Performance Measurement, Forecasting and Optimization Models for Construction Projects

Seyedeh-Sara Fanaei

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By: Seyedeh-Sara Fanaei

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______________________________ Chair
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______________________________ External Examiner
Dr. A. Bouferguene

______________________________ External to Program
Dr. G. Gopakumar

______________________________ Examiner
Dr. S. H. Han

______________________________ Examiner
Dr. A. Bagchi

______________________________ Thesis Co-Supervisor
Dr. O. Moselhi

______________________________ Thesis Co-Supervisor
Dr. S. T. Alkass

Approved by ____

Dr. A. Bagchi, Chair, Department of Building, Civil & Environmental Engineering

June 11, 2019 ____

Dr. A. Asif, Dean, Gina Cody School of Engineering and Computer Science

ABSTRACT

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Seyedeh-Sara Fanaei, Ph.D.
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Performance evaluation facilitates tracking and controlling project progress. Project control consists of two main steps: measurement and decision-making. In the measurement step, key performance indicators (KPIs) are designed to evaluate a project's different aspects and are used as a thermometer to determine the health status of the project. In the decision-making step project performance is forecasted and analyzed to support needed management actions. While considerable work is available on the quantitative performance of projects, less attention is directed to qualitative performance. This research presents a framework for qualitative measurement, prediction, and optimization of construction project performance to enhance the progress reporting process and to support management in taking corrective actions, if needed. The framework has three newly developed models; KPI prediction model, performance indicator (PI) prediction model and performance optimization model (POM). The framework is developed for performance measurement, prediction, and optimization of construction projects based on six selected KPIs (cost, time, quality, safety, client satisfaction, and project team satisfaction). The selection is based on the results of a questionnaire and the literature review. Qualitative data of KPIs was collected from 119 construction projects and were then utilized in the development of the three models.

The first model maps the KPIs of three critical project stages to the whole project KPIs, based on soft computing methods. Three different soft computing techniques are studied for this purpose and their results are compared: the neuro-fuzzy technique, using Fuzzy C-means algorithm (FCM), and subtractive clustering, and artificial neural networks (ANN). The neuro-fuzzy model is developed for predicting the KPIs of the next stages of a project. The second model used the forecasted results of the first model to generate a single composite PI expressing the health status of the project. The relative weight of each KPI used in calculating the project PI is determined using the Analytic Hierarchy Process (AHP) and Genetic Algorithm (GA).

Performance Optimization Model (POM) is the third model. It is used for selecting suitable corrective actions considering the project status expressed by the six KPIs stated above. The developed model can be applied in the initial and middle stage of the project to assist owners in the improvement of the overall project PI and in the improvement of individual KPIs. Different possible modes are considered for project activities based on different ways, referee to here as modes, for resource allocation, execution methods, and/or choice of different materials. GA is applied to choose among different activity modes and optimize project performance using POM. The number of activities and their modes are flexible and do not have any limitations. MATLAB software is used for developing the models in this research. The developed framework and its three models are expected to assist owners and their agents in managing their project effectively.

Validation was conducted by using the data from 16 real projects to confirm the model's effectiveness and to compare the results of the soft computing techniques. These results indicate that a neuro-fuzzy technique using subtractive clustering performs better than both the neuro-fuzzy technique with FCM and ANN in predicting project KPIs. The automated framework employs a set of performance indicators to evaluate, predict, and optimize the construction project's performance, qualitatively. It applies different soft computing techniques and compares their results to choose the best technique. The developed framework can be used in construction projects to help decision-makers evaluate and improve the performance of their projects.

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To My Beloved Mother, Dear Father

and

My Husband

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF NOTATIONS

ACWP: Actual Cost of Work Performed

AHP: Analytical Hierarchy Process

ANN: Artificial Neural Network

BCWP: Budgeted Cost of Work Performed

BCWS: Budgeted Cost of Work Scheduled

BPI: Billing Performance Index

BRWP: Billed Revenue of Work Performed

BSC: Balanced Scorecard

CCG: Construction Cost Growth

CFRI: Construction Field Rework Index

CII: Construction Industry Institute

COV: Coefficient of Variation

CPI: Cost Performance Index

CPPSI: Contractor's Professional Profit Satisfaction Index

CSFs: Critical Success Factors

CSI: Client Satisfaction Index

DCC: Defense Construction Canada

DCF: Discounted Cash Fellow

DOD: US Department of Defense

EFQM: European Foundation for Quality Management

EOT: Extension of Time

EPI: Environmental Performance Index

ERWP: Earned Revenue of Work Performed

EVMS: Earned-Value Management System

FA-GRNN: Fuzzy Adaptive Generalized Regression Neural Network

FCM: Fuzzy C-Means

FIS: Fuzzy Inference System

GA: Genetic Algorithm

GP: Gap Performance Index

GPCS: Global Project Control Specification

IPI: Investment Performance Index

KPIs: Key Performance Indicators

LTI: Number of Lost Time Incidents to date

LWCIR: Lost Workday Case Incident Rate

MAE: Mean Absolute Error

MAPE: Mean Absolute Percentage Error

MF: Membership Function

MLR: Multiple Linear Regression

MPCS: Multidimensional Project Control System

MSE: Mean Square Error

PDM: Project Delivery Method

PERT: The Program Evaluation and Review Technique

PI: Performance Indicator

PMS: Project Measurement Systems

PPI: profitability performance index

PQR: Project Quarterback Rating

QPI: Quality Performance Index

R^2: Coefficient of Determination

RAE: Relative Absolute Error

RMSE: Root Mean Square Error

RRSE: Root Relative Square Error

SFI: Safety Performance Index

SPI: Schedule Performance Index

TQM: Total Quality Management

TSI: Team Satisfaction Index

WBS: Work Breakdown Structure

CHAPTER 1: INTRODUCTION

1.1 Problem Statement and Research Motivation

Project management uses project monitoring and control to evaluate how successful a project is, and if necessary, to determine which preventive or corrective action should be undertaken. Evaluating the performance facilitates monitoring a project's progress. It is accepted that one of the major causes of project failure is the lack of monitoring and control of construction operations.

In project monitoring and control, any deviation of a project from its baseline should be identified. Corrective actions can then be suggested to minimize the variance. The performance of the project should also be assessed by offering a comprehensive performance measurement system.

For the effective monitoring of a construction project's progress, different aspects of performance should be quantified and integrated. The motivation of this research is to develop a framework to manage various project performance attributes by using different Key Performance Indicators (KPIs). This framework helps to monitor and control construction operations by forecasting the project performance to deliver a successful project.

By dynamic project performance prediction, dynamic information (new information that becomes available during the project) can be used to enhance project performance prediction. Although this subject has been studied in the literature, the following limitations have been identified. First, in existing methods, project control systems generally use cost and time indicators and neglect other main aspects of performance such as quality, safety, client satisfaction, etc. Second, only limited work has been done on forecasting project performance using KPIs at the project level.

Third, most of the previous work has focused on the quantitative performance forecasting of projects, and less attention has been directed to qualitative methods. However, many construction KPIs, such as client satisfaction, quality and safety have a qualitative nature and cannot be measured quantitatively. Also, for other KPIs such as time and cost, issues of confidentiality and a lack of data are the norm in construction projects. Therefore, it is more feasible to develop a qualitative rather than a quantitative framework to measure and forecast project KPIs. Fourth, most of the previous works measure project performance only after completion, and not during the construction phase (Haponava and Al-Jibouri 2012). The benefits of measuring the performance during the project are that stakeholders can use the measurements to suggest corrective action and to forecast the rest of the project's performance.

1.2 Objectives

The primary objective of this research is to define a framework for qualitatively measuring and forecasting, as well as improving construction project performance. This research objective is further broken down into the following sub-objectives:

- Define a model for qualitatively measuring and forecasting performance during construction projects.
- Formalize the process of performance evaluation by defining a set of performance indicators and identifying KPIs.
- Forecast construction project performance during the project by applying and evaluating various soft computing techniques.
- Define a model to optimize project performance at any stage of the project considering various KPIs.

1.3 Research Methodology

The methodology of this research is described in detail in Chapter 3. A brief description of this methodology is presented here.

1. Literature Review

The existing studies are reviewed to identify relevant works in the construction projects performance area. A comprehensive literature review is performed for two aspects of project performance measurement and forecasting. The definitions of project performance and key performance indicators are also reviewed.

2. KPIs Identification

To identify the most important key performance indicators (KPIs), an extensive investigation of the literature is performed. A list of used KPIs in literature at the project level is prepared, and their frequencies are indicated. The KPIs with highest frequencies are chosen as the most important KPIs. To further justify the selection of KPIs, the expert option is also considered by distributing questionnaires.

3. KPI Prediction Models

The KPIs of three critical project stages are used to predict whole project KPIs using two main techniques: Artificial Neural Networks (ANNs) and neuro-fuzzy. In using the neuro-fuzzy technique both subtractive clustering and the FCM are applied to develop the models. The results of the three above techniques are compared to find the best technique for predicting the performance of construction projects.

4. KPI Trend Forecasting Model

Models for predicting the KPIs of the next stages and KPI trends are also developed. The neuro-fuzzy technique is used to predict the KPIs of the next stages. Next, linear interpolation is used to predict the KPIs at different progress percentages during the project. Visualizations of KPI trends for a better analysis of the project are also developed.

5. PI Prediction Model

The weighted sum is used as the basic formula for evaluating the overall performance indicator (PI) in this model. Two different methods are used to determine the weight for each of the indicators, the Analytical Hierarchy Process (AHP) and the Genetic Algorithm (GA) method.

6. Performance Optimization Model (POM)

This model develops a decision support system to improve project performance using a genetic algorithm. In this approach, different scenarios are considered for project activities to find the best scenario and achieve the desired PI. This approach allows for increasing the overall project performance as much as possible based on available scenarios.

1.4 Organization of the Thesis

This thesis contains six chapters that are summarized below:

Chapter 2 presents a comprehensive review of the related literature in performance forecasting and performance measurement methods. A list of KPIs and their frequencies in the literature are explained. The frequencies are then used to select the final KPIs.

Chapter 3 developed the methodology of this research for qualitatively predicting project performance. A methodology for developing models for forecasting KPIs by applying Artificial

Neural Network (ANN) and neuro-fuzzy technique is developed. This chapter also discusses a model for predicting the KPIs of the next stages and KPIs trends. Also, chapter 3 offers an integration method to determine the overall project performance indicator (PI) using AHP (Analytical Hierarchy Process) and GA (Genetic Algorithm) methods. Lastly, a performance optimization model based on KPIs is developed to assist the decision making process and to improve project performance.

Chapter 4 contains the data collection and analysis. It explains how data was collected using questionnaires and how the data was analyzed. Chapter 5 explains the model development and implementation based on the methodology described in Chapter 3. The results from KPI forecasting models developed with different computing methods are compared in this chapter. A comparison between the predicted performance indicators of the model and the performance indicators derived from the questionnaires is also developed. Also, the validation process is performed in this chapter.

Chapter 6 contains the conclusions and highlights the contributions of this research. It also includes research limitations and offers recommendations for future work.

CHAPTER 2: LITERATURE REVIEW

2.1 Chapter overview

By offering a comprehensive performance measurement system, a better project control tool implemented for managing construction operations. Project management is becoming more integrated, creating the need for a project performance measurement system capable of evaluating all project's attributes. Our purpose is to identify and measure the project performance indicators for evaluating project performance.

Project control consists of two steps, measurement, and decision-making. The measurement phase consists of, defining a project baseline and collecting data, evaluating the performance of the project. Forecasting performance and decision-making consist of analyzing the variance, listing the corrective actions and carrying out the corrective action for improving performance (Nassar 2005).

This chapter developed a comprehensive review of the literature. The next section reviews the existing literature on project performance, including the definition and use of project performance measurement approaches in section 2.2. Section 2.3 presents a review of the existing approaches for forecasting project performance. The last section, Section 2.4, explain an overview of the related research tools. Section 2.5 elaborates findings, limitations, and research gaps in this area.

2.2 Project Performance

2.2.1 Definition

Performance is defined as the amount of efficiency and effectiveness in all of a project's objectives (Nassar and AbouRizk 2014). Efficiency means doing things right, in other words, getting the most output for the least input, and effectiveness means "doing the right things" that means attaining organizational goals.

"Project performance assessment is the process of comparing actual project performance against planned performance and identifying variances from planned performance" (Hollmann 2012). Each stakeholder does performance evaluation to ensure profit achievement due to the different benefits for different stakeholders. The first step in defining a project's success is identifying from whose point of view the success will be measured. The performance measurement by different stakeholders such as owners, project managers, or contractors can vary.

Project success was based on three objectives in 1980: 1) completed on time;2) completed within budget, and 3) completed with desirable quality. All of these focus on the internal performance of the project and do not include other important factors such as customer satisfaction and safety (Khosravi and Afshari 2011). The logical way of improving performance by measuring and comparing your performance against others is referred to as benchmarking (Swan and Kyng 2004).

Nyariki (2014) mentions that the definition of project success may change due to the project type, size, and stakeholders. He also identifies success as the achievement of goals and objectives plus good results in a project that will have a positive impact on people's lives. Next section illustrates an overview of construction project performance measurement methods in the literature.

2.2.2 Project Performance Measurement

Most performance measurement methods are related to the work on project control. It helps to carry out accurate and timely corrective actions. Measuring performance is vital for all project stakeholders. However, different project stakeholders want different forms of project control and performance measurement. Previous researchers have worked on performance measurement systems (PMS) and developed key performance indicators (KPIs) to quantify the concept of project performance.

Earned Value is a classic project control method that uses time and cost. This method is based on the work breakdown structure (WBS) tool to define work packages. "In 1967, the US Department of Defense (DOD) issued their Cost/Schedule Control Systems Criteria, known as C/SCSC. Currently, these criteria are known as the Earned-Value Management System (EVMS) criteria "(Nassar 2005). This method is an integrated control of projects' time and cost. It uses three S-curves for controlling project time and cost, the Budgeted Cost of Work Performed (BCWP), the Budgeted Cost of Work Scheduled (BCWS), and the Actual Cost of Work Performed (ACWP). Project performance is measured using the EV method by using the Cost Performance Index (CPI) and the Schedule Performance Index (SPI).

The Program Evaluation and Review Technique (PERT) method was introduced by the US Navy in 1957. The S-curve and PERT methods use cost and schedule indicators independently to evaluate performance, while the earned value method integrates cost and schedule indicators. They did not mention other performance aspects such as quality and safety. Other models are therefore needed to comprehensively measure the performance of a construction project.

Freeman and Beale (1992) used seven criteria as project success criteria. Their study uses a measuring system that consists of a discounted cash flow (DCF) principle. One of the shortcomings of this method is that it requires information that can be calculated only after a project's completion.

Ashley et al. (1987) used ten criteria to evaluate project success. The criteria's are budget performance, schedule performance, client satisfaction, functionality, contractor satisfaction, project management team satisfaction, follow-on work, capabilities build up, end-user satisfaction, and specification (quality). The main problem of this method is that the four latter criteria are not well defined. Also, the defined criteria are not inclusive to cover all project aspects.

Alarcón and Ashley (1996) developed a model based on knowledge of project experts, the experience of a project's team and decision analysis techniques. Their model uses four performance indicators: cost, schedule, value to the owner, and effectiveness. A general performance model is developed using experience captured from experts and assessments from the project team. Chua et al. (1999) evaluated project success through three objectives, cost, schedule, and quality. Sixty-seven critical success factors (CSFs) that influence the performance of these three objectives and affect overall project success are defined by a survey using experts' opinions. This approach uses the analytical hierarchical process (AHP) to determine these success factors and assess the importance of the three objectives of construction project success. This paper does not consider other criteria that affect the success of a project, such as safety and client satisfaction.

Griffith et al. (1999) measured industrial project performance by calculating a success index that combines four variables, budget achievement (B), schedule achievement (S), design capacity (C), and plant utilization (U), and then multiplied the variables in their weight based on Equation 2-1.

$$\text{Success Index} = 0.35\text{B} + 0.25\text{S} + 0.28\text{C} + 0.12\text{U} \qquad \text{2-1}$$

Where design capacity is "measured in percent of units of product produced as compared with the planned amount". And plant utilization is "the percentage of days in a year the plant actually produces product". The weight of variables is derived from the interview process. Each variable amount must then be classified into three separate values (1-3-5) based on how well its performance measured against the project's original plan. The shortcomings are that these indexes do not consider all aspects of project success such as safety and quality. And due, to the variable's definition, the success index can only assess performance after six months of operation. Also, this equation mixes construction performance indicators with design and operations success variables.

Cheng et al. (2000) built a model that determined the degree of success of partnering by subjective measures (individual perceptual scales) and objective measures (cost variation). Only a couple of the measures used in partnering construction projects are defined, and this model did not mention how to evaluate and assign weight to each measure. The measures here are cost variation, rejection of work, client satisfaction, quality of work, schedule variation, change in scope, profit variation, safety measure, rework, litigation, and tender efficiency.

