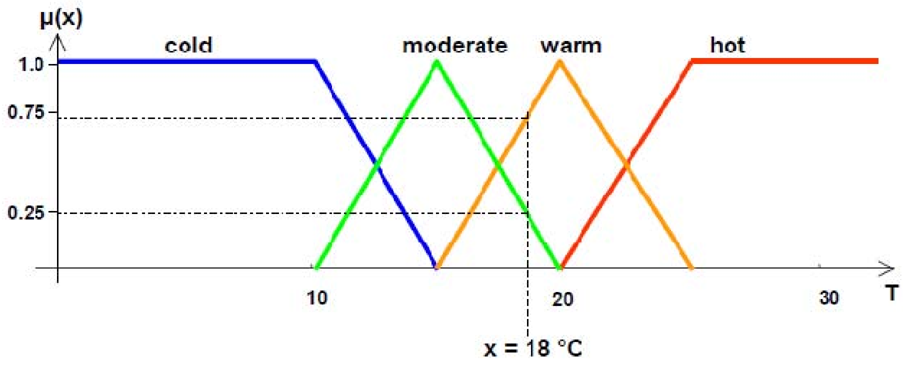


Figure 4.3: Membership functions for the linguistic variable ‘temperature’

In this example, triangular and trapezoidal shape membership functions are defined. In practice, any kind of membership functions that are suitable for the problem in hand can be defined and used. Some common functions are depicted in Figure 4.4.

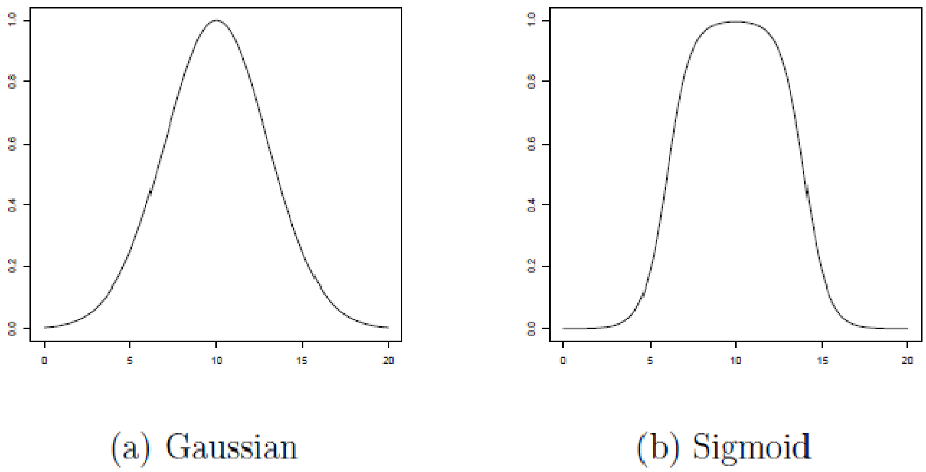


Figure 4.4: Some common membership functions

In order to perform inference, rules, which connect input variables to output variables in ‘IF ... THEN ...’ form, are used to describe the desired system response in terms of linguistic variables (words) rather than mathematical formulae. The ‘IF’ part of the rule is referred to as the ‘antecedent’, the ‘THEN’ part is referred to as the ‘consequent’. The number of rules depends on the number of inputs and outputs, and the desired behavior of the system. Once the rules have been established, such a system can be viewed as a non-linear mapping from inputs to outputs.

Based on this general form of fuzzy rules, several alternative ways of defining fuzzy rules have been used for fuzzy knowledge engineering (Kasabov, N.K. (1998). These several types of fuzzy rules are:

- Mamdani-style fuzzy rules.
- Fuzzy rules with confidence degrees.,
- Takagi-Sugeno's fuzzy rules.
- Gradual fuzzy rules.
- Generalized production rules with degrees of importance, noise tolerance, and sensitivity factors.
- Generalized production rules with variables.
- Recurrent fuzzy rules.

In this research the simple form of Mamdani-style fuzzy rules (Mamdani and Assilian (1975)) was implemented. Advantages of the Mamdani's approach are: a) It is intuitive, b) It has widespread acceptance, c) It well suits to human input. (Fuzzy Logic Toolbox™ 2 User's Guide (2008), MATLAB, The MathWorks, Inc.)

In Mamdani's approach, rules are of the form:

$$R_i : \text{if } (x_1 \text{ is } A_{i1}) \text{ and ... and } (x_r \text{ is } A_{ir}) \text{ then } (y \text{ is } C_i) \text{ for } i = 1, 2, ..., L$$

where L is the number of rules, x_j (j =1, 2, 3, ..., r) are input variables, y is the output variable, and A_{ij} and C_i are fuzzy sets that are characterized by membership functions $A_{ij}(x_j)$ and $C_i(y)$, respectively. In the fuzzy reasoning process, each rule is evaluated in order to determine the degree of fulfillment of the rule (Hishammuddin, A. (2008)).

4.4 Fuzzy Operators

The main fuzzy operations defined by Zadeh (1965) are as follows:

Let A and B be two fuzzy sets with membership functions $\mu A(x)$ and $\mu B(x)$ respectively. The intersection operation (which corresponds to the logical 'AND') is defined as:

$$\mu A \cap B(x) = \min [\mu A(x), \mu B(x)] \quad (4.1)$$

and the union operation (which corresponds to the logical 'OR') is defined as:

$$\mu A \cup B(x) = \max [\mu A(x), \mu B(x)] \quad (4.2)$$

In addition, the complement operator (which corresponds to the logical 'NOT') is defined as:

$$\mu_{\bar{A}}(x) = 1 - \mu A(x) \quad (4.3)$$

A graphical representation of these operations is shown in Figure 4.5 (Hishammuddin, A. (2008)).

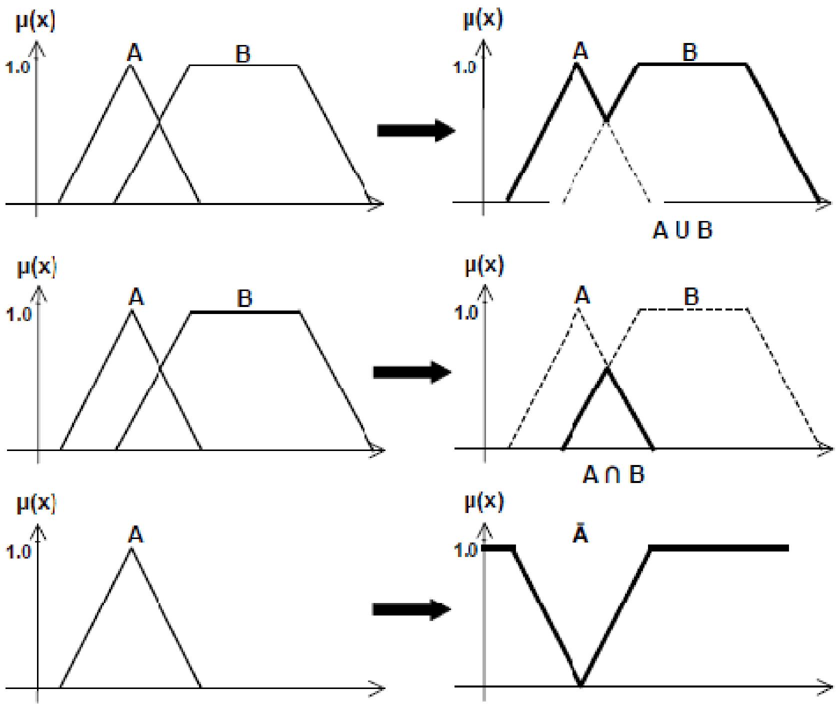


Figure 4.5: Fuzzy sets operations (Negnevitsky, M. (2002))

4.5 Fuzzy Hedges

In addition to the primary linguistic values (terms), it is also possible to apply the concept of fuzzy modifiers, called hedges. Terms such as very, more or less, and slightly are examples of hedges. Hedges are applied to linguistic values in order to modify the shape of the particular fuzzy sets. The ability to define hedges provides more flexibility in defining fuzzy statements that are closer to everyday language. In practice, the terms categorized as hedges have mathematical expressions that define their operations. Some examples of hedges with their mathematical expressions and graphical representations are shown in Figure 4.6. However, the actual definition of hedges and their operations for any particular problem are, again, subjective and dependent on the desired behavior of the fuzzy system.

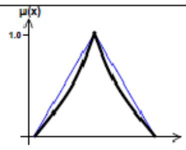
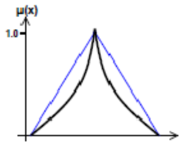
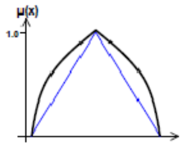
Hedge	Mathematical expression	Graphical representation
Slightly	$[\mu_A(x)]^{1.7}$	
Very	$[\mu_A(x)]^2$	
More or less	$\sqrt{\mu_A(x)}$	

Figure 4.6: Examples of hedges (Negnevitsky, M. (2002))

For the graphical representation, the thicker line is the new shape when the hedge act on the linguistic value.

Figure 4.7 depicts the application of the hedge ‘very’ to the linguistic value ‘warm’. A room temperature of 18°C has 0.7 degree of membership in the fuzzy set ‘warm’, and so belongs to the fuzzy set ‘very warm’ with a membership degree of 0.49. (Hishammuddin, A. (2008)).

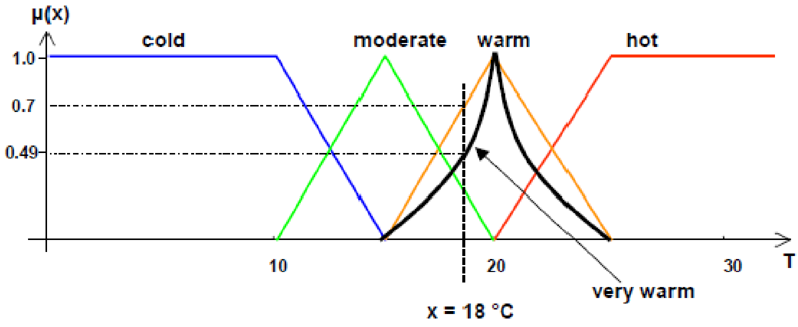


Figure 4.7: Apply hedge 'very' onto linguistic value 'warm'

4.6 Defuzzification Methods

The final output of a Mamdani system is one or more arbitrarily complex fuzzy sets which (usually) need to be defuzzified. Defuzzification is a mathematical process used to extract crisp output from fuzzy output set(s). This process is necessary because all fuzzy sets inferred by fuzzy inference in the fuzzy rules must be aggregated to produce one single number as the output of the fuzzy model. Various types of defuzzification have been suggested in literature (Cox, E. and O'Hagen, M. (1998)).The properties of the specific application being developed will determine which defuzzification method can be utilized. However, there is no systematic procedure to choose which method is the most suitable for any given application. In the following sections, the five most often used defuzzification methods are described (Hishammuddin, A. (2008)).

4.6.1 Center of Gravity (COG) Method

Probably the common form of defuzzification is termed the 'center of gravity' method, as it is based upon the notion of finding the centroid of a planar figure. This method can be expressed mathematically as follows:

$$x^* = \frac{\int_a^b \mu(x) \cdot x dx}{\int_a^b \mu(x) dx}$$

Theoretically, the output is calculated over a continuum of points in the aggregate membership function. In practice, an approximate value can be derived by calculating it over a sample of points. The formula is given by:

$$x^* = \frac{\sum_a^b \mu(x) \cdot x}{\sum_a^b \mu(x)}$$

Figure 4.8 shows a graphical illustration of the method of finding the point representing the center of gravity in the interval [a, b] for the output fuzzy set. (Hishammuddin, A. (2008)).

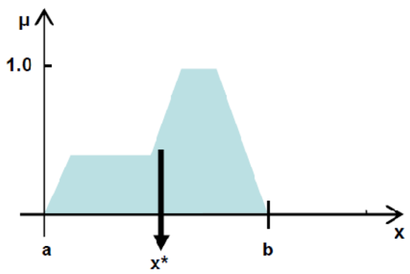


Figure 4.8: The Center of Gravity (COG) method of defuzzification

4.6.2 The Mean of Maxima (MOM) Method

The Mean of Maxima method returns the average of the base-variable values at which their membership values reach the maximum. The formula is given by:

$$x^* = \sum_{j=1}^{k} \frac{x_j}{k}$$

where k is the number of discrete elements of the output fuzzy set that reach the maximum memberships. The graphical illustration of the method is shown in Figure 4.9. (Hishammuddin, A. (2008)).

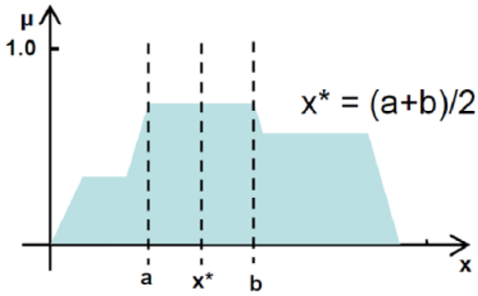


Figure 4.9: The Mean of Maxima (MOM) method of defuzzification

4.6.3 The Smallest of Maxima (SOM) and the Largest of Maxima (LOM) Methods

The Smallest of Maxima method returns the smallest value of x that belongs to [a, b] at which their membership values reach the maximum. Meanwhile, The Largest of Maxima method returns the largest value of x that belongs to [a, b].

A graphical illustration of these methods is shown in Figure 4.10. (Hishammuddin, A. (2008)).

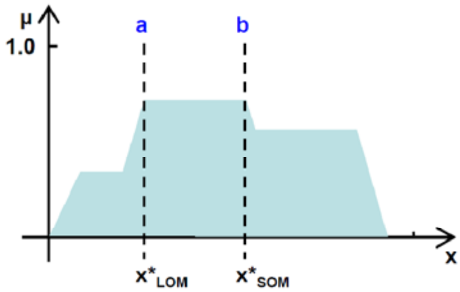


Figure 4.10: The Smallest of Maxima (SOM) and The Largest of Maxima (LOM) methods of defuzzification

4.6.4 The Bisector of Area (BOA) Method

The Bisector of Area (BOA) Method returns the vertical line that partitions the region into two sub-regions of equal area. This method satisfies;

$$\int_{\alpha}^{x*} \mu_A(x)dx = \int_{x*}^{\beta} \mu_A(x)dx$$

where,

$$\alpha = min\{x|x \in X\} \text{ and } \beta = max\{x|x \in X\}$$

A graphical illustration of this method is shown in Figure 4.11. (Hishammuddin, A. (2008)).

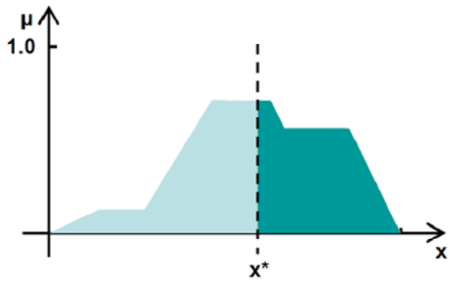


Figure 4.11: The Bisector of Area (BOA) method of defuzzification

4.7 Overview of Fuzzy Systems

Figure 4.12 shows the five interconnected components of a fuzzy system. The fuzzification component computes the membership grade for each crisp input variable based on the membership functions defined. The inference engine then conducts the fuzzy reasoning process by applying the appropriate fuzzy operators in order to obtain the fuzzy set to be accumulated in the output variable. The defuzzifier transforms the output fuzzy set to a crisp output by applying a specific defuzzification method.

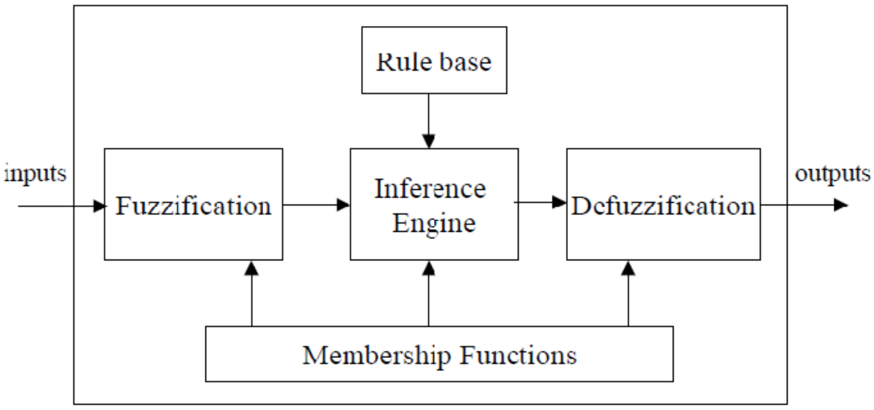


Figure 4.12: Components of fuzzy system

Briefly, the main steps in fuzzy system design are as follows:

- Analyze and understand the problem in consideration.
- Determine the linguistic variables (the inputs and outputs). For each linguistic variable, identify the linguistic values and define the fuzzy sets (membership functions).
- Identify and define the fuzzy rule set.
- Choose the appropriate methods for fuzzification, fuzzy inference and defuzzification.
- Evaluate the system.

If necessary, this sequence of steps is then repeated an arbitrary number of times while fine tuning the fuzzy system by modifying the fuzzy input/output sets and/or fuzzy rules.

In reality, modeling a fuzzy system is a difficult task. Finding a sufficiently good system can be viewed as a search problem in high-dimensional space, in which each point represents a rule set, the membership functions, and the evaluation function is some measure of the corresponding system behavior. This is due to the fact that the performance of a fuzzy system is highly dependent on how the system developer defines the linguistic variables, the membership functions, fuzzy rules set and so on. No formal methods exist to determine the appropriate fuzzy model in a given context. The term 'fuzzy model' is used to mean the combination of selected linguistic variables (input and output variables), membership functions for each linguistic variable and a rule set. Most of the time, the system is either built based on expert knowledge or by systematically training the system using the available data. There are many alternative ways in which this general fuzzy methodology can be implemented in any given problem. In this thesis, the standard Mamdani style fuzzy inference was used with standard Zadeh operators.

Consider a simple example, in order to understand how Mamdani style fuzzy inference works. This example is for a fuzzy system with two input variables and one output variable. The purpose of this example is to illustrate how the final crisp output is obtained for the particular input values. (Hishammuddin, A. (2008)).

