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FUZZY LOGIC INTEGRATION INTO CONSTRUCTION MANAGEMENT PLANNING

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Summary

A construction of an asset is challenging work associated with huge responsibilities. Project manager’s main challenges in construction are generally Time-Cost-Quality dependent. In addition to these factors, Project Managers or construction Manager have to deal with numerous uncertainties in the process of construction. Considering its diverse nature and activity performed in construction. Here major role playing factor in success of a project is efficient scheduling of the construction project. While scheduling a project, the factors which are considered are mostly tangible, such as resources, labor and capital.

My main objective in this research is to reduce the duration of the activity involved in construction, while considering qualitative factors like site organization, Labor Skills and quality of equipment used and reveal the effect of these tangible factors on duration of the project. Since these factors are difficult to be measured using classical mathematic theories. We have opted Fuzzy Logic Theory as our base, which can measure mathematically with use of Fuzzy Logic Tool Box in MATLAB®. In order to implement the proposed technique, various membership functions need to be estimated using judgement and guidance of experts. One of the main advantage of the proposed technique is that it can be easily implemented in existing computer programs and thus having a possibility to schedule a project efficiently.
Dedication

This thesis is dedicated to my beloved Father “RACHAKONDA KRISHNA RAO”. Who was very unwilling to send me abroad, well at last managed to get his blessing, and embarked on my journey of Master's program. The education system which is running here is very diverse when compared to the education system I had experienced earlier. Everything was new and questioning my limits now and then. But, at last it has been very satisfying journey after all the turnaround I went through. I should thank two very special women in my life, My MOM & My SISTER, without their support I couldn’t have achieved this goal.

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# Table of Contents

CHAPTER 1 .................................................................................................................................................. 1  
1 Introduction ....................................................................................................................................... 1  
1.1 Motivation ....................................................................................................................................... 2  
1.2 Background .................................................................................................................................... 3  
1.3 Main Objectives ............................................................................................................................ 5  
1.4 Specific Goals ............................................................................................................................... 5  
1.5 Structure of the report .................................................................................................................... 6  

CHAPTER 2 .............................................................................................................................................. 7  
2 Introduction ....................................................................................................................................... 7  
2.1 Scheduling Techniques .................................................................................................................. 8  

CHAPTER 3 ............................................................................................................................................. 19  
3 Fuzzy Logic Theory ........................................................................................................................ 19  
3.1 FLIRT Methodology ................................................................................................................... 34  
3.2 Introduction to fuzzy tool box in MATLAB® ............................................................................. 37  

CHAPTER 4 .............................................................................................................................................. 54  
4 Application of “FLIRT” methodology to case study ........................................................................ 54  
4.1 Case study ....................................................................................................................................... 54  
4.2 Problem Description ..................................................................................................................... 55  
4.3 Fuzzy tool box in MATLAB® ....................................................................................................... 59  
4.4 Rescaling the parameters ............................................................................................................. 67  
4.5 Results & Discussion ................................................................................................................... 73  
4.6 Conclusions .................................................................................................................................... 75  
4.7 Interesting Future Work ............................................................................................................... 77  

5 Bibliography ....................................................................................................................................... 78  

6 Annexes ............................................................................................................................................. i
List of Tables

Table 1: Degree of membership of ‘tall men’ .......................................................... 26
Table 2: Table showing list of activities and corresponding duration and interdependencies 34
Table 3: Project Information .................................................................................. 54
Table 4: Activity Breakdown .................................................................................. 55
Table 5: Duration of Breakdown activities. ............................................................. 56
Table 6: Interdependencies of activities. ................................................................. 57
Table 7: Table of Preferences ................................................................................ 60
Table 8: Rescaling the range of Fuzzy Input Variables .......................................... 67
List of Figures

Figure 1: Gantt chart example showcasing Time on X-axis, Activities on Y-axis and........... 9
Figure 2: Showing Gantt chart and its corresponding Milestone chart. .......................... 10
Figure 3: Crisp Set (a), (b) Fuzzy sets of “tall men”...................................................... 26
Figure 4: CPM/PERT network diagram calculations..................................................... 35
Figure 5: Categorization of membership function......................................................... 36
Figure 6: Graphical User interface representation......................................................... 39
Figure 7: Trapezoidal Membership Function. ................................................................. 42
Figure 8: Example showing how the Fuzzy sets are represented in universe of discourse. 43
Figure 9: An example of Multi Neural network for evaluating condition state of cracking. 43
Figure 10: The Centre of Gravity Method of defuzzification......................................... 48
Figure 11: The Bisector of Area (BOA) method of defuzzification................................. 49
Figure 12: The Smallest of Maxima (SOM) and the Largest of Maxima (LOM) methods of defuzzification................................................................. 50
Figure 13: Network Model ............................................................................................. 58
Figure 14: CPM Calculations.......................................................................................... 58
Figure 15: Fuzzy Logic design for the construction asset case study.............................. 59
1 Introduction

Project Management is a highly challenging work which requires vast knowledge and experience in the subject to deal with the management obstacles to be faced in the course of construction. Project scheduling is a crucial stage where everything can be done smoothly if planned well or it can be a disaster if done irrationally. There must be good decisions making in terms of choice of technology, resources and estimates for every particular activity involved in the course of construction. Wrong decisions might take a toll on the construction asset effecting the duration of the project and directly increasing the budget of the project. So communication between different teams involved is utmost necessary. Communication between civil, mechanical and electrical engineer teams plays a crucial role in the project completion. Sometime communication acts as a strong barrier in the field of construction. Any communication breakdown between the teams involved has high effect on the project. The success of a project depends on how well the construction phase is planned and executed in real time. Efficient planning and economical construction is particularly important because of the increasing complexity in the structures which are being built. The availability of improved materials and construction equipment, the high level of competition in the industry, high interest rates, high labor cost, inflation, and regulations make construction more challenging than ever before. The budget of a project is directly dependent on precise and in-depth analysis of the project in earlier phases of the project. Planning, Organizing, Motivating and capability to control resources and deadlines are not achieved by gift but by having a well-organized management, equipped with a good team of employees.

Creating efficient schedule for a construction project means strategizing an approach with a particular sequence of activities and keeping the resources, time and work force constraints. Scheduling project is highly challenging because:

- There are lot of independent activities to be performed with no connection to the scheduled approach.
Many constraints are to be satisfied for example: deadlines involved in construction phases to be carried out, budget and time constraints. To complete an activity with time and budget construction is regarded as a metaphor.

Finally, the reason why it is so difficult to make a schedule is the complexity and the computational analysis of work involved.

Modern techniques for project management are being developed continuously and are being put into use by project and construction managers. A well organized and maintained project will be completed not only quickly but will also be economically beneficial.

1.1 Motivation

Choosing this particular topic as my master’s thesis research is a dream come true. The real situational experiences I have faced in my professional work life have had much influence to pursue this particular topic. Construction of an asset is an enormous responsibility for a project manager and for different teams involved in the project. Project scheduling plays a major role in defining the project duration and budget, everyone will keep harping on making a best schedule for their project. But what they exactly miss in their perspective towards planning a schedule is considering the grade of a contractor hired, the skills of labor and employees participating in construction activities, organization management they possess in their company and the type of communication they maintain and have with their fellow employees in their company. As specified earlier, communication between employees and teams involved in the company is utterly important aspect in the field of construction. The urge to solve problems in real time is what I’m was very interested in my earlier days, but as my days progressed in my work life the perception of solving a problem or obtaining a solution to a problem in real time has vanished, urge to detect difficulties in a particular construction project have been developing more and more as days passed in my work life. I was totally interested with management side. In few months of on field experience I have experienced and I have developed a particular passion: make a plan for a construction project, and schedule it efficiently.
1.2 Background

Before getting a real time experience in a construction project everybody will be an optimist. But after having an experience of onsite project this particular perception will be gradually changing in no time. A project is much effected in duration and budget far more when these qualitative factors are being considered in a particular project. The factors which can have a great effect on duration of a project can be identified as:

I. Site organization
II. Labor Skills/skills.
III. Equipment used/

These are called qualitative factors because the effect on duration depends on the type of quality they possess in the particular construction project.

Site Organization

All organizations have a management structure that determines and defines relationships between the different activities and the members, and subdivides and assigns roles, responsibilities, and authority to carry out different tasks. Organizations are open systems--they affect and are affected by its environment. One of the important factor which has its profound effect on duration of a project, this might be lack of organizational skills in a particular company. Site organization can effect a construction project in various ways. Procurement services, planning, scheduling, progress monitoring of a project can be seen as main work and objectives. Any error in these particular tasks might have a great effect on the project in terms of duration and increasing the cost.
Labor Skills/skills

Labor Skills is a predominant factor which is experienced by almost every company in the construction sector. The deficiency of experience and skill in the labor has been effecting construction companies highly in terms of project duration and budget inflation.

Skill is a measure of the amount of workers expertise and specialization they have in a particular field. Skilled workers are generally highly trained and paid and vice-versa with low trained or low skilled labors. Increasing the skill of labor can make lot of changes in the work environment and have positive influences on the work place. Generally workers who participate in the construction activities have no skills. Educating them helps them to raise his particular level of skills he is in.