Gao et al. (2002) identified 16 factors for project success factors (CSFs) listed in the literature; four of these are cost, schedule, technical performance, and client satisfaction. They identified criteria required for the success of a project based on interviews with experts and literature analysis, but they did not suggest ways for measuring them and also do not consider other aspects of success such as safety and profitability.

Rad (2003) measured the success or failure of a project based on a subjective approach. He proposed a model to evaluate the success of the project from two different aspects, the client, and the project team. He also defined a series of success indicators for client success and success factors for project team success using a WBS structure. However, he did not mention how to calculate and quantify their proposed indicators and their weights.

Tucker et al. (2003) built a model to quantify construction phase success (CPS) from the viewpoints of both clients and contractors. The study reviewed 209 industrial projects in North America. The indicators used are cost performance (cost growth: CGS), schedule performance (schedule growth: SGS), quality performance (rework factor: RFS) and safety performance (lost workday case incident rate: LWCIRS), as shown in Equation 2-2:

$$\mathrm{CPS} = [\mathrm{C}_1/\mathrm{C}_T]\,\mathrm{CGS} + [\mathrm{C}_2/\mathrm{C}_T]\,\mathrm{SGS} + [\mathrm{C}_3/\mathrm{C}_T]\,\mathrm{RFS} + [\mathrm{C}_4/\mathrm{C}_T]\,\mathrm{LWCIRS} \qquad \text{2-2}$$

where C_1 is the cost of the average construction phase cost growth, C_2 is the cost of the average construction phase schedule growth, C_3 is the average rework factor cost, C_4 is the cost of the average number of lost workday case incidents, and C_T is the total cost. The weight of each indicator is defined using a cost ratio according to Equation 2-3.

$$\mathrm{CPS} = 0.4\mathrm{CGS} + 0.25\mathrm{SGS} + 0.3\mathrm{RFS} + 0.05\mathrm{LWCIRS} \qquad \text{2-3}$$

The main shortcomings of this model are that it is not applicable to an ongoing project and thus can only be used when a project is finished when it is too late to carry out any corrective action. Also, the weights for variables are based on cost ratios, which may not always be true.

Rozenes et al. (2004) proposed a multidimensional Project Control System (MPCS) that quantitatively evaluated project performance by measuring the performance of eight criteria defined in two categories that are functional and operational category. The MPCS uses a quantitative approach to define a deviation from the planned phase. This model evaluates project performance by measuring the Gap Performance Index (GPI), which is the gap existing between the planned and actual performance. It is obvious that the ideal amount of GP is zero. The primary shortcoming of this model is that there is no clear distinction between the success factor and the project success criteria.

Bassioni et al. (2004) reviewed methods in the performance measurement framework and identified gaps in this area. Their emphasis is on the application of these frameworks in construction firms in the United Kingdom from the view of internal management.

Nassar (2005) proposed a model for defining project performance from a contractor's view. The Earned Value Management Indicators are used plus six more indicators. Then proposed mathematical relation for calculating the project performance indexes. After normalizing some of the indicators, he incorporated them in a comprehensive model for calculating the success of a project from the contractor's perspective. The main shortcoming of this model is that it does not consider the difference between the success factor and project success criteria in the definitions of some of its indicators.

Menches and Hanna (2006) proposed a process for converting a project manager's qualitative assessment of "successful performance" to a quantitative amount. Six indicators were used that are actual percent profit, percent schedule overrun, amount of time given, communication between team members, budget achievement, and change in work hours. Twenty-seven random electrical contractors throughout the United States were selected to collect planning and performance data. Companies were asked to give information about two projects, one successful and one less successful project, by completing a questionnaire and being interviewed about the planning and performance of their submitted projects. Validation was used which indicated that the model was useful for quantitatively measuring successful performance based on the project managers' point of view.

Khosravi and Afshari (2011) developed a successful measurement model by providing a project success index for every finished project in the Mapna Special Projects Construction & Development Co (MD-3). The model is from the view of the performing organization. Their model was designed to compare finished projects and create a benchmark for improving project success.

Cha and Kim (2011) defined a quantitative performance measurement system by using eighteen key performance indicators for residential building projects. They defined the performance indicators based on a literature review and interviews with experts and assigned weight to each project performance indicator. These weighted indicators were used to develop a mathematical model to quantifiably assess project performance.

Deng et al. (2012) assessed the literature on PMS (Project Measurement Systems), especially at the company level and identified gaps. They found that traditional performance measurement is inappropriate because it does not consider non-financial measures such as productivity. They identified the need to focus more on the design and implementation issues of PMS in construction and showed the essential need for future research in performance measurement (PM) in construction projects and firms.

Heravi and Ilbeigi (2012) used a quantitative method to measure construction project success from the contractor's perspective based on the Baccarini (1999) definition of success, where project success consists of two elements, product success, and project management success. They identified critical performance indices for product success and project management success. To measure project success, the indicators were quantified by defining the exact equation with which to measure each one, to define the weight for each indicator by the project manager. This method measure project performance after project completion. Due to the various ranges of quantity and different desirable limits for each indicator the amount of indicators needs to be normalized, and then the performance indicators must be integrated to obtain the overall project performance as shown in Equations 2-4 and 2-5.

$$\text{Product success function: (PSF)} =$$
$$W_1\text{PPI} + W_2\text{QPIprouct} + W_3\text{CPPSI} + W_4\text{CSI} + W_5\text{IP}, \quad \sum_{i=1}^{5} W_i = 1 \qquad 2\text{-}4$$

$$\text{Project management success: (PMSF)} =$$
$$U_1\text{CPI} + U_2\text{BPI} + U_3\text{SPI} + U_4\text{SFI} + U_5\text{QPIprocess} + U_6\text{EPI}\ , \quad \sum_{i=1}^{6} U_i = 1 \qquad 2\text{-}5$$

profitability performance index (PPI), product quality performance index (QPI Product), client satisfaction index (CSI), contractor's professional profit satisfaction index (CPPSI), and the investment performance index (IPI)., cost performance index (CPI), billing performance index (BPI), schedule performance index (SPI), safety performance index (SFI), process quality performance index (QPI Process), and the environmental performance index (EPI)

Haponava and Al-Jibouri (2012) measured project performance in three phases dynamically, using some process-based performance indicators. Their system relied on questions related to both process completeness and process quality. The project is divided into three stages, the pre-project stage, design stage, and construction stage. To develop a generic system for measuring process performance. KPIs are measured in two aspects; the first is for process completeness, defining the question of "how much sub-processor is complete? ", and the second is process quality, which answers the query of "how the completed part is done?"

Ali et al. (2013) defined a set of important KPIs that can be used to measure the performance of construction companies. They identified 47 KPIs from the literature and designed a questionnaire to define the main KPIs as well as to rank the importance of each KPI (1= very low importance, 2 = low importance, 3= medium importance, 4= high importance, and 5 = very high importance). Twenty-four surveys were analyzed, resulting in ten indicators for measuring company performance. They used a statistical method to analyze the questionnaires' data about the importance of each KPI.

Wester (2013) recognized key performance indicators in the design stage for advanced high-technological construction projects using a qualitative approach. Although this research only focused on identifying KPIs during the design stage of projects and did not consider other stages, also it did not predict performance indicators.

Kam et al. (2013) proposed using KPIs to help construction project teams in Virtual Design and Construction (VDC) /Building Information Modeling (BIM) decision-making. They suggested using statistical methods to identify relations between KPIs. In their proposal, they recommended providing models for benchmarking, decision-prioritization, and performance prediction. However, this is a proposal, and the implemented work is not presented and not yet implemented.

Nassar and AbouRizk (2014) used a quantitative approach to measure project performance from the contractor's perspective during the construction phase. KPIs were used for controlling the project during the execution phase. The first step was to identify the project objectives and its performance indexes and sub-indexes. The project manager defined the project objectives. The indexes were determined from discussions with fifteen contractors and in accordance with the authors' experience. A hierarchy for project performance is proposed in which each indicator is divided into sub-indicators, but its applicability was checked for each project, as each project is unique. The second step is to quantify the project indexes as shown in Table 2-1.

Table 2-1: KPIs description (Nassar and AbouRizk 2014).

Index	Description	Calculation
Cost Performance Index (CPI)	Cost efficiency of the project	CPI = BCWP/ACWP
Schedule Performance Index (SPI)	Schedule efficiency of the project	SPI = BCWP/BCWS
Billing Performance Index (BPI)	The efficiency of invoicing the client for earned work; determines cash flow	BPI = BRWP/ERWP
Profitability Performance Index (PPI)	Profitability of the project to date	PPI = ERWP/ACWP
Safety Performance Index (SFI)	Safety of project to date	SFI = LTI × C/M
Quality Performance Index (QPI)	Consistency in application of project standards and procedures	QPI = CFRI
Team Satisfaction Index (TSI)	Satisfaction of the project team	$\mathrm{TSI} = \sum_{i=1}^{12} \mathrm{WiRi}$
Client Satisfaction Index (CSI)	Satisfaction of the client	$\mathrm{CSI} = \sum_{i=1}^{12} \mathrm{WiRi}$

BCWP = Budgeted cost of work performed: the cumulative budgeted cost for work completed to date, or the cost allowed (based on budget) to spend on the actual work done.
ACWP = Actual cost of work performed: the cumulative cost incurred to complete the accomplished work to date.
BCWS = Budgeted cost of work scheduled: the budgeted cost for work scheduled (as per budget) to date.
BRWP = Billed revenue of work performed, or the cumulative amount of invoices.
ERWP = Earned revenue of work performed or the cumulative revenue earned for the actual work accomplished to date.
LTI = Number of lost time incidents to date.
C = a constant (200,000), which represents 100 employees working for a full year (100 × 2; 000).
M = Total work hours expended to date.
CFRI = Construction field rework index: the total direct and indirect cost of rework performed in the field/total field construction phase cost.
W_i = Relative weights (determined by the AHP method) for various areas of concern to the client or project team.

R_i = Satisfaction ratings from 1-10 for various areas of concern to the client or project team.

Each sub-index is calculated by the above formula and then summed to get the value of the index. The weight shows how important each factor is for defining the total project performance. The AHP (Analytical Hierarchy process) was used to define the weight (w) of each factor. The third step was to normalize the indexes. The fourth step was to calculate the total project performance by integrating the indexes according to Equation 2-6. By using the assumption that every two indexes are mutually independent, they can calculate the project performance by summing up eight performance indices with their weights.

$$\mathrm{PI} = \mathrm{W_1 CPI} + \mathrm{W_2 SPI} + \mathrm{W_3 BPI} + \mathrm{W_4 PPI} + \mathrm{W_5 SFI} + \mathrm{W_6 QPI} + \mathrm{W_7 TSI} + \mathrm{W_8 CSI} \qquad 2\text{-}6$$

CPI: normalized performance index Wi: weight of each index

Hanna et al. (2014) used a mathematical formula for the calculation of performance metrics called project quarterback rating (PQR), which quantitatively assesses cumulative project performance by using important key performance metrics based on Equation 2-7. This model is from the contractor's view and produces a single metric to assess the overall project performance.

$$\mathrm{PQR} = \mathrm{W_1 S_1} + \mathrm{W_2 S_2} + \mathrm{W_3 S_3} + \mathrm{W_4 S_4} + \mathrm{W_5 S_5} \qquad 2\text{-}7$$

Si: scaled version of performance metrics Wi: weight of this metrics

The five performance metrics are customer satisfaction (S_1), schedule (S_2), cost (S_3), profit (S_4), and communication (S_5). This model can use any other metrics and weights for calculation purposes, as projects and their objectives are different.

Constructing Excellence publishes the construction industry’s KPIs each year using performance data collected from the UK construction sector. It establishes the engines called KPI engine and KPI zone to help different stakeholders measure the performance of their projects. KPI Engine offers a method of monitoring and benchmarking project performance data. It contains a varied range of reporting options and the chance to modify a performance measurement system (BIS 2012). KPI zone is an easy way to measure and benchmark performance against national data, as can be seen in Figure 2-1. It also contains definitions, methods of measurement and calculations for any of the Constructing Excellence KPIs (BIS 2012).

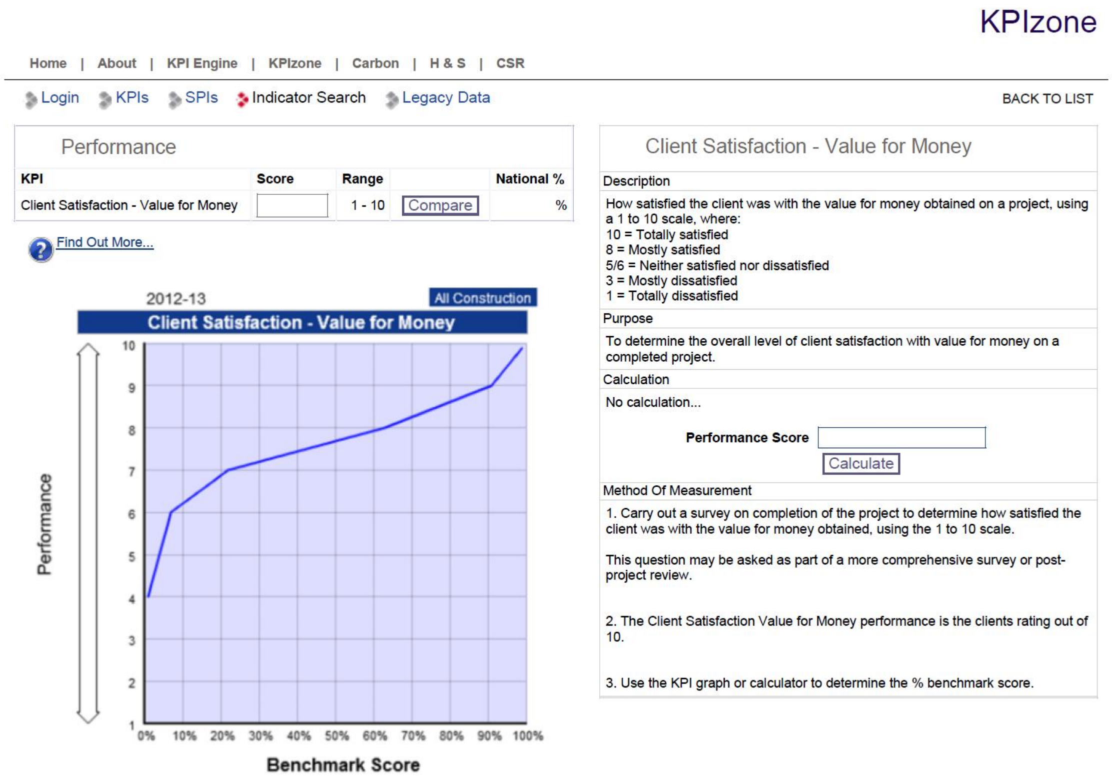

Figure 2-1: KPI zone interface

CII (Construction Industry Institute) is the research and development center based at The University of Texas at Austin. This institute developed a system for performance assessment and benchmarking for the capital projects industry from both contractor and owner viewpoint. The CII Performance Assessment Program defines quantitative project performance information. It employs questionnaires to get information about the project from users. It also includes a data miner interface that allows a customer to customize the questions and to do more generic reporting. The comparison data can be filtered to be evaluated with a specific project. CII defined performance metric categories that are: schedule, safety, changes, rework. Several performance metrics are defined for each of the four categories (CII 2014).

For example, CII (2018) in report number RT-284 focused on safety indicators of construction projects. They claimed that traditional monitoring of indicators of safety performance did not achieve the desired improvement in construction safety. This report suggested that using leading safety indicators can significantly improve construction safety practices. Construction leading indicators can be divided into two types: passive and active. Passive indicators refer to safety strategies before construction begins. On the other hand, active indicators refer to strategies during the construction phase. It identified ten key passive safety leading indicators and 14 active safety indicators (CII 2018).

CII's newest approach for benchmarking of capital projects is introduced in the 10-10 program (CII 2018). This program illustrates an important linkage with the CII Performance Assessment System: CII Performance Assessment System defines performance measurement of project execution, while 10-10 program defines a system for ongoing project diagnostic. Therefore, 10-10 program allows practitioners to identify problems and to take corrective action for improving ongoing projects. CII's 10-10 program is based on surveying members of a project's management team about the performance, team dynamics, and organizational relationships of their project.

The 10-10 Program is based on questionnaires for five project phases: (1) front end planning, (2) engineering and design, (3) procurement, (4) Construction, and 5) commissioning and Startup. At the end of each phase, customers will have an assessment of that part. Ten leading indicators or input measures are obtained using questionnaires: Planning, Organizing, Leading, Controlling, Design, Human resources, Quality, Sustainability, Supply, and Safety. These measures can warn management team of future problems. Ten outcome measures or lagging indicators are suggested by the system to inform the management team about how the project is proceeding (CII 2018).

Ngacho and Das (2015) developed a performance assessment framework of construction projects based on six KPIs: time, cost, quality, safety, site disputes and environmental impact. These KPIs were recognized through interviews and a literature review. They used several characteristic features, called critical success factors (CSFs), to assess the performance of these KPIs.