Step 1 -Determining linguistic variables and fuzzy sets. Let the two inputs be represented as linguistic variables A and B; and the output as linguistic variable C. A_1, A_2 and A_3 are linguistic values for A; B_1, B_2 and B_3 are linguistic values for B; C_1, C_2 and C_3 are linguistic values for C with membership functions as shown in the graphical representations given in Figure 4.13.

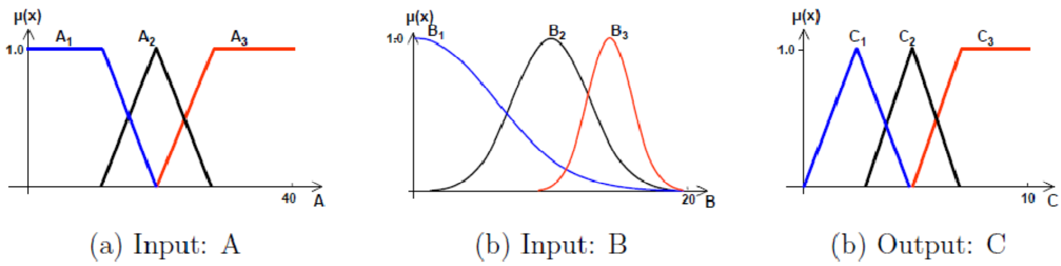


Figure 4.13: Characteristic of linguistic variables

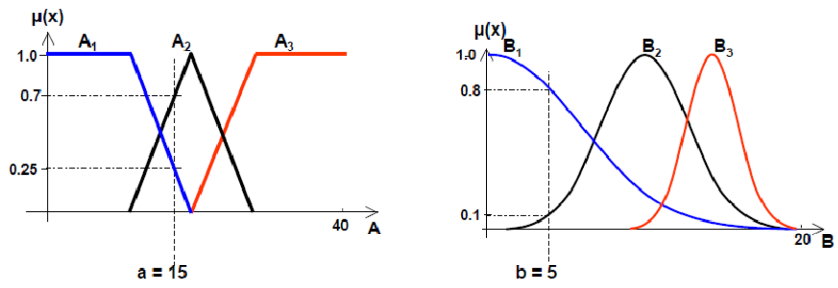
Rules are defined as follows:

Rule 1: IF (a is A_1) AND (b is B_1) THEN (c is C_1)

Rule 2: IF (a is A_2) OR (b is B_2) THEN (c is C_2)

Rule 3: IF (a is A_3) AND (b is B_3) THEN (c is C_3)

Step 2 -Fuzzification. The fuzzified values for input values a = 15 and b = 5 are shown in Figure 4.14.



(a) Input: A (b) Input: B

Figure 4.14: The fuzzified value for both input linguistic variables

Step 3 -Fuzzy Inferencing (Evaluate Rules). The firing level for each rule is determined using the min-max operator shown in Equations (4.1) and (4.2). If the AND operator appears in the antecedents part, the minimum fuzzified value will be selected. On the other hand, if the OR operator appears, the maximum fuzzified value will be selected. Figure 4.15 shows the process graphically. It can be seen that Rule 3 is not activated because both input values (i.e. a = 15 and b = 5) have zero membership degree for the linguistic values A3 and B3 respectively.

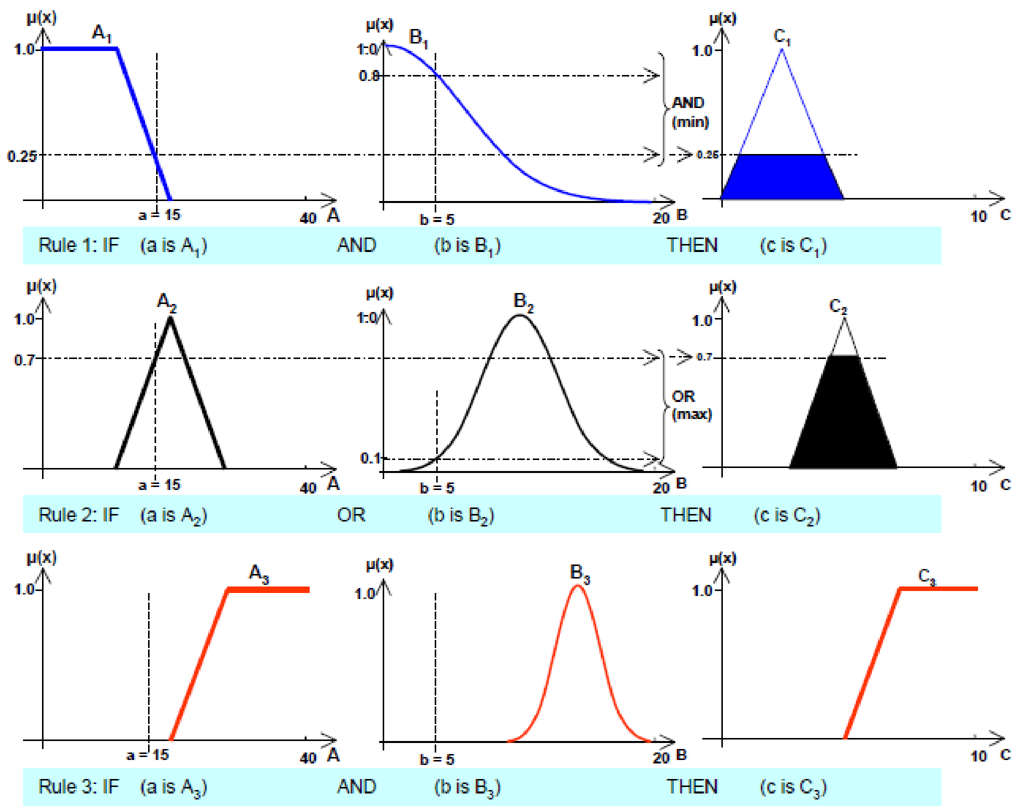


Figure 4.15: Evaluation of rules fulfillment (firing levels)

Step 4 -Rules Output Aggregation. Having evaluated all the rules, the final shape of the output is determined by combining all of the activated rule consequents. The aggregation result is shown in Figure 4.16.

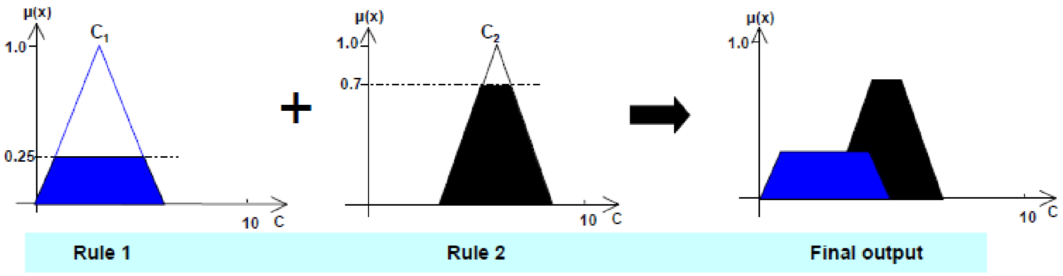


Figure 4.16: Aggregation of rules

Step 5 -Defuzzification. Center of Gravity method of defuzzification is used to defuzzify the output fuzzy set. Figure 4.17 shows the calculated 'center of gravity' of the final output fuzzy set for this simple example problem.

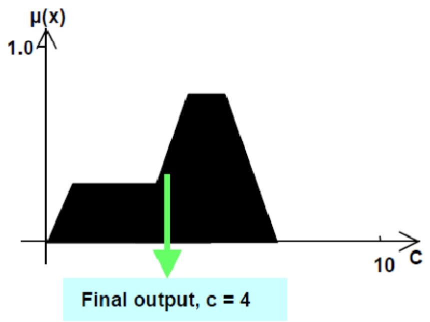


Figure 4.17: Defuzzification of final shape

Even when created with expert knowledge, the system invariably needs to be fine tuned in order to obtain a satisfactory system performance (where 'satisfactory' may be defined in terms of how good is the fuzzy system is compared to the equivalent manual system; or perhaps in terms of whether the system behaves as previously specified; etc.). (Hishammuddin, A. (2008)).

In spite of the fact that sophisticated search techniques are often utilized in fuzzy tuning, it was outside the scope of this thesis to perform any extensive application of such methods.

4.8 Chapter Summary

This chapter presented the basics of fuzzy set theory, fuzzy inference and fuzzy modeling. Although the presented material only covers a very small part of the huge body of fuzzy set theory and fuzzy techniques in general, it was designed to be enough for the unfamiliar reader to understand the conceptual framework of the fuzzy methodologies that were implemented in the rest of this thesis. The basic definitions and rules of fuzzy set theory explained above were the bases of the proposed schedule delay analysis tool. Based on these concepts, the necessary calculations will be carried out by using Fuzzy Logic Toolbox of the MATLAB Program Software in the following chapters.

CHAPTER 5

QUANTIFICATION OF RELATIVE IMPORTANCES OF SCHEDULE DELAY FACTORS BY RELATIVE IMPORTANCE INDEX (RII) METHOD

5.1 Introduction & Methodology

In chapter 3, a total number of eighty three (83) factors in nine (9) groups of causes of schedule delays in construction projects were identified by the author through detailed literature review. Table 5.1 shows the complete groups and factors that may cause schedule delays in construction projects.

The aim of this chapter is to quantify relative importances of schedule delay factors.

The results of this chapter will demonstrate the ranking of the factors and groups according to their importance level on schedule delay. The results of this chapter will also serve to determine the fuzzy rules' weights to construct "the fuzzy assessment model to estimate the probability of schedule delay" in the following chapter.

The following steps will be followed to quantify relative importances of schedule delay factors.

Step 1: An assessment case study will be introduced. An interview will be developed to evaluate the schedule delay factors according to their relative importances on schedule delay.

Step 2: Relative Importance Index (RII) method will be used as data analysis method to assess the relative importances of schedule delay factors. A five-point Likert Scale will be adopted.

Step 3: Results of analysis will be presented. The relative importance index, RII, was computed for each factor to identify the most and the least significant schedule delay factors in construction projects. Results will be discussed.

Table 5.1: Groups and factors that may cause schedule delays in construction projects

Groups of factors	No	Factors causing schedule delays
1) Consultant Related Factors	1	Lack of experience of consultant in construction projects
	2	Conflicts between consultant and design engineer
	3	Delay in approving major changes in the scope of work by consultant
	4	Delay in performing inspection and testing
	5	Inaccurate site investigation
	6	Inadequate project management assistance
	7	Late in reviewing and approving design documents
	8	Poor communication and coordination with other parties
2) Contractor Related Factors	1	Frequent change of subcontractors
	2	Inadequate contractor experience
	3	Inappropriate construction methods
	4	Incompetent project team
	5	Ineffective project planning and scheduling
	6	Obsolete technology
	7	Poor communication and coordination with other parties
	8	Poor site management and supervision
	9	Rework due to errors
	10	Unreliable subcontractors
3) Design Related Factors	1	Complexity of project design
	2	Design changes by owner or his agent during construction
	3	Design errors made by designers
	4	Insufficient data collection and survey before design
	5	Lack of experience of design team in construction projects
	6	Mistakes and delays in producing design documents
	7	Misunderstanding of owner's requirements by design engineer
	8	Poor use of advanced engineering design software
	9	Unclear and inadequate details in drawings
4) Equipment Related Factors	1	Equipment allocation problem
	2	Frequent equipment breakdowns
	3	Improper equipment
	4	Inadequate modern equipment
	5	Low efficiency of equipment
	6	Shortage of equipment
	7	Slow mobilization of equipment
5) External Related Factors	1	Accidents during construction
	2	Changes in government regulations and laws
	3	Conflict, war, and public enemy
	4	Delay in obtaining permits from municipality
	5	Delay in performing final inspection and certification by a third party
	6	Delay in providing services from utilities (such as water, electricity)
	7	Global financial crisis
	8	Loss of time by traffic control and restriction at job site
	9	Natural disasters (flood, hurricane, earthquake)
	10	Price fluctuations
	11	Problem with neighbors
	12	Slow site clearance
	13	Unexpected surface& subsurface conditions (such as soil, hw table)
	14	Unfavorable weather conditions

Table 5.1: Groups and factors that may cause schedule delays in construction projects (cont'd)

Groups of factors	No	Factors causing schedule delays
6) Labor Related Factors	1	Absenteeism
	2	Low motivation and morale of labor
	3	Low productivity of labor
	4	Personal conflicts among labor
	5	Shortage of labor
	6	Slow mobilization of labor
	7	Strike
	8	Unqualified / inadequate experienced labor
7) Material Related Factors	1	Changes in material types and specifications during construction
	2	Damage of sorted materials
	3	Delay in manufacturing materials
	4	Escalation of material prices
	5	Late delivery of materials
	6	Poor procurement of construction materials
	7	Poor quality of construction materials
	8	Shortage of construction materials
	9	Unreliable suppliers
8) Owner Related Factors	1	Change orders
	2	Conflicts between joint-ownership
	3	Delay in approving design documents
	4	Delay in progress payments
	5	Delay in site delivery
	6	Improper project feasibility study
	7	Lack of capable representative
	8	Lack of experience of owner in construction projects
	9	Lack of incentives for contractor to finish ahead of schedule
	10	Poor communication and coordination with other parties
	11	Slowness in decision making
	12	Suspension of work by owner
9) Project Related Factors	1	Complexity of the project
	2	Inadequate definition of substantial completion
	3	Ineffective delay penalties
	4	Legal disputes between project participants
	5	Original contract duration is short
	6	Unfavorable contract clauses

5.2 An Assessment Case Study

An interview was developed to assess the perceptions of a leading Turkish Construction Company on the relative importance of causes of schedule delays in construction industry. This company has a significant experience in construction projects such as; industrial plants, oil and gas pipelines, roads and railways, water and waste water, tunnels, hospitals, hotels, military facilities, administrative buildings and mass housing projects. The company has served in the construction sector approximately for 30 years. The company has extensive construction activities all over the world. The company can be considered as an expert of construction projects. One of the main focus areas of the company is oil and gas works. The last completed project, which will be analyzed in detail in the following chapter as a case study, was the construction of a complete natural gas compressor station. The project was individually carried out by the company in Çorum, TURKEY. This compressor station had 2 main and 1 auxiliary units. The total installed power is 45.9 Megawatts. The owner of the project was BOTAŞ (Petroleum Pipeline Corporation). Scheduled duration was 400 calendar days. Payment type was lump sum. The contract price was 42.888.979, 52 US Dollars.

The interview was focused on the causes of schedule delay in construction projects. The company was requested to form a commission of decision makers to perform the following tasks:

1) To check the questionnaire form about schedule delay factors in construction projects prepared by the author through detailed literature survey. (A total number of eighty three (83) factors.)
2) To check the groups of schedule delay factors in construction projects prepared by the author through detailed literature survey. (A total number of nine (9) groups.)
3) To cite additional factors if necessary.
4) To fill the questionnaire form by weighting (assigning values) the factors ranging from 1 (very low important) to 5 (very high important) considering the relative importances of schedule delay factors.

Company formed commission, whose members were composed of ten (10) experienced civil engineers including site managers, technical office managers, technical office engineers, procurement managers and technical consultants. It was assumed that:

1) The commission members had significant information about schedule delay factors construction projects.
2) The commission members allocated necessary time to perform the required tasks.
3) The commission members were experts of construction projects.

The commission members checked and evaluated the eighty three (83) well organized the schedule delay factors based on their professional judgment considering the consultant, contractor, design, equipment, external, labor, materials, owner and project related delay factor groups. They filled in the questionnaire form by weighting (assigning numbers) the factors ranging from 1 (very low important) to 5 (very high important) considering the relative importances of the schedule delay factors. The sample questionnaire form was shown in Table B.1 in Appendix B.

5.3 Data Analysis Method

Kometa, S.T. et al. (1994) and Sambasivan, M. and Soon, Y. W. (2007) used the Relative Importance Index (RII) method to determine the relative importance of the various causes of delays. The same method was adopted in this study. The five-point Likert scale ranged from 1 (very low important) to 5 (very high important) was adopted and transformed to relative importance indices (RII) for each factor as follows:

$$\mathrm{RII} = \frac{\sum W}{A * N}$$

where W is the weighting given to each factor by the respondents (ranging from 1 to 5), A is the highest weight (i.e. 5 in this case), and N is the total number of respondents. The RII value had a range from 0 to 1 (0 not inclusive), higher the value of RII, more important was the cause of delays.

The RII was used to rank (R) the different causes. These rankings made it possible to cross-compare the relative importance of the factors as perceived by the respondents (i.e. commission members). Each individual cause's RII perceived by all respondents were used to assess the general and overall rankings in order to give an overall picture of the causes of construction delays.

The Likert Scale was named after its originator, Rensis Likert. The Likert Scale is an ordered, one-dimensional scale from which respondents choose one option that best aligns with their view. There are typically between four and seven options. Five is very common. All options usually have labels, although sometimes only a few are offered and the others are implied. A common form is an assertion, with which the person may agree or disagree to varying degrees. In scoring, numbers are usually assigned to each option (such as 1 to 5). A benefit is that questions used are usually easy to understand and so lead to consistent answers. A disadvantage is that only a few options are offered, with which respondents may not fully agree. As with any other measurement, the options should be a carefully selected from set of questions or statements that act together to give a useful and coherent picture. A problem can occur where people may become influenced by the way they have answered previous questions. For example if they have agreed several times in a row, they may continue to agree. They may also deliberately break the pattern, disagreeing with a statement with which they might otherwise have agreed. This patterning can be broken up by asking *reversal questions*, where the sense of the question is reversed. (Website: http://changingminds.org/explanations/research/measurement/likert_scale.htm)

A five-point Likert Scale, which had a common use in the previous literature, ranged from 1 (very low important) to 5 (very high important) was adopted by the author in this thesis as shown in Figure 5.1:

Importance				
1: Very low important	2: Low important	3: Medium important	4: High important	5: Very high important

Figure 5.1: A five point Likert Scale

5.4 Results of Analysis

The relative importance index, RII, was computed for each factor to identify the most and the least significant schedule delay factors in construction projects. According to the computed RII values, these factors were ranked. Table 5.2 shows factors and groups of schedule delay factors, respondent’s scorings (from 1=very low important to 5=very high important), computed RII’s, and ranks.