Equipment Used

This is the least dominant factor of all. It has vast effect on duration of a project in real time. Since the technology have been evolving a lot in few decades there are lot of new machinery equipment available for construction activities. If there is any deficit in their quality of service in the real time of construction activities, then it will affect the project duration in real time. Which will have a drastic effect on the project schedule and budget. Thus, having a good conditioned equipment is important fact in the construction industry.
1.3 Main Objectives

The main objective of this thesis work is to prove that, there can be reduction of duration in activities, involved in the project. While considering qualitative factors and opting for a particular methodology. While measuring qualitative factors might be a difficult task ahead, but finding a method to adapt is all the main objective of this thesis work. A project is scheduled mostly by mapping the resources, time and cost constraints which are basically tangibles, but the focus in this thesis was more on the qualitative factors point of view, which can said to be are Site organization, Labor Skills, Equipment Quality since these factors have uncertainty in within them.

1.4 Specific Goals

This research was approached with three main goals kept in mind. To understand the theory of Fuzzy Logic and Fuzzy Logic tool box in MATLAB®. Get a certain direction to know how to integrate this theory and the tool box in the research work to generate necessary results and steps to know how to reduce activity duration to satisfy aim of research.

- Steps identify necessary linguistic variables.
- Establish a relation between linguistic variables and Duration.
- Determine Fuzzy implications and inference process.
- Estimate the minimum duration of project by applying CPM Method.
- Use Fuzzy Tool Box in MATLAB®
- Analyse all necessary interpreted results.
- Compare the results obtained.
- Finally disclose the duration required for the project to complete.
- Describe how these linguistic variables effect the duration of activities in conclusion.
1.5 **Structure of the report**

- **Chapter 2:** In this particular section a review, progress and the evolution of Fuzzy logic is being described in the field of Construction Management. The effort has been put in to showcase the whole evolution of the Fuzzy logic techniques explored in this thesis.

- **Chapter 3:** This section gives a glance about, Fuzzy Logic and its uses, introduction to Fuzzy Sets Theory. A classic example of “tall men” is showcased using Fuzzy sets theory, then followed by explaining the theory of Fuzzy sets, a general review on Fuzzy logic. Application of adapted “FLIRT” methodology to an example and finally a small tutorial to get introduced to Fuzzy Logic Tool Box in MATLAB®.

- **Chapter 4:** In this section we introduce you to a case study and application of “FLIRT” methodology to the respective case study, and finally followed up by results and discussions.
CHAPTER 2
State of the art of scheduling

In this particular section a review, progress and the evolution of Fuzzy logic is being described in the field of Construction Management. The effort has been put in to showcase the whole evolution of the Fuzzy logic techniques explored in this thesis.

2 Introduction

Project scheduling is the process for identifying the necessary activities required to perform in a particular construction project. Identifying the sequence and aligning the activities based on interdependencies to successfully complete the project. The interdependencies provide for a major need of effective project scheduling.

Why do we need project scheduling?

Project scheduling enables a project manager to identify risks involved in the project, to understand the proper sequencing of the activities in the project and attain control over the project work flow which allows project manager in resource planning and developing a set of goals or necessary deadlines for teams involved in the project.

Project Managers always, were on constant observation for new techniques to be evolved to satisfy their needs, and to have complete control over the ongoing project work. Since the emergence of Project Management in construction sector critical path method approach have been considered as big breakthrough. It has greatly assisted him in breaking a huge project into small activities and thus having a better estimates for the individual activities and resources needed.
2.1 **Scheduling Techniques**

Management is continually seeking new and better control techniques to cope with the complexities, masses of data, and tight deadlines that are characteristic of highly competitive industries. Managers also want better methods for presenting technical and cost data to customers.

Scheduling techniques were always handy and helped them to achieve these goals. The most common techniques are:

- Gantt or bar charts
- Milestone charts
- Program Evaluation and Review Technique (PERT)
- Critical Path Method (CPM)
- Graphical Evaluation and Review Technique (GERT)

**Gantt charts:**

Gantt charts illustrates the start and end dates of activities involved in the project. It shows the activity break down of a project and enables user to have a current status report by displaying the percentage of work completion in a project. Recently there have been modifications to the Gantt charts so that they can show interdependencies of activities involved in the project. Gantt charts are available in many software’s like Microsoft office, Microsoft project, Primavera, etc. When dealing with complex projects, a tool that can pictorially showcase various jobs/activities to be done when there are different types of factors involving like time, resources constraints and job activities will be greatly helpful and gets handy. This is one such pictorial chart which was developed by *Henry Gantt* around 1900. It consists of two coordinate axes one, which is X-axis representing the time elapsed and other, which is y-axis representing jobs or activities performed. The jobs are represented in the form of bars as show in fig 1-1. The length of the bar indicates the duration of the job or activity.
Figure 1: Gantt chart example showcasing Time on X-axis, Activities on Y-axis and.

- Gantt chart does not show interdependencies clearly, and thus cannot reflect toleration in duration of time involved in different activities.
Milestone charts

Since there were defects and deficiencies in the Gantt charts or bar charts which couldn’t fulfill requirements of project management exactly, there were constant efforts focused on modifying and addition of some new features and elements. One such modification which was introduced is “Project progress”. This progress is called Mile Stone chart system.

Mile stones are the key or important, events or stages in time which can be identified when they are completed in a particular as project progress is on the run. In Gantt chart a bar actually represents a job/activity, this long term job is broken into several pieces of activities, each which stands for identifiable major event. Each event is numbered and a description chart or table is showcased accordingly. Thus breaking the work into several activities gives the depth of understanding the interdependencies between the tasks.

Figure 2: Showing Gantt chart and its corresponding Milestone chart.
While Milestone charts were definitely an improvement on Bar or Gantt charts, it still had one great deficiency, i.e., it did not clearly show the interdependencies between the activities. In the Milestone charts the events are in chronological, but not in a logical sequence.

**Networking techniques:**

A natural extension of Milestone chart is a network. Until 1950s, the managers had to rely on bar charts for planning, scheduling and controlling various construction activities. In 1956, the Critical Path Method (CPM) was first formulated and implemented on a computer to schedule construction projects. In 1957, a technique called the Program Evaluation and Review Technique (PERT) was developed to integrate and coordinate contractors working on a single project. This method uses probability theory, and it is considered a stochastic Critical Path Method. PERT enables management to plan and control projects by knowing the probabilities of occurrence of events. Recently, a method called Graphical Evaluation and Review Techniques (GERT) was developed. GERT is the simplest way of showing the dovetailed operations in a construction project, and is useful when performance of all the operations is not necessary for the completion of a project. Nowadays, the use of these methods is increasing due to the ease of implementing them on computers.

All these methods can be broadly divided into two groups: deterministic and probabilistic. When the information needed for a particular method is assumed to be known during the analysis, it can be considered deterministic. Bar charts and CPM may be classified as deterministic methods. In reality, however, most of the information used in these methods is nondeterministic in nature. In other words, a particular value of a parameter, such as the duration of an activity, is not known with certainty. The incorporation of uncertainty in the parameters in project scheduling techniques leads to probabilistic methods. In these methods, each parameter is generally expressed in terms of mean, standard deviation, coefficient of variation (COV), and appropriate probability distribution. The mean value indicates the expected or average value of a parameter, e.g., duration. The standard deviation indicates the dispersion or scatter of the data from the mean value. The COV is a non-dimensional quantity which is the ratio of mean and standard deviation, and is a measure of uncertainty in the parameter. PERT and GERT can be classified as probabilistic methods.
CPM/PERT Techniques

CPM/PERT are the most common and widely used techniques in the project management and mainly for the project scheduling and management. These are also classified as networking techniques. These two methods were developed in 1950's to help a project manager to schedule and also guide him to monitor and control large and complex projects. The first time when CPM was put into use was in 1957, to assist in the development and building of chemical plants within the DuPont Corporation. PERT was independently developed following the research within the special projects office of US Navy, this technique was introduced in 1958. Even though they were considered as break through techniques these techniques happen to have defects in them.

Criticism and review of classical techniques by authors:

Ali Jaafari [5] has presented a model for project planning, in which he has stated that though CPM has been a great and helping technique for project managers in construction. He criticized this technique for lack of satisfying the planning needs in construction projects. He also states that the assumption of an activity having a fixed time and discrete in nature are unrealistic. But CPM is best for scheduling when it deals with linear kind projects. He also proposed an equation for expected completion of activity duration when given to a team.

\[ d = \frac{Q}{f} \times q \]

Where:

\( d \) = Duration taken by a crew to complete the activity in real time.
\( Q \) = total quantity of work in an activity allotted.
\( q \) = ideal productivity of the crew or team involved.
\( f \) = Job-Management efficiency factor.
But, later after making a research study it has been revealed that,

- Lack of experience and willingness on part of contractors.
- General variation such as day to day outputs tends to vary, even in repetitive operations.
- Multiple contract system, lack of detailed design are main problems effecting CPM.
- Status reports takes time to reach manager or decision maker, by the time they receive these the information contained in them tend to be out of date.