Nilashi et al. (2015) focused on finding the importance of factors and calculating the weight as well as the interdependencies among their selected criteria. This paper does not define an approach for predicting KPIs based on the status of the project.

Stillman and Norwood (2015) proposed a method of performance assessment using KPI within programs and organizations. They developed three concepts that are identifying the root causes of critical issues, employing visual graphs to clarify trends and opportunities, and adjusting KPIs to impact change at all levels. They claimed that by applying these concepts to programs and organizations, positive change during the execution of the work can be derived.

Defense Construction Canada (DCC) used two sets of performance indicators to measure the success of Canadian projects from contractor viewpoint: key performance indicators (KPIs) and business performance indicators (BPIs). Key performance indicators (KPIs) measure DCC's success in achieving strategic objectives, such as leadership and governance. The KPIs' outcomes are published in the Annual Report and in the Corporate Plan Summary. Business performance indicators (BPIs) measure DCC's achievement in tactical points, such as business management and service delivery objectives (DCC 2016).

Ingle and Mahesh (2016) developed a project quarter back rating (PQR) system that is for project benchmarking. PQR identified seven project performance metrics, responsible for the successful completion of a project. It then combined these performance metrics to evaluate the overall performances of projects.

Wan (2017) used KPIs to forecast performance of E-Commerce companies to indicate their progress and to confirm attaining business goals. The main objective was to enhance the forecasting of KPIs using past data applying Linear and non-linear models. Though, this study was focused on E-Commerce companies' performance and did not mention construction projects. Shaikh and Darade (2017) focused on quality of activities by considering KPIs in the planning stage. This study tried to find KPIs of activities and prepared a Project Quality Plan for activities and their importance. However, this research did not predict performance and only focused on quality indicators without considering other KPIs

Project performance management framework consists of performance measurement, and forecasting combined with defining and optimizing the corrective actions for improving the performance of the remaining work. Project Performance Management frameworks are described below.

Balanced Scorecard (BSC) is a concept created in 1992 (Kaplan and Norton 1992). It has four main perspectives, financial perspective, customer perspective, internal process perspective and innovation perspective as shown in Figure 2-2. The main purpose of BSC is to use the objectives of an organization. Indicators should be defined for each perspective to be able to measure them correctly. The limitations of this framework are that the four perspectives have the same weight, and that it does not cover all aspects of performance.

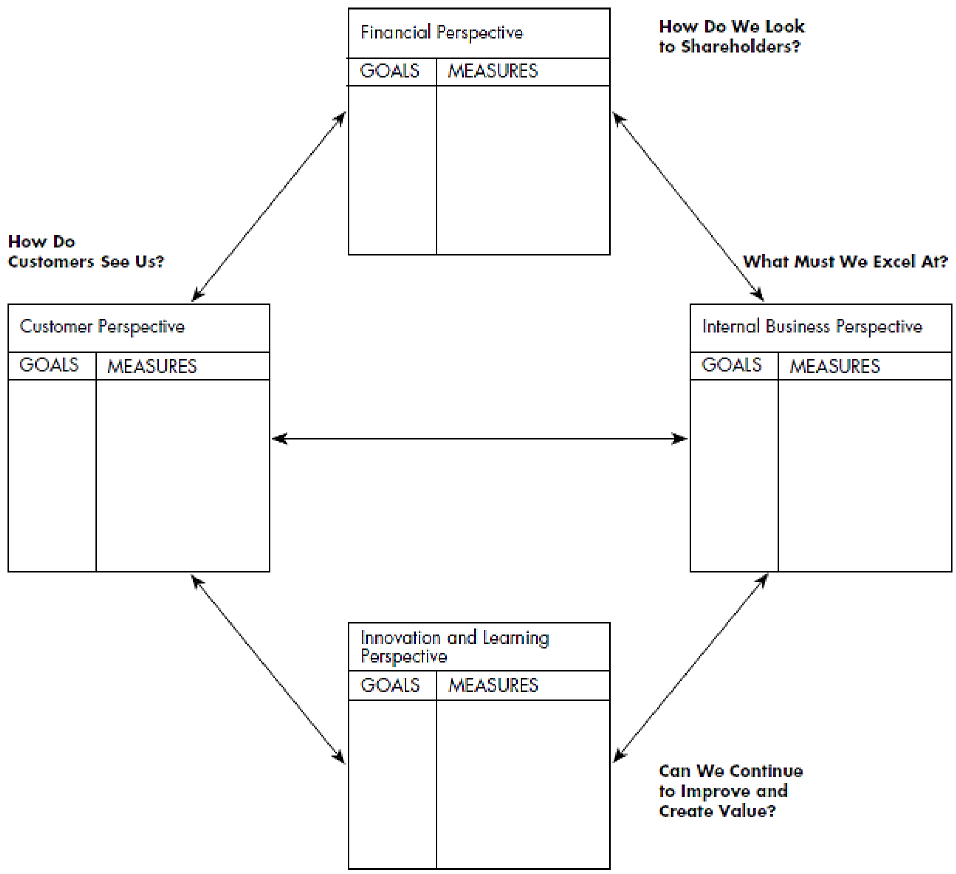

Figure 2-2: The balanced scorecard (Norton, 1992)

The EFQM Excellence Model (European Foundation for Quality Management) is based on Total Quality Management (TQM) principles developed by the European Foundation for Quality Management. “EFQM assesses performance through nine weighted criteria and their respective sub-criteria”(Vukomanovic and Radujkovic 2013). As can be seen in Figure 2-3, the five criteria are referred to as the “Enabler” cover what an organization controls, and four other criteria considered as the “Result” which show what an organization will achieve (Wongrassamee et al. 2003).

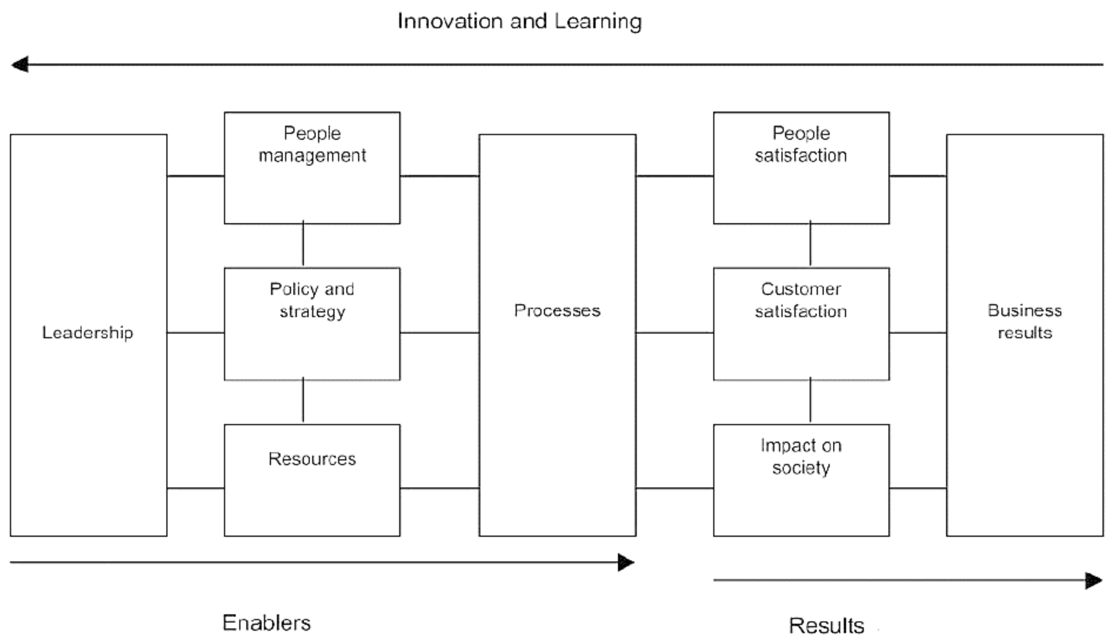

Figure 2-3: The EFQM Excellence Model (Wongrassamee et al., 2003)

Key performance indicators (KPIs) are one of three main performance measurement frameworks that are used in construction projects, as presented in Figure 2-4.

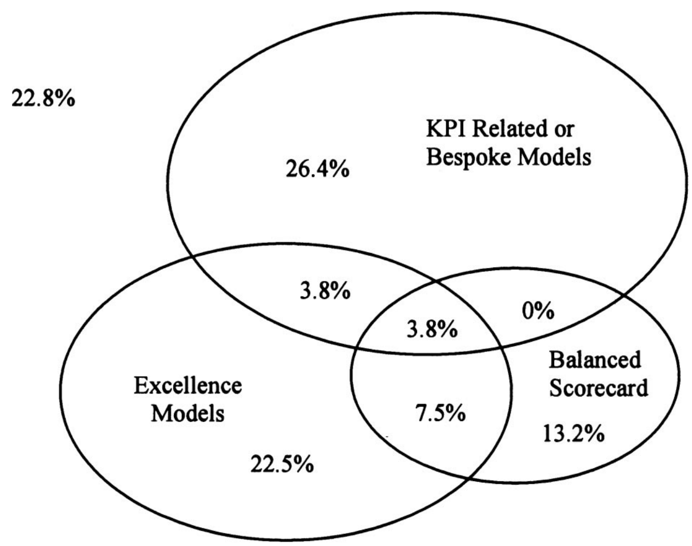

Figure 2-4: The use of performance measurement frameworks in leading construction firms (Bassioni et al., 2004)

2.2.3 Key Performance Indicators (KPIs)

Egan (1998) states that Rethinking Construction, the construction best practice program, launched the KPI for performance (CBPP-KPI 2002) (Bassioni et al. 2004). “KEY = a major contributor to the success or failure of the project. PERFORMANCE = a metric that can be measured, quantified, adjusted and controlled. The metric must be controllable to improve performance. INDICATOR = reasonable representation of present and future performance".

In the literature, both "index" and "indicator" have been used for performance measures. According to the Oxford dictionary (Simpson 1989), the definition of "indicator" is "A thing that indicates the state or level of something," this definition is more relevant to this research. Thus, in this research, the word "indicator" has been chosen.

KPIs tried to make a benchmark for evaluating project performance. KPIs used for monitoring the performance of a project and KPIs in a project work the same as a thermometer and show how healthy the project is. "The ultimate purposes of a KPI are the measurement of items directly relevant to performance and to provide information on controllable factors appropriate for decision-making such that it will lead to positive outcomes"(Kerzner 2011).

The critical purposes of a KPI are the measurement of items directly related to performance and to define information on controllable factors suitable for decision-making such that it will lead to positive outcomes. They also answer the question "What is really important for different stakeholders to monitor on the project?" (Kerzner 2011).

KPIs are interrelated performance measurements that are essential for achieving project objectives. By integrating several KPIs, one can find an exact picture of a project's status. KPIs should be defined and agreed upon by the project manager, client, and stakeholders. Usually, the standard for the number of KPIs is between six to ten items. KPIs are different for different stakeholders. There are a large number of studies that use KPIs, but still, there is less amount of work focused on using KPIs in the construction industry.

There is a difference between CSFs (Critical Success Factors) and KPIs. Factors (reasons) of performance or success cause the project to be successful or fail, such as weather condition. Performance indicators (or measures) of success are criteria for evaluating the success or failure of a construction project, such as a project's cost and schedule indicators (Nassar 2005). Our purpose is to identify and measure the project performance indicators for evaluating project performance, and not the identification of success factors.

Some researchers divide KPIs into two categories: lagging indicators that show what has already happened in a project such as cost and time, and leading indicators that may indicate possible future performance, such as absences that may have an impact on future project performance (Vukomanovic and Radujkovic 2013). Some researchers have identified other categories to separate between KPIs. They can be divided into Generic and Specific KPIs. Another classification is to categorize KPIs to qualitative (subjective) and quantitative (objectives).

In projects where KPIs were used to monitor performance during the construction, there were higher levels of both client and contractor satisfaction (BIS 2012). This research is designed to accurately measure the key performance indicators for evaluating project performance.

2.2.4 KPIs Definitions

The various ways in which KPIs are calculated in the literature are described here. There are a number of indicators such as cost, time, quality, safety that can be calculated quantitatively.

Heravi and Ilbeigi (2012) use a Cost Performance Index (CPI) that is one of the earned value management indexes to evaluate the cost of a project as calculated from Equation 2-8.

$$\mathrm{CPI} = (\mathrm{BCWP})/(\mathrm{ACWP}) \tag{2-8}$$

where BCWP is the budgeted cost of work performed and ACWP is the actual cost of work performed.

Chan and Chan (2004) measured the cost in terms of unit cost calculated based on Equation 2-9. “Unit cost is a measure of relative cost and is defined by the final contract sum divided by the gross floor area “(Chan and Chan 2004).

$$\text{Unit cost} = \frac{\text{Final contract sum}}{\text{Gross floor area }(\text{m}^2)} \tag{2-9}$$

Chan and Chan (2004) indicated cost over and cost underrun by a percentage net variation over the final cost, which is the ratio of net variations to the final contract sum expressed in percentage, calculated as shown in Equation 2-10.

$$\text{Percent NETVAR} = \frac{\text{Net value of variations}}{\text{Final contract sum}} \times 100\text{percent} \tag{2-10}$$

where Net value of variations = Final contract sum – Base and

Base = Original contract sum + Final rise and fall - Contingency allowance

Tucker et al. (2003) used construction cost growth (CCG) indexes to represent the cost component computed from Equation 2-11.

$$CCG = \frac{\text{Actual Construction Phase Cost - Initial Predicted Construction Phase Cost}}{\text{Initial Predicted Construction PhaseCost}} \quad \text{2-11}$$

Heravi and Ilbeigi (2012) used the Schedule performance index (SPI) to measure the scheduling efficiency of a project (Heravi and Ilbeigi 2012). The SPI is defined by the standard of the EVM, as shown in Equation 2-12.

$$\text{SPI}=(\text{BCWP})/(\text{BCWS}) \quad \text{2-12}$$

where BCWP is the budgeted cost of work performed and BCWS the budgeted cost of work scheduled.

“If the project’s delay leads to the postponing of the end of the project, after passing the primary deadline, the quantity of the BCWS will remain constant, and in continuation of the project, the result of Equation 2-12 will not show the scheduling efficiency of the project. Consequently, an improvement is needed to apply to Equation 2-12. Therefore, they have suggested another equation for the calculation of SPI presented in Equation 2-13.

$$\text{SPI}=[(\text{BCWP})/(\text{BCWS})] \times [(\text{DUR})/(\text{DUR}+\text{DLY})] \quad \text{2-13}$$

where DUR is the primary duration of the project and DLY is the amount of delay after the primary date of the project’s finish date.

Chan and Chan (2004) used three formulae to evaluate the time category: construction time, the speed of construction and time variation. They define construction time as the absolute time, calculated as the number of days/weeks from the start on site to practical completion of the project, as shown in Equation 2-14.

$$\text{Construction time} = \text{Practical completion date- Project commencement date} \quad \text{2-14}$$

Chan and Chan (2004) evaluated the speed of construction in relative time, which is defined by the gross floor area divided by the construction time:

$$\text{Speed of construction}=\frac{\text{Gross floor area (m}^2\text{)}}{\text{Construction time (days/weeks)}} \quad 2\text{-}15$$

They measured time variation by using the percentage of increase or decrease in the estimated project time in days/weeks, discounting the effect of the extension of time (EOT) granted by the client, as presented in Equation 2-16.

$$\text{Time variation}=\frac{\text{Construction time - Revised contract period}}{\text{Revised contract period}}\times 100 \text{ per cent} \quad 2\text{-}16$$

Revised contract period = Original contract period + EOT

Tucker et al. (2003) used construction schedule growth to represent the schedule component, as calculated in Equation 2-17. If the construction schedule growth is positive, it means the owner probably loses revenue because the project will be completed late, and if the scheduled growth is negative, the owner has the chance to use the constructed facility early to produce revenue (Tucker et al. 2003).

Construction schedule growth =

$$\frac{\text{Actual Construction Phase Duration - Initial Predicted Construction Phase Duration}}{\text{Initial Predicted Construction Phase Duration}} \quad 2\text{-}17$$

Heravi and Ilbeigi (2012) used two different indexes for evaluating quality: a Product Quality Performance Index (QPI Product) and a Process Quality Performance Index (QPI Process). The QPI Product reflects the quality of the final project product calculated from Equation 2-18.

$$\mathrm{QPI}_{\mathrm{Product}} = (\mathrm{SELQ}_{\mathrm{Prd}})/(\mathrm{TECP}) \quad 2\text{-}18$$

where $\mathrm{SELQ}_{\mathrm{Prd}}$ is the sum of direct and indirect expenses due to a lack of quality of the final project product and TECP is the total expenses of the project’s construct phases.

The Process Quality Performance Index (QPI Process) is the index for evaluating the quality of the process of a project and focuses only on the execution process of the project, calculated as in Equation 2-19.

$$\mathrm{QPI}=(\mathrm{SELQ}_{\mathrm{Prs}})/(\mathrm{TECP}) \quad 2\text{-}19$$

Where SELQPrs is the sum of the direct and indirect expenses due to a lack of quality in the project process, and TECP is the total expenses of a project's construction phases. The TECP consists of all the direct costs of construction phases such as materials, machinery, sub-contractors, etc.