Table 5.2: Factors and groups of schedule delay factors, respondent's scorings, computed RII's, and ranks

Groups of factors	No	Factors causing schedule delays	Number of respondents scoring					RII	Rank
			1:Very low important	2:Low important	3: Medium important	4: High important	5: Very high important		
1) Consultant Related Factors	1	Lack of experience of consultant in construction projects	0	1	2	5	2	0,760	16
	2	Conflicts between consultant and design engineer	1	5	2	2	0	0,500	51
	3	Delay in approving major changes in the scope of work by consultant	1	2	4	3	0	0,580	37
	4	Delay in performing inspection and testing	0	1	1	2	6	0,860	5
	5	Inaccurate site investigation	2	4	3	1	0	0,460	62
	6	Inadequate project management assistance	0	3	4	3	0	0,600	33
	7	Late in reviewing and approving design documents	0	2	5	2	1	0,640	31
	8	Poor communication and coordination with other parties	0	1	3	5	1	0,720	24
2) Contractor Related Factors	1	Frequent change of subcontractors	2	5	2	1	0	0,440	67
	2	Inadequate contractor experience	0	0	1	4	5	0,880	2
	3	Inappropriate construction methods	2	4	3	1	0	0,460	62
	4	Incompetent project team	1	2	5	2	0	0,560	42
	5	Ineffective project planning and scheduling	0	0	1	4	5	0,880	2
	6	Obsolete technology	4	3	2	1	0	0,400	74
	7	Poor communication and coordination with other parties	0	2	1	4	3	0,760	16
	8	Poor site management and supervision	0	0	2	4	4	0,840	8
	9	Rework due to errors	2	3	3	2	0	0,500	51
	10	Unreliable subcontractors	1	1	3	4	1	0,660	29
3) Design Related Factors	1	Complexity of project design	3	4	1	2	0	0,440	67
	2	Design changes by owner or his agent during construction	0	0	3	2	5	0,840	8
	3	Design errors made by designers	1	2	4	2	1	0,600	33
	4	Insufficient data collection and survey before design	2	3	3	1	1	0,520	48
	5	Lack of experience of design team in construction projects	0	3	2	4	1	0,660	29
	6	Mistakes and delays in producing design documents	1	1	3	3	2	0,680	27
	7	Misunderstanding of owner's requirements by design engineer	3	4	1	2	0	0,440	67
	8	Poor use of advanced engineering design software	5	2	2	1	0	0,380	77
	9	Unclear and inadequate details in drawings	1	2	4	2	1	0,600	33
4) Equipment Related Factors	1	Equipment allocation problem	2	1	3	3	1	0,600	33
	2	Frequent equipment breakdowns	2	2	4	2	0	0,520	48
	3	Improper equipment	2	4	3	1	0	0,460	62
	4	Inadequate modern equipment	0	2	1	5	2	0,740	19
	5	Low efficiency of equipment	0	1	2	6	1	0,740	19
	6	Shortage of equipment	2	4	2	2	0	0,480	60
	7	Slow mobilization of equipment	3	3	3	1	0	0,440	67
5) External Related Factors	1	Accidents during construction	1	4	3	2	0	0,520	48
	2	Changes in government regulations and laws	2	4	1	3	0	0,500	51
	3	Conflict, war, and public enemy	1	4	2	2	1	0,560	42
	4	Delay in obtaining permits from municipality	4	3	1	2	0	0,420	72
	5	Delay in performing final inspection and certification by a third party	1	3	3	3	0	0,560	42
	6	Delay in providing services from utilities (such as water, electricity)	3	2	4	1	0	0,460	62
	7	Global financial crisis	0	1	0	3	6	0,880	2
	8	Loss of time by traffic control and restriction at job site	5	2	2	1	0	0,380	77
	9	Natural disasters (flood, hurricane, earthquake)	2	4	2	1	1	0,500	51
	10	Price fluctuations	1	3	3	2	1	0,580	37
	11	Problem with neighbors	0	2	3	4	1	0,680	27
	12	Slow site clearance	3	3	2	2	0	0,460	62
	13	Unexpected surface& subsurface conditions (such as soil, hw table)	0	1	2	4	3	0,780	14
	14	Unfavorable weather conditions	0	1	2	2	5	0,820	11

Table 5.2: Factors and groups of schedule delay factors, respondent's scorings, computed RII's, and ranks (cont'd)

Groups of factors	No	Factors causing schedule delays	Number of respondents scoring					RII	Rank
			1:Very low important	2:Low important	3: Medium important	4: High important	5: Very high important		
6) Labor Related Factors	1	Absenteeism	5	3	0	2	0	0,380	77
	2	Low motivation and morale of labor	2	4	2	1	1	0,500	51
	3	Low productivity of labor	2	2	5	1	0	0,500	51
	4	Personal conflicts among labor	3	4	3	0	0	0,400	74
	5	Shortage of labor	0	1	3	1	5	0,800	12
	6	Slow mobilization of labor	4	2	3	1	0	0,420	72
	7	Strike	5	3	1	1	0	0,360	83
	8	Unqualified / inadequate experienced labor	0	1	3	4	2	0,740	19
7) Material Related Factors	1	Changes in material types and specifications during construction	0	1	2	5	2	0,760	16
	2	Damage of sorted materials	1	2	4	3	0	0,580	37
	3	Delay in manufacturing materials	4	4	1	1	0	0,380	77
	4	Escalation of material prices	2	2	5	1	0	0,500	51
	5	Late delivery of materials	0	1	2	4	3	0,780	14
	6	Poor procurement of construction materials	1	3	3	3	0	0,560	42
	7	Poor quality of construction materials	3	4	1	2	0	0,440	67
	8	Shortage of construction materials	0	0	2	4	4	0,840	8
	9	Unreliable suppliers	2	1	5	2	0	0,540	46
8) Owner Related Factors	1	Change orders	0	0	1	3	6	0,900	1
	2	Conflicts between joint-ownership	2	4	2	1	1	0,500	51
	3	Delay in approving design documents	0	2	2	4	2	0,720	24
	4	Delay in progress payments	0	2	5	2	1	0,640	31
	5	Delay in site delivery	0	1	3	4	2	0,740	19
	6	Improper project feasibility study	1	4	4	1	0	0,500	51
	7	Lack of capable representative	5	2	1	2	0	0,400	74
	8	Lack of experience of owner in construction projects	0	2	1	5	2	0,740	19
	9	Lack of incentives for contractor to finish ahead of schedule	1	5	3	1	0	0,480	60
	10	Poor communication and coordination with other parties	0	1	0	4	5	0,860	5
	11	Slowness in decision making	0	1	2	3	4	0,800	12
	12	Suspension of work by owner	1	3	3	2	1	0,580	37
9) Project Related Factors	1	Complexity of the project	3	5	2	0	0	0,380	77
	2	Inadequate definition of substantial completion	4	4	1	1	0	0,380	77
	3	Ineffective delay penalties	1	4	3	1	1	0,540	46
	4	Legal disputes between project participants	1	3	3	2	1	0,580	37
	5	Original contract duration is short	0	2	2	4	2	0,720	24
	6	Unfavorable contract clauses	0	0	2	3	5	0,860	5

Table 5.3 summarized RII and ranking of the groups of factors of schedule delay as perceived by the respondents.

Table 5.3: RII and ranking of the groups of factors of schedule delay

Group of factors	RII	Rank
Owner Related Factors	**0,655**	**1**
Consultant Related Factors	**0,640**	**2**
Contractor Related Factors	**0,638**	**3**
Material Related Factors	**0,598**	**4**
External Related Factors	**0,579**	**5**
Project Related Factors	**0,577**	**6**
Design Related Factors	**0,573**	**7**
Equipment Related Factors	**0,569**	**8**
Labor Related Factors	**0,513**	**9**

Based on the ranking, the top fifteen (15) most important factors causing schedule delays were shown in Table 5.4 below:

Table 5.4: List of top fifteen (15) most important factors causing schedule delays in construction projects

No	Top fifteen (15) most important factors causing schedule delays	Group of factor	RII	Rank
1	Change orders	Owner related	**0,900**	**1**
2	Inadequate contractor experience	Contractor related	**0,880**	**2**
3	Ineffective project planning and scheduling	Contractor related	**0,880**	**2**
4	Global financial crisis	External related	**0,880**	**2**
5	Delay in performing inspection and testing	Consultant related	**0,860**	**5**
6	Poor communication and coordination with other parties	Owner related	**0,860**	**5**
7	Unfavorable contract clauses	Project related	**0,860**	**5**
8	Poor site management and supervision	Contractor related	**0,840**	**8**
9	Design changes by owner or his agent during construction	Design related	**0,840**	**8**
10	Shortage of construction materials	Material related	**0,840**	**8**
11	Unfavorable weather conditions	External related	**0,820**	**11**
12	Shortage of labor	Labor related	**0,800**	**12**
13	Slowness in decision making	Owner related	**0,800**	**12**
14	Late delivery of materials	Material related	**0,780**	**14**
15	Unexpected surface& subsurface conditions (such as soil, hw table)	External related	**0,780**	**14**

Based on the same ranking, the top ten (10) least important factors causing schedule delays were shown in Table 5.5 below:

Table 5.5: List of top ten (10) least important factors causing schedule delays in construction projects

No	Top ten (10) least important factors causing schedule delays	Group of factor	RII	Rank
1	Strike	Labor related	0,360	83
2	Poor use of advanced engineering design software	Design related	0,380	77
3	Loss of time by traffic control and restriction at job site	External related	0,380	77
4	Absenteeism	Labor related	0,380	77
5	Delay in manufacturing materials	Material related	0,380	77
6	Complexity of the project	Project related	0,380	77
7	Inadequate definition of substantial completion	Project related	0,380	77
8	Obsolete technology	Contractor related	0,400	74
9	Personal conflicts among labor	Labor related	0,400	74
10	Lack of capable representative	Owner related	0,400	74

5.5 Discussion of Results

1. Owner: The owner related group of schedule delay factors was the most important group to cause schedule delays. This was mainly due to factors “Change orders (RII=0.900)”, “Poor communication and coordination with other parties (RII=0.860)”, and “Slowness in decision making (RII=0.800)”.

2. Consultant: Second important group was the consultant related group, having the factors “Delay in performing inspection and testing (RII=0.860)”, “Lack of experience of consultant in construction projects (RII=0.760)”, “Poor communication and coordination with other parties (RII=0.720)”.

3. Contractor: After the consultant, the contractor related group of schedule delay factors took place as the third most important group. The outstanding factors were “Inadequate contractor experience (RII=0.880)”, “Ineffective project planning and scheduling (RII=0.880)”, and “Poor site management and supervision (RII=0.840)”.

4. Material: Following the contractor, the material related group of schedule delay factors ranks as the fourth most important group. The noticeable factors were "Shortage of construction materials (RII=0.840)", "Late delivery of materials (RII=0.780)", and "Changes in material types and specifications during construction (RII=0.760)".

5. External: Fifth important group was the external related group. The prominent factors were "Global financial crisis (RII=0.880)", "Unfavorable weather conditions (RII=0.820)", and "Unexpected surface& subsurface conditions (such as soil, hw table) (RII=0.780)".

6. Project: After the external, the project related group of schedule delay factors took place as the sixth most important group. The outstanding factors were "Unfavorable contract clauses (RII=0.860)" and "Original contract duration is short (RII=0.720)".

7. Design: Following the project, the design related group of schedule delay factors ranked as the seventh most important group. The noticeable factors were "Design changes by owner or his agent during construction (RII=0.840)", "Mistakes and delays in producing design documents (RII=0.680)", and "Lack of experience of design team in construction projects (RII=0.660)".

8. Equipment: Eighth important group was the equipment related group. The prominent factors were "Inadequate modern equipment (RII=0.740)" and "Low efficiency of equipment (RII=0.740)".

9. Labor: The labor related group of schedule delay factors was the last and the least important group. The noticeable factors were "Shortage of labor (RII=0.800)", "Unqualified / inadequate experienced labor (RII=0.740)".

5.6 Chapter Summary

The results of this chapter have demonstrated the ranking of the factors and groups according to their importance level on schedule delay by using relative importance index (RII) method. The computed RII's of factors will make it possible to assign the fuzzy rules' weights to construct "the fuzzy assessment model to estimate the probability of schedule delay" in the following chapter.

CHAPTER 6

FUZZY ASSESSMENT MODEL TO ESTIMATE THE PROBABILITY OF SCHEDULE DELAY

6.1 Introduction & Methodology

Probability analysis has in its essence uncertainty and impreciseness. Any analysis made ignoring this uncertainty and impreciseness may cause information to be seriously misleading, therefore, contributing to large mistakes. Fuzzy logic is based upon uncertainties where there is an inherent impreciseness. It provides mathematical tools to deal with imprecise, uncertain, and vague data (Shull, P. (2006)).

In this chapter, the proposed fuzzy assessment model to estimate the probability of schedule delay will be explained. The following steps will be followed to construct this model.

Step 1: Schedule delay factors which were identified in the chapter 3 will be base input factors of this assessment model.

Step 2: Groups of schedule delay factors which were identified in the chapter 3 will be base input groups of factors of this assessment model.

Step 3: The linguistic variables & fuzzy membership functions will be determined.

Step 4: The fuzzy rules (if-then rules) will be constructed, the relative importance indices (RII's) of factors and groups of factors which were achieved in chapter 5 will be assigned as the fuzzy rules' weights and aggregation & defuzzification methods will be determined to construct "the fuzzy assessment model to estimate the probability of schedule delay".

Step 5: The constructed fuzzy assessment model will be developed by using Fuzzy Logic Toolbox of the MATLAB Program Software.

Step 6: The constructed fuzzy assessment model will be tested in a real case study.

6.2 Base Input Factors and Groups of Factors to Construct the Model

Step 1 and step 2 will be covered in this part. As it was mentioned in the introduction & methodology part, schedule delay factors which were identified in the Chapter 3 will be base input factors of this assessment model. These factors and groups of factors were achieved through the literature review which was done through books, engineering journals, conference papers, master theses, the internet, and interview with experts from a leading Turkish Construction Company.

These base input factors and groups of factors to construct the assessment model were shown in Table 6.1. To simplify the long sentences, the acronyms of the factors were also demonstrated in the same table.

Table 6.1: Base input factors and groups of factors to construct the assessment model

Groups of factors	No	Factors causing schedule delays	Acronyms of factors causing schedule delays
1) Consultant Related Factors	1	Lack of experience of consultant in construction projects	LOE1
	2	Conflicts between consultant and design engineer	CBC
	3	Delay in approving major changes in the scope of work by consultant	DIA1
	4	Delay in performing inspection and testing	DIP1
	5	Inaccurate site investigation	ISI
	6	Inadequate project management assistance	IPM
	7	Late in reviewing and approving design documents	LIR
	8	Poor communication and coordination with other parties	PCC1
2) Contractor Related Factors	1	Frequent change of subcontractors	FCO
	2	Inadequate contractor experience	ICE
	3	Inappropriate construction methods	ICM
	4	Incompetent project team	IPT
	5	Ineffective project planning and scheduling	IPP
	6	Obsolete technology	OT
	7	Poor communication and coordination with other parties	PCC2
	8	Poor site management and supervision	PSM
	9	Rework due to errors	RDT
	10	Unreliable subcontractors	US
3) Design Related Factors	1	Complexity of project design	COP
	2	Design changes by owner or his agent during construction	DCB
	3	Design errors made by designers	DEM
	4	Insufficient data collection and survey before design	IDC
	5	Lack of experience of design team in construction projects	LOE2
	6	Mistakes and delays in producing design documents	MAD
	7	Misunderstanding of owner's requirements by design engineer	MOO
	8	Poor use of advanced engineering design software	PUO
	9	Unclear and inadequate details in drawings	UAİ
4) Equipment Related Factors	1	Equipment allocation problem	EAP
	2	Frequent equipment breakdowns	FEB
	3	Improper equipment	IE
	4	Inadequate modern equipment	IME
	5	Low efficiency of equipment	LEO
	6	Shortage of equipment	SOE
	7	Slow mobilization of equipment	SMO1
5) External Related Factors	1	Accidents during construction	ADC
	2	Changes in government regulations and laws	CIG
	3	Conflict, war, and public enemy	CWP
	4	Delay in obtaining permits from municipality	DIO
	5	Delay in performing final inspection and certification by a third party	DIP
	6	Delay in providing services from utilities (such as water, electricity)	DIP2
	7	Global financial crisis	GFC
	8	Loss of time by traffic control and restriction at job site	LOT
	9	Natural disasters (flood, hurricane, earthquake)	ND
	10	Price fluctuations	PF
	11	Problem with neighbors	PWN
	12	Slow site clearance	SSC
	13	Unexpected surface& subsurface conditions (such as soil, hw table)	USS
	14	Unfavorable weather conditions	UWC

Table 6.1: Base input factors and groups of factors to construct the assessment model (cont'd)

Groups of factors	No	Factors causing schedule delays	Acronyms of factors causing schedule delays
6) Labor Related Factors	1	Absenteeism	A
	2	Low motivation and morale of labor	LMA
	3	Low productivity of labor	LPO
	4	Personal conflicts among labor	PCA
	5	Shortage of labor	SOL
	6	Slow mobilization of labor	SMO2
	7	Strike	S
	8	Unqualified / inadequate experienced labor	UEL
7) Material Related Factors	1	Changes in material types and specifications during construction	CIM
	2	Damage of sorted materials	DOS
	3	Delay in manufacturing materials	DIM
	4	Escalation of material prices	EOM
	5	Late delivery of materials	LDO
	6	Poor procurement of construction materials	PPO
	7	Poor quality of construction materials	PQO
	8	Shortage of construction materials	SOC
	9	Unreliable suppliers	US2
8) Owner Related Factors	1	Change orders	CO
	2	Conflicts between joint-ownership	CBJ
	3	Delay in approving design documents	DIA2
	4	Delay in progress payments	DIP3
	5	Delay in site delivery	DIS
	6	Improper project feasibility study	IPF
	7	Lack of capable representative	LOC
	8	Lack of experience of owner in construction projects	LOE3
	9	Lack of incentives for contractor to finish ahead of schedule	LOI
	10	Poor communication and coordination with other parties	PCC3
	11	Slowness in decision making	SID
	12	Suspension of work by owner	SOW
9) Project Related Factors	1	Complexity of the project	COT
	2	Inadequate definition of substantial completion	IDO
	3	Ineffective delay penalties	IDP
	4	Legal disputes between project participants	LDB
	5	Original contract duration is short	OCD
	6	Unfavorable contract clauses	UCC

6.3 Linguistic Variables & Fuzzy Membership Functions

Step 3 will be covered in this part. Trapezoidal and triangular forms of membership functions had a common usage in the previous literature. Some examples of the use of trapezoidal and triangular forms of membership functions are: Tah, J.H.M. and Carr, V.