Kaara and Nasr [6] have proposed a model for multi project resource planning and sharing for the whole project. A resource management model for scheduling construction projects based on optimal resource utilization was presented. The main objective function is to minimize the cost of leasing additional resources.

\[
\text{Minimize } Z = \sum_{r \in R} \sum_{j \in J} \sum_{i=ES_j}^{LF} C_{rij} RR_{rij}
\]

Where:

\( C_{rij} \) = Cost of leasing an additional unit of resource type r to use it in activity j on day I;
\( RR_{rij} \) = Number of leased additional units of resource type r to be allocated to activity j on day I;
\( R \) = Set of all types of resources;
\( J \) = Set of all activities;
\( I \) = Set of all days within the duration;
\( ES_j \) = Earliest start of jth activity;
\( LS_j \) = Latest finish of the jth activity.

It has been concluded that this model can be used as tool since, the logistics of the construction project is the output of the resource optimization. It can also be used in multi-project planning, by running a number of projects as a single project center.
Adeli and Karim [7] provided a new approach to overcome the shortcomings of network scheduling methods. They proposed a new cost optimization method which provides a capability of both CPM and linear scheduling methods for optimum schedule and minimum construction cost and also their approach provides greater flexibility for studying the effects of change on construction costs. Diaz and Hadipriono [4] compared and evaluated techniques such as PERT, Probabilistic Networking Technique (PNET), Narrow Reliability Bounds (NRB), Monte Carlo Simulation (MCS) and Simplified Monte Carlo Simulation (SMCS) by incorporating uncertainty variables for construction project scheduling. Cottrell [3] developed a simplified version of PERT to reduce the level of effort required by conventional PERT. This saves time for large projects.
CHAPTER 3
Fuzzy Logic Theory

3 Fuzzy Logic Theory

Since its inception in 1965, the theory of fuzzy sets have been gaining a huge response from academic field and has been growing ever since. Fuzzy set theory has advanced in many direction as rapidly as possible. Application of fuzzy theory in different stream of engineering such as in artificial intelligence, computer science, operation research, pattern recognition, and robotics. Mathematical developments are advancing to very high standards and are still forth coming today. In this review, the basic mathematical frame work of fuzzy set theory will be described, as well as the most important applications of this theory to other theories and techniques available.

Introduction

Project management and construction of projects are very challenging and are complex by its very nature, which are packed with uncertainties. Project managers and decision makers must work with a certainty and perspective in their view towards their goal where there is a need of decision making. Numerous decisions are taken in construction project which involves decision in perspective of time and money. These decisions are mostly made with intuition based on limited information available. Taking good decisions in these kind of situations depends mostly on two factors:

- Experience of experts involved in decision making.
- Quality of knowledge accumulated from previous experiences.

Decision making and dealing with uncertainties is a natural phenomenon in construction of projects. Decision making in these kinds of circumstances plays a vital role. Decision making can be defined as a result obtained after a follow-up of an evaluation process which lead to particular choice or take up a particular decision among several alternatives available. Where
every decision making produces a final choice. Thus it's concluded that output can be an action or opinion of choice.

So, here making a decision exactly implies that there are other alternatives which are available and which can also be considered for making a precise decision. In that case, we not only want to choose an alternative but choose a best one that has highest probability of success, effectiveness and the one which best fits with our goals, values, etc.

Taking a good decision has always been a metaphor from ages. There have been research carried in this direction for ages until when Lofti Zadeh has made a progress in determining a theory called Fuzzy Sets. It is well known fact that decisions taken in real world are generally taken in a habitat where the goals, constraints and results are unknown precisely. Thus it has a large probability of taking wrong decisions. Fuzzy sets theory comes handy exactly when these type of circumstances are prevailing in the surrounding habitat. Fuzzy sets theory deals with the vagueness of data available and defuzzify the vague data into crisp output to make a sense to a particular problem.

**Fuzzy Logic**

*What is fuzzy logic?*

Fuzzy logic is a branch of mathematics, which can also be said in a narrow sense is an extension to "Many-value Logic". Fuzzy Logic deals with approximate reasoning instead of fixed and exact reasoning. Fuzzy logic is an inculcating theory which has a unique way of utilizing linguistic variables which are words rather than numbers. In a way we can view fuzzy logic as a methodology for computing with words rather than numbers. Although words are less precise than numbers, their use is very close to human intuition. Furthermore computing with words exploits the tolerance for imprecision and thereby lowers the cost of solution. Fuzzy logic uses membership functions which is a truth value assigned to a linguistic variable. The range of the value will be between [0 1].

Fuzzy logic is a fascinating area of research because it does a good job in trading off the differences between significance and precision, something that humans have been managing for a very long time. And this sense, Fuzzy logic is both old and new because, although the
modern and methodical science of Fuzzy logic is still young, the concepts of Fuzzy logic relies on age-old skills of human reasoning.

**Why use Fuzzy Logic?**

Here is a list of general observations about fuzzy logic:

- Fuzzy logic is conceptually easy to understand.
  
  The mathematical concepts behind fuzzy reasoning are very simple. Fuzzy logic is a more intuitive approach without the far-reaching complexity.

- Fuzzy logic is flexible.
  
  With any given system, it is easy to layer on more functionality without starting again from scratch.

- Fuzzy logic is tolerant of imprecise data.
  
  Everything is imprecise if you look closely enough, but more than that, most things are imprecise even on careful inspection. Fuzzy reasoning builds this understanding into the process rather than tacking it onto the end.

- Fuzzy logic can be built on top of the experience of experts.
  
  In direct contrast to neural networks, which take training data and generate opaque, impenetrable models, fuzzy logic lets you rely on the experience of people who already understand your system.

- Fuzzy logic can be blended with conventional control techniques.
  
  Fuzzy systems don’t necessarily replace conventional control methods. In many cases fuzzy systems augment them and simplify their implementation.

- Fuzzy logic is based on natural language.
  
  The basis for fuzzy logic is the basis for human communication. This observation underpins many of the other statements about fuzzy logic. Because fuzzy logic is built on the structures of qualitative description used in everyday language, fuzzy logic is easy to use.
Why use fuzzy risk analysis for construction projects

PMBOK\(^1\) defines risk as a measure of probability and consequence of not achieving a defined project goal. Risk has two primary components for a given event:

- A probability of occurrence of that event.
- Impact (consequence) of event occurring.

Consequently the risk for each event can be defined as a function of probability and consequence (impact); Probability theory cannot deal with important aspects of project uncertainty and cannot explain some important aspects of observed project management practice.

Probability theory has some limitations:

- Probability theory deals with some assumption of randomness, whereas project deals with planned consciously planned human actions that are generally not random.
- Probability theory assumes that future states are known and definable: however uncertainty and ignorance are to be kept in view.

Conception of Fuzzy

We as human beings are been gifted with enormous sense of understanding of everything that's going around us. We either use our sense of intuition or use the experience we have gathered in the years, in which we have spent years living in different areas of knowledge or by understanding. Likewise, when we are presented with vague or ambiguous questions/answers, we have a problem to make certain decisions. Fuzzy logic deals with the very concept of vagueness and help to find a solution with a particular design process.

\(^1\) http://www.works.gov.bh/English/ourstrategy/Project\%20Management/Documents/Other\%20PM\%20Resources/ConstructionExtension.pdf
Composition of Fuzzy relations

Fuzzy relations defined on different Cartesian products can be combined with each other in a number of different ways through composition. Composition is a bridge that allows connecting one product space to another, provided that there is a common boundary. Given two fuzzy relations, one in X to Y and another on Y to Z, which can be associated directly the elements of X and Z, the set Y is the common boundary. Composition results in a new relation that directly relates X to Z. Extensive research has suggested additional definitions for fuzzy set operations, such as max-min composition, max-star composition, max product composition and max average composition. The common composition applied to engineering related problems is max-min composition.

Fuzzy sets

The concept of a Fuzzy set is fundamental to mathematics. However, our own language is the supreme expression of sets. For example, car indicates the set of cars. When we say a car, we mean one out of the set of cars.

Let X be a classical (crisp) set and x an element. Then the element x either belongs to X (x ∈ X) or does not belong to X (x ∉ X). That is, classical set theory imposes a sharp boundary on this set and gives each member of the set the value of 1, and all members that are not within the set a value of 0. This is known as the principle of dichotomy. Let us now dispute this principle. Consider the following classical paradoxes of logic.

- Pythagorean School (400 BC):
  Question: Does the Cretan philosopher tell the truth when he asserts that 'All Cretans always lie'?
  Boolean logic: This assertion contains a contradiction.
  Fuzzy logic: The philosopher does and does not tell the truth!

- Russell's Paradox:
  The barber of a village gives a haircut only to those who do not cut their hair themselves.
  Question: Who cuts the barber’s hair?
  Boolean logic: This assertion contains a contradiction.
  Fuzzy logic: The barber cuts and doesn’t cut his own hair!
Crisp set theory is governed by a logic that uses one of only two values: true or false. This logic cannot represent vague concepts, and therefore fails to give the answers on the paradoxes. The basic idea of the fuzzy set theory is that an element belongs to a fuzzy set with a certain degree of membership. Thus, a proposition is not either true or false, but may be partly true (or partly false) to any degree. This degree is usually taken as a real number in the interval $[0, 1]$.