Tucker et al. (2003) represented quality by the rework factor, which is calculated based on Equation 2-20.

$$\text{Rework Factor} = \frac{\text{Total Direct Cost of Field Rework}}{\text{Actual Construction PhaseCost}} \qquad 2\text{-}20$$

Heravi and Ilbeigi (2012) used a Safety Performance Index (SFI), the sum of two sub-indices as calculated from Equation 2-21.

$$\begin{aligned} &\text{SFI} = x_1 \times \text{SFI}_c + x_2 \times \text{SFI}_s \\ &\sum x_i = 1 \end{aligned} \qquad 2\text{-}21$$

Where SFIc is the safety performance index of the project outcome in terms of expenses and SFIs the safety performance index of the project outcome in terms of scheduling. The SFI of the project outcome in terms of expenses (SFIc) is computed from Equation 2-22.

$$\text{SFI}_c = (\text{ELSO})/(\text{TECP}) \qquad 2\text{-}22$$

Where ELSO is the expense arising from damages due to the lack of safety observance and TECP is the total expenses of the project's construction phases. The SFI of a project's outcome in terms of scheduling (SFIs) is calculated based on Equation 2-23.

$$\text{SFI}_s = (\text{IDWH})/(\text{TIHW}) \qquad 2\text{-}23$$

Where IDWH is the number of the individual or missed working hours due to a lack of safety observance, and TIWH is the total number of individuals or working hours in the construction phase. Used the accident rate to represent project safety as shown in Equation 2-24.

Accident rate = (Total no. of reportable construction site accidents) / (Total no. of workers employed, or man-hours worked on a specific project) × 1,000 2-24

Tucker et al. (2003) used the Lost Workday Case Incident Rate (LWCIR) to define project safety. LWCIR is calculated based on Equation 2-25.

$$LWCIR = \frac{\text{Number of Lost Workday Cases} \times 200{,}000}{\text{Site Craft Workhours}} \qquad 2\text{-}25$$

2.3 **Project Performance Forecasting**

The accurate forecasting of project performance in the construction industry is vital for controlling a construction project. The prediction of construction performance has been carried out by different methods.

Ling et al. (2004) used multiple linear regression (MLR) modeling and SPSS software to predict project performance. The limitation of this paper is that they predicted 11 performance criteria (measures) but did not define an overall project performance metric. Wong (2004) used the logistic regression approach to predict the performance of construction contractors for the United Kingdom. They proposed using clients' tender evaluation preferences to forecast contractor performance. The proposed performance prediction model is only for tender stage and not during the construction stage. Nassar (2005) performed a probabilistic forecast using a Markov Chain and then used a genetic algorithm for corrective action optimization. His model predicts performance at the completion of the project and any other future point. Nassar (2005) only chose Markov Chain technique and did not compare other techniques for predicting project performance. The choice of Markov Chain technique has the limitation of not considering the performance of previous project stages on the overall project performance. This is because the Markov process is based on the "memoryless" assumption meaning that the probability of upcoming project performance depends only on the present project performance and not any past conditions of performance. He also did not consider the difference between the success factor and project success criteria in the definitions of some of its indicators.

Cheung et al. (2006) predicted the performance of the successful tenderers through neural networks. However, their developed model was for the tender stage. Also, some important aspects of project performance such as safety have not been considered. Li et al. (2006) used a forecasting method for predicting the potential cost overrun and schedule delay on construction projects based on a set of performance indicators identified by employing a fuzzy inference process. The model forecasted time and cost overrun of the project and did not consider other important aspects such as quality and safety.

Dissanayake and Fayek (2008) developed a model for monitoring performance and identifying the causes of performance failures for Canadian projects using fuzzy, Artificial Neural Network (ANN) and Genetic Algorithm (GA) methods. They have performed a qualitative diagnosis and prediction of the causes of construction performance deviations at the activity level of construction projects on a daily basis. Their model did not consider overall project performance and only focus on activity.

Hedberg and Skjutar (2010) used ANNs for predicting team performance based on past individual achievements. Their developed model did not consider overall project performance and only focus on team performance. Jha and Chockalingam (2011) used the ANNs to predict the schedule performance of Indian construction projects. They employed a comprehensive list of factors impacting schedule performance but did not consider other performance metrics. Wang et al. (2012) used ANNs and support vector machines classification models for predicting construction cost and schedule success. But, they did not consider other performance aspects such as quality and safety. Tang et al. (2012) used system dynamics for forecasting the capability of a construction organization. The developed model only predicts the financial performance of construction organizations and is not capable of forecasting project performance.

Mohamad et al. (2014) used the neural network and Genetic algorithm for modeling the financial performance of construction companies. However, the focus of this research is not performance during the construction phase and only financial aspects of performance are considered.

Salari and Khamooshi (2016) presented a framework that estimates project performance based on past performance data. Their model used a fuzzy time series forecasting model in the estimation process. They only consider project performance from a cost and schedule perspective. Reenu et al. (2017) showed how the success of construction projects depends mostly on the success of a project's performance. ANN technique was employed to predict project performance based on four performance metrics of cost, schedule, quality, and satisfaction performance. Their model only focused on predicting performance metrics individually and did not predict the overall project performance. Also, other projects aspects such as safety were not considered.

Leon et al. (2017) developed a system dynamics (SD) model using eight construction project performance indicators (cost, schedule, quality, profitability, safety, environment, team satisfaction, and client satisfaction) to predict construction project performance. Overall project performance is not developed. Nilashi et al. (2017) applied machine learning techniques to develop a hybrid intelligent system for prediction of Heating and Cooling Loads of residential buildings. Adaptive Neuro-Fuzzy Inference System is compared with other techniques for predicting buildings' energy performance. The results indicate a better accuracy of prediction when using neuro-fuzzy. However, neuro-fuzzy has not been previously utilized for predicting construction performance indicators.

A summary of developed performance prediction models in the literature is presented in Table 2-2.

Table 2-2: Forecasting project performance in the literature

Method	Author	Developed Model	Limitation
Regression Models	Ling et al. (2004)	Predict project performance using Multiple linear regression and SPSS software for design-build and design-bid-build projects	Only used data of 89 project, did not specify an overall performance metric
	Wong (2004)	Used the logistic regression approach to predict the performance of construction contractors for the United Kingdom.	The proposed performance prediction model is only for tender stage and not during construction
ANN	Cheung et al. (2006)	The predicted performance of the successful tenderers through neural networks	Their developed model was for the tender stage. Also, some important aspects of project performance such as safety have not been considered
	Hedberg and Skjutar (2010)	Predicts team performance based on past individual achievements	Their developed model did not consider overall project performance and only focus on team performance
	Jha and Chockalingam (2011)	Prediction of schedule performance of Indian construction projects using an Artificial neural network	Focused only on schedule performance and did not consider other performance metrics

Method	Author	Developed Model	Limitation
	Wang et al. (2012)	Predicts construction cost and schedule success using artificial neural network ensemble and support vector machine classification models	They did not consider other performance aspects such as quality and safety
	Mohamad et al. (2014)	Models the financial performance of construction companies using Neural Network and Genetic Algorithm	The focus is not performance during the construction phase and only financial aspects of performance are considered
	Reenu et al. (2017)	ANN technique was employed to predict project performance based on four performance metrics	Their model only focused on predicting performance metrics individually and did not predict the overall project performance. Also, other projects aspects such as safety were not considered
System dynamics model	Tang et al. (2012)	Forecasts the capability of a construction organization mode using system dynamic	The developed model only predicts the financial performance of construction organizations and is not capable of forecasting project performance
	Leon et al. (2017)	A system dynamics (SD) model to predict project performance using eight construction project performance indicators	Overall project performance is not determined
Fuzzy	Li et al. (2006)	Use a set of performance indicators by employing a fuzzy inference process to predict cost and schedule performance	The model forecast time and cost overrun of the project and did not consider other important aspects such as quality and safety
	Dissanayake and Fayek (2008)	Developed a model to monitor performance and to identify the causes of performance failures using fuzzy set theory, ANN and GA.	Their proposed approach is daily based and for individual activities and did not consider the project level

Method	Author	Developed Model	Limitation
	Salari and Khamooshi (2016)	Presented a fuzzy time series forecasting model for project performance based on past performance data	They only consider project performance from cost and schedule perspective
Other	Nassar (2005)	Probabilistic forecasting using Markov Chains and a uses genetic algorithm for corrective action optimization Performance forecasting at the completion of the project and at any other future point	The choice of Markov Chain technique has the limitation of not considering the performance of previous project stages on the overall project performance.
	Nilashi et al. (2017)	Developed a hybrid intelligent system for prediction of Heating and Cooling Loads of residential buildings.	The focus is not construction performance

2.4 **Related Research Tools**

2.4.1 Fuzzy Inference System (FIS)

The fuzzy set theory was introduced by Zadeh in 1965 (Zadeh 1965). A fuzzy set assigns a membership degree between 0 and 1 to each of the values of a universal set *U*. The membership degree of 0 for an element means that that the element is not a member of the fuzzy set, while membership 1 indicates the complete membership of an element. The values between 0 and 1 indicate the degrees that the elements are compatible with the properties of the fuzzy set (Zadeh 1965). The curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1 is defined as a membership function (MF) (Jang and Gulley 2015).

A fuzzy inference system (FIS) is a system that uses fuzzy reasoning to map an input space to output space (Jang and Gulley 2015). A fuzzy inference system can model the qualitative aspects of human reasoning by employing fuzzy if-then rules (Jang 1993). Two main types of FIS are available: Mamdani-type and Takagi-Sugeno-type. A Mamdani-type fuzzy rule-based system contains four main components, as illustrated in figure 2-5 (Jang 1993):

1) Knowledgebase component: This component contains the if-then rules that are expressed linguistically as well as in a database. The database contains the membership function of each of the linguistic terms.
2) Fuzzification component: This component is used to match the inputs of the model to the degree of truth of each of the linguist terms.
3) Fuzzy inference component: This component performs the aggregation of different rules based on their degrees of truth to estimate the output.
4) Defuzzification component: This component transforms the fuzzy results of the model in the Mamdani-type inference system into a crisp output.

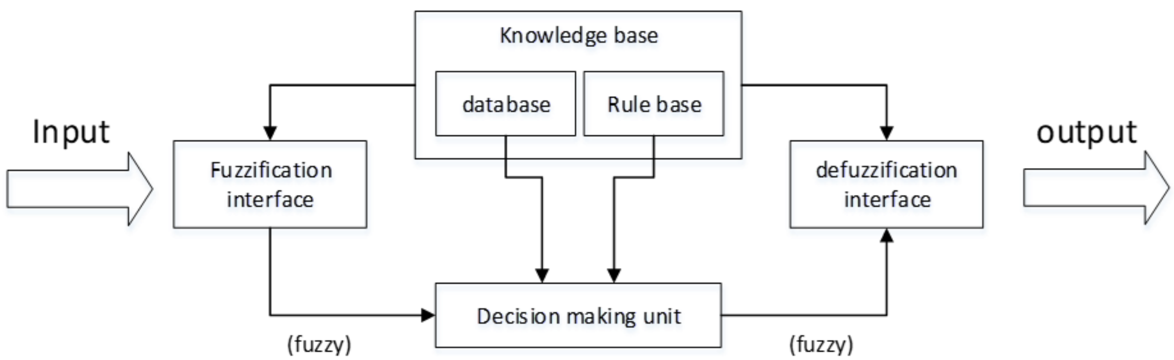

Figure 2-5: Fuzzy inference system (Jang 1993)

Fuzzification is the first step in a fuzzy inference system. The membership values are generated for a fuzzy variable using membership functions. In the last step, which is defuzzification, the output of a fuzzy inference system is transformed into a crisp (non-fuzzy) output (Jang and Gulley 2015).

Genfis1 generates a Fuzzy Inference System (FIS) structure from data using a grid partition and generates a Takagi-Sugeno-type (Sugeno-type) FIS structure (Jang and Gulley 2015). Genfis2 generates a Takagi-Sugeno-type FIS structure from data using subtractive clustering. When there is only one output, genfis2 may be used to generate an initial FIS for ANFIS training. Genfis2 accomplishes this by extracting a set of rules that model the data behavior. The rule extraction method first uses the Subcluster function (that finds cluster centers with subtractive clustering) to define the number of rules and membership functions and then uses linear least squares estimation to determine each rule's consequent equations (Jang and Gulley 2015).

Genfis3 generate FIS structure from data using the Fuzzy C-means algorithm (FCM) clustering, clustering by extracting a set of rules that model the data behavior. As with genfis2, when there is only one output, genfis3 may be used to generate an initial FIS for ANFIS training. Fuzzy c-means clustering is a data clustering technique in which each data point belongs to a cluster with its degree specified by a membership grade (Jang and Gulley 2015).

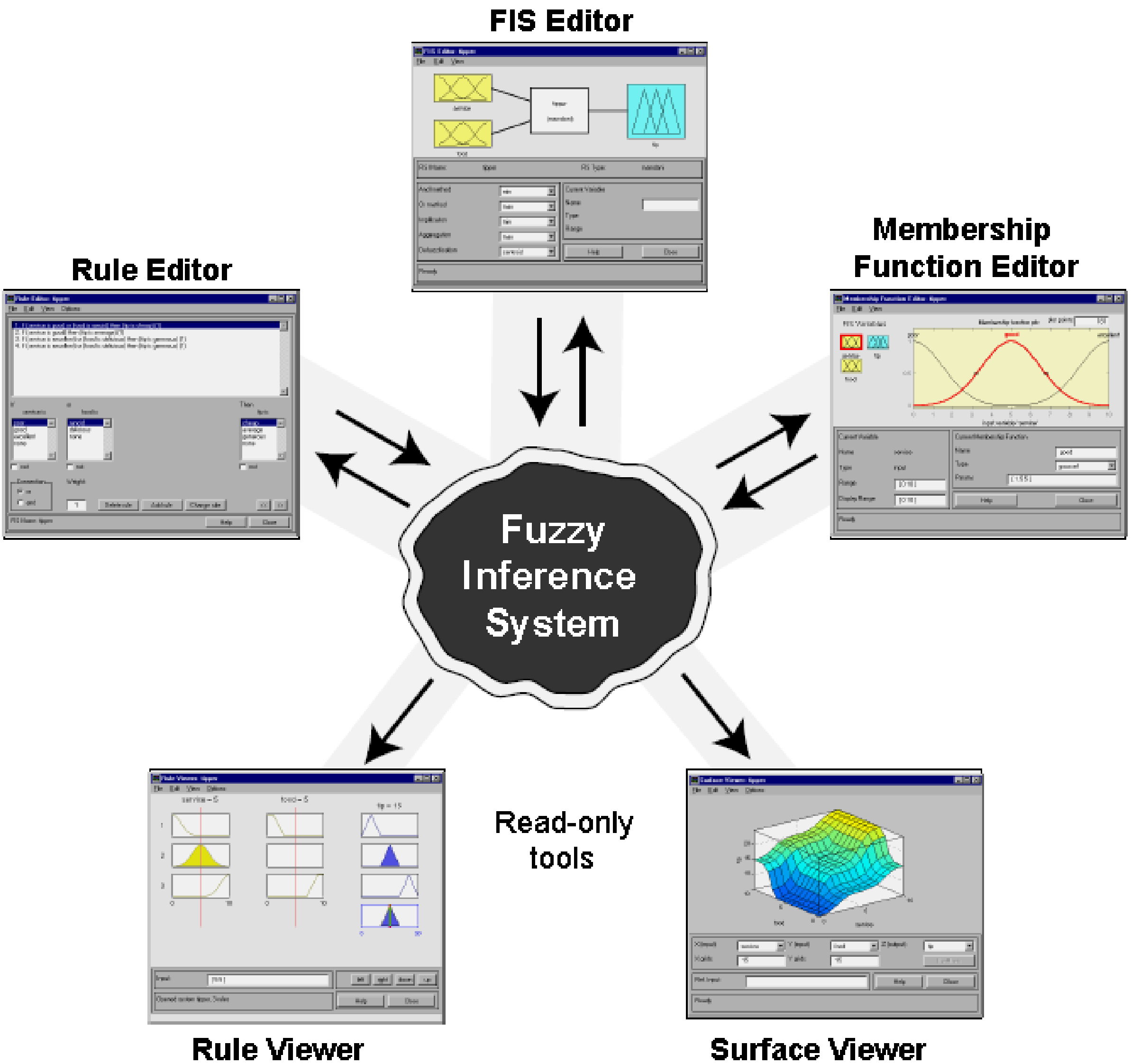

Figure 2-6: Main components of a FIS (Jang and Gulley 2015)

The main difference between Sugeno and Mamdani fuzzy inference system is in the output of the if-then rules. In Mamdani-type inference, the output of each rule is a fuzzy set. The output fuzzy sets are combined through the aggregation operator. The resulted fuzzy set is lastly defuzzified to obtain the final output of the system (Jang and Gulley 2015). On the other hand, in Sugeno-type fuzzy interference, the output membership functions are either linear or constant; therefore, no defuzzification is required. (Jang and Gulley 2015).