(2000), Tah, J.H.M. and Carr, V. (2001), Yolaç, U. and Yalçınöz (2003), Özek, A. and Sinecen, M. (2004), Han, S (2005), Taş, F. (2005), Gürcanlı, G.E. and Müngen, U. (2006), Tanyıldızı, H.and Yazıcıoğlu, S. (2006), Murat, Y.Ş. (2006), Öztürk, F. (2006), Görgülü, Ö. (2007), Zeng, J. et al. (2007).

According to literature findings mentioned above, in this thesis, the author determined the linguistic variables to be defined as "very low, low, medium, high, and very high" out of a scale ranging from zero (0) to a hundred (100). The scale used here was very similar to five (5) point Likert scale used in the chapter 5. Likert scales were explained in detail in the chapter 5. Five (5) membership functions were defined for all linguistic variables. All of them were represented by a combination of trapezoidal and triangular form of fuzzy numbers. In this step, to the respondent's evaluation of the value of factors by linguistic terms was transformed to a combination of trapezoidal and triangular forms of fuzzy numbers by the predetermined membership functions given in Figure 6.1.

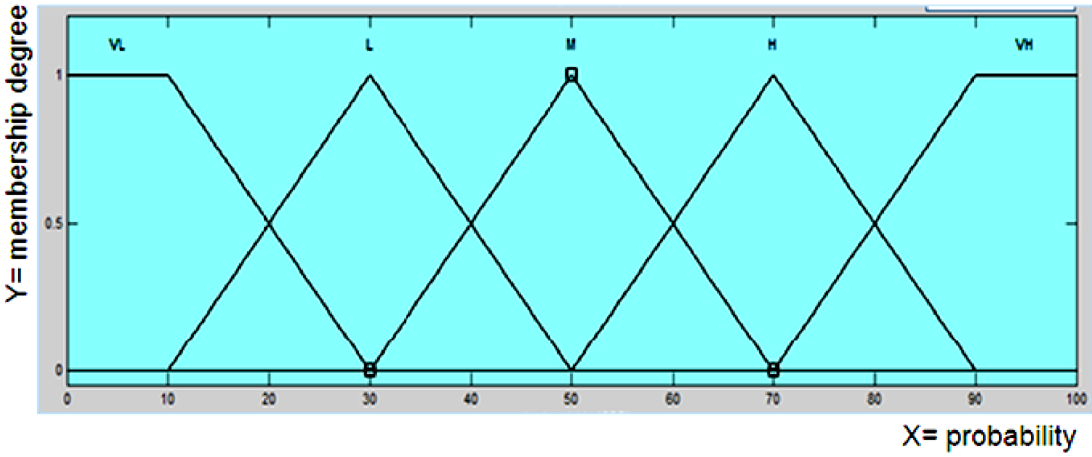


Figure 6.1: Membership functions for all linguistic variables (for all inputs and outputs) (VL: very low, L: low, M: medium, H: high, and VH: very high)

6.4 Construction of the fuzzy rules (if-then rules), assigning weights to the rules, and aggregation & defuzzification operations

Step 4 will be covered in the following three (3) parts. They are: 1) Construction of the fuzzy rules (if-then rules), 2) Assigning weights to the rules, and 3) Aggregation & defuzzification operations.

6.4.1 Construction of the Fuzzy Rules (if-then rules)

It is important to develop the interrelationship between the inputs (schedule delay factors) to output (probability of schedule delay) in a natural language format. This format is actually what makes this proposed assessment method so attractive, since it allows decision makers, project managers or project management teams the freedom of expressing all the schedule delay factors in a natural language format while not binding them to define exact values. These decision makers must have some sort of expertise or find experts in this field to define the interrelationship and memberships of the schedule delay factors they encounter; or they can use the model developed in this thesis, by adding factors, interrelationships, and memberships (in other words by adding new rules), or by manipulating, or even eliminating present rules.

As it was mentioned in chapter 4, in order to perform fuzzy inference, rules which connect input variables to output variables in 'IF ... THEN ...' forms were used to describe the desired model in terms of linguistic variables (words) rather than mathematical formulae.

In chapter 4, several alternative ways of defining fuzzy rules have been defined. These several types of fuzzy rules were:

- Mamdani-style fuzzy rules.
- Fuzzy rules with confidence degrees.
- Takagi-Sugeno's fuzzy rules.
- Gradual fuzzy rules.
- Generalized production rules with degrees of importance, noise tolerance, and sensitivity factors.
- Generalized production rules with variables.
- Recurrent fuzzy rules.

In this research the simple form of Mamdani-style fuzzy rules (Mamdani and Assilian (1975)) was implemented by the author by taking into account of advantages of the Mamdani's approach being intuitive, well suited to human input, and having widespread acceptance. (Fuzzy Logic Toolbox™ 2 User's Guide (2008), MATLAB, The MathWorks, Inc.) Mamdani-style fuzzy rules have been widely used in the previous literature. Some examples of the use of simple form of Mamdani-style fuzzy rules are: Yolaç, U. and Yalçınöz (2003), Özek, A. and Sinecen, M. (2004), Han, S (2005), Taş, F. (2005), Gürcanlı, G.E. and Müngen, U. (2006), Tanyıldızı, H.and Yazıcıoğlu, S. (2006), Murat, Y.Ş. (2006), Öztürk, F. (2006), Görgülü, Ö. (2007), Hishammuddin, A. (2008)

Then, the if-then rules were constructed as a result of extensive literature survey findings and expert opinions from a leading Turkish Construction Company.

6.4.1.1 Interview with Experts on the Construction of Fuzzy Rules

As similar in the chapter 5, a second interview was developed to assess the perceptions of a leading Turkish Construction Company on the construction of fuzzy rules to establish proposed fuzzy assessment model to estimate the probability of schedule delay in construction industry. Detailed information about the company, activities, expert areas, focuses, experiences, and the latest completed project were explained in the chapter 5. The interview was focused on the construction of fuzzy rules. The company was requested to form a commission of decision makers to perform the following tasks:

1) To check the linguistic variables and the membership functions of the inputs and the output.
2) To check the fuzzy rules on the establishment of the fuzzy assessment model.
3) To make necessary changes and additions.

Company has formed the same commission as in the previous chapter, whose members were composed of ten (10) experienced civil engineers including site managers, technical office managers, technical office engineers, procurement managers and technical consultants. The assumptions made were;

1) The commission members had significant information about linguistic variables, membership functions, and if-then rules of the schedule delay factors in construction projects.

2) The commission members allocated necessary time to perform the required tasks.
3) The commission members were experts of construction projects.

The commission members checked linguistic variables, membership functions, and if-then rules based on their professional judgment considering the consultant, contractor, design, equipment, external, labor, materials, owner and project related delay factor groups.

As a result of the interview, the fuzzy rules were constructed. The acronyms previously shown in Table 6.1 were used in the rules of the factors. The remaining acronyms were listed as below:

The **acronyms** of the *linguistic variables* were;

Very low: **VL**, *Low*: **L**, *Medium*: **M**, *High*: **H**, *Very High*: **VH**

The **acronyms** of the *groups of factors (inputs)* were;

Consultant related group: **CRG1**, *contractor related group:* **CRG2**, *design related group:* **DRG**, *equipment related group:* **ERG1**, *external related group:* **ERG2** *labor related group:* **LRG**, *materials related group:* **MRG**, *owner related group:* **ORG** and *project related group:* **PRG.**

The **acronym** of *the schedule delay probability (output)*: **SDP.**

Samples of the fuzzy rules created for the model were shown in tables below; for the whole set of rules refer to Appendix D.

6.4.1.2 A sample of fuzzy rules of Consultant Related Group (CRG1),

Table 6.2: A Sample of Fuzzy Rules of Consultant Related Group (CRG1)

Rule #	Probability of schedule delay rules				Consequence			
1	If	LOE1	is	VL	Then	CRG1	is	VL
7	If	CBC	is	L	Then	CRG1	is	L
13	If	DIA1	is	M	Then	CRG1	is	M
19	If	DIP1	is	H	Then	CRG1	is	H
25	If	ISI	is	VH	Then	CRG1	is	VH

A couple of examples showing the meanings of the rules were presented below.

Rule 1: If the probability of the factor "Lack of experience of consultant in construction projects" (LOE1) is *very low* ***then*** consultant related delay group will have *a very low* probability to cause schedule delays.

Rule 19: If the probability of the factor "Delay in performing inspection and testing" (DIP1) is *high* ***then*** consultant related delay group will have *a high* probability to cause schedule delays.

6.4.1.3 A sample of fuzzy rules of Contractor Related Group (CRG2)

Table 6.3: A Sample of Fuzzy Rules of Contractor Related Group (CRG2)

Rule #	Probability of schedule delay rules				Consequence			
1	If	FCO	is	VL	Then	CRG2	is	VL
7	If	ICE	is	L	Then	CRG2	is	L
13	If	ICM	is	M	Then	CRG2	is	M
19	If	IPT	is	H	Then	CRG2	is	H
25	If	IPP	is	VH	Then	CRG2	is	VH

6.4.1.4 A sample of fuzzy rules of Design Related Group (DRG)

Table 6.4: A Sample of Fuzzy Rules of Design Related Group (DRG)

Rule #	**Probability of schedule delay rules**				**Consequence**			
1	If	COP	is	VL	Then	DRG	is	VL
7	If	DCB	is	L	Then	DRG	is	L
13	If	DEM	is	M	Then	DRG	is	M
19	If	IDC	is	H	Then	DRG	is	H
25	If	LOE2	is	VH	Then	DRG	is	VH

6.4.1.5 A sample of fuzzy rules of Equipment Related Group (ERG1)

Table 6.5: A Sample of Fuzzy Rules of Equipment Related Group (ERG1)

Rule #	**Probability of schedule delay rules**				**Consequence**			
1	If	EAP	is	VL	Then	ERG1	is	VL
7	If	FEB	is	L	Then	ERG1	is	L
13	If	IE	is	M	Then	ERG1	is	M
19	If	IME	is	H	Then	ERG1	is	H
25	If	LEO	is	VH	Then	ERG1	is	VH

6.4.1.6 A sample of fuzzy rules of External Related Group (ERG2)

Table 6.6: A Sample of Fuzzy Rules of External Related Group (ERG2)

Rule #	**Probability of schedule delay rules**				**Consequence**			
1	If	ADC	is	VL	Then	ERG2	is	VL
7	If	CIG	is	L	Then	ERG2	is	L
13	If	CWP	is	M	Then	ERG2	is	M
19	If	DIO	is	H	Then	ERG2	is	H
25	If	DIP	is	VH	Then	ERG2	is	VH

6.4.1.7 A sample of fuzzy rules of Labor Related Group (LRG)

Table 6.7: A Sample of Fuzzy Rules of Labor Related Group (LRG)

Rule #	Probability of schedule delay rules				Consequence			
1	If	A	is	VL	Then	LRG	is	VL
7	If	LMA	is	L	Then	LRG	is	L
13	If	LPO	is	M	Then	LRG	is	M
19	If	PCA	is	H	Then	LRG	is	H
25	If	SOL	is	VH	Then	LRG	is	VH

6.4.1.8 A sample of fuzzy rules of Material Related Group (MRG)

Table 6.8: A Sample of Fuzzy Rules of Material Related Group (MRG)

Rule #	Probability of schedule delay rules				Consequence			
1	If	CIM	is	VL	Then	MRG	is	VL
7	If	DOS	is	L	Then	MRG	is	L
13	If	DIM	is	M	Then	MRG	is	M
19	If	EOM	is	H	Then	MRG	is	H
25	If	LDO	is	VH	Then	MRG	is	VH

6.4.1.9 A sample of fuzzy rules of Owner Related Group (ORG)

Table 6.9: A Sample of Fuzzy Rules of Owner Related Group (ORG)

Rule #	Probability of schedule delay rules				Consequence			
1	If	CO	is	VL	Then	ORG	is	VL
7	If	CBJ	is	L	Then	ORG	is	L
13	If	DIA2	is	M	Then	ORG	is	M
19	If	DIP3	is	H	Then	ORG	is	H
25	If	DIS	is	VH	Then	ORG	is	VH

6.4.1.10 A sample of fuzzy rules of Project Related Group (PRG)

Table 6.10: A Sample of Fuzzy Rules of Project Related Group (PRG)

Rule #	Probability of schedule delay rules				Consequence			
1	If	COT	is	VL	Then	PRG	is	VL
7	If	IDO	is	L	Then	PRG	is	L
13	If	IDP	is	M	Then	PRG	is	M
19	If	LDB	is	H	Then	PRG	is	H
25	If	OCD	is	VH	Then	PRG	is	VH

6.4.1.11 A sample of fuzzy rules of Schedule Delay Probability (SDP)

Table 6.11: A Sample of Fuzzy Rules of Schedule Delay Probability (SDP)

Rule #	Probability of schedule delay rules				Consequence			
1	If	CRG1	is	VL	Then	SDP	is	VL
7	If	CRG2	is	L	Then	SDP	is	L
13	If	DRG	is	M	Then	SDP	is	M
19	If	ERG1	is	H	Then	SDP	is	H
25	If	ERG2	is	VH	Then	SDP	is	VH

6.4.2 Assigning Weights (computed RII's) to the Fuzzy Rules

The relative importance indices (RII's) of factors and groups of factors which were achieved in Chapter 5 were assigned as the fuzzy rules' weights to construct "the fuzzy assessment model to estimate the probability of schedule delay". Since the RII's of the schedule delay factors have different values, the fuzzy rules' weights will differ accordingly. In other words, each if-then rule will have different weights, showing relative importances of fuzzy rules'.

A sample of the fuzzy rules with assigned weights created for the assessment model were shown in Table 6.12 below; for the whole set of rules refer to Appendix D.

Table 6.12: A sample of fuzzy rules with Assigned Weights for the assessment model

Rule #	Probability of schedule delay rules				Consequence				Rule Weight
1	If	LOE1	is	VL	Then	CRG1	is	VL	0,76
7	If	CBC	is	L	Then	CRG1	is	L	0,50
13	If	DIA1	is	M	Then	CRG1	is	M	0,58
19	If	DIP1	is	H	Then	CRG1	is	H	0,86
25	If	ISI	is	VH	Then	CRG1	is	VH	0,46

6.4.3 Aggregation & Defuzzification Operations

The author encountered different aggregation methods in the previous literature such as: max, sum, probabilistic or. In this thesis, the aggregation method was selected as "max" (maximum) by the author as being most popular in the literature. Some examples of the use of Maximum Method as the aggregation method are: Özek, A. and Sinecen, M. (2004), Gürcanlı, G.E. and Müngen, U. (2006), Tanyıldızı, H.and Yazıcıoğlu, S. (2006), Öztürk, F. (2006), Görgülü, Ö. (2007).

The author encountered various defuzzification methods in the previous literature such as: COG, MOM, SOM, LOM and BOA. In this thesis, the defuzzification method was selected as Center of Gravity (COG) Method by the author as being most popular in the literature. Some examples of the use of Center of Gravity (COG) Method as the defuzzification method are: Özek, A. and Sinecen, M. (2004), Gürcanlı, G.E. and Müngen, U. (2006), Tanyıldızı, H.and Yazıcıoğlu, S. (2006), Öztürk, F. (2006), Shull, P. (2006), Görgülü, Ö. (2007).

The aggregation and defuzzification calculations explained above cannot be facilitated without a computer support. Thus, Fuzzy Logic Toolbox of the MATLAB Program Software was utilized to simplify the process. Brief information and some screenshots of this program will be demonstrated in the next part.

6.5 Model Development by Using Fuzzy Logic Toolbox of the MATLAB Program Software

Step 5 will be covered in this part. The fuzzy assessment model will be developed by using Fuzzy Logic Toolbox of the MATLAB Program Software.

6.5.1 Fuzzy Logic Toolbox Description

Fuzzy Logic Toolbox™ software is a collection of functions built on the MATLAB® technical computing environment. It provides tools to create and edit fuzzy inference systems within the framework of MATLAB.

There are five primary graphical user interface tools for building, editing, and observing fuzzy inference systems in the toolbox shown in Figure 6.2.:

1. *Fuzzy Inference System (FIS) Editor:* To define input and output parameters.
2. *Membership Function Editor:* To define the shapes of all the membership functions associated with each variable.
3. *Rule Editor:* For editing the list of rules that defines the behavior of the system.
4. *Rule Viewer*: As a diagnostic, it can show (for example) which rules are active, or how individual membership function shapes are influencing the results.
5. *Surface Viewer:* To display the dependency of one of the outputs on any one or two of the inputs—that is, it generates and plots an output surface map for the system. (Fuzzy Logic Toolbox™ 2 User's Guide (2008), MATLAB, The MathWorks, Inc.)