**MAX-MIN Composition**

If $R$ is a fuzzy relation from $X$ to $Y$, and $S$ is a fuzzy relation from $Y$ to $Z$, the composition of $R$ and $S$ is a fuzzy relation that is described by the following membership function:

$$
\mu_{RoS}(X_i, Z_k) = \max\{\min[\mu_R(X_j, Y_i), \mu_S(Y_j, Z_k)]\}
$$

The above equation basically evaluates a fuzzy relation between the fuzzy subsets $X$ and $Z$ using the fuzzy relations of $X$ and $Z$ to the common fuzzy subset $Y$.

The goal in the composition is to compute grades of membership of pairs $(x, z)$ in the composed relation namely; $\mu(x, z)$. Composition is very important for inference procedures used in the linguistic description and is explicitly used in this project.

The activity data is estimated for each activity and over thirty factors have been identified duly consulting various experts from construction industry. The fuzzy concepts are then applied to model the uncertainty associated with time for obtaining realistic solutions. Construction projects are complex and consist of large number of operations. Each operation requires certain amount of resources which induce time, labor, material and money. Hence, there is a vast scope for application of linear programming problems. Optimum duration can be evaluated with the use of linear programming as the objective of the problem and the resource constraint can be expressed as mathematical functions. Linear programming techniques can be effectively used to make optimal utilization of resources.
An Example of fuzzy sets

The classical example in the fuzzy set theory is *tall men*. The elements of the fuzzy set ‘tall men’ are all men, but their degrees of membership depend on their height, as shown in Table 1. Suppose, for example, Mark at 205 cm tall is given a degree of 1, and Peter at 152cm is given a degree of 0. All men of intermediate height have intermediate degrees. They are partly tall. Obviously, different people may have different views as to whether a given man should be considered as tall. However, our candidates for *tall men* could have the memberships presented in Table 1.

It can be seen that the crisp set asks the question, ‘Is the man tall?’ and draws a line at, say, 180cm. *Tall men* are above this height and *not tall men* below. In contrast, the fuzzy set asks, ‘How tall is the man?’ The answer is the partial membership in the fuzzy set, for example, Tom is 0.82 tall.

A fuzzy set is capable of providing a graceful transition across a boundary, as shown in Figure 3. We might consider a few other sets such as ‘very short men’, ‘short men’, ‘average men’ and ‘very tall men’.

In Figure 3 the horizontal axis represents the universe of discourse – the range of all possible values applicable to a chosen variable. In our case, the variable is the human height. According to this representation, the universe of men’s heights consists of all tall men. However, there is often room for
Fuzzy logic integration into Project Management & Planning

<table>
<thead>
<tr>
<th>Name</th>
<th>Height, cm</th>
<th>Degree of membership</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Crisp</td>
</tr>
<tr>
<td>Chris</td>
<td>208</td>
<td>1</td>
</tr>
<tr>
<td>Mark</td>
<td>205</td>
<td>1</td>
</tr>
<tr>
<td>John</td>
<td>198</td>
<td>1</td>
</tr>
<tr>
<td>Tom</td>
<td>181</td>
<td>1</td>
</tr>
<tr>
<td>David</td>
<td>179</td>
<td>0</td>
</tr>
<tr>
<td>Mike</td>
<td>172</td>
<td>0</td>
</tr>
<tr>
<td>Bob</td>
<td>167</td>
<td>0</td>
</tr>
<tr>
<td>Steven</td>
<td>158</td>
<td>0</td>
</tr>
<tr>
<td>Bill</td>
<td>155</td>
<td>0</td>
</tr>
<tr>
<td>Peter</td>
<td>152</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1: Degree of membership of ‘tall men’

![Diagram](image1.png)

(a) Crisp Set (a), (b) Fuzzy sets of “tall men”
Discretion, since the context of the universe may vary. For example, the set of ‘tall men’ might be part of the universe of human heights or mammal heights, or even all animal heights.

The vertical axis in Figure 4 represents the membership value of the fuzzy set. In our case, the fuzzy set of ‘tall men’ maps height values into corresponding membership values. As can be seen from Figure 4, David who is 179cm tall, which is just 2cm less than Tom, no longer suddenly becomes a not tall (or short) man (as he would in crisp sets). Now David and other men are gradually removed from the set of ‘tall men’ according to the decrease of their heights.

**Fuzzy Set Theory**

**What is a fuzzy set?**

A fuzzy set can be simply defined as a set with fuzzy boundaries.

Let $X$ be the universe of discourse and its elements be denoted as $x$. In classical set theory, crisp set $A$ of $X$ is defined as function $f_A(x)$ called the characteristic function of $A$

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

Where:

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

This set maps universe $X$ to a set of two elements. For any element $x$ of universe $X$, characteristic function $f_A(x)$ is equal to 1 if $x$ is an element of set $A$, and is equal to 0 if $x$ is not an element of $A$.

In the fuzzy theory, fuzzy set $A$ of universe $X$ is defined by function $\mu_A(x)$ called the membership function of set $A$. 


\[ \mu_A(x) = X \to [0,1]. \]

Where,

\[ \mu_A(x) = 1 \text{ if } x \text{ is totally in A}; \]
\[ \mu_A(x) = 0 \text{ if } x \text{ is not in A}; \]
\[ 0 < \mu_A(x) < 1 \text{ if } x \text{ is partly in A}. \]

\[ \mu_A(x) = \begin{cases} 1, & \text{if } x \in A. \\ 0, & \text{if } x \not\in A. \end{cases} \]

This set allows a continuum of possible choices. For any element \( x \) of universe \( X \), membership function \( \mu_A(x) \) equals the degree to which \( x \) is an element of set \( A \). This degree, a value between 0 and 1, represents the degree of membership, also called membership value, of element \( x \) in set \( A \). From, above equation we can only expect either being a member or non-member, but if \( X \) is allowed to take a range between 0 and 1, it is called **fuzzy set**.

Let us take an example of this dissertation, we have the fuzzy input variable “Site Organization”. As we have categorized every fuzzy variable into V.Poor, Poor, medium, High, Very High. We can write a fuzzy membership function for Very Poor as follows since we have taken Trapezoidal membership function. Since trapezoidal membership function has only 4 values to be give which are \( a, b, c, d \).

**Very Poor Site Org, A** = \[ \begin{bmatrix} 1 & 0.80 & 0.55 & 0 \\ a & b & c & d \end{bmatrix} \]

**Poor Site Org, B** = \[ \begin{bmatrix} 0.5 & 0.80 & 1 & 0.5 \\ a & b & c & d \end{bmatrix} \]

**Medium Site Org, C** = \[ \begin{bmatrix} 0.40 & 1 & 0.25 \\ a & b & c & d \end{bmatrix} \]

**High Site Org, D** = \[ \begin{bmatrix} 0.60 & 0.80 & 1 & 0.65 \\ a & b & c & d \end{bmatrix} \]
Very High Site Org, \( E = \left[ \frac{0.80}{a}, \frac{0.95}{b}, \frac{1}{c}, \frac{1}{d} \right] \)

In general, any subset \( A \) may be represented by \( m \) discrete values (or continuous intervals) of \( x \) together with membership values (or continuous membership functions). But since we have chosen trapezoidal membership function (trapmf) in Fuzzy Tool box since giving 4 values \( a,b,c,d \). would suffice., as follows:

\[
A = \left[ \frac{\mu_A(a)}{a}, \frac{\mu_A(b)}{b}, \frac{\mu_A(c)}{c}, \frac{\mu_A(d)}{d} \right];
\]

**Fuzzy operators**

The union, \( U \), of fuzzy subsets \( A \) and \( B \) of a universe, \( X \), corresponds to the connective "or," and its membership function is

\[
\mu_{A \cup B}(x) = \max [\mu_A(x), \mu_B(x)]
\]

The intersection, \( \cap \), of fuzzy subsets \( A \) and \( B \) correspond to the connective "and" and its membership function is

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

The "Complement" of a fuzzy subset \( A \) is denoted by \( A^C \), and its membership function is

\[
\mu_{A^C}(x) = 1 - \mu_A(x)
\]
Historical Background Review on Fuzzy Logic

In fact, “Fuzzy” is widely accepted as a branch of modern mathematics when compared with traditional mathematics although its history has just over 40 years (Zimmermann 2001). Its origin can be tracked back when Zadeh [14] wrote a seminal paper in 1965 in which he introduced fuzzy sets (sets with uncertain boundaries). Fuzzy sets are typically able to represent linguistic terms, for instance, warm, hot, high, and low. After 1994, “Fuzzy Techniques” are continuously applied to the research area of construction management. The new Millennium 2000 starts with over 30,000 publications in the area of “computational intelligence” or “soft computing” (Zimmermann 2001). These are terms which have been coined during the first half of the 1990s, when Fuzzy Set, Neural Networks and evolutionary computing joined forces because they felt that there were strong synergies between these areas. Zimmermann (2001) further stated that evolutionary computing has its strength in optimization while neural nets are particularly strong in pattern recognition and automatic learning. Fuzzy Set/Fuzzy Logic has its strength in modelling, interfacing humans with computers and modelling certain uncertainties. The USA, Japan, and Mainland China are probably the most important nations to develop Fuzzy Theories and Fuzzy Technology.