When comparing Sugeno and Mamdani systems, Sugeno systems are more efficient computationally, and they can be used more easily in adaptive techniques to customize the membership functions by learning from the data (Jang and Gulley 2015). On the other hand, the rules in Mamdani systems are more interpretable.

2.4.2 Neuro-Fuzzy Technique

The neuro-fuzzy technique is a combination of ANN (Artificial Neural Networks) and fuzzy logic and has been used in resolving various research problems in construction management. The main advantage of the neuro-fuzzy technique is that it does not assume a pre-defined mathematical expression. On the other hand, the neuro-fuzzy technique captures each variable's effect on the output without requiring a priori knowledge.

Neuro-Fuzzy Inference Systems allows fuzzy systems to learn from the training data, and thereby automatically tune Sugeno-type inference systems (Jang and Gulley 2015). The neuro-fuzzy method trains the parameters of an initial FIS model from training data (Jang 1993). In the training process of the neuro-fuzzy inference system, the membership functions of variables are fine-tuned to obtain better results.

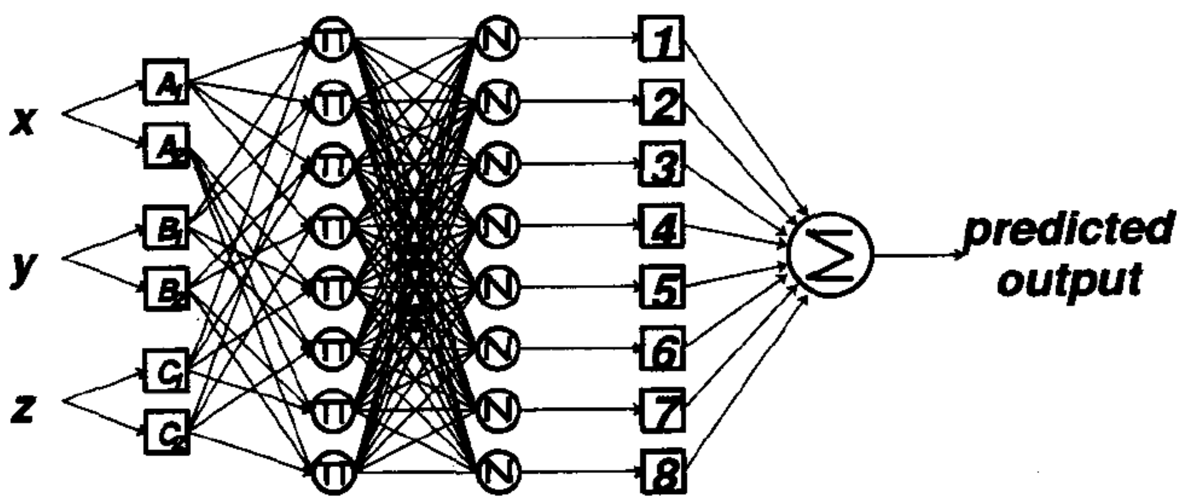

Figure 2-7: The ANFIS architecture (Jang 1993)

The Adaptive Network-Based Fuzzy Inference System (ANFIS) is a version of neuro-fuzzy first introduced by Jang in 1993 as illustrated in Figure 2-7. ANFIS is the neuro-fuzzy inference system toolbox in MATLAB. It develops a model to transform human knowledge or experience into a set of fuzzy rules and simultaneously fine-tunes the membership functions of fuzzy sets. ANFIS applies the Takagi-Sugeno method in the fuzzy modeling step due to the advantages of this system. It uses the backpropagation algorithm alone or in combination with the least squares method to identify parameters. It is trained to imitate any given training data. ANFIS is utilized in this research to improve and adjust FIS models; it optimizes membership function parameters and controls overfitting with test data.

Clustering can be employed to identify natural groupings in data. The identified cluster centers can represent a system's behavior (Jang and Gulley 2015). Clustering can be used to automatically generate fuzzy inference systems from data. Each of the clusters represents a rule in the fuzzy rule-based system. The fuzzy membership functions for the rules are formed based on the projection of the developed clusters on the input space (Delgado et al. 1997, Nauck and Kruse 1999). The main clustering methods found in the literature for generating fuzzy inference systems are subtractive clustering and Fuzzy C-means (FCM) (Jang and Gulley 2015).

Subtractive clustering was proposed by Chiu in 1994 (Chiu 1994). In Subtractive clustering, each data point is a candidate for being a cluster center, and a density measure for each data point is defined. The density measure of a data point is considered to be high if it has many neighboring data points. Two data points are neighbors to each other if their distance is less than the radius value *r*. This radius value is the input parameter of the subtractive clustering algorithm that should be defined. A very small value for this radius will neglect the effect of neighboring data points, while a very large value for r will give the assumption that all the data points are in the neighborhood of each point results in canceling the effect of the cluster (Hammouda and Karray 2000).

The first cluster center is defined as the point with the highest density value. The density measure of each data point is then revised to reduce the density measure of the data point neighboring to the first cluster center. The next data point with the greatest density value is then selected as the next cluster center. This process continues until all data have been clustered.

“The subclust function finds the clusters by using the subtractive clustering method. The genfis2 function builds upon the subclust function to provide a fast, one-pass method to take input-output training data and generate a Sugeno-type fuzzy inference system that models the data behavior”(Jang and Gulley 2015).

In Fuzzy C-Means clustering method, each data point in non-fuzzy clustering is either a member or not a member of a cluster. In fuzzy clustering, however, a degree of membership is assigned to each data point for each cluster. Dunn (1973) developed the Fuzzy C-Means (FCM) algorithm, which is a type fuzzy clustering algorithm. Bezdek (1981) later enhanced the FCM technique. In the FCM algorithm, data points farther to the cluster center have a lesser membership degree compared with points closer to the cluster center. The initial input of the FCM algorithm is the number of clusters. The FCM algorithm works based on the following procedure:

1) Randomly assume initial cluster centers
2) Estimate the membership degree of each data point in each of the clusters based on their distance from those cluster centers
3) Re-Calculate the cluster centers based on the membership degrees of each of the data points
4) Continue to step 2 if the termination condition is not reached

The termination condition can be a specific threshold for the difference between the newly calculated cluster centers and previous cluster centers. Or, the termination condition may also be a threshold for the number of the algorithm’s iterations.

2.4.3 Artificial Neural Network (ANN)

Artificial Neural Network (ANN) can model comprehensive and complex real systems by learning from examples (Gurney 2014). Learning can be either supervised or unsupervised. In supervised learning the output is available in the training phase, otherwise it is unsupervised. ANN technique is based on the learning mechanism of the human brain. The neural network tries to find a relationship between the input and output data.

ANN includes neurons and layers. Each layer contains a number of neurons that are working together. Generally, a neural network has an input layer, hidden layer(s) and an output layer. The analysis is based on the input data that is provided to the input layer. On the other hand, the output layer gives the outcome of the model.

connection lines have used the neurons of one layer to the next layer. A weight is assigned to each connection line. These weights are multiplied with the output of the starting neuron and summed with bias ultimately to calculate the value of the ending neuron, neuron “NET”(Moselhi et al. 1991). The accuracy of the model is evaluated using the Mean Square Error (MSE) (Gurney 2014).

The structures and numbers of hidden layers are determined using trial and error. This process is used as an acceptable practice by many researchers (Hegazy et al. 1994; Moselhi et al. 1991). Neural network points to several learning techniques; Back-propagation is the most common leaning approach employed in ANN used in construction management (Hegazy et al. 1994).

Backpropagation was successfully performed to model complicated scientific functions (Moselhi et al. 1992). In ANN, an initial structure is decided for the network and during the process of learning the parameters of the nodes and arrows of that network are optimized (Hegazy et al. 1994).

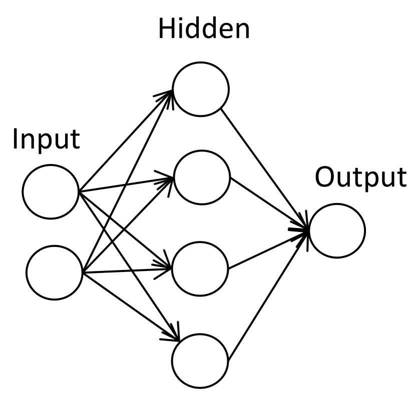

Figure 2-8: An example of an ANN network with three layers

ANN has many advantages and some drawbacks. The key benefit is in its capability to learn from historical data by modifying the model weights until output values become as close as possible to target values. On the other hand, there are some disadvantages with this method: firstly, models developed using ANN are black boxes; one can “create a successful net without understanding how it worked” (Gurney 2014). Secondly, to develop an accurate ANN, a large amount of data is required.

2.4.4 Analytical Hierarchy Process (AHP)

The AHP gives weights to a set of variables by organizing knowledge of persons into a hierarchical structure. This structure demonstrates the relationships between parameters. It can be said that the goal of the AHP is to collect expert's judgments.

The AHP was proposed by Saaty (1988). It is one of the best ways to organize assessment and decision-making. The basis of AHP has paired values for comparison that offers the opportunity to assess different choices.

The use of AHP is supported by two reasons: first, AHP is capable of considering both qualitative and quantitative factors. Second, the AHP can be used to define the weights and priorities of different parameters based on project managers' experiences and knowledge (Nassar 2005). The steps for the Analytical Hierarchy Process (AHP) are as follows:

1. Questionnaires are used to define the relative importance of indicators based on paired comparisons. Pairwise Comparison is defined as the relative importance of one criterion over another; one is equal, three moderate, five strong, seven very strong. The following matrix represents a pairwise comparison matrix of 3 parameters.

$$A = \begin{matrix} a11 & a12 & a13 \\ a21 & a22 & a23 \\ a31 & a32 & a33 \end{matrix}$$

In this matrix, a_{ij} is the relative importance of parameter i over parameter j.

$a_{ij} = 1 / a_{ji}$

$a_{ii} = 1$

2. Each value is divided by the sum of its column to normalize the relative importance matrix:

$$\begin{matrix} b11 & b12 & b13 \\ b21 & b22 & b23 \\ b31 & b32 & b33 \end{matrix}$$

where b_{ij} is the normalized relative importance calculated using the following equation.

$b_{ij} = a_{ij} / \Sigma(a_{ij}) \quad i = 1,2,3$

3. To define the relative importance of each parameter, the average of each row is calculated as w_1, w_2, and w_3:

$w_i = \Sigma (b_{ij}) / n \qquad j = 1,2,3$

where n is the number of parameters

$$w = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix}$$

$$A * w = \lambda_{max} * w$$

λ_{max} is calculated by solving the above formula (Saaty 1988). The Consistency Index (CI) is calculated using the following formula:

$CI = (\lambda_{max} - n) / (n-1)$

The Consistency Ratio (CR) is calculated to decide if the relative importance defined by an expert for each parameter is appropriate.

$CR = CI / RI$

where RI is the Random Index determined from the following table based on n , the number of indicators (Saaty 1988).

Table 2-3: Random Index value (Saaty 1988)

N	RI
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41

The calculated value for CR indicates if the relative importance matrix is appropriate or not. If $CR \leq 0.1$ the matrix is appropriate, and the relative weights calculated for each of the parameters (w_i) are reliable. However, if $CR > 0.1$, the matrix is not appropriate, and experts should review the relative importance matrix.

2.4.5 Genetic Algorithm (GA)

John Holland (1975) introduced Genetic Algorithms for the first time. The Genetic Algorithm (GA) is an optimization algorithm inspired by the process of natural selection (Adeli and Hung 1994). In a GA, any possible solution to a problem is presented as a chromosome. A fitness function is defined for the problem to be optimized. The input argument of the fitness function is a chromosome representing a solution to the problem. The output of a fitness function is the degree of optimality, adaptation, or quality of that solution. GA is based on generations, where each generation includes a population of chromosomes.

For the first generation, a random population of chromosomes is generated representing possible solutions to the problem. The parents of the next generations are selected based on their fitness values from the chromosomes of each generation. For this selection, a chromosome with a higher fitness value has a higher probability to be selected. Crossover and mutation operations are applied to parent chromosomes to generate new child chromosomes for the next generation. Crossover combines sections of parent chromosomes based on one-point, two points or more points in the parent chromosomes. Mutation randomly substitutes one or more values in a chromosome with another value. The process of producing new generations is repeated in GA until the termination condition is reached. Termination conditions are usually defined as reaching a satisfactory fitness level or a maximum number of generations. The result of a GA is the chromosome with the best fitness value among all of the generated chromosomes.

Haupt et al. (1998) summarized the GA implementation as follows:

1. Initialize the first population: The first population of parents is randomly generated. This population size should be selected so that a favourite solution can be accomplished. However, a very big size could increase the running time of the algorithm.
2. Determine the fitness function: The objective function for the problem is presented as the fitness function. Then, find the fitness value for each solution.
3. If the results are satisfactory, then present the best solution and terminate the optimization process.

4. Otherwise, choose new parents based on their fitness values.
5. Crossover: mix chromosomes of parents to generate a new solution.
6. Mutation: change a few genes randomly by replacing them with new and undiscovered genes in the population.
7. Go to step 2 to find the optimum solution.

The major advantages of GA in comparison to other methods is that it can consider both discrete and continuous variables. Also, it is capable of providing a list of solutions and not only one solution.

2.5 **Findings, Limitations, and Research Gaps**

There has been extensive effort to evaluate and predict project performance in previous research. However, according to the literature review most existing research have not developed a comprehensive model that predicts project KPIs as well as overall project performance.

In many common project performance measurement and forecasting models, only a few aspects of project performance (such as cost and time) are considered, and other important aspects are overlooked. For the effective monitoring of a construction project's progress, different aspects of performance should be quantified and integrated.

Most of the previous work has focused on the quantitative performance forecasting of projects, and less attention has been directed to qualitative methods. However, many construction KPIs, such as client satisfaction, quality and safety have a qualitative nature and cannot be measured quantitatively. Also, for other KPIs such as time and cost, issues of confidentiality and a lack of data are the norm in construction projects. Therefore, it is more feasible to develop a framework that can qualitatively measure and forecast all project KPIs

Also, in most previous research, the performance of the project is measured at its end. However, it also very important to measure the performance while a project is in progress, and not only after its completion. Forecasting the performance for the rest of the project is only possible when the performance measurement is measured during the project. The benefit of measuring the performance during the project is that stakeholders can forecast the rest of the project's performance and suggest corrective action(s). The effect of project performance during project progress on the rest of the project has not been examined in previous research.

In the literature review, several powerful techniques were found such as neural network, fuzzy logic and system dynamics. However, a limited study comparing different methods in predicting KPIs and project performance was conducted in the literature. Also, limited work has been done on forecasting project using KPIs at the project level. Instead many previous researches focused on productivity at the activity level or organization level.

Limited studies focused on the effect of Project Delivery Method (PDM) on the project performance evaluation framework. Less attention has been paid for defining the role (impact) of each stakeholder on the performance of a construction project (success or failure of the project).

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Overall Research Methodology

The flowchart of the research methodology framework is presented in Figure 3-1. The first step is to perform a comprehensive literature review in performance measurement and performance forecasting for construction projects. The limitations of the current works are then clearly identified, and the problem statement is elaborated.

The next step is to define construction project objectives and goals. Objectives or goals define a sense of direction to the project management team. By defining the objectives, a team's attention can be directed towards specific priorities in order to better monitor progress during the construction phase (Nassar 2009). Because of the different benefits for different stakeholders, it should be specified whose point of view must be considered for defining project success.

Then, the main project KPIs should be identified through both literature review and expert opinion. Afterwards, it should define how each KPI will be measured. Data are collected for all KPIs using a designed questionnaire. A qualitative method using a 1 to 7 scale based on method suggest by Dissanayake and Fayek (2008) is used for measuring KPIs. This is done since many construction KPIs such as client satisfaction, quality, and safety are qualitative in nature and cannot be measured quantitatively. Meanwhile, for other KPIs such as time and cost, confidentiality issues and lack of data that are usually faced in construction projects complicate quantification. The questionnaire is designed using this scale to collect the KPIs for three critical project stages: initial, middle, and finishing stage.

The prediction models for forecasting KPIs are developed in this step. These models for predicting the whole project KPIs are developed using both ANN and neuro-fuzzy techniques. The neuro-fuzzy technique is applied by FCM and subtractive clustering methods. The results of the developed models are compared to find the method with the highest prediction accuracy. A model for forecasting KPI trends during a project is also developed. For this purpose, the KPIs of the next stage of a project are predicted, and then the trend of these KPIs are visualized.

The second model developed is designed to predict the overall project performance indicator (PI). The KPIs' weights are defined using both AHP and GA methods. Their results are compared to find the best method for calculating the overall PI.

An automated system is developed allowing to decide between different activity modes to achieve the highest possible PI value. This model performs PI optimization based on KPIs using a genetic algorithm for choosing corrective action. Validation is done to see if the model works correctly or not. The last step is to develop a decision support system for users.