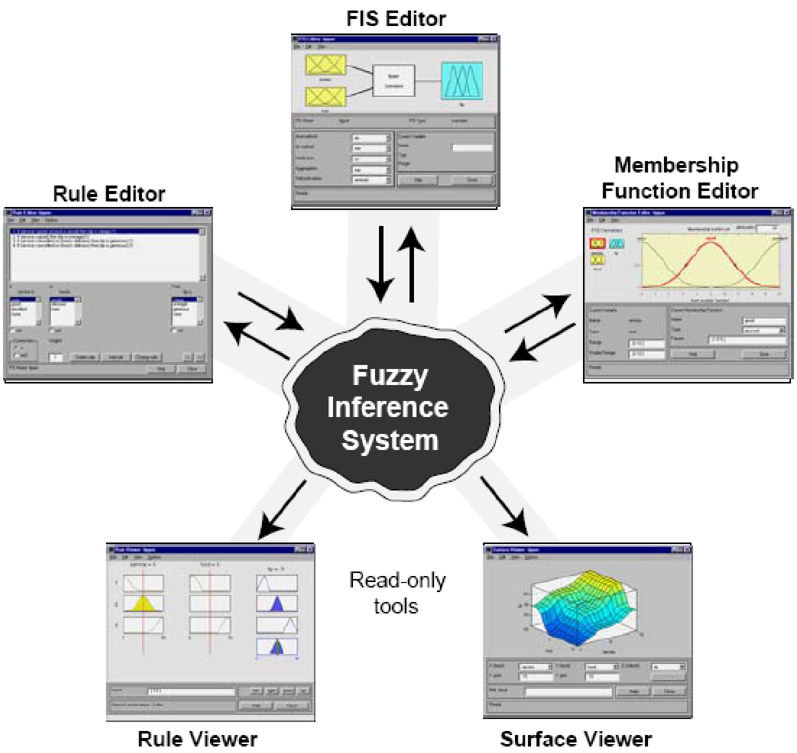


Figure 6.2: Graphical user interface tools in the fuzzy logic toolbox

6.5.2 Some Screenshots of the Fuzzy Logic Toolbox

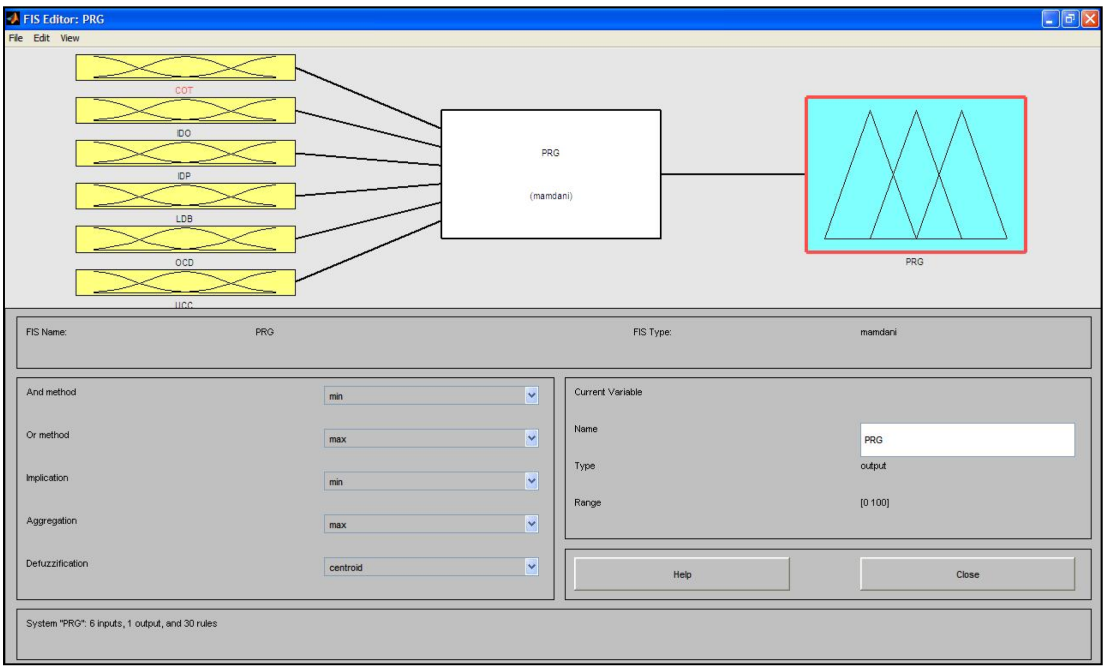


Figure 6.3: Fuzzy Inference System (FIS) Editor

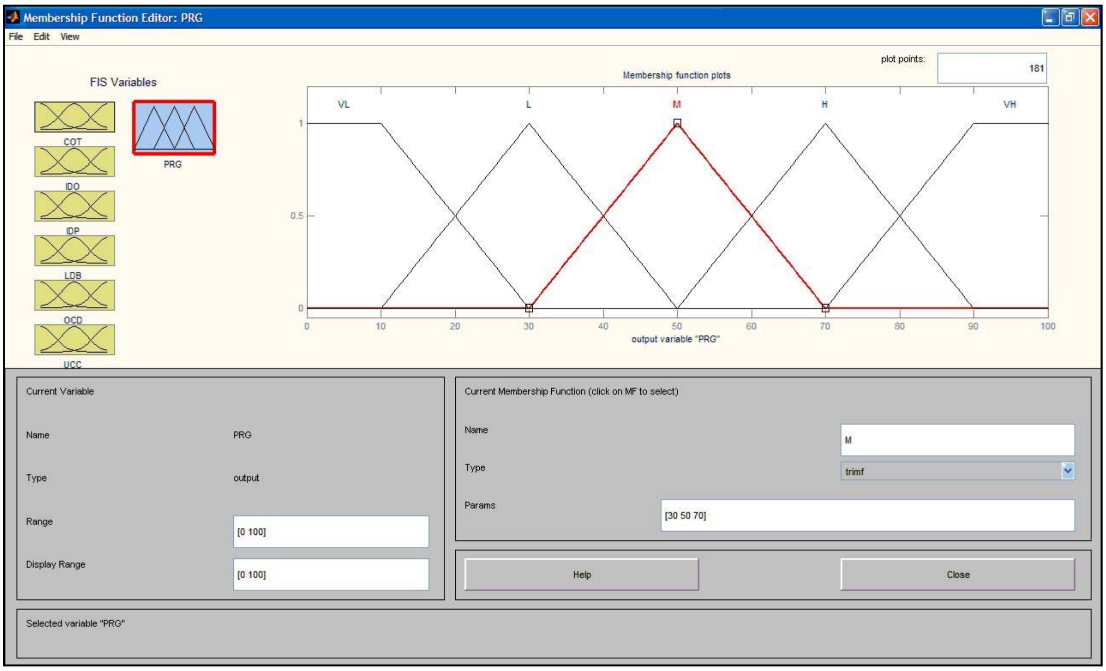


Figure 6.4: Membership Function Editor

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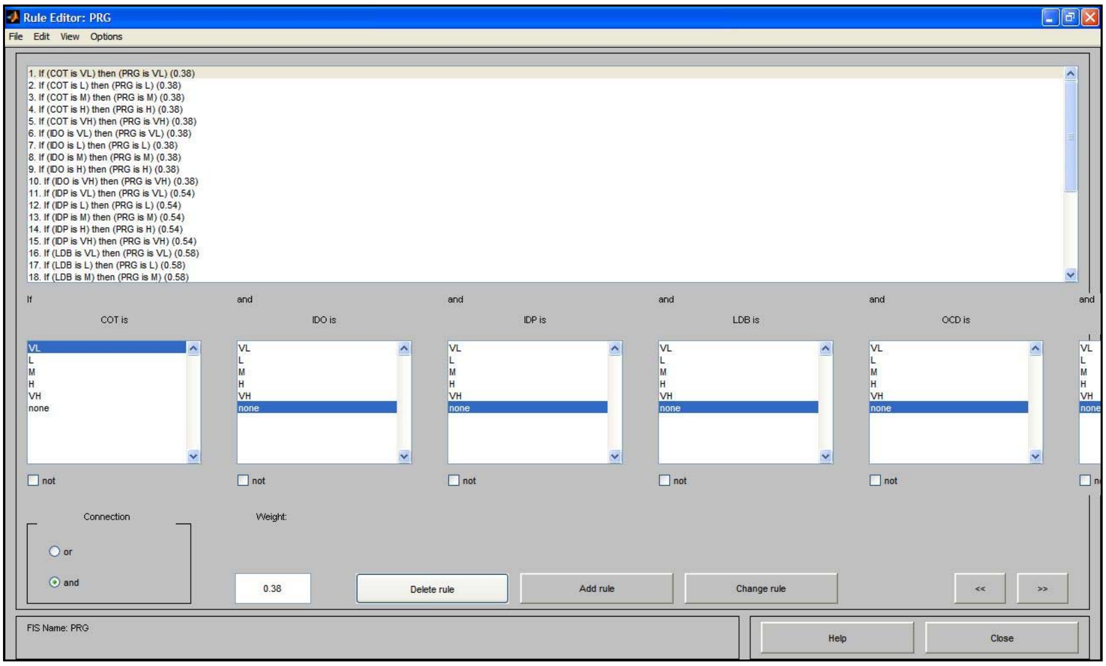

Figure 6.5: Rule Editor

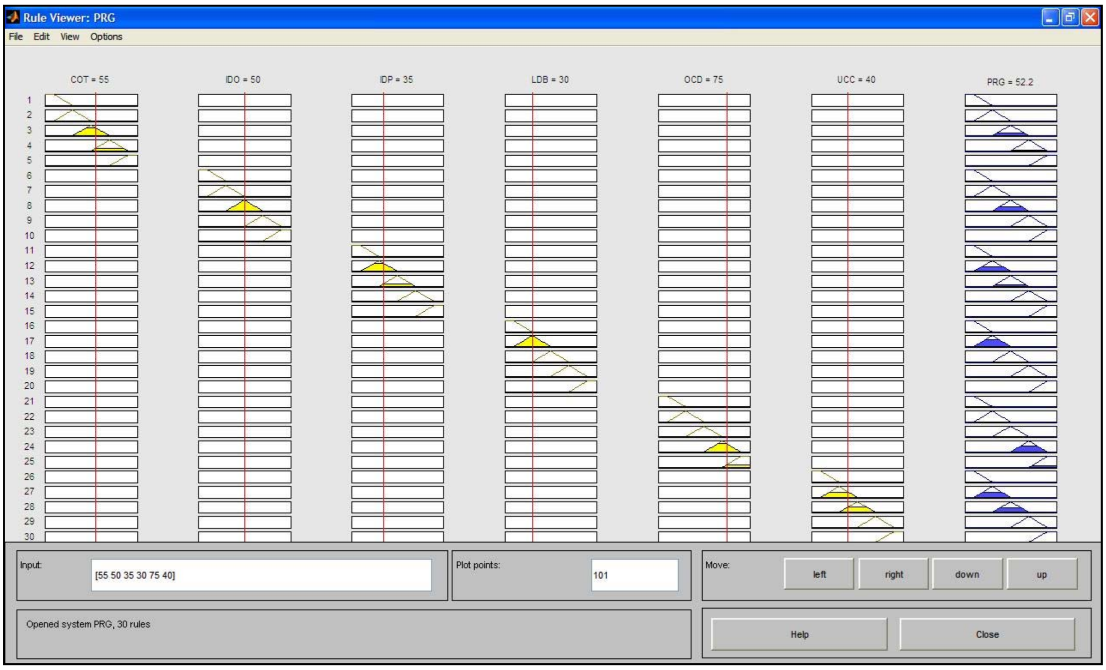

Figure 6.6: Rule Viewer

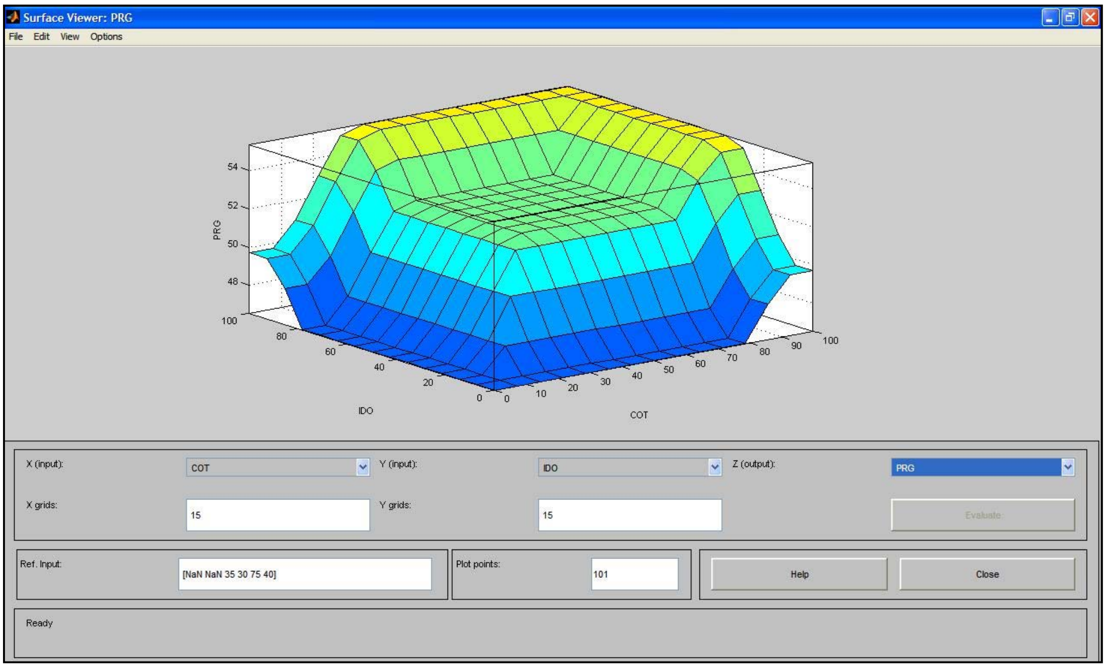

Figure 6.7: Surface Viewer

6.5.3 Fuzzy Logic Toolbox Summary

By using Fuzzy Logic Toolbox of the MATLAB Program Software, firstly, input and output parameters were defined. Secondly, the shapes of all the membership functions associated with each variable were defined. Thirdly, list of rules and aggregation & defuzzification methods establishing the behavior of the system were defined. Fourthly, outputs were generated and plots were displayed. Finally, a quantifiable assessment model to estimate the probability of the schedule delay was developed which may help the decision maker (project manager or project management team) to determine a reliable time contingency before bidding stage in order to achieve project success.

6.6 A Real Case Study

Step 6 will be covered in this part. The proposed fuzzy assessment model was tested in a project. A third and final interview was developed to assess the perceptions of a leading Turkish Construction Company to test the proposed fuzzy assessment model considering the latest project conducted by the company.

This company has a significant experience in construction projects such as; industrial plants, oil and gas pipelines, roads and railways, water and waste water, tunnels, hospitals, hotels, military facilities, administrative buildings and mass housing projects. The company has served in the construction sector approximately for 30 years. The company has extensive construction activities all over the world. The company can be considered as an expert of construction projects. One of the main focus areas of the company is oil and gas works. The last completed project, which was analyzed in detail in the following chapter as a case study, was the construction of a complete natural gas compressor station. The project was individually carried out by the company in Çorum, TURKEY. This compressor station had 2 main and 1 auxiliary units. The total installed power is 45.9 Megawatts. The owner of the project was BOTAŞ (Petroleum Pipeline Corporation). Scheduled duration was 400 calendar days. Payment type was lump sum. The contract price was 42.888.979, 52 US Dollars.

The company was requested to form a commission of decision makers to perform the following tasks:

1) To fill in the evaluation form of schedule delay probability by assigning input values (schedule delay factors) from 1 (probability is very low: VL) to 100 (probability is very high: VH).
2) To estimate the probability of schedule delay of the project.

Company has formed commission, whose members were composed of ten (10) experienced civil engineers including site managers, technical office managers, technical office engineers, procurement managers and technical consultants. It was assumed that:

1) The commission members had significant information about schedule delay factors in construction projects.
2) The commission members allocated necessary time to perform the required tasks.
3) The commission members were experts of construction projects.

The commission members checked and filled in the form including eighty three (83) well organized the schedule delay factors based on their professional judgment considering the consultant, contractor, design, equipment, external, labor, materials, owner and project related delay factor groups. The commission members filled the questionnaire form as shown in the Table 6.13. The commission members also estimated a range from ***45-55*** showing a ***medium probability of schedule delay*** of the project.

Table 6.13: Probability evaluation form filled by commission members

Groups of factors	No	Factors causing schedule delays	**Evaluation of factors** (scale: 1-100) 1: Probability is very low (VL) 100: Probability is very high (VH)
1) Consultant Related Factors	1	Lack of experience of consultant in construction projects	**75**
	2	Conflicts between consultant and design engineer	**70**
	3	Delay in approving major changes in the scope of work by consultant	**30**
	4	Delay in performing inspection and testing	**25**
	5	Inaccurate site investigation	**40**
	6	Inadequate project management assistance	**60**
	7	Late in reviewing and approving design documents	**65**
	8	Poor communication and coordination with other parties	**45**
2) Contractor Related Factors	1	Frequent change of subcontractors	**30**
	2	Inadequate contractor experience	**30**
	3	Inappropriate construction methods	**35**
	4	Incompetent project team	**40**
	5	Ineffective project planning and scheduling	**50**
	6	Obsolete technology	**35**
	7	Poor communication and coordination with other parties	**50**
	8	Poor site management and supervision	**55**
	9	Rework due to errors	**70**
	10	Unreliable subcontractors	**75**
3) Design Related Factors	1	Complexity of project design	**80**
	2	Design changes by owner or his agent during construction	**75**
	3	Design errors made by designers	**65**
	4	Insufficient data collection and survey before design	**50**
	5	Lack of experience of design team in construction projects	**70**
	6	Mistakes and delays in producing design documents	**65**
	7	Misunderstanding of owner's requirements by design engineer	**50**
	8	Poor use of advanced engineering design software	**25**
	9	Unclear and inadequate details in drawings	**65**
4) Equipment Related Factors	1	Equipment allocation problem	**55**
	2	Frequent equipment breakdowns	**70**
	3	Improper equipment	**40**
	4	Inadequate modern equipment	**50**
	5	Low efficiency of equipment	**60**
	6	Shortage of equipment	**35**
	7	Slow mobilization of equipment	**25**
5) External Related Factors	1	Accidents during construction	**30**
	2	Changes in government regulations and laws	**80**
	3	Conflict, war, and public enemy	**15**
	4	Delay in obtaining permits from municipality	**75**
	5	Delay in performing final inspection and certification by a third party	**70**
	6	Delay in providing services from utilities (such as water, electricity)	**60**
	7	Global financial crisis	**100**
	8	Loss of time by traffic control and restriction at job site	**30**
	9	Natural disasters (flood, hurricane, earthquake)	**20**
	10	Price fluctuations	**60**
	11	Problem with neighbors	**80**
	12	Slow site clearance	**35**
	13	Unexpected surface& subsurface conditions (such as soil, hw table)	**30**
	14	Unfavorable weather conditions	**30**

Table 6.13: Probability evaluation form filled by commission members (cont'd)

Groups of factors	No	Factors causing schedule delays	Evaluation of factors (scale: 1-100) 1: Probability is very low (VL) 100: Probability is very high (VH)
6) Labor Related Factors	1	Absenteeism	25
	2	Low motivation and morale of labor	40
	3	Low productivity of labor	50
	4	Personal conflicts among labor	50
	5	Shortage of labor	70
	6	Slow mobilization of labor	45
	7	Strike	15
	8	Unqualified / inadequate experienced labor	60
7) Material Related Factors	1	Changes in material types and specifications during construction	70
	2	Damage of sorted materials	25
	3	Delay in manufacturing materials	40
	4	Escalation of material prices	60
	5	Late delivery of materials	80
	6	Poor procurement of construction materials	50
	7	Poor quality of construction materials	40
	8	Shortage of construction materials	70
	9	Unreliable suppliers	60
8) Owner Related Factors	1	Change orders	80
	2	Conflicts between joint-ownership	30
	3	Delay in approving design documents	50
	4	Delay in progress payments	70
	5	Delay in site delivery	30
	6	Improper project feasibility study	50
	7	Lack of capable representative	40
	8	Lack of experience of owner in construction projects	25
	9	Lack of incentives for contractor to finish ahead of schedule	30
	10	Poor communication and coordination with other parties	60
	11	Slowness in decision making	65
	12	Suspension of work by owner	50
9) Project Related Factors	1	Complexity of the project	55
	2	Inadequate definition of substantial completion	50
	3	Ineffective delay penalties	35
	4	Legal disputes between project participants	30
	5	Original contract duration is short	75
	6	Unfavorable contract clauses	40

Since fuzzy model calculations were so much time consuming, Fuzzy Logic Toolbox of the MATLAB Program Software was utilized to save time.