Fuzzy Set Applications in Performance

Bilal M. Ayyub and Achintya Haldar [1] made a significant research on fuzzy concepts their thesis was focused on application of Zadeh’s Fuzzy set theory. They translated some of the linguistic variables in to mathematical measures using fuzzy set theory and a problem related to construction management, i.e., estimation of duration of an activity have been solved using this theory. In order to implement the fuzzy set theory, various membership functions have been estimated using the judgment of experts. In this thesis the notions of fuzzy set theory were explained using examples. Finally, an example have been solved by taking weather (good, medium, bad) and Labor Skills (large, medium, small) as linguistic variables and mean (indicates the expected value of the parameter ex: duration), standard deviation (scatter of the data from mean value) and co-variance (measure of uncertainty) have been reported. It was observed here that the proposed technique is not sensitive to small variations in the membership values. This is a very desirable property. However, the method is sensitive to the choice of the fuzzy relation between the consequences and the duration of an activity. This relation could be modified with more applications in various projects. The uncertainty in the
fuzzy relations needs to be transformed in such a way that it can be used with other sources of uncertainties obtained by using classical statistical methods. A new method is proposed for the problem under consideration that maximizes the product of the sum of the membership associations for a certain frequency of occurrence and the corresponding frequency of occurrence. This technique is proposed is superior to other available methods since it utilizes all the available information. One of the main advantages of the proposed technique is that it can be easily implemented in existing computer programs for project scheduling. Lorterapong and Moselhi (1996) presented a new network scheduling method based on Fuzzy Set Theory to estimate the durations of construction activities. The proposed method incorporated a number of new techniques that facilitate:

1. The representation of imprecise activity durations; 
2. The calculation of scheduling parameters; and 
3. The interpretation of the fuzzy results generated.

Knight and Fayek [9] used fuzzy logic to predict potential cost overruns on engineering design projects. Which assisted them in assessing the amount of possible risk on a project and the likelihood of making a profit on the job. In particular, the research used fuzzy logic to model the relationships between the characteristics of a project and the potential risk events that may occur, and the associated cost overruns caused by combinations of the project characteristics and risk events. Kishk [8] developed a practical procedure to handle statistically significant data and expert evaluations within the same whole-life costing model calculation. The proposed model was implemented into a computational algorithm using probability distribution function or fuzzy numbers in a manner consistent with the nature of the information in hand.

Bonnal et al. (2004) pointed out that stochastic project-scheduling approaches are used by many project schedulers. However, the axiom associated with the theory of probabilities is always incompatible with decision making situations. They analyzed that fuzzy project scheduling approaches are most suited to fuzzy situations, and they proposed a framework, which was based on fuzzy sets, to address the resource-constrained fuzzy project-scheduling problem.

Oliveros and Fayek [11] developed a fuzzy logic model that integrates daily site reporting of activity progress and delays, with a schedule updating and forecasting system for construction project monitoring and control. This model can help with the analysis of the effects of delays on a project’s completion date because the use of fuzzy logic allows linguistic and subjective
assessments to be made, and thereby suiting the actual practices commonly used in the construction industry.

**Fuzzy Set Applications in Evaluation/Assessment**

*Kumar et al. (2000)* asserted that assessment of working capital requirement in construction projects was subjective and based on uncertainty. There is an inherent difficulty in the classical approach to assess the effect of qualitative factors for the evaluation of working capital requirement. *Kumar et al. (2000)* developed a methodology to incorporate linguistic variables into workable mathematical propositions for the assessment of working capital using Fuzzy Set Theory after considering the uncertainty associated with many of the project resource variables. *Tah and Carr (2000)* used a hierarchical risk breakdown structure representation to develop a formal model for qualitative risk assessment. To do so, a common language for describing risks was first presented which included terms for quantifying likelihoods and impacts in order to achieve consistent quantification. The relationships between risk factors, risks, and their consequences are represented on cause and effect diagrams through the application of fuzzy logic, and the concepts of fuzzy association and fuzzy composition. *Shang et al. (2005)* developed an innovative risk assessment approach for distributing project teams. The approach was based on a client and server architecture and used fuzzy logic and web-based technology. It was found that the use of a web-based risk assessment system for distributing project team members had major benefits in terms of use of linguistic terms to express risk assessment, ease of communication, ease of maintenance, and greater consistency. *Choi et al. (2004)* presented a risk assessment methodology for underground construction projects, in which they developed a formalized procedure and associated tools to evaluate and manage the risks involved in underground construction. The main tool of the proposed risk assessment methodology is the risk analysis software and this software is built upon an Uncertainty model based on fuzzy set. In more details, the fuzzy-based uncertainty model was designed to consider the uncertainty range that represented the degree of uncertainties involved in both probabilistic parameter estimates and subjective judgments. *Sánchez et al. (2005)* developed a fuzzy set-based approach for representing and synthesizing information about the various kinds of variables involved in the evaluation of a project’s value in the context of construction in civil engineering. This methodology for summarizing and normalizing values aims at contributing to decision making analysis in the context of multiple criteria evaluation and group decision making. *Holt (1998)* pointed out that
the need for judicious construction contractor selection is increasing. For this reason, he reviewed a number of contractor evaluation and selection modelling methods. The methods include:

(1) Bespoke approaches; (2) Multi-attribute analysis; (3) Multi-attribute utility theory; (4) Cluster analysis; (5) Multiple regression; (6) Fuzzy Set Theory; and (7) Multivariate discriminant analysis. The merits and demerits as well as previous and future applications of each methodology were discussed.

Fuzzy Set Applications in Modelling

Okoroh and Torrance [10] developed a Subcontractor Selection and Appointment Model for analyzing the subcontractor’s risk elements in construction refurbishment projects. The model is based on the use of Fuzzy Set Theory with the fuzzy set representing the overall weighted average rating of refurbishment contractors’ criterion for the selection of subcontractors. It was believed that the implementation of the model in linguistic terms enables the user to interact with the system in a very friendly manner using natural language expressions. Wei and Wang (2004) developed a comprehensive framework, which combined objective data obtained both from external professional report and subjective data derived from internal interviews with vendors, to select an appropriate Enterprise Resource Planning (ERP) project. By doing so, a hierarchical attribute structure was suggested to evaluate the ERP projects systematically. In addition, Fuzzy Set Theory was adopted to aggregate the linguistic evaluation descriptions and weights. Leu et al. (2001) proposed a new optimal construction time-cost trade-off model in which the effects of both uncertain activity duration and time-cost trade-off were taken into consideration. Fuzzy Set Theory was adopted to model the uncertainties of activity durations. A searching technique using genetic algorithm (GA) was used to search for the optimal construction project time-cost trade-off profiles under different risk levels. This method provided an insight into the optimal balance of time and cost under various risk levels as defined by decision makers.
3.1 FLIRT Methodology

This section summarizes adapted “FLIRT” methodology for this thesis work and whole approach of work is penned with a good notion to get clear idea of this dissertation showcased as follows.

- Taking up a case study, and assimilating the data of case study.
- Planning for a Network Diagram.
- Applying CPM to a chosen case study.
- “FLIRT” methodology integration to the case study.

Here, let us consider an assumption case, which is casting of floor. Now, to get clear idea of different types of activities involved in the particular work, work is broken down into small parts of activities. Now, proceeding to further part of the methodology.

**Casting of floor:**

<table>
<thead>
<tr>
<th>Activities</th>
<th>Duration of activities in days</th>
<th>Interdependencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttering</td>
<td>2</td>
<td>--</td>
</tr>
<tr>
<td>Bar bending schedule</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>Reinforcement of Beams, Columns &amp; Slab.</td>
<td>3</td>
<td>A,B</td>
</tr>
<tr>
<td>Inspection</td>
<td>1</td>
<td>C</td>
</tr>
<tr>
<td>RMC Casting</td>
<td>1</td>
<td>D</td>
</tr>
<tr>
<td>Curing</td>
<td>2</td>
<td>E</td>
</tr>
</tbody>
</table>

Table 2: Table showing list of activities and corresponding duration and interdependencies
So from the above calculations we can observe that the critical path obtained is A-C-D-E-F. The critical duration 9 days.

As mentioned earlier, qualitative factors or linguistic variables (terms) are routinely used in construction project scheduling. These linguistic measures add to the overall uncertainty in the final outcome of any decision process. In order to incorporate these uncertainties in the analysis, the linguistic terms (or variables) need to be translated into mathematical measures.

A linguistic variable is defined as a variable, the values of which are words, phrases, or sentences in a given language. For example, Site Organization, Labor Skills and Quality of equipment used can be considered as linguistic variables. The values of these considered variables can be classified into 5 types: Very Poor, Poor, Medium, High, and Very High. These are not clearly defined but are meaningful classifications.