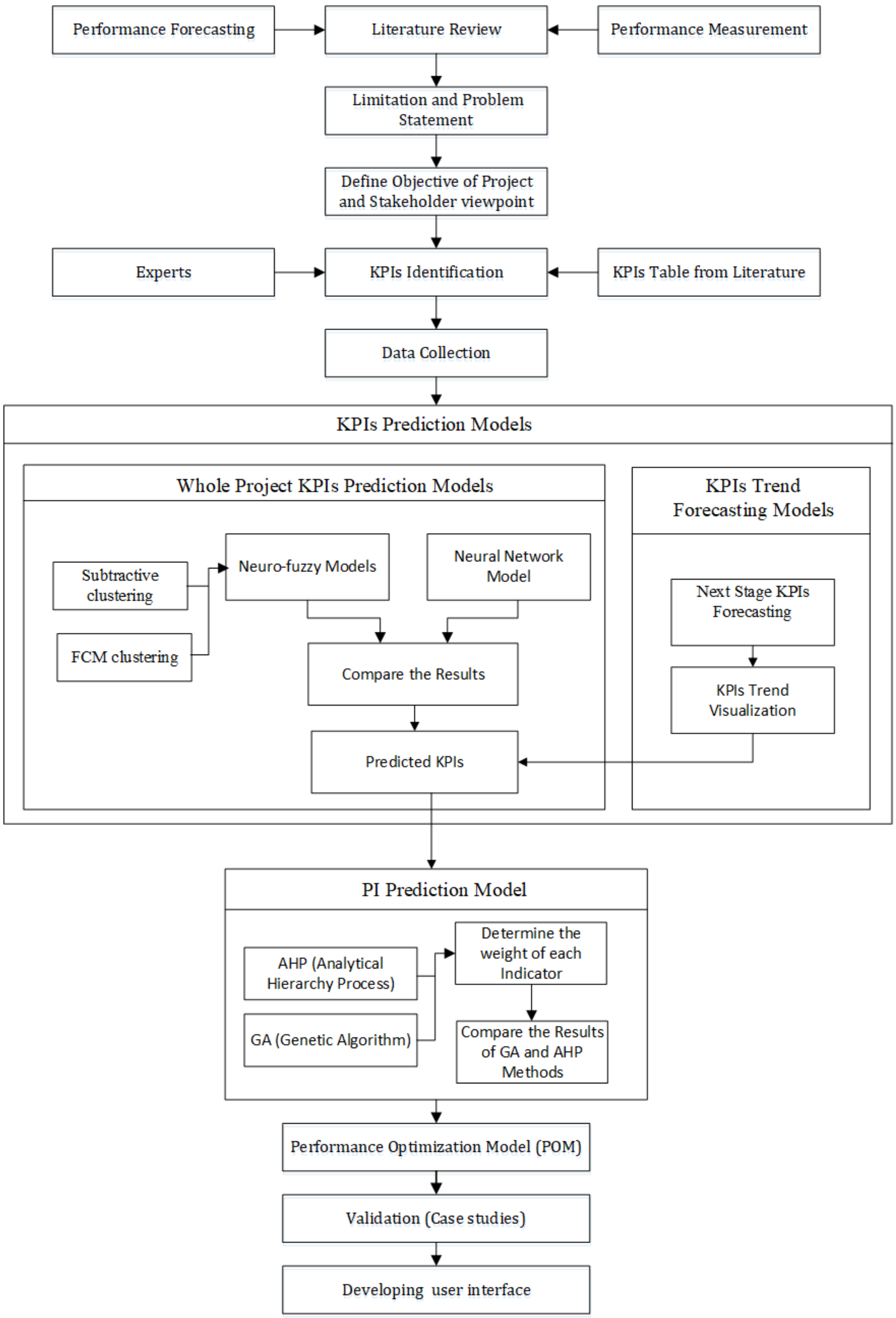

Figure 3-1: Overall research methodology framework

3.2 **KPIs Identification**

Table 3-1 presents a list of the KPIs used in the literature at the project level. The frequency of KPIs was found in 31 references from the literature. The frequency of each KPI in the reviewed literature is indicated in the last column of table 3-1. Figure 3-2 shows a histogram of the KPIs' frequencies derived from Table 3-1. It is obvious that the top-ranked six KPIs are used by approximately fifty percent and more of the studies in the literature. So these six KPIs are our indicators to develop the model. These KPIs are generic for building construction projects based on previous studies.

Table 3-1: KPI table

	Researcher	(Ashley et al., 1987)	(Freeman & Beale, 1992)	(Alarcón & Ashley, 1996)	(Chua, Kog, & Loh, 1999)	(Griffith et al., 1999)	(DETR, 2000)	(Cox et al., 2003)	(Tucker et al., 2003)	(Rad, 2003)	(Ling et al., 2004)	(Chan & Chan, 2004)	(Bassioni et al., 2004)	(Cheung et al., 2004)	(Swan & Kyng, 2005)	(CURT, 2005)	(Li et al. 2006)	(Menches & Hanna, 2006)	(Roberts & Latorre, 2009)	(Lauras et al., 2010)	(Cha & Kim, 2011)	(Khosravi & Afshari, 2011)	(Marques et al., 2011)	(Heravi & Ilbeigi, 2012)	(Haponava & Al-Jibouri, 2012)	(BIS, 2012)	(Wang, Yu, & Chan, 2012)	(Parsanejad, 2013)	(Hanna et al., 2014)	(Nassar & AbouRizk, 2014)	(CII, 2014)	(CCI, 2014)	**Frequency**
	Year	**1987**	**1992**	**1996**	**1999**	**1999**	**2000**	**2003**	**2003**	**2003**	**2004**	**2004**	**2004**	**2004**	**2005**	**2005**	**2006**	**2006**	**2009**	**2010**	**2011**	**2011**	**2011**	**2012**	**2012**	**2012**	**2012**	**2013**	**2014**	**2014**	**2014**	**2014**	
1	**Cost**	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**31**
2	**Time**	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**31**
3	**Quality (Technical Specification)**	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓			✓		✓		✓	**22**
4	**Safety**						✓	✓	✓			✓		✓	✓	✓			✓		✓	✓		✓		✓				✓	✓	✓	**15**
5	**Client Satisfaction**	✓	✓		✓		✓			✓	✓	✓		✓					✓			✓		✓		✓		✓		✓		✓	**15**
6	**Project Team Satisfaction**	✓	✓		✓					✓		✓	✓	✓			✓		✓							✓	✓	✓		✓		✓	**14**
7	**Productivity (Efficiency)**	✓	✓	✓			✓	✓								✓	✓		✓		✓					✓				✓		✓	**12**
8	**Environment**											✓		✓					✓		✓	✓		✓		✓						✓	**8**
9	**Profitability (contractor)**						✓								✓			✓	✓					✓		✓			✓			✓	**8**
10	**User satisfaction**	✓	✓								✓	✓												✓				✓	✓				**7**
11	**Communication(collaboration)**				✓									✓				✓							✓				✓				**5**
12	**Rework and Defects**															✓			✓							✓					✓	✓	**5**
13	**Information management**		✓		✓	✓									✓										✓								**5**
14	**Billing**																							✓						✓			**2**
15	**Predictability (time-cost)**														✓				✓							✓						✓	**4**
16	**Change**		✓		✓		✓									✓		✓													✓		**6**
17	**Profitability for Owner**			✓																													**1**
18	**Risk Management**																			✓			✓										**2**
19	**Design Team Satisfaction**										✓																	✓					**2**
20	**Scope**				✓					✓																							**2**

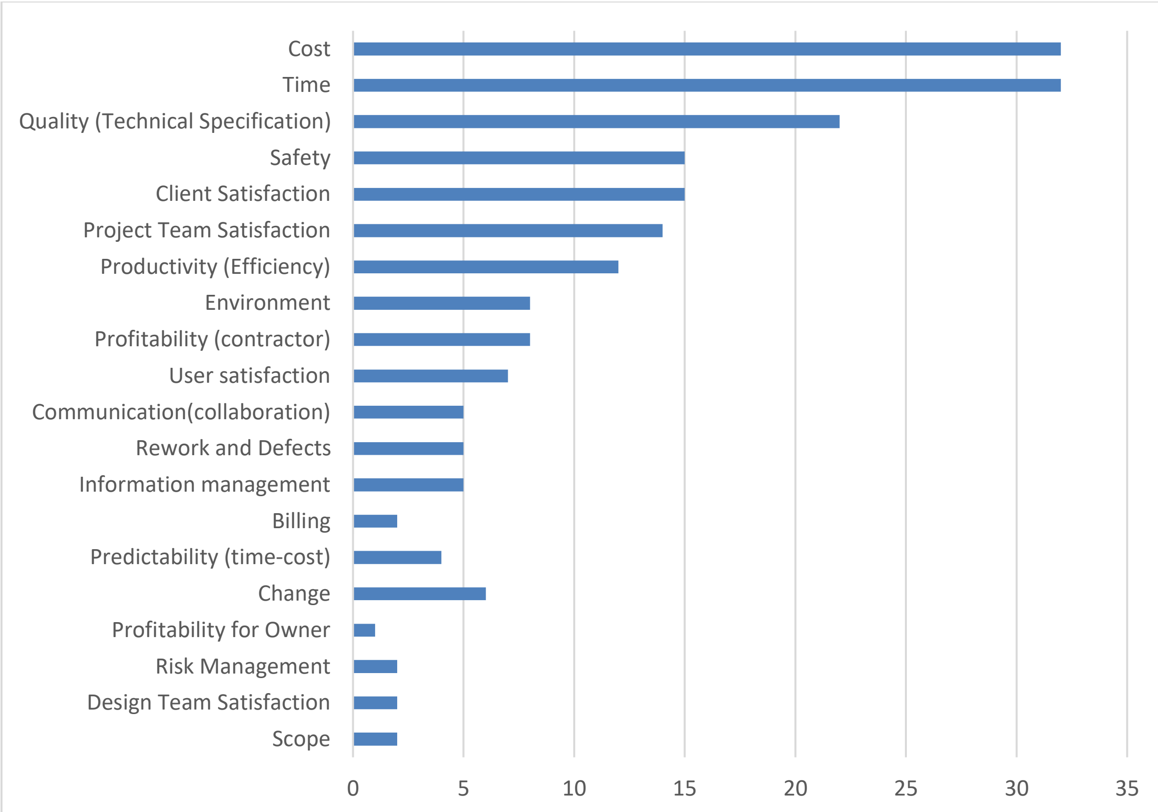

Figure 3-2: Histogram of KPIs frequency

Figure 3-3 further demonstrates the justification for the use of the first six KPIs. This figure prepared based on the questionnaires distributed to experts. The questionnaires were distributed to 34 owners of building construction projects who are asked to define a score between 1 to 7 for each of the KPIs (Fanaei et al. 2016). Fig 3-3 demonstrates sum of the scores of each of the KPIs from the questionnaire. The scores represent the importance level of each of the KPIs defined by experts. This is used to justify using six selected KPIs for model development. Based on the questionnaire outcomes, the top six KPIs got 40 to 90 percent of the score, with the seventh KPI receiving a score of 27, and the remaining KPIs receiving a score of 20 to 27 percent. Given the tangibly larger score ratio between KPI number six and seven in the questionnaire, it is fair to conclude that the experts found the first six KPIs more important than the others. Based on the literature review and the questionnaire, this study decided to select the first six KPIs, cost, time, quality, safety, client satisfaction, and project team satisfaction to develop the model. The selected KPIs comply with previous Canadian studies (DCC 2016; Dissanayake and Fayek 2008; Nassar and AbouRizk 2014). The study in this area should be concise in order to cover different aspects of the project and do not mention each issue more than once. These six KPIs are used to design the questionnaire for data collection. All indicators are measured to consider the profits and damages to the owner qualitatively.

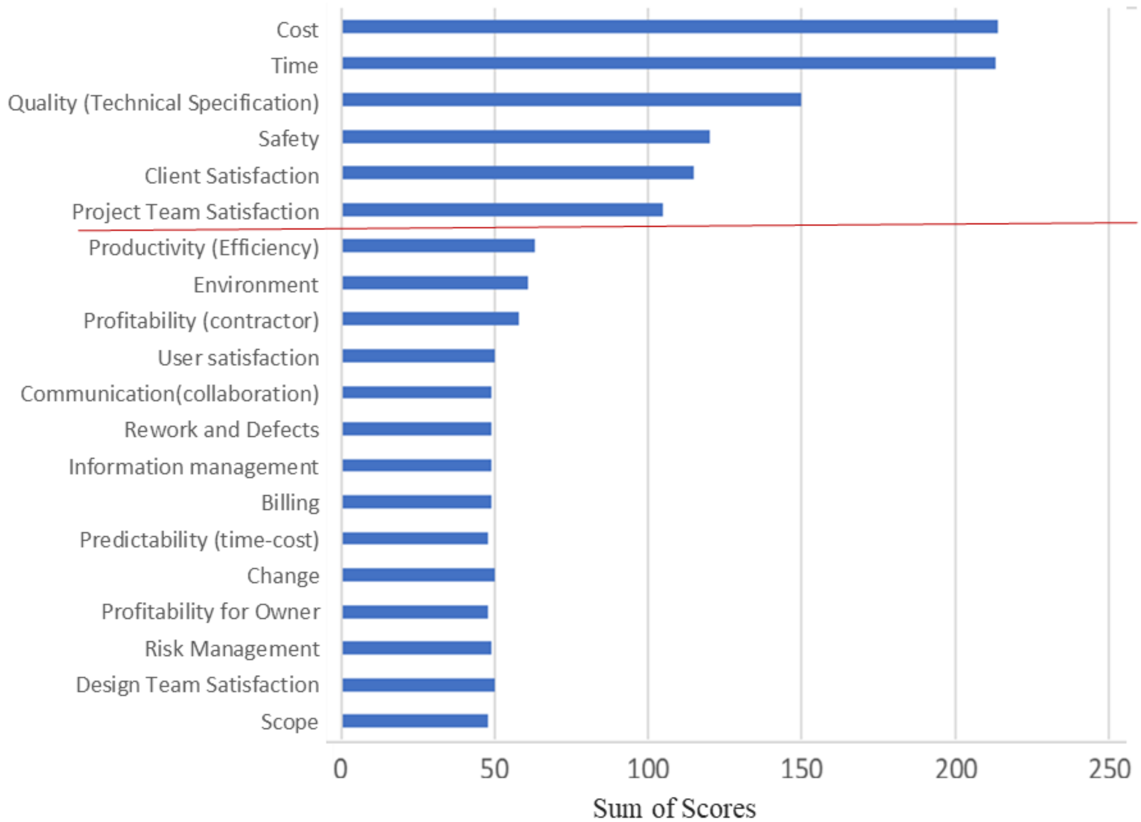

Figure 3-3: Sum of Scores of selected KPIs from the questionnaire

3.3 **KPI Prediction Model**

A model is developed for measuring and forecasting a set of qualitative KPIs using soft computing approaches. This research applies neuro-fuzzy as well as neural network to forecast the Key Performance Indicators of building construction projects.

As can be seen in Figure 3-4, The project is assumed to have three stages, an initial stage (0 to 30 % physical progress), a middle stage (30% to 70 % physical progress) and a finishing stage (70% to 100 % physical progress), and thus a forecasting model must be generated for each stage. Since data should be collected for the 6 KPIs of each stage from an expert, increasing the number of stages hugely impacts the number of required inputs from experts. Therefore, in this research, three stages that almost equally divide a project's progress are assumed. The number of stages and how they are divided can be flexible depending on data availability. The physical progress of the project is defined by the Gantt chart (MS Project and Primavera software) or a project's monthly report.

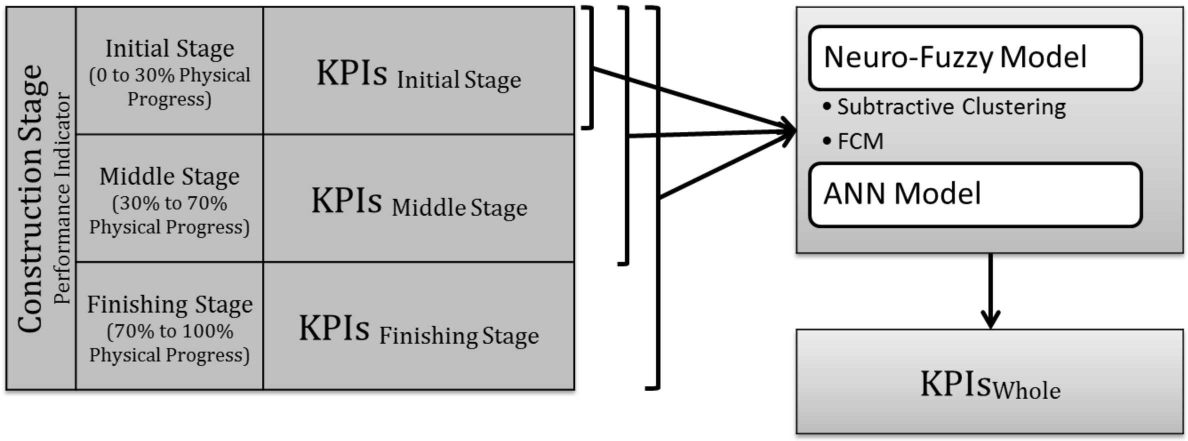

Figure 3-4: Developing KPI prediction models

The model development using the neuro-fuzzy technique with both FCM and subtractive clustering is explained. The ANN technique is then applied to develop the prediction models. Lastly, a comparison is demonstrated between the results of three applied techniques for predicting the whole project KPIs. In the validation section 5.6.1, Table 5-18 shows a comparison between these methods.