The schedule delay probability outputs of the case study was obtained by using Fuzzy Logic Toolbox of the MATLAB Program Software and shown in the Table 5.42.

Table 6.14: The probability outputs of the case study (In alphabetic order)

Groups of factors	**Probability output** (0-100)
Consultant related factors	49,1
Contractor related factors	49,9
Design related factors	55,9
Equipment related factors	50,3
External related factors	54,6
Labor related factors	50,6
Material related factors	56
Owner related factors	53
Project related factors	52,2
Schedule delay	**53,9**

6.7 Discussion of the results

6.7.1 Consultant Related Delay Factors

Probability output for the consultant related delay factors was calculated as ***49.1*** showing a range of ***low - medium*** probability level. The most contributing factors for this category's probability were:

"Lack of experience of consultant in construction projects" having ***75*** (*high-very high probability)*,

"Conflicts between consultant and design engineer" having ***70*** (*high probability)*,

"Late in reviewing and approving design documents" having ***65*** (*medium-high probability)*.

6.7.2 Contractor Related Delay Factors

Probability output for the contractor related delay factors was calculated as ***49.9*** showing a range of ***low - medium*** probability level. The most contributing factors for this category's probability were:

"Unreliable subcontractors" having ***75*** (*high-very high probability)*,

"Rework due to errors" having ***70*** (*high probability)*,

"Poor site management and supervision" having ***55*** (*medium-high probability)*.

6.7.3 Design Related Delay Factors

Probability output for the design related delay factors was calculated as ***55.9*** showing a range of ***medium - high*** probability level. The most contributing factors for this category's probability were:

"Complexity of project design" having ***80*** (*high-very high probability)*,

"Design changes by owner or his agent during construction" having ***75*** (*high-very high probability)*,

"Lack of experience of design team in construction projects" having ***70*** (*high probability)*.

6.7.4 Equipment Related Delay Factors

Probability output for the equipment related delay factors was calculated as ***50.3*** showing a range of ***medium - high*** probability level. The most contributing factors for this category's probability were:

"Frequent equipment breakdowns" having ***70*** (*high probability)*,

"Low efficiency of equipment" having ***60*** (*medium-high probability)*, “Equipment allocation problem” having ***55*** (*medium-high probability)*.

6.7.5 External Related Delay Factors

Probability output for the external related delay factors was calculated as ***54.6*** showing a range of ***medium - high*** probability level. The most contributing factors for this category’s probability were:

“Global financial crisis” having ***100*** (very *high probability)*,

“Changes in government regulations and laws” having ***80*** (*high-very high probability)*,

“Problem with neighbors” having ***80*** (*high-very high probability)*.

6.7.6 Labor Related Delay Factors

Probability output for the labor related delay factors was calculated as ***50.6*** showing a range of ***medium - high*** probability level. The most contributing factors for this category’s probability were:

“Shortage of labor” having ***70*** (*high probability)*,

“Unqualified / inadequate experienced labor” having ***60*** (*medium-high probability)*,

“Low productivity of labor” having ***50*** (*medium probability)*.

6.7.7 Material Related Delay Factors

Probability output for the material related delay factors was calculated as ***56*** showing a range of ***medium - high*** probability level. The most contributing factors for this category’s probability were:

“Late delivery of materials” having ***80*** (*high-very high probability)*, “Changes in material types and specifications during construction” having ***70*** (*high probability)*,

“Shortage of construction materials” having ***70*** (*high probability)*.

6.7.8 Owner Related Delay Factors

Probability output for the owner related delay factors was calculated as ***53*** showing a range of ***medium - high*** probability level. The most contributing factors for this category’s probability were:

“Change orders” having ***80*** (*high-very high probability)*,

“Delay in progress payments” having ***70*** (*high probability)*,

“Slowness in decision making” having ***65*** (*medium-high probability)*.

6.7.9 Project Related Delay Factors

Probability output for the project related delay factors was calculated as ***52.2*** showing a range of ***medium - high*** probability level. The most contributing factors for this category’s probability were:

“Original contract duration is short” having ***75*** (*high-very high probability)*,

“Complexity of the project” having ***55*** (*medium-high probability)*,

“Inadequate definition of substantial completion” having ***50*** (*medium probability)*.

6.7.10 Schedule Delay

Schedule delay probability output was calculated as ***53.9*** showing a range of ***medium - high*** probability level for this specific project.

The **highest** probability output for the groups was found as:

"Material Related Delay Factors" by ***56*** (*medium - high probability level)* and,

The **lowest** probability output was found as:

"Consultant Related Delay Factors" by ***49.1*** (*low-medium probability level).*

Since the commission members estimated a range of ***45-55*** for the ***probability of schedule delay*** of the project, they found this result satisfactory. Therefore, as a result of the case study, it is conceivable to say that the assessment model results were acceptable and adequate for the purpose.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

In a construction project where time truly equals money, the management of time is critical (Duran, O. (2006)), thus predicting the likelihood of schedule delay may play a key role towards project success (Luu, et. al (2009)). There existed a need to develop a probabilistic schedule delay analysis model in construction projects as a decision support tool for contractors before the bidding stage.

This research aimed to propose a decision support tool for contractors before the bidding stage to quantify the probability of schedule delay in construction projects by using fuzzy logic incorporated with relative importance index (RII) method.

There were seven (7) objectives of this study which have been achieved in previous chapters.

The ***first*** objective was to identify the schedule delay factors in construction projects. Through detailed literature review and interview with experts from a leading Turkish Construction Company, a total number of eighty three (83) schedule delay factors were identified.

The ***second*** objective was to categorize the schedule delay factors in construction projects by utilizing Ishikawa (Fish Bone) Diagrams. The identified schedule delay factors were grouped into nine (9) groups as follows: Consultant related delay factors, contractor related delay factors, design related delay factors, equipment related delay factors, external related delay factors, labor related delay factors, material related delay factors, owner related delay factors, and project related delay factors. The demonstration of these groups of schedule delay factors was achieved by utilizing Ishikawa (Fish Bone) Diagrams.

The ***third*** objective was to quantify relative importances of schedule delay factors and demonstrate the ranking of the factors and groups according to their importance level on schedule delay. This objective was achieved through interviews with a commission of experts formed by a leading Turkish Construction Company. All factors and groups were ranked according to the computed relative importance indices. The most and the least important factors and groups were also achieved according to these rankings.

The ***fourth*** objective was ***a)*** to determine the linguistic variables & fuzzy membership functions, ***b)*** to construct fuzzy rules (if-then rules), ***c)*** to determine the rules' weight by using Relative Importance Index (RII) method findings, and ***d)*** carry out aggregation & defuzzification operations to construct "the fuzzy assessment model to estimate the probability of schedule delay". ***a)*** According to literature findings the linguistic variables to be defined as "very low, low, medium, high, and very high probability" out of a scale ranging from zero (0) to a hundred (100). Five (5) membership functions were defined for all linguistic variables. All of them were represented by a combination of trapezoidal and triangular form of fuzzy numbers. ***b)*** As a result of extensive literature survey findings and interviews with a commission of experts formed by a leading Turkish Construction Company, the simple form of Mamdani-style fuzzy rules (if-then rules) were constructed. ***c)*** The relative importance indices (RII's) of factors and groups of factors which were achieved in previous chapters were assigned as the fuzzy rules' weights. ***d)*** By analyzing the common uses in the previous literature, the aggregation method was selected as "max" (maximum) and the defuzzification method was selected as "center of gravity" (COG) method. The aggregation and defuzzification calculations were achieved with the aid of Fuzzy Logic Toolbox of the MATLAB Program Software.

The ***fifth*** objective was to propose a delay analysis model by using Fuzzy Theory in order to determine a realistic time contingency by taking into account of delay factors characterized in construction projects. The assessment model was developed by using Fuzzy Logic

Toolbox Software of the MATLAB Program Software. Brief information about the capabilities of this software was presented.

The ***sixth*** objective was to test the proposed methodology in a real case study and to evaluate the probability of schedule delay. A final interview was developed to assess the perceptions of a leading Turkish Construction Company to test the proposed fuzzy assessment model considering the latest project conducted by the company. The commission members of the company estimated the probability of schedule delay for the latest construction project a range from ***45-55*** showing a ***medium probability of schedule delay*** of the project. The proposed fuzzy assessment model calculated the probability of schedule delay as ***53.9*** showing a range of ***medium - high*** probability level for this specific project. Therefore, as a result of the case study, it was conceivable to say that the assessment model results were acceptable and adequate for the purpose.

The ***seventh*** objective was to address the most contributing factors and groups to cause schedule delays (i.e., to discuss the probability of the factors and groups that need attention). This objective was achieved through discussion of the case study results. The highest probability output for the groups was found as "Material related delay factors" by ***56*** showing a range of ***medium - high*** probability level for the case study project. For each groups, the three (3) most contributing factors to cause schedule delay were presented.

In this research, Ishikawa (Fish Bone) Diagrams were utilized to identify and demonstrate the groups of schedule delay factors as they were capable of showing factors, interrelations between different groups of factors, and consequences affected from factors.

In this research, Fuzzy Theory was proposed as an effective probability analysis technique in construction projects, since; fuzzy theory is based upon uncertainties where there is an inherent impreciseness and it provides mathematical tools to deal with imprecise, uncertain, and vague data. Since probability analysis has in its essence uncertainty and impreciseness, any analysis made ignoring this uncertainty and impreciseness may cause information to be seriously misleading, therefore, contributing to large mistakes.

In this research the simple form of Mamdani-style fuzzy rules was implemented taking into account of the advantages of the Mamdani's approach (being most popular in the literature, being intuitive, having widespread acceptance, and well suiting to human input).

In this research, the probability assessment model was developed by using Fuzzy Logic Toolbox of the MATLAB Program Software which can be easily utilized by the decision maker by entering the required probability value of factors (input). The program carried out the complex calculations and obtained the probability outputs. By considering the probability outputs, decision maker may determine a reasonable time contingency for the construction project before the bidding stage.

As a final conclusion, decision makers may test the tool proposed by the author in their different projects and determine whether it produces reasonable results and revise the model parameters if necessary.

7.2 Recommendations for Future Study

Future studies could be performed for different specific types of construction projects, such as road and railway construction projects, building housing projects, utility projects, highways, viaducts and dam construction projects, etc.

Future studies can be designed by utilizing different model parameters such as: different number and group of schedule delay factors, linguistic variables and membership functions, fuzzy rules, weights of rules, aggregation and defuzzification methods. This thesis opens up a realm of possibilities where future researchers can produce more powerful, user friendly softwares that can analyze all the possible schedule delay factors, producing fast and reliable results.

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APPENDIX A

GROUPS OF SCHEDULE DELAY FACTORS

Table A.1: Number and Groups of factors to cause schedule delay in construction projects

No	Groups of factors	Number of factors
1	Consultant related factors	8
2	Contractor related factors	10
3	Design related factors	9
4	Equipment related factors	7
5	External related factors	14
6	Labor related factors	8
7	Material related factors	9
8	Owner related factors	12
9	Project related factors	6
	TOTAL	83

APPENDIX B

SAMPLE QUESTIONNAIRE FORM

Table B.1: Sample Questionnaire Form distributed to commission members (experts)

Groups of factors	No	Factors causing schedule delays	Importance				
			1:Very low important	2:Low important	3: Medium important	4: High important	5: Very high important
1) Consultant Related Factors	1	Lack of experience of consultant in construction projects					
	2	Conflicts between consultant and design engineer					
	3	Delay in approving major changes in the scope of work by consultant					
	4	Delay in performing inspection and testing					
	5	Inaccurate site investigation					
	6	Inadequate project management assistance					
	7	Late in reviewing and approving design documents					
	8	Poor communication and coordination with other parties					
2) Contractor Related Factors	1	Frequent change of subcontractors					
	2	Inadequate contractor experience					
	3	Inappropriate construction methods					
	4	Incompetent project team					
	5	Ineffective project planning and scheduling					
	6	Obsolete technology					
	7	Poor communication and coordination with other parties					
	8	Poor site management and supervision					
	9	Rework due to errors					
	10	Unreliable subcontractors					
3) Design Related Factors	1	Complexity of project design					
	2	Design changes by owner or his agent during construction					
	3	Design errors made by designers					
	4	Insufficient data collection and survey before design					
	5	Lack of experience of design team in construction projects					
	6	Mistakes and delays in producing design documents					
	7	Misunderstanding of owner's requirements by design engineer					
	8	Poor use of advanced engineering design software					
	9	Unclear and inadequate details in drawings					
4) Equipment Related Factors	1	Equipment allocation problem					
	2	Frequent equipment breakdowns					
	3	Improper equipment					
	4	Inadequate modern equipment					
	5	Low efficiency of equipment					
	6	Shortage of equipment					
	7	Slow mobilization of equipment					
5) External Related Factors	1	Accidents during construction					
	2	Changes in government regulations and laws					
	3	Conflict, war, and public enemy					
	4	Delay in obtaining permits from municipality					
	5	Delay in performing final inspection and certification by a third party					
	6	Delay in providing services from utilities (such as water, electricity)					
	7	Global financial crisis					
	8	Loss of time by traffic control and restriction at job site					
	9	Natural disasters (flood, hurricane, earthquake)					
	10	Price fluctuations					
	11	Problem with neighbors					
	12	Slow site clearance					
	13	Unexpected surface& subsurface conditions (such as soil, hw table)					
	14	Unfavorable weather conditions					

Table B.1: Sample Questionnaire Form distributed to commission members (experts) (cont'd)

Groups of factors	No	Factors causing schedule delays	Importance				
			1:Very low important	2:Low important	3: Medium important	4: High important	5: Very high important
6) Labor Related Factors	1	Absenteeism					
	2	Low motivation and morale of labor					
	3	Low productivity of labor					
	4	Personal conflicts among labor					
	5	Shortage of labor					
	6	Slow mobilization of labor					
	7	Strike					
	8	Unqualified / inadequate experienced labor					
7) Material Related Factors	1	Changes in material types and specifications during construction					
	2	Damage of sorted materials					
	3	Delay in manufacturing materials					
	4	Escalation of material prices					
	5	Late delivery of materials					
	6	Poor procurement of construction materials					
	7	Poor quality of construction materials					
	8	Shortage of construction materials					
	9	Unreliable suppliers					
8) Owner Related Factors	1	Change orders					
	2	Conflicts between joint-ownership					
	3	Delay in approving design documents					
	4	Delay in progress payments					
	5	Delay in site delivery					
	6	Improper project feasibility study					
	7	Lack of capable representative					
	8	Lack of experience of owner in construction projects					
	9	Lack of incentives for contractor to finish ahead of schedule					
	10	Poor communication and coordination with other parties					
	11	Slowness in decision making					
	12	Suspension of work by owner					
9) Project Related Factors	1	Complexity of the project					
	2	Inadequate definition of substantial completion					
	3	Ineffective delay penalties					
	4	Legal disputes between project participants					
	5	Original contract duration is short					
	6	Unfavorable contract clauses					

APPENDIX C

ACRONYMS OF SCHEDULE DELAY FACTORS

Table C.1: Groups and factors that may cause schedule delays in construction projects and their acronyms