1. Very low – [VL]
2. Low – [L]
3. Medium – [M]
4. High – [H]
5. Very High – [VH]
So all the activities in the project will be standardized to any of the categories mentioned above w.r.t qualitative factors we have considered earlier.

- The values of membership function may also change with respect to activity.
- The results obtained from the simulation of different graphs are thus interpreted and modified as per requirements of duration change.
- Thus the interpreted and modified results are showcased.

![Figure 5: Categorization of membership function](image-url)
3.2 *Introduction to fuzzy tool box in MATLAB®*

MATLAB® is an important platform for solving many mathematical and programming problems faced in everyday life. Since its existence, in late 1970's it has gained enormous reputation. Which was from included people from diverse background, all around the world.

Now, let us consider three important Fuzzy variables/qualitative factors which have been chosen. And are believed to have an effect on the duration of activities performed in construction project.

The Linguistic variables qualitative factors are:

- Site Organization
- Labor Skills
- Equipment Used

With the help of Fuzzy Tool Box in MATLAB® the effect of duration on activities will be quantified. Firstly, in MATLAB® the inputs are given and then the required output are given. Then rules are to be decided for Fuzzy inference system.

**Inputs & Outputs**

Fuzzy Logic Designer in fuzzy logic tool box requires three necessary categories to be defined by the user which are

I. Inputs  
II. Outputs  
III. Rule Base

Here, the images which are showcased below are of inputs and outputs in Fuzzy Logic Designer. The necessary variables for inputs and outputs are chosen and defined by user based on his experience and necessary requirements to generate results.
Inputs

What are inputs in Fuzzy Tool Box?

Inputs are fuzzy variables in a way where user believe they might have profound influence on the duration of work or activity. Fuzzy variables inputs are decided for a particular fuzzy system based on the experience and knowledge of experts. We can choose N number of inputs, though they depend on the space required on hard drive. Mostly, the fuzzy inputs which are been chosen will or may be have relation with other Fuzzy input variables.

Output/s

What is an output?

Output is a crisp result which is obtained after undergoing the process of

1. Pre-processing
2. Fuzzification
3. Rule Base
4. Inference Engine
5. Defuzzification

The output can be decided by user to obtain required result after the whole inference process, which can be desired result of whole designed fuzzy system.
A Pictorial view of Fuzzy Inference System in MATLAB®

Figure 6: Graphical User interface representation
Fuzzy logic integration into Project Management & Planning

Inputs = Fuzzy variables

Output = Crisp result
**Membership function editor**

The difference between traditional set and fuzzy set theory lies in the degree of membership which elements may possess in a set. Traditional set theory dictates that an element is either a member of a set or it is not; Its membership values are defined as 1 or 0. In fuzzy set theory this membership value can take any real value from 0 to 1 and this value defines the degree of membership of a given set. A membership function is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The only condition a membership function must really satisfy is that it must very between 0 and 1.

Here, are some images shown to present the membership function editor to for every Input factor and Output factor. Every input and output has a range from [0 1]. Which are divided into 5 different categories as mentioned in earlier section, then the effect of these three qualitative factors are shown using rule viewer in later section.

Fuzzy toolbox in MATLAB® is preloaded with 11 different types of functions which have their own specialties and simplicities.

1. Triangular membership function.
2. Trapezoidal membership function.
3. Gaussian membership function.
4. Sigmoidal, two sigmoidal and product of two sigmoidal.
5. Z shaped, PI shaped, S shaped.

But in this case study, the membership functions of the linguistic terms are characterized by Trapezoidal fuzzy numbers. Trapezoidal fuzzy numbers are very often use in applications such as managerial decision making, and we found it very apt to our study.
A trapezoidal membership function is decided by four parameters \(\{a,b,c,d\}\) as follows:

\[
\text{trapezoid}(x; a, b, c, d) = \begin{cases} 
0, & \text{for } x \leq a. \\
\frac{x - a}{b - a}, & \text{for } a \leq x \leq b. \\
1, & \text{for } a \leq x \leq b. \\
\frac{d - x}{d - c}, & \text{for } c \leq x \leq d. \\
0, & \text{for } d \leq x.
\end{cases}
\]

Figure 7: Trapezoidal Membership Function.

The figure shown below is an example of Fuzzy sets representation in a universe of discourse, here the linguistic variable is height, and the linguistic values are short, medium, and tall as shown below. The general range of values will be in [0 1].

![Membership functions](image)

Figure 8: Example showing how the Fuzzy sets are represented in universe of discourse.

The figure shown below is an example of Multi Neural Network for condition state of cracking, in which we can see the aggregation of the antecedents and corresponding to consequents. Thus, generating an output.

![Multi Neural network](image)

Figure 9: An example of Multi Neural network for evaluating condition state of cracking.
Trapezoidal membership function. It has \([a, b, c, d]\).

Displays the range of membership function. General range would be \([0, 1]\).
Fuzzy logic integration into Project Management & Planning

Parameters for particular linguistic variables

Linguistic Variables
Fuzzy rule base

Fuzzy inference system has a section called rule editor, where necessary rules are set according to our requirements. We can set N number of rules depending on the inputs and linguistic variables chosen. Rule base is a part of fuzzy inference system which is the most important part of fuzzy logic designer, rules are added as per the required necessities it helps in producing results which we are expecting or to be solved[2, 13].

How to design a rule?

This is a procedure usually done systematically: for every combination of input sets of variables that may reasonably expected to occur in practice, the necessary output value is estimated by expert and a rule is written expressing the relation. This requires that the designer has sufficient knowledge on the whole project or the system he is designing for.

For adding a rule in the form of “if A and B and C, then D” with fuzzy logic, two definitions are needed to be defined. How connective “and” is modelled in fuzzy logic, and how implication “if…then” is modelled.

The “AND” operator in the fuzzy rule editor is modelled with fuzzy intersection (the min operator), and the “OR” operator is modelled with the union (the max operator) in fuzzy logic[12].
Every rule which has been added to the inference system has its own and unique output set. The weighting of a rule is associated with the output set. Every rule added in the inference system has an option to have its own weight put in for its influence on the output result.
Types of Defuzzification methods

Defuzzification is a process of producing a quantifiable result in fuzzy logic, for a given fuzzy sets and corresponding membership functions. There are different types of De-fuzzification methods in Mat Lab®. Which are:

I. Centroid
II. Bisector
III. Middle, Smallest and Largest of Maximum.

Centroid

Centroid defuzzification is a type of method where the result returns the center of area under the curve. If you think of the area as a plate of equal density, the centroid is the point along the x axis about which this shape would balance.

The practice, mathematical formula is given by:

\[ x^* = \frac{\sum_b \mu(x) \cdot x}{\sum_b \mu(x)} \]

![Figure 10: The Centre of Gravity Method of defuzzification](image-url)
The bisector is the vertical line that will divide the region into two sub-regions of equal area. It is sometimes, but not always coincident with the centroid line.

\[ \int_{\alpha}^{x^*} \mu_A(x) \, dx = \int_{x^*}^{\beta} \mu_A(x) \, dx \]

Where:

\[ \alpha = \min\{x/\, x \in X\}, \quad \text{and} \quad \beta = \max\{x/\, x \in X\} \]

Figure 11: The Bisector of Area (BOA) method of defuzzification
Middle, Smallest, and Largest of Maximum

MOM, SOM, and LOM stand for Middle, Smallest, and Largest of Maximum, respectively. These three methods key off the maximum value assumed by the aggregate membership function. In this example, because there is a plateau at the maximum value, they are distinct. If the aggregate membership function has a unique maximum, then MOM, SOM, and LOM all take on the same value.

![Diagram of Middle, Smallest, and Largest of Maximum]

For this particular case study we have chosen centroid defuzzification method, we believe that this method showcases the best possible result as we desire.

Rule viewer

Here, we have three inputs which are categorized into 5 linguistic variables. So, aggregation of each linguistic variable gives us 125 combination of rules with a consequent of output. As it is said earlier every rule has its unique set of result. By moving the cursor along the rule bars, we have a possibility to observe results for different scenarios we need. But creating 125 rules is not a good idea, taking expert’s advice and having a good idea on the situation prevailing can result in reducing and selecting particular rules which are apt for providing solution to our problem. In this case 10 rules are chosen for generating required results.
Here, the image which is being displayed below is where the three fuzzy variable inputs has its cursor at very poor and results for which is an output showcases that it has very negative impact on duration.

Here, the image being displayed below is where the three fuzzy variables inputs has its cursor at poor and results for which is an output showcases that it has very negative impact on duration.
The image displayed below is where the three fuzzy variables inputs has its cursor placed at medium/moderate and results for which is an output showcases that it has negative impact on duration.
The image displayed below, has its cursor placed at very high in terms of quality on the fuzzy input variables. And therefore result, which is an output showcases that these qualitative factors being on high terms of quality has very positive impact on duration. Where there will be a reduction of actual duration of the activity performed.

Since we have concluded the results. It was very interesting to know that there will be a decrease in activity duration, which is known by tuning cursor available in rules bar. So, it would be very interesting to try this adapted methodology for a real case study and find out the necessary results.
CHAPTER 4
Flirt Methodology

4 Application of “FLIRT” methodology to case study

In this following section a case study is being showcased on which we have been working on, as a part of thesis research study. And relevant “FLIRT” Methodology for case study is presented.