3.3.1 Neuro-fuzzy Technique

A novel model for qualitatively measuring and predicting six important construction project KPIs using the neuro-fuzzy technique is developed. Neuro-fuzzy models are developed to map the KPIs of three critical project stages to the whole project KPIs. In the developed model , the neuro-fuzzy technique is applied to forecast the whole project KPIs automatically from data (Fanaei et al. 2018).

The neuro-fuzzy technique is a combination of ANN and fuzzy logic, which was used in resolving different research problems in construction management. An advantage of the neuro-fuzzy technique is that it does not assume a pre-defined mathematical expression. In addition, it also captures each variable's effect on the output without requiring a priori knowledge (Jang and Gulley 2015).

One of the disadvantages of using the neuro-fuzzy technique is that it only has one output. Therefore, multiple neuro-fuzzy models are developed to predict each whole project performance indicator for the three critical project stages. Six different neuro-fuzzy models are developed for the initial stage. Each model in this stage has six inputs and one output. For each middle and finishing stage, six different neuro-fuzzy models have been developed as well, resulting in a total of 18 neuro-fuzzy models, as shown in Figure 3-5.

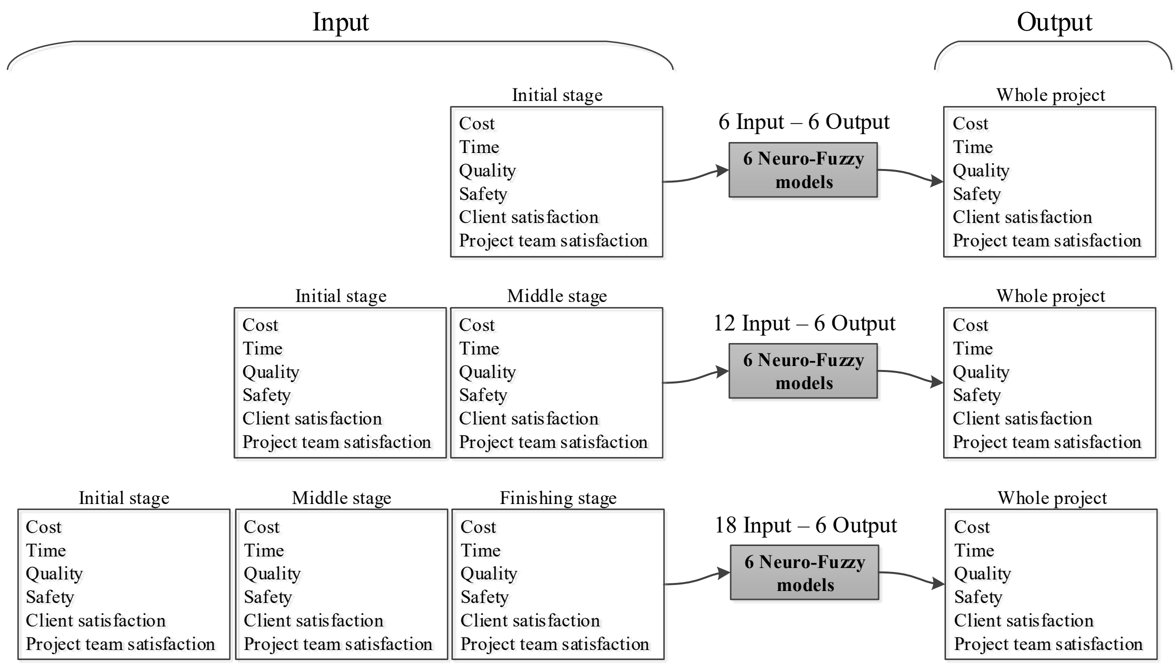

Figure 3-5: Developing 18 neuro-fuzzy models for predicting six KPIs for three critical stages

The development of neuro-fuzzy models consists of two main steps: the development of an initial Fuzzy Inference System (FIS) and the optimization of the initial FIS model using the ANN technique. Subtractive clustering and Fuzzy C-means methods are utilized to automatically generate initial Fuzzy Inference System (FIS) models.

The data collected for the KPIs are used to develop prediction models. The data was divided into two groups: train and test. The training data is used to train the models, while the test data is used to control the results. The training data contains the experimental data utilized for tuning the FIS model parameters during the training stage, whereas the test dataset includes new data that has not yet been introduced to the FIS model. The test dataset is utilized to make sure the model is not overfitted. Overfitting means a model corresponds too closely to the training dataset but cannot precisely predict future data. Figure 3-6 shows the structure of the model.

Shahin et al. (2004) illustrate how considering the statistical consistency between train and test data can improve the performance of a prediction model. They concluded that considering the statistical parameters between test and train data should be part of the data division process. Therefore, in this research, data are divided into test and train datasets in a way that ensures the statistical parameters are as close to each other as possible and thus represent the same statistical population while assuring that an optimal model is achieved. Mean, standard deviation, minimum, and maximum are statistical parameters that are compared using trial and error to achieve this objective (Shahin et al. 2004). The training dataset contains 70 percent of the collected data and the remaining 30 percent are used for the test dataset (Shahin et al. 2004).

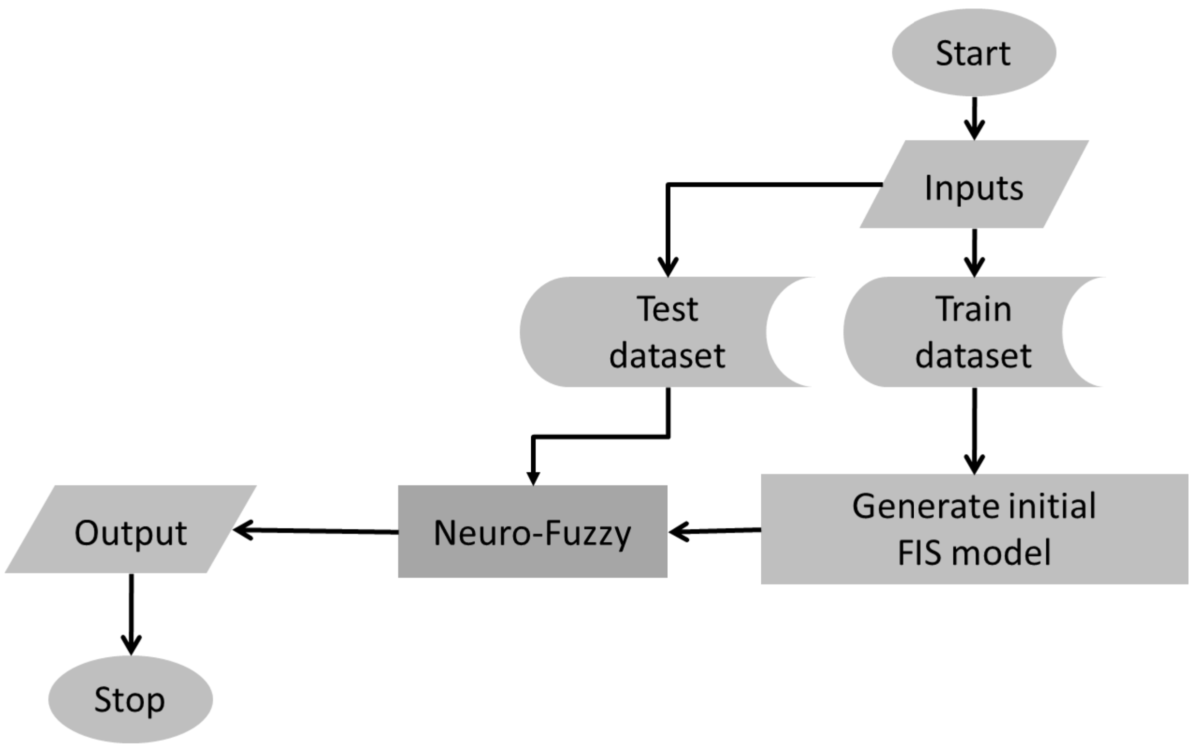

Figure 3-6: Neuro-fuzzy model structure

The subtractive Clustering method is applied as illustrated in the following. To develop the initial FIS model, subtractive clustering is utilized. Subtractive clustering has been suggested as a reliable and precise method for developing prediction models. There are multiple reasons why subtractive clustering is used. First it has less unknown variable and better logic, second it has a simpler model and fewer calculations, and lastly, it minimizes and optimizes the number of rules; fewer rules is especially important when generating FIS from a large amount of data.

Subtractive clustering can be used to extract cluster centers that represent the FIS model (Chiu 1994). Each cluster center describes a characteristic of an input/output relationship and is used to represent fuzzy rules as follows: “IF input is near a cluster center THEN output is near the output value of the cluster center”(Nasrollahzadeh and Basiri 2014)

In subtractive clustering, the radius chosen for developing clusters impacts the number of fuzzy rules. A bigger radius results in a smaller number of fuzzy rules. On the other hand, a smaller radius results in a higher number of fuzzy rules but increases the chance of overfitting. Overfitting means a model corresponds too closely to the training dataset but cannot precisely predict future data. Therefore, the cluster radius should be optimized to achieve optimum precision without overfitting the training dataset (Nasrollahzadeh and Basiri 2014).

As illustrated in Figure 3-7, the cluster radius of each of the FIS models is optimized by changing the cluster radius from 0 to 1 (the acceptable range in subtractive clustering) as suggested by Nasrollahzadeh and Basiri (2014). For each radius value, a FIS model is generated, resulting in multiple FIS models. The errors of the developed FIS models are measured for each cluster radius in two separate groups: train and test datasets. Several error measurements including Mean Absolute Percentage Error (MAPE), Root Mean Square Error (RMSE), and Coefficient of Variation (COV) are calculated between the model results of the train and test datasets. Lower values of MAPE indicate a higher accuracy; the values are divided into four ranges: high accuracy forecast (MAPE < 10%), sound forecast (10% < MAPE < 20%), feasible forecast (20% < MAPE < 50%), and error forecast (MAPE > 50%) (Jia et al. 2015).

For the RMSE, large values (close to 1.0) reflect a model’s poor ability to accurately predict performance; for a good predictive model the RMSE values should be low, <0.3. The COV amount should be between -1 and +1.

A model is considered to be an optimum when the errors calculated for the test dataset are at their lowest but also as close as possible to the training dataset. This approach ensures the generalization capability of the model and prevents the problem of overfitting (Nasrollahzadeh and Basiri 2014). When two FIS models perform similarly regarding the error measures, the model with fewer (a smaller cluster radius) is preferred.

The above approach of changing the radius values is used to select the best initial FIS models. The neuro-fuzzy technique is then utilized to optimize the initial FIS models’ parameters to reduce model error as much as possible. The neuro-fuzzy inference system develops a FIS whose membership function parameters are tuned using a backpropagation algorithm in combination with the least squares method. This tuning allows the FIS model to learn from the data it is modeling (Jang and Gulley 2015).

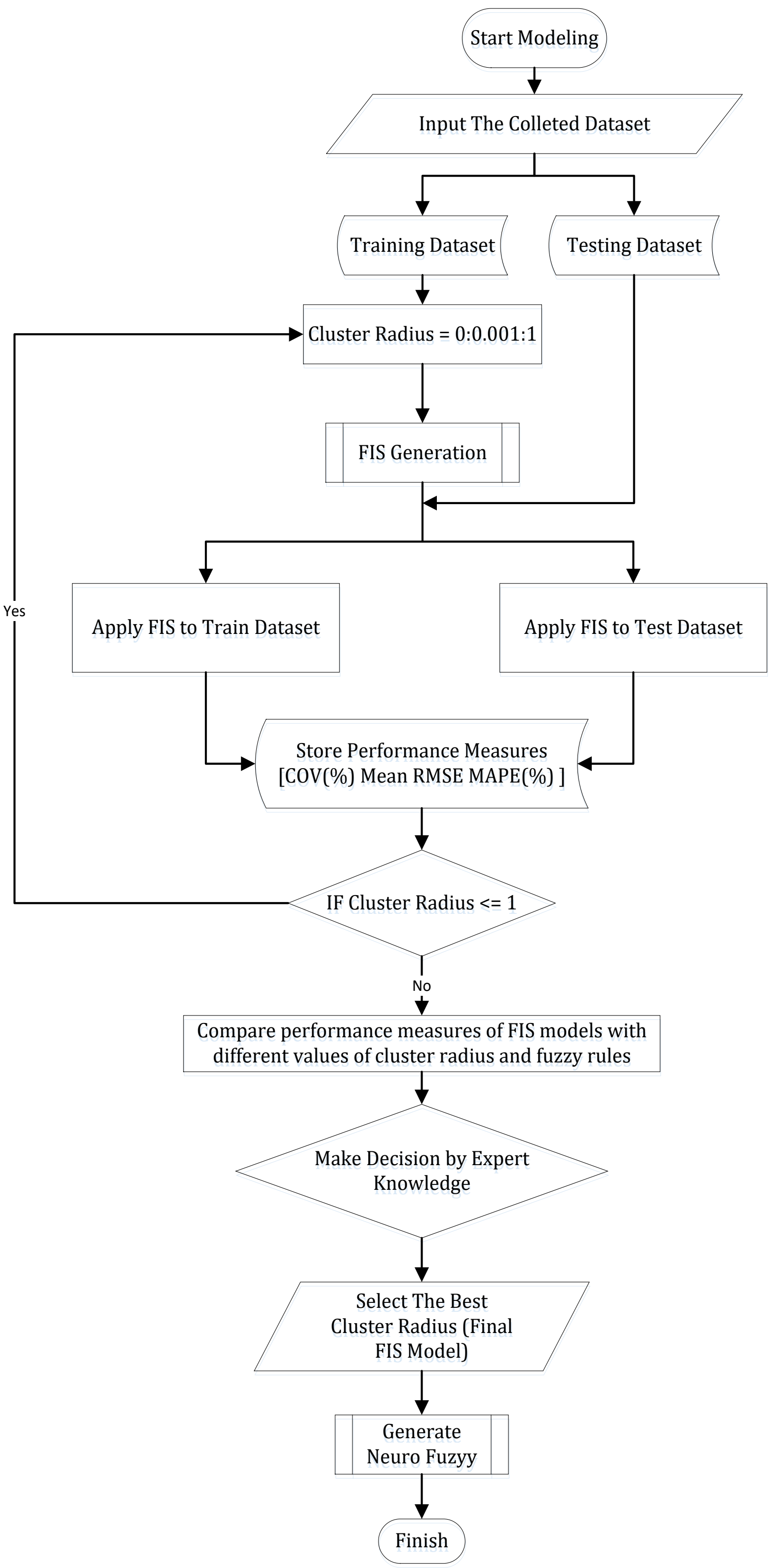

Figure 3-7: Flowchart of modeling the initial FIS using subtractive clustering

Fuzzy C-means (FCM) Clustering method is applied as illustrated in the following. To develop the initial FIS model, the Fuzzy C-means (FCM) clustering approach is applied to be compared to the subtractive clustering approach in the previous section. FCM is a very common and popular approach for fuzzy clustering. It defines a methodology for grouping data points to populate some multidimensional space into a specific number of different clusters. FCM assigns a membership degree for each cluster and iteratively updates the cluster centers and the membership degrees to minimize the objective function. The objective function is the distance from any given data point to a cluster center weighted by that data point's membership degree (Bezdek 1981).

In FCM, instead of changing the cluster radius as described in subtractive clustering, the number of rules (clusters) is changed to find the optimum number of clusters. Thus, in this research, the number of rules is changed within the range of 1 to 50 to find the optimum number of cluster centers that is equal to the number of fuzzy rules in the initial FIS model, as shown in Figure 3-8.

The errors of the developed FIS models are measured for each number of clusters in two separate groups: train and test datasets. Several error measures including MAPE, RMSE, and COV are calculated between the model results of the train and test datasets. The optimum model is chosen when the errors calculated for the test dataset are at their lowest but also as close as possible to train dataset. This approach ensures the generalization capability of the model and prevents the problem of overfitting (Nasrollahzadeh and Basiri 2014).