Groups of factors	No	Factors causing schedule delays	Acronyms of factors causing schedule delays
1) Consultant Related Factors	1	Lack of experience of consultant in construction projects	LOE1
	2	Conflicts between consultant and design engineer	CBC
	3	Delay in approving major changes in the scope of work by consultant	DIA1
	4	Delay in performing inspection and testing	DIP1
	5	Inaccurate site investigation	ISI
	6	Inadequate project management assistance	IPM
	7	Late in reviewing and approving design documents	LIR
	8	Poor communication and coordination with other parties	PCC1
2) Contractor Related Factors	1	Frequent change of subcontractors	FCO
	2	Inadequate contractor experience	ICE
	3	Inappropriate construction methods	ICM
	4	Incompetent project team	IPT
	5	Ineffective project planning and scheduling	IPP
	6	Obsolete technology	OT
	7	Poor communication and coordination with other parties	PCC2
	8	Poor site management and supervision	PSM
	9	Rework due to errors	RDT
	10	Unreliable subcontractors	US
3) Design Related Factors	1	Complexity of project design	COP
	2	Design changes by owner or his agent during construction	DCB
	3	Design errors made by designers	DEM
	4	Insufficient data collection and survey before design	IDC
	5	Lack of experience of design team in construction projects	LOE2
	6	Mistakes and delays in producing design documents	MAD
	7	Misunderstanding of owner's requirements by design engineer	MOO
	8	Poor use of advanced engineering design software	PUO
	9	Unclear and inadequate details in drawings	UAİ
4) Equipment Related Factors	1	Equipment allocation problem	EAP
	2	Frequent equipment breakdowns	FEB
	3	Improper equipment	IE
	4	Inadequate modern equipment	IME
	5	Low efficiency of equipment	LEO
	6	Shortage of equipment	SOE
	7	Slow mobilization of equipment	SMO1
5) External Related Factors	1	Accidents during construction	ADC
	2	Changes in government regulations and laws	CIG
	3	Conflict, war, and public enemy	CWP
	4	Delay in obtaining permits from municipality	DIO
	5	Delay in performing final inspection and certification by a third party	DIP
	6	Delay in providing services from utilities (such as water, electricity)	DIP2
	7	Global financial crisis	GFC
	8	Loss of time by traffic control and restriction at job site	LOT
	9	Natural disasters (flood, hurricane, earthquake)	ND
	10	Price fluctuations	PF
	11	Problem with neighbors	PWN
	12	Slow site clearance	SSC
	13	Unexpected surface& subsurface conditions (such as soil, hw table)	USS
	14	Unfavorable weather conditions	UWC

Table C.1: Groups and factors that may cause schedule delays in construction projects and their acronyms (cont'd)

Groups of factors	No	Factors causing schedule delays	Acronyms of factors causing schedule delays
6) Labor Related Factors	1	Absenteeism	A
	2	Low motivation and morale of labor	LMA
	3	Low productivity of labor	LPO
	4	Personal conflicts among labor	PCA
	5	Shortage of labor	SOL
	6	Slow mobilization of labor	SMO2
	7	Strike	S
	8	Unqualified / inadequate experienced labor	UEL
7) Material Related Factors	1	Changes in material types and specifications during construction	CIM
	2	Damage of sorted materials	DOS
	3	Delay in manufacturing materials	DIM
	4	Escalation of material prices	EOM
	5	Late delivery of materials	LDO
	6	Poor procurement of construction materials	PPO
	7	Poor quality of construction materials	PQO
	8	Shortage of construction materials	SOC
	9	Unreliable suppliers	US2
8) Owner Related Factors	1	Change orders	CO
	2	Conflicts between joint-ownership	CBJ
	3	Delay in approving design documents	DIA2
	4	Delay in progress payments	DIP3
	5	Delay in site delivery	DIS
	6	Improper project feasibility study	IPF
	7	Lack of capable representative	LOC
	8	Lack of experience of owner in construction projects	LOE3
	9	Lack of incentives for contractor to finish ahead of schedule	LOI
	10	Poor communication and coordination with other parties	PCC3
	11	Slowness in decision making	SID
	12	Suspension of work by owner	SOW
9) Project Related Factors	1	Complexity of the project	COT
	2	Inadequate definition of substantial completion	IDO
	3	Ineffective delay penalties	IDP
	4	Legal disputes between project participants	LDB
	5	Original contract duration is short	OCD
	6	Unfavorable contract clauses	UCC

APPENDIX D

FUZZY RULES

Table D.1: List of if-then rules of consultant related delay factors

Rule #	Probability of schedule delay rules				Consequence				Rule Weight
1	If	LOE1	is	VL	Then	CRG1	is	VL	0,76
2	If	LOE1	is	L	Then	CRG1	is	L	0,76
3	If	LOE1	is	M	Then	CRG1	is	M	0,76
4	If	LOE1	is	H	Then	CRG1	is	H	0,76
5	If	LOE1	is	VH	Then	CRG1	is	VH	0,76
6	If	CBC	is	VL	Then	CRG1	is	VL	0,50
7	If	CBC	is	L	Then	CRG1	is	L	0,50
8	If	CBC	is	M	Then	CRG1	is	M	0,50
9	If	CBC	is	H	Then	CRG1	is	H	0,50
10	If	CBC	is	VH	Then	CRG1	is	VH	0,50
11	If	DIA1	is	VL	Then	CRG1	is	VL	0,58
12	If	DIA1	is	L	Then	CRG1	is	L	0,58
13	If	DIA1	is	M	Then	CRG1	is	M	0,58
14	If	DIA1	is	H	Then	CRG1	is	H	0,58
15	If	DIA1	is	VH	Then	CRG1	is	VH	0,58
16	If	DIP1	is	VL	Then	CRG1	is	VL	0,86
17	If	DIP1	is	L	Then	CRG1	is	L	0,86
18	If	DIP1	is	M	Then	CRG1	is	M	0,86
19	If	DIP1	is	H	Then	CRG1	is	H	0,86
20	If	DIP1	is	VH	Then	CRG1	is	VH	0,86
21	If	ISI	is	VL	Then	CRG1	is	VL	0,46
22	If	ISI	is	L	Then	CRG1	is	L	0,46
23	If	ISI	is	M	Then	CRG1	is	M	0,46
24	If	ISI	is	H	Then	CRG1	is	H	0,46
25	If	ISI	is	VH	Then	CRG1	is	VH	0,46
26	If	IPM	is	VL	Then	CRG1	is	VL	0,60
27	If	IPM	is	L	Then	CRG1	is	L	0,60
28	If	IPM	is	M	Then	CRG1	is	M	0,60
29	If	IPM	is	H	Then	CRG1	is	H	0,60
30	If	IPM	is	VH	Then	CRG1	is	VH	0,60
31	If	LIR	is	VL	Then	CRG1	is	VL	0,64
32	If	LIR	is	L	Then	CRG1	is	L	0,64
33	If	LIR	is	M	Then	CRG1	is	M	0,64
34	If	LIR	is	H	Then	CRG1	is	H	0,64
35	If	LIR	is	VH	Then	CRG1	is	VH	0,64
36	If	PCC1	is	VL	Then	CRG1	is	VL	0,72
37	If	PCC1	is	L	Then	CRG1	is	L	0,72
38	If	PCC1	is	M	Then	CRG1	is	M	0,72
39	If	PCC1	is	H	Then	CRG1	is	H	0,72
40	If	PCC1	is	VH	Then	CRG1	is	VH	0,72

Table D.2: List of if-then rules of contractor related delay factors

Rule #	Probability of schedule delay rules				Consequence				Rule Weight
1	If	FCO	is	VL	Then	CRG2	is	VL	0,44
2	If	FCO	is	L	Then	CRG2	is	L	0,44
3	If	FCO	is	M	Then	CRG2	is	M	0,44
4	If	FCO	is	H	Then	CRG2	is	H	0,44
5	If	FCO	is	VH	Then	CRG2	is	VH	0,44
6	If	ICE	is	VL	Then	CRG2	is	VL	0,88
7	If	ICE	is	L	Then	CRG2	is	L	0,88
8	If	ICE	is	M	Then	CRG2	is	M	0,88
9	If	ICE	is	H	Then	CRG2	is	H	0,88
10	If	ICE	is	VH	Then	CRG2	is	VH	0,88
11	If	ICM	is	VL	Then	CRG2	is	VL	0,46
12	If	ICM	is	L	Then	CRG2	is	L	0,46
13	If	ICM	is	M	Then	CRG2	is	M	0,46
14	If	ICM	is	H	Then	CRG2	is	H	0,46
15	If	ICM	is	VH	Then	CRG2	is	VH	0,46
16	If	IPT	is	VL	Then	CRG2	is	VL	0,56
17	If	IPT	is	L	Then	CRG2	is	L	0,56
18	If	IPT	is	M	Then	CRG2	is	M	0,56
19	If	IPT	is	H	Then	CRG2	is	H	0,56
20	If	IPT	is	VH	Then	CRG2	is	VH	0,56
21	If	IPP	is	VL	Then	CRG2	is	VL	0,88
22	If	IPP	is	L	Then	CRG2	is	L	0,88
23	If	IPP	is	M	Then	CRG2	is	M	0,88
24	If	IPP	is	H	Then	CRG2	is	H	0,88
25	If	IPP	is	VH	Then	CRG2	is	VH	0,88
26	If	OT	is	VL	Then	CRG2	is	VL	0,4
27	If	OT	is	L	Then	CRG2	is	L	0,4
28	If	OT	is	M	Then	CRG2	is	M	0,4
29	If	OT	is	H	Then	CRG2	is	H	0,4
30	If	OT	is	VH	Then	CRG2	is	VH	0,4
31	If	PCC2	is	VL	Then	CRG2	is	VL	0,76
32	If	PCC2	is	L	Then	CRG2	is	L	0,76
33	If	PCC2	is	M	Then	CRG2	is	M	0,76
34	If	PCC2	is	H	Then	CRG2	is	H	0,76
35	If	PCC2	is	VH	Then	CRG2	is	VH	0,76
36	If	PSM	is	VL	Then	CRG2	is	VL	0,84
37	If	PSM	is	L	Then	CRG2	is	L	0,84
38	If	PSM	is	M	Then	CRG2	is	M	0,84
39	If	PSM	is	H	Then	CRG2	is	H	0,84
40	If	PSM	is	VH	Then	CRG2	is	VH	0,84
41	If	RDT	is	VL	Then	CRG2	is	VL	0,5
42	If	RDT	is	L	Then	CRG2	is	L	0,5
43	If	RDT	is	M	Then	CRG2	is	M	0,5
44	If	RDT	is	H	Then	CRG2	is	H	0,5
45	If	RDT	is	VH	Then	CRG2	is	VH	0,5
46	If	US	is	VL	Then	CRG2	is	VL	0,66
47	If	US	is	L	Then	CRG2	is	L	0,66
48	If	US	is	M	Then	CRG2	is	M	0,66
49	If	US	is	H	Then	CRG2	is	H	0,66
50	If	US	is	VH	Then	CRG2	is	VH	0,66

Table D.3: List of if-then rules of design related delay factors

Rule #	Probability of schedule delay rules				Consequence				Rule Weight
1	If	COP	is	VL	Then	DRG	is	VL	0,44
2	If	COP	is	L	Then	DRG	is	L	0,44
3	If	COP	is	M	Then	DRG	is	M	0,44
4	If	COP	is	H	Then	DRG	is	H	0,44
5	If	COP	is	VH	Then	DRG	is	VH	0,44
6	If	DCB	is	VL	Then	DRG	is	VL	0,84
7	If	DCB	is	L	Then	DRG	is	L	0,84
8	If	DCB	is	M	Then	DRG	is	M	0,84
9	If	DCB	is	H	Then	DRG	is	H	0,84
10	If	DCB	is	VH	Then	DRG	is	VH	0,84
11	If	DEM	is	VL	Then	DRG	is	VL	0,6
12	If	DEM	is	L	Then	DRG	is	L	0,6
13	If	DEM	is	M	Then	DRG	is	M	0,6
14	If	DEM	is	H	Then	DRG	is	H	0,6
15	If	DEM	is	VH	Then	DRG	is	VH	0,6
16	If	IDC	is	VL	Then	DRG	is	VL	0,52
17	If	IDC	is	L	Then	DRG	is	L	0,52
18	If	IDC	is	M	Then	DRG	is	M	0,52
19	If	IDC	is	H	Then	DRG	is	H	0,52
20	If	IDC	is	VH	Then	DRG	is	VH	0,52
21	If	LOE2	is	VL	Then	DRG	is	VL	0,66
22	If	LOE2	is	L	Then	DRG	is	L	0,66
23	If	LOE2	is	M	Then	DRG	is	M	0,66
24	If	LOE2	is	H	Then	DRG	is	H	0,66
25	If	LOE2	is	VH	Then	DRG	is	VH	0,66
26	If	MAD	is	VL	Then	DRG	is	VL	0,68
27	If	MAD	is	L	Then	DRG	is	L	0,68
28	If	MAD	is	M	Then	DRG	is	M	0,68
29	If	MAD	is	H	Then	DRG	is	H	0,68
30	If	MAD	is	VH	Then	DRG	is	VH	0,68
31	If	MOO	is	VL	Then	DRG	is	VL	0,44
32	If	MOO	is	L	Then	DRG	is	L	0,44
33	If	MOO	is	M	Then	DRG	is	M	0,44
34	If	MOO	is	H	Then	DRG	is	H	0,44
35	If	MOO	is	VH	Then	DRG	is	VH	0,44
36	If	PUO	is	VL	Then	DRG	is	VL	0,38
37	If	PUO	is	L	Then	DRG	is	L	0,38
38	If	PUO	is	M	Then	DRG	is	M	0,38
39	If	PUO	is	H	Then	DRG	is	H	0,38
40	If	PUO	is	VH	Then	DRG	is	VH	0,38
41	If	UAI	is	VL	Then	DRG	is	VL	0,6
42	If	UAI	is	L	Then	DRG	is	L	0,6
43	If	UAI	is	M	Then	DRG	is	M	0,6
44	If	UAI	is	H	Then	DRG	is	H	0,6
45	If	UAI	is	VH	Then	DRG	is	VH	0,6

Table D.4: List of if-then rules of equipment related delay factors

Rule #	Probability of schedule delay rules				Consequence				Rule Weight
1	If	EAP	is	VL	Then	ERG1	is	VL	0,6
2	If	EAP	is	L	Then	ERG1	is	L	0,6
3	If	EAP	is	M	Then	ERG1	is	M	0,6
4	If	EAP	is	H	Then	ERG1	is	H	0,6
5	If	EAP	is	VH	Then	ERG1	is	VH	0,6
6	If	FEB	is	VL	Then	ERG1	is	VL	0,52
7	If	FEB	is	L	Then	ERG1	is	L	0,52
8	If	FEB	is	M	Then	ERG1	is	M	0,52
9	If	FEB	is	H	Then	ERG1	is	H	0,52
10	If	FEB	is	VH	Then	ERG1	is	VH	0,52
11	If	IE	is	VL	Then	ERG1	is	VL	0,46
12	If	IE	is	L	Then	ERG1	is	L	0,46
13	If	IE	is	M	Then	ERG1	is	M	0,46
14	If	IE	is	H	Then	ERG1	is	H	0,46
15	If	IE	is	VH	Then	ERG1	is	VH	0,46
16	If	IME	is	VL	Then	ERG1	is	VL	0,74
17	If	IME	is	L	Then	ERG1	is	L	0,74
18	If	IME	is	M	Then	ERG1	is	M	0,74
19	If	IME	is	H	Then	ERG1	is	H	0,74
20	If	IME	is	VH	Then	ERG1	is	VH	0,74
21	If	LEO	is	VL	Then	ERG1	is	VL	0,74
22	If	LEO	is	L	Then	ERG1	is	L	0,74
23	If	LEO	is	M	Then	ERG1	is	M	0,74
24	If	LEO	is	H	Then	ERG1	is	H	0,74
25	If	LEO	is	VH	Then	ERG1	is	VH	0,74
26	If	SOE	is	VL	Then	ERG1	is	VL	0,48
27	If	SOE	is	L	Then	ERG1	is	L	0,48
28	If	SOE	is	M	Then	ERG1	is	M	0,48
29	If	SOE	is	H	Then	ERG1	is	H	0,48
30	If	SOE	is	VH	Then	ERG1	is	VH	0,48
31	If	SMO1	is	VL	Then	ERG1	is	VL	0,44
32	If	SMO1	is	L	Then	ERG1	is	L	0,44
33	If	SMO1	is	M	Then	ERG1	is	M	0,44
34	If	SMO1	is	H	Then	ERG1	is	H	0,44
35	If	SMO1	is	VH	Then	ERG1	is	VH	0,44

Table D.5: List of if-then rules of external related delay factors

Rule #	Probability of schedule delay rules				Consequence				Rule Weight
1	If	ADC	is	VL	Then	ERG2	is	VL	0,52
2	If	ADC	is	L	Then	ERG2	is	L	0,52
3	If	ADC	is	M	Then	ERG2	is	M	0,52
4	If	ADC	is	H	Then	ERG2	is	H	0,52
5	If	ADC	is	VH	Then	ERG2	is	VH	0,52
6	If	CIG	is	VL	Then	ERG2	is	VL	0,5
7	If	CIG	is	L	Then	ERG2	is	L	0,5
8	If	CIG	is	M	Then	ERG2	is	M	0,5
9	If	CIG	is	H	Then	ERG2	is	H	0,5
10	If	CIG	is	VH	Then	ERG2	is	VH	0,5
11	If	CWP	is	VL	Then	ERG2	is	VL	0,56
12	If	CWP	is	L	Then	ERG2	is	L	0,56
13	If	CWP	is	M	Then	ERG2	is	M	0,56
14	If	CWP	is	H	Then	ERG2	is	H	0,56
15	If	CWP	is	VH	Then	ERG2	is	VH	0,56
16	If	DIO	is	VL	Then	ERG2	is	VL	0,42
17	If	DIO	is	L	Then	ERG2	is	L	0,42
18	If	DIO	is	M	Then	ERG2	is	M	0,42
19	If	DIO	is	H	Then	ERG2	is	H	0,42
20	If	DIO	is	VH	Then	ERG2	is	VH	0,42
21	If	DIP	is	VL	Then	ERG2	is	VL	0,56
22	If	DIP	is	L	Then	ERG2	is	L	0,56
23	If	DIP	is	M	Then	ERG2	is	M	0,56
24	If	DIP	is	H	Then	ERG2	is	H	0,56
25	If	DIP	is	VH	Then	ERG2	is	VH	0,56
26	If	DIP2	is	VL	Then	ERG2	is	VL	0,46
27	If	DIP2	is	L	Then	ERG2	is	L	0,46
28	If	DIP2	is	M	Then	ERG2	is	M	0,46
29	If	DIP2	is	H	Then	ERG2	is	H	0,46
30	If	DIP2	is	VH	Then	ERG2	is	VH	0,46
31	If	GFC	is	VL	Then	ERG2	is	VL	0,88
32	If	GFC	is	L	Then	ERG2	is	L	0,88
33	If	GFC	is	M	Then	ERG2	is	M	0,88
34	If	GFC	is	H	Then	ERG2	is	H	0,88
35	If	GFC	is	VH	Then	ERG2	is	VH	0,88
36	If	LOT	is	VL	Then	ERG2	is	VL	0,38
37	If	LOT	is	L	Then	ERG2	is	L	0,38
38	If	LOT	is	M	Then	ERG2	is	M	0,38
39	If	LOT	is	H	Then	ERG2	is	H	0,38
40	If	LOT	is	VH	Then	ERG2	is	VH	0,38