4.1 Case study

In this section, a case study is showcased which is a beach farm house is built in Surat – Gujrat, India. The name of the asset being Kabutarwala Farm house. According to data acquired from the company, it has been unveiled that construction of this particular project has been started on October 10\textsuperscript{th}, 2013 and handover of asset to the client was on August 30\textsuperscript{th}, 2014.

<table>
<thead>
<tr>
<th>Name of Project: Kabutarwala farm house</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site area: 2251 Sq. Meters</td>
</tr>
<tr>
<td>Built up area: 494 Sq. Meters</td>
</tr>
<tr>
<td>Address: Kabutarwala farm house, Dumas Beach, Surat-Gujarat, India</td>
</tr>
</tbody>
</table>

Table 3: Project Information
4.2 Problem Description

Here, a construction asset which is a beach farm house is been considered in this dissertation of “Fuzzy Logic integration into Project Management”. The total site area of the asset is 2251 Mts$^2$ and Built up/Constructed area is 494 Mts$^2$.

Using the data available, Project is broken down into 14 activities. Which are as follows:

<table>
<thead>
<tr>
<th>Serial. No.</th>
<th>Activity Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Site Clearance &amp; Mobilization</td>
</tr>
<tr>
<td>2</td>
<td>Excavation</td>
</tr>
<tr>
<td>3</td>
<td>Foundation</td>
</tr>
<tr>
<td>4</td>
<td>Casting of Floor</td>
</tr>
<tr>
<td>5</td>
<td>Structural Frame Work</td>
</tr>
<tr>
<td>6</td>
<td>Construction of Wall</td>
</tr>
<tr>
<td>7</td>
<td>Roofing( Fabrication of Roof &amp; False Ceiling)</td>
</tr>
<tr>
<td>8</td>
<td>Plastering</td>
</tr>
<tr>
<td>9</td>
<td>Floor Finish</td>
</tr>
<tr>
<td>10</td>
<td>Electric Work &amp; Plumbing</td>
</tr>
<tr>
<td>11</td>
<td>Carpentry</td>
</tr>
<tr>
<td>12</td>
<td>Painting</td>
</tr>
<tr>
<td>13</td>
<td>Landscaping</td>
</tr>
<tr>
<td>14</td>
<td>Finishing Works &amp; Hand Over</td>
</tr>
</tbody>
</table>

Table 4: Activity Breakdown
And the duration for particular activity are assigned accordingly:

<table>
<thead>
<tr>
<th>Serial. No.</th>
<th>Activity Name</th>
<th>Duration (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Site Clearance &amp; Mobilization</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Excavation</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Foundation</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>Casting of Floor</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Structural Frame Work</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>Construction of Wall</td>
<td>45</td>
</tr>
<tr>
<td>7</td>
<td>Roofing( Fabrication of Roof &amp; False Ceiling)</td>
<td>25</td>
</tr>
<tr>
<td>8</td>
<td>Plastering</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>Floor Finish</td>
<td>21</td>
</tr>
<tr>
<td>10</td>
<td>Electric Work &amp; Plumbing</td>
<td>35</td>
</tr>
<tr>
<td>11</td>
<td>Carpentry</td>
<td>45</td>
</tr>
<tr>
<td>12</td>
<td>Painting</td>
<td>25</td>
</tr>
<tr>
<td>13</td>
<td>Landscaping</td>
<td>45</td>
</tr>
<tr>
<td>14</td>
<td>Finishing Works &amp; Hand Over</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 5: Duration of Breakdown activities.

Necessary resources are allocated using Microsoft Project, and then Critical Path Method is used for calculation of minimum duration by assigning interdependencies.
<table>
<thead>
<tr>
<th>Activity Name</th>
<th>Duration (Days)</th>
<th>Nodes</th>
<th>Identification</th>
<th>Interdependencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Clearance &amp; Mobilization</td>
<td>7</td>
<td>1</td>
<td>A</td>
<td>_</td>
</tr>
<tr>
<td>Excavation</td>
<td>10</td>
<td>2</td>
<td>B</td>
<td>_</td>
</tr>
<tr>
<td>Foundation</td>
<td>15</td>
<td>3</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>Casting of Floor</td>
<td>6</td>
<td>4</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>Structural Frame Work</td>
<td>25</td>
<td>5</td>
<td>E</td>
<td>D</td>
</tr>
<tr>
<td>Construction of Wall</td>
<td>45</td>
<td>6</td>
<td>F</td>
<td>E</td>
</tr>
<tr>
<td>Roofing( Fabrication of Roof &amp; False Ceiling)</td>
<td>25</td>
<td>7</td>
<td>G</td>
<td>F</td>
</tr>
<tr>
<td>Plastering</td>
<td>3</td>
<td>8</td>
<td>H</td>
<td>G</td>
</tr>
<tr>
<td>Floor Finish</td>
<td>21</td>
<td>9</td>
<td>I</td>
<td>G</td>
</tr>
<tr>
<td>Electric Work &amp; Plumbing</td>
<td>35</td>
<td>10</td>
<td>J</td>
<td>G</td>
</tr>
<tr>
<td>Carpentry</td>
<td>45</td>
<td>11</td>
<td>K</td>
<td>H,I,J</td>
</tr>
<tr>
<td>Painting</td>
<td>25</td>
<td>12</td>
<td>L</td>
<td>K</td>
</tr>
<tr>
<td>Landscaping</td>
<td>45</td>
<td>13</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Finishing Works &amp; Hand Over</td>
<td>15</td>
<td>14</td>
<td>N</td>
<td>M</td>
</tr>
</tbody>
</table>

Table 6: Interdependencies of activities.

Thus by assigning duration, nodes and interdependencies, we now have the province to model a network diagram and compute CPM calculations.

Now, the network diagram is modelled according to the interdependencies facilitated in above table.
As per the assigned interdependencies we have modelled a network diagram. Now the CPM calculation is carried out in the process to get minimum duration of the path.

According to CPM calculation the project can’t be finished before 291 days.
4.3 *Fuzzy tool box in MAT LAB®*

The whole construction of the project involves 14 activities, for which the fuzzy simulation has to be done.

![Fuzzy Logic design for the construction asset case study](image)

As shown in the above image, inputs are chosen to be Site Organization, Labor skills and Equipment Used which are considered to be qualitative factors. These fuzzy input variables are categorized into 5 linguistic variables which are Very poor, poor, Moderate, High, Very High as described in earlier chapter.

So, from here on the experts advice and self-experience will play a major role in producing results which we can confide on. As every activity has its own nature of diversity in work. So, preferences for fuzzy input variables may be different for each activity which have taken place within the project.
<table>
<thead>
<tr>
<th>Activities involved in project</th>
<th>Preferences of Fuzzy variables in accordance to activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site clearance &amp; Contractor Mobilization</td>
<td>Site Org</td>
</tr>
<tr>
<td>Excavation</td>
<td>Labor Skills</td>
</tr>
<tr>
<td>Foundation</td>
<td>Labor Skills</td>
</tr>
<tr>
<td>Casting of Floor</td>
<td>Labor Skills</td>
</tr>
<tr>
<td>Structural Frame Work</td>
<td>Labor Skills</td>
</tr>
<tr>
<td>Construction of Walls</td>
<td>Labor Skills</td>
</tr>
<tr>
<td>Roofing</td>
<td>Labor Skills</td>
</tr>
<tr>
<td>Plastering</td>
<td>Labor Skills</td>
</tr>
<tr>
<td>Floor Finish</td>
<td>Labor Skills</td>
</tr>
<tr>
<td>Electric &amp; Plumbing work</td>
<td>Labor Skills</td>
</tr>
<tr>
<td>Carpentry</td>
<td>Labor Skills</td>
</tr>
<tr>
<td>Painting</td>
<td>Labor Skills</td>
</tr>
<tr>
<td>Landscaping</td>
<td>Labor Skills</td>
</tr>
<tr>
<td>Finishing works &amp; Hand over</td>
<td>Site Org</td>
</tr>
</tbody>
</table>

Table 7: Table of Preferences
As mentioned in above table, we have clearly chosen the importance of fuzzy input variables according to activity of work involved. Thus we have a clear idea to represent a membership function precisely to derive particular solution.

For this particular case study we have chosen a trapezoidal membership function. And opted for centroid defuzzification method. And the Fuzzy inference system which is being used is Mamdani Inference system.

**Foundation**

This activity has been completed in 15 days as of data acquired from the Company. Now let us make a fuzzy design system so that we can test the results and the fuzzy variables influence on the Duration of the activity.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Inputs</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation</td>
<td>Site Organization</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Labor Skills</td>
<td>Duration reduced or Increased</td>
</tr>
<tr>
<td></td>
<td>Equipment Used</td>
<td></td>
</tr>
</tbody>
</table>
Observations & output:

Image which is displayed below is Rule Viewer in Fuzzy Tool Box, which is an output result generated for the activity named “Foundation” included in the project.