Table D.5: List of if-then rules of external related delay factors (cont'd)

Rule #	Probability of schedule delay rules				Consequence				Rule Weight
41	If	ND	is	VL	Then	ERG2	is	VL	0,5
42	If	ND	is	L	Then	ERG2	is	L	0,5
43	If	ND	is	M	Then	ERG2	is	M	0,5
44	If	ND	is	H	Then	ERG2	is	H	0,5
45	If	ND	is	VH	Then	ERG2	is	VH	0,5
46	If	PF	is	VL	Then	ERG2	is	VL	0,58
47	If	PF	is	L	Then	ERG2	is	L	0,58
48	If	PF	is	M	Then	ERG2	is	M	0,58
49	If	PF	is	H	Then	ERG2	is	H	0,58
50	If	PF	is	VH	Then	ERG2	is	VH	0,58
51	If	PWN	is	VL	Then	ERG2	is	VL	0,68
52	If	PWN	is	L	Then	ERG2	is	L	0,68
53	If	PWN	is	M	Then	ERG2	is	M	0,68
54	If	PWN	is	H	Then	ERG2	is	H	0,68
55	If	PWN	is	VH	Then	ERG2	is	VH	0,68
56	If	SSC	is	VL	Then	ERG2	is	VL	0,46
57	If	SSC	is	L	Then	ERG2	is	L	0,46
58	If	SSC	is	M	Then	ERG2	is	M	0,46
59	If	SSC	is	H	Then	ERG2	is	H	0,46
60	If	SSC	is	VH	Then	ERG2	is	VH	0,46
61	If	USS	is	VL	Then	ERG2	is	VL	0,78
62	If	USS	is	L	Then	ERG2	is	L	0,78
63	If	USS	is	M	Then	ERG2	is	M	0,78
64	If	USS	is	H	Then	ERG2	is	H	0,78
65	If	USS	is	VH	Then	ERG2	is	VH	0,78
66	If	UWC	is	VL	Then	ERG2	is	VL	0,82
67	If	UWC	is	L	Then	ERG2	is	L	0,82
68	If	UWC	is	M	Then	ERG2	is	M	0,82
69	If	UWC	is	H	Then	ERG2	is	H	0,82
70	If	UWC	is	VH	Then	ERG2	is	VH	0,82

Table D.6: List of if-then rules of labor related delay factors

Rule #	**Probability of schedule delay rules**				**Consequence**				**Rule Weight**
1	If	A	is	VL	Then	LRG	is	VL	0,38
2	If	A	is	L	Then	LRG	is	L	0,38
3	If	A	is	M	Then	LRG	is	M	0,38
4	If	A	is	H	Then	LRG	is	H	0,38
5	If	A	is	VH	Then	LRG	is	VH	0,38
6	If	LMA	is	VL	Then	LRG	is	VL	0,5
7	If	LMA	is	L	Then	LRG	is	L	0,5
8	If	LMA	is	M	Then	LRG	is	M	0,5
9	If	LMA	is	H	Then	LRG	is	H	0,5
10	If	LMA	is	VH	Then	LRG	is	VH	0,5
11	If	LPO	is	VL	Then	LRG	is	VL	0,5
12	If	LPO	is	L	Then	LRG	is	L	0,5
13	If	LPO	is	M	Then	LRG	is	M	0,5
14	If	LPO	is	H	Then	LRG	is	H	0,5
15	If	LPO	is	VH	Then	LRG	is	VH	0,5
16	If	PCA	is	VL	Then	LRG	is	VL	0,4
17	If	PCA	is	L	Then	LRG	is	L	0,4
18	If	PCA	is	M	Then	LRG	is	M	0,4
19	If	PCA	is	H	Then	LRG	is	H	0,4
20	If	PCA	is	VH	Then	LRG	is	VH	0,4
21	If	SOL	is	VL	Then	LRG	is	VL	0,8
22	If	SOL	is	L	Then	LRG	is	L	0,8
23	If	SOL	is	M	Then	LRG	is	M	0,8
24	If	SOL	is	H	Then	LRG	is	H	0,8
25	If	SOL	is	VH	Then	LRG	is	VH	0,8
26	If	SMO2	is	VL	Then	LRG	is	VL	0,42
27	If	SMO2	is	L	Then	LRG	is	L	0,42
28	If	SMO2	is	M	Then	LRG	is	M	0,42
29	If	SMO2	is	H	Then	LRG	is	H	0,42
30	If	SMO2	is	VH	Then	LRG	is	VH	0,42
31	If	S	is	VL	Then	LRG	is	VL	0,36
32	If	S	is	L	Then	LRG	is	L	0,36
33	If	S	is	M	Then	LRG	is	M	0,36
34	If	S	is	H	Then	LRG	is	H	0,36
35	If	S	is	VH	Then	LRG	is	VH	0,36
36	If	UEL	is	VL	Then	LRG	is	VL	0,74
37	If	UEL	is	L	Then	LRG	is	L	0,74
38	If	UEL	is	M	Then	LRG	is	M	0,74
39	If	UEL	is	H	Then	LRG	is	H	0,74
40	If	UEL	is	VH	Then	LRG	is	VH	0,74

Table D.7: List of if-then rules of material related delay factors

Rule #	Probability of schedule delay rules				Consequence				Rule Weight
1	If	CIM	is	VL	Then	MRG	is	VL	0,76
2	If	CIM	is	L	Then	MRG	is	L	0,76
3	If	CIM	is	M	Then	MRG	is	M	0,76
4	If	CIM	is	H	Then	MRG	is	H	0,76
5	If	CIM	is	VH	Then	MRG	is	VH	0,76
6	If	DOS	is	VL	Then	MRG	is	VL	0,58
7	If	DOS	is	L	Then	MRG	is	L	0,58
8	If	DOS	is	M	Then	MRG	is	M	0,58
9	If	DOS	is	H	Then	MRG	is	H	0,58
10	If	DOS	is	VH	Then	MRG	is	VH	0,58
11	If	DIM	is	VL	Then	MRG	is	VL	0,38
12	If	DIM	is	L	Then	MRG	is	L	0,38
13	If	DIM	is	M	Then	MRG	is	M	0,38
14	If	DIM	is	H	Then	MRG	is	H	0,38
15	If	DIM	is	VH	Then	MRG	is	VH	0,38
16	If	EOM	is	VL	Then	MRG	is	VL	0,5
17	If	EOM	is	L	Then	MRG	is	L	0,5
18	If	EOM	is	M	Then	MRG	is	M	0,5
19	If	EOM	is	H	Then	MRG	is	H	0,5
20	If	EOM	is	VH	Then	MRG	is	VH	0,5
21	If	LDO	is	VL	Then	MRG	is	VL	0,78
22	If	LDO	is	L	Then	MRG	is	L	0,78
23	If	LDO	is	M	Then	MRG	is	M	0,78
24	If	LDO	is	H	Then	MRG	is	H	0,78
25	If	LDO	is	VH	Then	MRG	is	VH	0,78
26	If	PPO	is	VL	Then	MRG	is	VL	0,56
27	If	PPO	is	L	Then	MRG	is	L	0,56
28	If	PPO	is	M	Then	MRG	is	M	0,56
29	If	PPO	is	H	Then	MRG	is	H	0,56
30	If	PPO	is	VH	Then	MRG	is	VH	0,56
31	If	PQO	is	VL	Then	MRG	is	VL	0,44
32	If	PQO	is	L	Then	MRG	is	L	0,44
33	If	PQO	is	M	Then	MRG	is	M	0,44
34	If	PQO	is	H	Then	MRG	is	H	0,44
35	If	PQO	is	VH	Then	MRG	is	VH	0,44
36	If	SOC	is	VL	Then	MRG	is	VL	0,84
37	If	SOC	is	L	Then	MRG	is	L	0,84
38	If	SOC	is	M	Then	MRG	is	M	0,84
39	If	SOC	is	H	Then	MRG	is	H	0,84
40	If	SOC	is	VH	Then	MRG	is	VH	0,84
41	If	US2	is	VL	Then	MRG	is	VL	0,54
42	If	US2	is	L	Then	MRG	is	L	0,54
43	If	US2	is	M	Then	MRG	is	M	0,54
44	If	US2	is	H	Then	MRG	is	H	0,54
45	If	US2	is	VH	Then	MRG	is	VH	0,54

Table D.8: List of if-then rules of owner related delay factors

Rule #	Probability of schedule delay rules				Consequence				Rule Weight
1	If	CO	is	VL	Then	ORG	is	VL	0,9
2	If	CO	is	L	Then	ORG	is	L	0,9
3	If	CO	is	M	Then	ORG	is	M	0,9
4	If	CO	is	H	Then	ORG	is	H	0,9
5	If	CO	is	VH	Then	ORG	is	VH	0,9
6	If	CBJ	is	VL	Then	ORG	is	VL	0,5
7	If	CBJ	is	L	Then	ORG	is	L	0,5
8	If	CBJ	is	M	Then	ORG	is	M	0,5
9	If	CBJ	is	H	Then	ORG	is	H	0,5
10	If	CBJ	is	VH	Then	ORG	is	VH	0,5
11	If	DIA2	is	VL	Then	ORG	is	VL	0,72
12	If	DIA2	is	L	Then	ORG	is	L	0,72
13	If	DIA2	is	M	Then	ORG	is	M	0,72
14	If	DIA2	is	H	Then	ORG	is	H	0,72
15	If	DIA2	is	VH	Then	ORG	is	VH	0,72
16	If	DIP3	is	VL	Then	ORG	is	VL	0,64
17	If	DIP3	is	L	Then	ORG	is	L	0,64
18	If	DIP3	is	M	Then	ORG	is	M	0,64
19	If	DIP3	is	H	Then	ORG	is	H	0,64
20	If	DIP3	is	VH	Then	ORG	is	VH	0,64
21	If	DIS	is	VL	Then	ORG	is	VL	0,74
22	If	DIS	is	L	Then	ORG	is	L	0,74
23	If	DIS	is	M	Then	ORG	is	M	0,74
24	If	DIS	is	H	Then	ORG	is	H	0,74
25	If	DIS	is	VH	Then	ORG	is	VH	0,74
26	If	IPF	is	VL	Then	ORG	is	VL	0,5
27	If	IPF	is	L	Then	ORG	is	L	0,5
28	If	IPF	is	M	Then	ORG	is	M	0,5
29	If	IPF	is	H	Then	ORG	is	H	0,5
30	If	IPF	is	VH	Then	ORG	is	VH	0,5
31	If	LOC	is	VL	Then	ORG	is	VL	0,4
32	If	LOC	is	L	Then	ORG	is	L	0,4
33	If	LOC	is	M	Then	ORG	is	M	0,4
34	If	LOC	is	H	Then	ORG	is	H	0,4
35	If	LOC	is	VH	Then	ORG	is	VH	0,4
36	If	LOE3	is	VL	Then	ORG	is	VL	0,74
37	If	LOE3	is	L	Then	ORG	is	L	0,74
38	If	LOE3	is	M	Then	ORG	is	M	0,74
39	If	LOE3	is	H	Then	ORG	is	H	0,74
40	If	LOE3	is	VH	Then	ORG	is	VH	0,74

Table D.8: List of if-then rules of owner related delay factors (cont'd)

Rule #	Probability of schedule delay rules				Consequence				Rule Weight
41	If	LOI	is	VL	Then	ORG	is	VL	0,48
42	If	LOI	is	L	Then	ORG	is	L	0,48
43	If	LOI	is	M	Then	ORG	is	M	0,48
44	If	LOI	is	H	Then	ORG	is	H	0,48
45	If	LOI	is	VH	Then	ORG	is	VH	0,48
46	If	PCC3	is	VL	Then	ORG	is	VL	0,86
47	If	PCC3	is	L	Then	ORG	is	L	0,86
48	If	PCC3	is	M	Then	ORG	is	M	0,86
49	If	PCC3	is	H	Then	ORG	is	H	0,86
50	If	PCC3	is	VH	Then	ORG	is	VH	0,86
51	If	SID	is	VL	Then	ORG	is	VL	0,8
52	If	SID	is	L	Then	ORG	is	L	0,8
53	If	SID	is	M	Then	ORG	is	M	0,8
54	If	SID	is	H	Then	ORG	is	H	0,8
55	If	SID	is	VH	Then	ORG	is	VH	0,8
56	If	SOW	is	VL	Then	ORG	is	VL	0,58
57	If	SOW	is	L	Then	ORG	is	L	0,58
58	If	SOW	is	M	Then	ORG	is	M	0,58
59	If	SOW	is	H	Then	ORG	is	H	0,58
60	If	SOW	is	VH	Then	ORG	is	VH	0,58

Table D.9: List of if-then rules of project related delay factors

Rule #	Probability of schedule delay rules				Consequence				Rule Weight
1	If	COT	is	VL	Then	PRG	is	VL	0,38
2	If	COT	is	L	Then	PRG	is	L	0,38
3	If	COT	is	M	Then	PRG	is	M	0,38
4	If	COT	is	H	Then	PRG	is	H	0,38
5	If	COT	is	VH	Then	PRG	is	VH	0,38
6	If	IDO	is	VL	Then	PRG	is	VL	0,38
7	If	IDO	is	L	Then	PRG	is	L	0,38
8	If	IDO	is	M	Then	PRG	is	M	0,38
9	If	IDO	is	H	Then	PRG	is	H	0,38
10	If	IDO	is	VH	Then	PRG	is	VH	0,38
11	If	IDP	is	VL	Then	PRG	is	VL	0,54
12	If	IDP	is	L	Then	PRG	is	L	0,54
13	If	IDP	is	M	Then	PRG	is	M	0,54
14	If	IDP	is	H	Then	PRG	is	H	0,54
15	If	IDP	is	VH	Then	PRG	is	VH	0,54
16	If	LDB	is	VL	Then	PRG	is	VL	0,58
17	If	LDB	is	L	Then	PRG	is	L	0,58
18	If	LDB	is	M	Then	PRG	is	M	0,58
19	If	LDB	is	H	Then	PRG	is	H	0,58
20	If	LDB	is	VH	Then	PRG	is	VH	0,58
21	If	OCD	is	VL	Then	PRG	is	VL	0,72
22	If	OCD	is	L	Then	PRG	is	L	0,72
23	If	OCD	is	M	Then	PRG	is	M	0,72
24	If	OCD	is	H	Then	PRG	is	H	0,72
25	If	OCD	is	VH	Then	PRG	is	VH	0,72
26	If	UCC	is	VL	Then	PRG	is	VL	0,86
27	If	UCC	is	L	Then	PRG	is	L	0,86
28	If	UCC	is	M	Then	PRG	is	M	0,86
29	If	UCC	is	H	Then	PRG	is	H	0,86
30	If	UCC	is	VH	Then	PRG	is	VH	0,86

Table D.10: List of if-then rules of schedule delay probability

Rule #	Probability of schedule delay rules				Consequence				Rule Weight
1	If	CRG1	is	VL	Then	SDP	is	VL	0,64
2	If	CRG1	is	L	Then	SDP	is	L	0,64
3	If	CRG1	is	M	Then	SDP	is	M	0,64
4	If	CRG1	is	H	Then	SDP	is	H	0,64
5	If	CRG1	is	VH	Then	SDP	is	VH	0,64
6	If	CRG2	is	VL	Then	SDP	is	VL	0,64
7	If	CRG2	is	L	Then	SDP	is	L	0,64
8	If	CRG2	is	M	Then	SDP	is	M	0,64
9	If	CRG2	is	H	Then	SDP	is	H	0,64
10	If	CRG2	is	VH	Then	SDP	is	VH	0,64
11	If	DRG	is	VL	Then	SDP	is	VL	0,57
12	If	DRG	is	L	Then	SDP	is	L	0,57
13	If	DRG	is	M	Then	SDP	is	M	0,57
14	If	DRG	is	H	Then	SDP	is	H	0,57
15	If	DRG	is	VH	Then	SDP	is	VH	0,57
16	If	ERG1	is	VL	Then	SDP	is	VL	0,57
17	If	ERG1	is	L	Then	SDP	is	L	0,57
18	If	ERG1	is	M	Then	SDP	is	M	0,57
19	If	ERG1	is	H	Then	SDP	is	H	0,57
20	If	ERG1	is	VH	Then	SDP	is	VH	0,57
21	If	ERG2	is	VL	Then	SDP	is	VL	0,58
22	If	ERG2	is	L	Then	SDP	is	L	0,58
23	If	ERG2	is	M	Then	SDP	is	M	0,58
24	If	ERG2	is	H	Then	SDP	is	H	0,58
25	If	ERG2	is	VH	Then	SDP	is	VH	0,58
26	If	LRG	is	VL	Then	SDP	is	VL	0,51
27	If	LRG	is	L	Then	SDP	is	L	0,51
28	If	LRG	is	M	Then	SDP	is	M	0,51
29	If	LRG	is	H	Then	SDP	is	H	0,51
30	If	LRG	is	VH	Then	SDP	is	VH	0,51
31	If	MRG	is	VL	Then	SDP	is	VL	0,60
32	If	MRG	is	L	Then	SDP	is	L	0,60
33	If	MRG	is	M	Then	SDP	is	M	0,60
34	If	MRG	is	H	Then	SDP	is	H	0,60
35	If	MRG	is	VH	Then	SDP	is	VH	0,60
36	If	ORG	is	VL	Then	SDP	is	VL	0,66
37	If	ORG	is	L	Then	SDP	is	L	0,66
38	If	ORG	is	M	Then	SDP	is	M	0,66
39	If	ORG	is	H	Then	SDP	is	H	0,66
40	If	ORG	is	VH	Then	SDP	is	VH	0,66
41	If	PRG	is	VL	Then	SDP	is	VL	0,58
42	If	PRG	is	L	Then	SDP	is	L	0,58
43	If	PRG	is	M	Then	SDP	is	M	0,58
44	If	PRG	is	H	Then	SDP	is	H	0,58
45	If	PRG	is	VH	Then	SDP	is	VH	0,58