When the cursor is placed in the range of V.Poor category in input fuzzy variables, then the generated output results shows that these factors have nearly 90% influence on the duration of the activity which has negative impact on duration.
When the cursor is placed in the range of Poor category of input fuzzy variables, then the generated output results shows that these factors have nearly 70% influence on the duration of the activity which has negative impact on duration.
When the cursor is placed in the range of Medium category in input fuzzy variables, then the generated output results shows that these factors have nearly no great influence on the duration of the activity either in Positive or negative way.
When the cursor is placed in the range of High category in input fuzzy variables, then the generated output results shows that these factors have nearly 25-30% influence on the duration of the activity which is positive impact on duration.
When the cursor is placed in the range of V.High category in input fuzzy variables, then the generated output results shows that these factors have nearly 0% influence on the duration of the activity which has positive impact on duration.

After simulation, it has been confirmed that the prevailing situations in the site was nearly very low in terms of Site Organization, Labor Skills, and Equipment Used. Due to these factors having negative influence on duration, the activity duration was Increased/Prolonged. If the fuzzy inputs or the qualitative factors were at least in moderate standardization the activity would have been completed much before than as in real case.
4.4 Rescaling the parameters

In this section. We are trying to rescale the range of the parameters in accordance to expert's idea and real time and data available. Instead of opting for classical range of [0 1] in fuzzy sets. We are rescaling the parameters range so that we can really generate results which can be easily comprehended.

Considering, activity “Construction of Foundation” in the case study. Let us rescale the parameters of the Fuzzy input variables. So that we can pull out the exact data needed which can easily be intercepted with real world.

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Organization</td>
<td>[0 1]</td>
</tr>
<tr>
<td>Labor Skills</td>
<td>[0 9] years</td>
</tr>
<tr>
<td>Equipment Used</td>
<td>[0 1]</td>
</tr>
<tr>
<td>Impact on Duration</td>
<td>[9 18] Days</td>
</tr>
</tbody>
</table>

Table 8: Rescaling the range of Fuzzy Input Variables
Description about range of parameters:

This is a process where the experience of the professionals are in need. The experts in the field of fuzzy logic and experts in the field of construction are needed for the guidance to rescale the parameters in order to generate a result which everyone can consider and believe in.

After rescaling the parameters range while taking expert’s advice, we have produced results which can be intercepted and can be understood well with the real world. From the defuzzification process the results we have are very appealing. It can be observed that if the situations prevailing in the project surrounding were improved to higher standards, then the outcome would have been different in terms of duration of completion of the activity.

According to Fuzzy logic Analysis results, we can get to a conclusion that the Site organization, Labor Skills & Equipment used were falling under the category of Poor. Therefore, it can be said that fuzzy variables must have had very much influence on the duration of the activity in negative way.
When the cursor is placed in the range of V.Poor category in input fuzzy variables, then the generated output results show that these factors have influence on the duration of the activity which is represented in the rule viewer. As we have the result which matches the real time finish of activity duration which is 15 days. According to this facility we can conclude that the quality or the range of Site Org, Labor Skills, Quality of Equipment used were falling in the category of Poor. Thus we can also standardize every activity included in the project.
Now, let’s see what happen when cursor is moved to higher category which is medium/moderate here. We can observe from the image below that when the cursor is moved to higher category there was a positive influence on duration due these factors, and thus reduced the activity duration to 13.5 days.
When cursor is moved to higher category which is “High”?

We can observe from the image below that when the cursor is moved to higher category there was a positive influence on duration due these factors, and thus reduced the activity duration to 10.4 days.
When cursor is moved to further higher category which is “Very High”?  

We can observe from the image showcased below that when the cursor is moved to higher category there was a positive influence on duration due these factors, and thus reducing the activity duration to 9 days.
4.5 Results & Discussion

When every activity involved in the project was analyzed in accordance to the adapted methodology, it’s been found that all activities were in the quality range showcased in the table below.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Site organization</th>
<th>Labor Skills</th>
<th>Quality of Equipment used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site clearance &amp; Mobilization</td>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>Excavation</td>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>Foundation</td>
<td>LOW</td>
<td>MEDIUM</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>Casting of Floor</td>
<td>LOW</td>
<td>MEDIUM</td>
<td>LOW</td>
</tr>
<tr>
<td>Structural Frame Work</td>
<td>MEDIUM</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>Construction of walls</td>
<td>LOW</td>
<td>LOW</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>Roofing</td>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>Plastering</td>
<td>MEDIUM</td>
<td>MEDIUM</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>Floor Finish</td>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>Electrical work &amp; Plumbing</td>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>Carpentry</td>
<td>VERY LOW</td>
<td>VERY LOW</td>
<td>VERY LOW</td>
</tr>
<tr>
<td>Painting</td>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>Landscaping</td>
<td>VERY LOW</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>Finishing &amp; Hand over</td>
<td>MEDIUM</td>
<td>LOW</td>
<td>LOW</td>
</tr>
</tbody>
</table>
4.6 Conclusions

- Major contribution from this thesis work can be said, that measuring the qualitative factors are very useful and also possible.
- And Fuzzy logic theory and Fuzzy logic tool box in MATLAB® provides a Fuzzy inference system to measure qualitative factors and convert them into mathematical output.
- Effect of these qualitative factors are very large on duration of a project, when we observe the results obtained.
- Qualitative factors are the fuzzy input variables which have their effect on whole project duration due to its existence.
- After working on this case study it can be said that, instead of maintaining higher quality in a particular department, it would be very wise and useful to maintain equal level of quality and skills in every department.
- Pre – Evaluation of the company in terms of these qualitative factors might result in greater good for a particular company.
4.7 **Interesting Future Work**

- Results obtained from above methodology are very interesting and captivating.
- It would be interesting to see, if this methodology could also include Qualitative and Quantitative analysis for further more realistic approach.
- Developing a necessary software for construction companies, which has capabilities of estimating the experience and which can measure employee’s skill, etc. This might largely benefit the construction sector in terms of improving and delivering the products.
- As Fuzzy logic has the capability to measure the qualitative factor, it would be a great improvement and asset, to confide on for the construction sector in near future.
5 Bibliography

6 Annexes

In this section, graphs will be presented in accordance to activities, and how the impact of duration is been changing in accordance to linguistic factors chosen.

**Site Clearance & Mobilization:**

Here we can see changes in accordance to quality of fuzzy variables inputs on the duration of the activity.

Site Clearence and Contractor mobilization - Impact on Duration

<table>
<thead>
<tr>
<th>Quality Level</th>
<th>Duration in Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standardized</td>
<td>7</td>
</tr>
<tr>
<td>Medium</td>
<td>6</td>
</tr>
<tr>
<td>High</td>
<td>5</td>
</tr>
<tr>
<td>Very High</td>
<td>4</td>
</tr>
</tbody>
</table>
Excavation:
This is duration impact of fuzzy variables on activity Excavation, according to below graph it can be noticed that, impact of duration on the activity very rapidly in accordance the quality of the work done in the activity. Similarly, necessary graphs are shown for every activity involved in the Project.

![Excavation - Impact on Duration](image)

Foundation:

![FOUNDATION - DURATION IMPACT](image)
Casting of Floor:

![Graph showing impact of casting of floors on duration]

Structural Frame Work:

![Graph showing impact of structural frame work on duration]
Construction of walls:

![Construction of Walls - Impact on Duration](chart)

Roofing:

![Roofing - Impact on Duration](chart)
Plastering:

![Plastering Impact on Duration Graph]

<table>
<thead>
<tr>
<th>Standardized</th>
<th>Medium</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2.5</td>
<td>2</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Floor Finish:

![Floor Finish Impact on Duration Graph]

<table>
<thead>
<tr>
<th>Standardized</th>
<th>Medium</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>19</td>
<td>15</td>
<td>14.5</td>
</tr>
</tbody>
</table>
Electrical & Plumbing:

![Graph showing impact of electrical and plumbing on duration]

Carpentry:

![Graph showing impact of carpentry on duration]
**Painting:**

<table>
<thead>
<tr>
<th>Impact Level</th>
<th>Duration in Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standardized</td>
<td>25</td>
</tr>
<tr>
<td>Medium</td>
<td>22.5</td>
</tr>
<tr>
<td>High</td>
<td>20</td>
</tr>
<tr>
<td>Very High</td>
<td>18</td>
</tr>
</tbody>
</table>

![Painting Impact on Duration Graph]

**Landscaping:**

<table>
<thead>
<tr>
<th>Impact Level</th>
<th>Duration in Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standardized</td>
<td>45</td>
</tr>
<tr>
<td>Medium</td>
<td>38</td>
</tr>
<tr>
<td>High</td>
<td>31</td>
</tr>
<tr>
<td>Very High</td>
<td>30</td>
</tr>
</tbody>
</table>

![Landscaping Impact on Duration Graph]
Finishing works and Handover:

<table>
<thead>
<tr>
<th>Impact Level</th>
<th>Duration in Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standardized</td>
<td>15</td>
</tr>
<tr>
<td>Medium</td>
<td>13</td>
</tr>
<tr>
<td>High</td>
<td>11</td>
</tr>
<tr>
<td>Very High</td>
<td>10</td>
</tr>
</tbody>
</table>