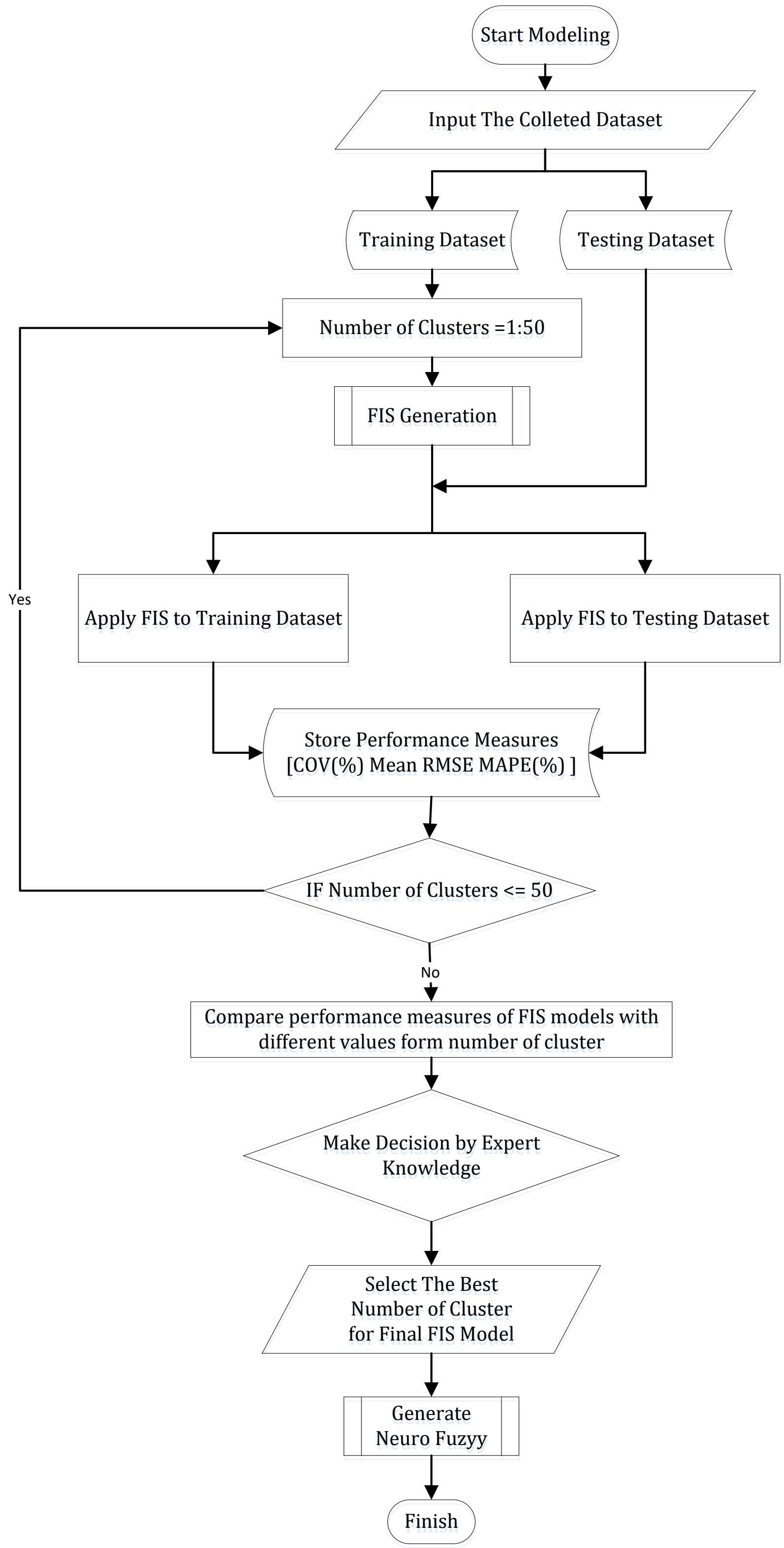

Figure 3-8: Flowchart of modeling initial FIS using FCM

The above approach of changing the number of clusters is used to select the best initial FIS models. The neuro-fuzzy technique is then utilized to optimize the initial FIS models' parameters to reduce model error as much as possible. The neuro-fuzzy inference system develops a FIS whose membership function parameters are tuned using a backpropagation algorithm in combination with the least squares method, similar to the approach applied for subtractive clustering. After developing the models for predicting KPIs using both subtractive clustering and FCM, the results of the models are compared using validation data to decide which method performs better. For this purpose, different error measures are compared based on the output of the developed models and the actual values of the validation data.

3.3.2 Artificial Neural Network Technique

In Artificial Neural Network technique is applied to estimate the KPIs of construction projects. The neural network can predict the non-linear and complex of unknown functions. As described in the literature review, the main advantage of ANN is its learning ability. ANN models can find relationships between inputs and outputs using training examples. The trained model can then be used to predict the outputs of new inputs.

In this research, the ANN model is used to predict the KPIs of the project. Six KPIs: Cost, Time, Quality, Safety, Client satisfaction, Project team Satisfaction are used. The input of the prediction models is 18 KPIs, 6 KPIs for each of the three stages. The outputs are 6 KPIs of the whole project. ANN models were developed, trained and tested in MATLAB 2016a.

Figure 3-9 represents the overall flowchart for developing and selecting the final model. The models were developed using three training algorithms available for neural networks: the Levenberg–Marquardt (LM), Bayesian Regularization (BR) and the Scaled Conjugate Gradient (SCG). Additionally, different models are developed using different neuron numbers. The neurons number is changed between 5 to 50 neurons with a spacing of 5. which leads to 10 models for each training algorithm. Considering the different training algorithms and neuron numbers, 30 different models are developed and the results compared.

The performance of the models is assessed based on the Coefficient of determination (R^2), the mean absolute error (MAE), the relative absolute error (RAE), the root relative square error (RRSE) and the mean absolute percentage error (MAPE) and the amounts of each error index.

R^2 is a coefficient for statistical analysis that ranges between [0, 1] and evaluates the total difference in percentage between the target value (t_i) and the predicted values (o_i) as shown in Equation 3-1. Higher values of R^2 indicate a better performing model. The MAE is an absolute measure and an alternative for the mean square error (MSE) that ranges from 0 to $+\infty$, calculated from Equation 3-2.

$$R^2 = 1 - \frac{\sum_i (t_i - o_i)^2}{\sum_i \left(t_i - \frac{1}{n}\sum_i t_i\right)^2} \tag{3-1}$$

$$MAE = \frac{1}{n}\sum_i |t_i - o_i| \tag{3-2}$$

The relative absolute error (RAE) and the root relative square error (RRSE) are also used to assess the performance of a forecasting model as shown in Equations 3-3 and 3-4 (Makridakis and Hibon 1995). Lower values of RAE and RRSE indicate better performance of the forecasting model.

$$RAE = \frac{\sum_i |t_i - o_i|}{\sum_i \left|t_i - \frac{1}{n}\sum_i t_i\right|} \tag{3-3}$$

$$RRSE = \sqrt{\frac{\sum_i (t_i - o_i)^2}{\sum_i \left(t_i - \frac{1}{n}\sum_i t_i\right)^2}} \tag{3-4}$$

The MAPE is usually used for evaluating the accuracy of a model and is calculated based on Equation 3-5. Lower values of MAPE indicate the higher accuracy of the model. Four ranges can be used to divide this index: high accuracy forecast (MAPE < 10%), sound forecast (10% < MAPE < 20%), feasible forecast (20% < MAPE < 50%), and error forecast (MAPE > 50%) (Jia et al. 2015).

$$MAPE = \frac{100}{n}\sum_i \frac{|t_i - o_i|}{t_i} \tag{3-5}$$

The five above mentioned error values are calculated for three different algorithms of BR, LM, and SCG with 5 to 50 neurons. The model with the lowest error values is chosen as the final model for predicting the whole project KPIs.

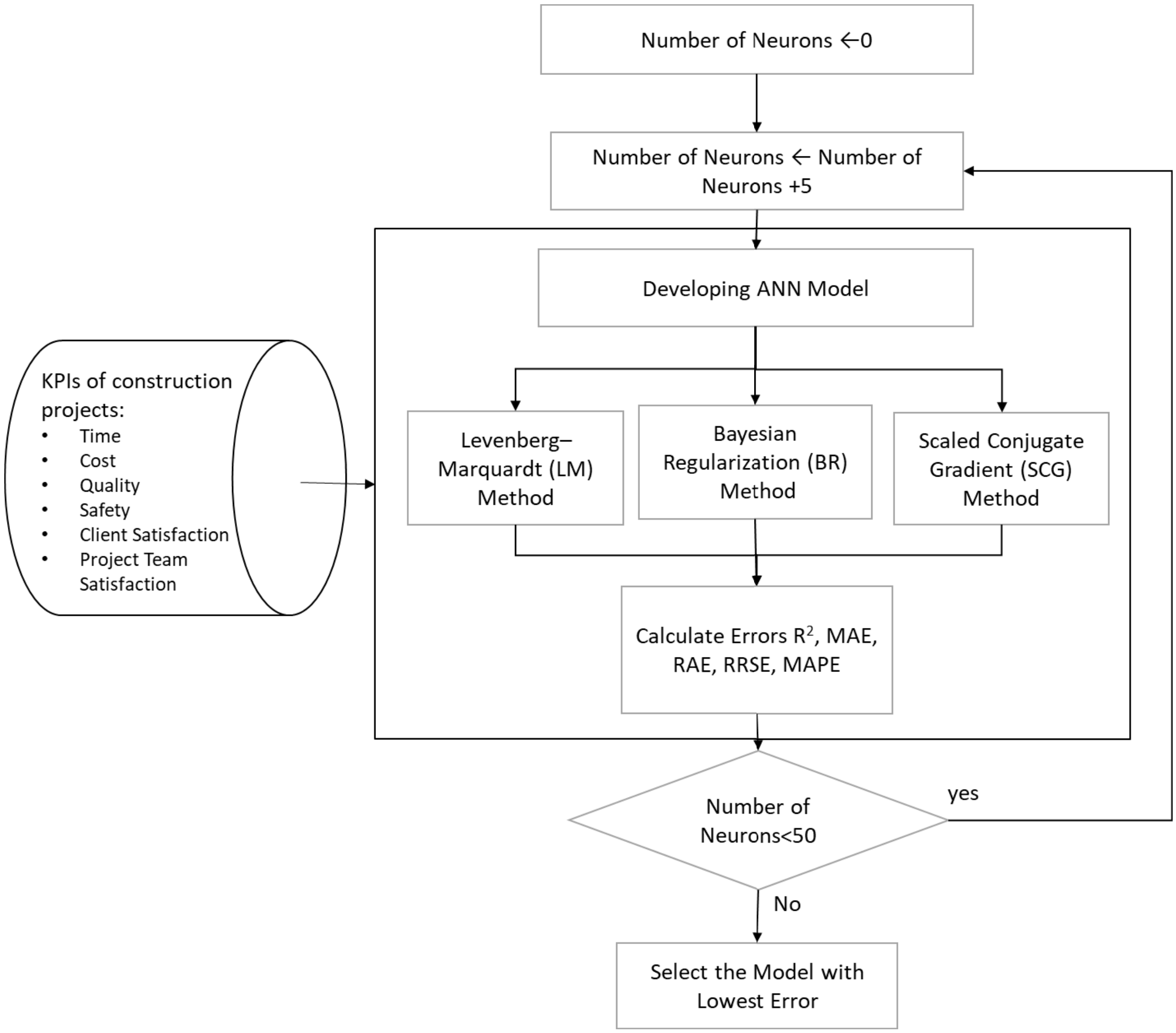

Figure 3-9: ANN model development steps

3.4 **KPIs Trend Forecasting Model**

This section represents a model for predicting the KPIs of the next stages and for the visualization of a project's KPIs trends. First, the KPIs of the next stage are predicted using the neuro-fuzzy approach. Next, the KPIs are predicted based on the project's progress percentage and the KPI trends are visualized, as illustrated in Figure 3-10.

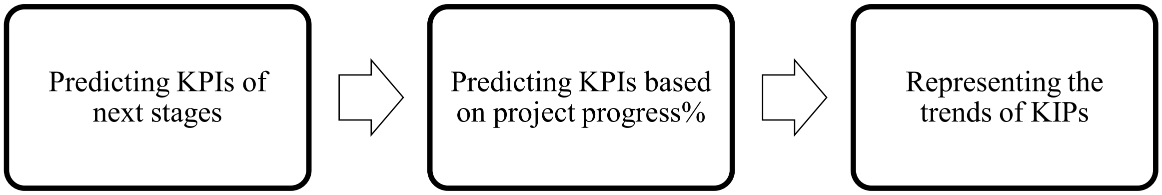

Figure 3-10: Steps for predicting KPIs of next stages and KPIs Trends

For predicting the KPIs of the next stages, three stages are developed in this research: Initial stage, Middle stage, and Finishing stage. When the project is in the initial stage, the main KPIs of the project at this stage are used to predict the KPIs of the next stages. As discussed in the previous section, 6 KPIs: Cost, Time, Quality, Safety, Client satisfaction, and Project team satisfaction are used here. Therefore, for the first stage, 12 models should be developed to predict the KPIs of the middle stage and finishing stage. When the project is in the middle stage, the KPIs of the initial stage and middle stage are available. Therefore, six prediction models should be developed to predict the KPIs of finishing stages based on the 12 available KPIs. Figure 3-11 represents the structure of the developed model for predicting the KPIs of the next stages. In this figure, the KPI_{ij} means the i^{th} KPI of the j^{th} stage, where the KPIs from 1 to 6 are Cost, Time, Quality, Safety, Client satisfaction, and Project team satisfaction, respectively. Stage 1 is the initial stage, stage 2 is the middle stage, and stage 3 is the finishing stage. For example, KPI_{23} means the time indicator of finishing the stage. For the development of these 18 prediction models, the neuro-fuzzy technique is utilized as discussed in the previous section.

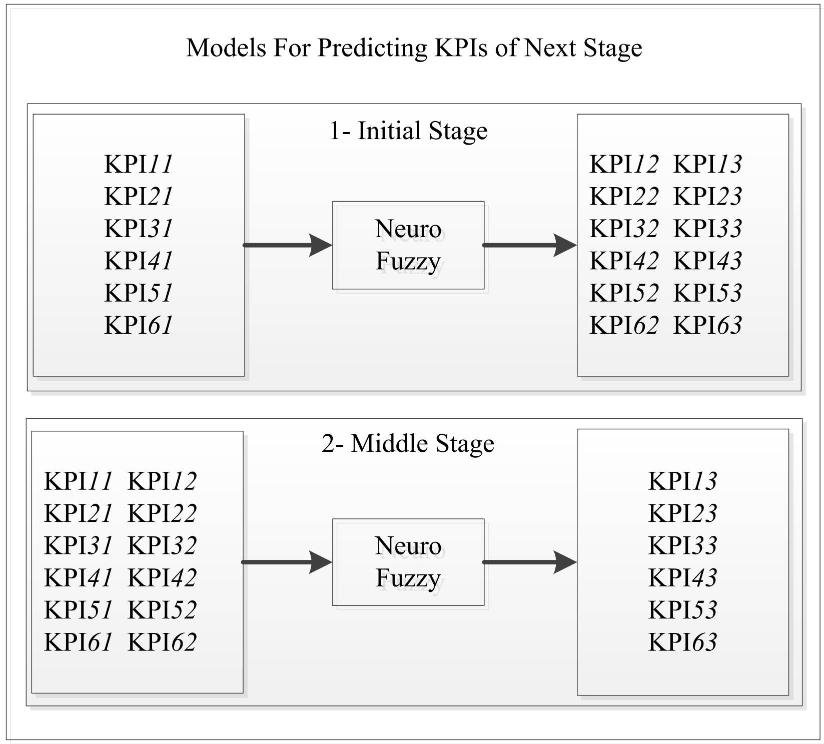

Figure 3-11: The prediction models for predicting the KPIs of the next stages

By using the developed prediction models, the KPIs of the initial stage, the middle stage, and the finishing stage are all made accessible. In order to represent the trend of KPI variations during the project, interpolation between the available data points can be used. Interpolation is a mathematical method for curve fitting on the available data points which allows predicting the values in points where data are not available. This research assumes the middle points of the ranges of each stage as the approximate point for performing interpolation. Therefore, 15%, 50%, and 85% are used for the KPIs of the initial stage, middle stage, and finishing stages, respectively. Figure 3-12 shows an example of how interpolation is performed using the KPIs of three stages to visualize a KPI trend.

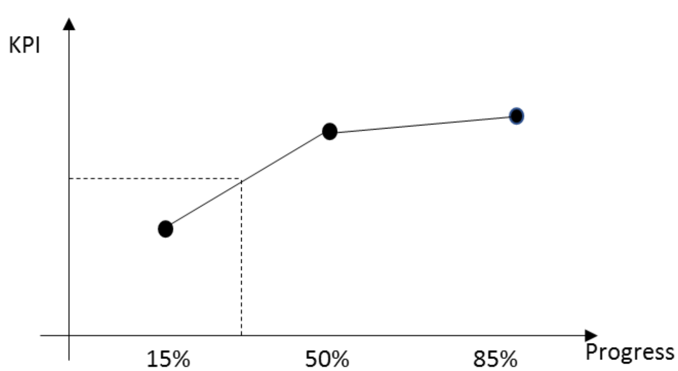

Figure 3-12: Interpolation for predicting KPIs trends

Visualizing KPIs can facilitate project management by providing whole project KPI trends. Using the above- developed interpolation technique, the KPIs trends of a project can be visualized during the project. Figure 3-13 illustrates the developed model for predicting the KPIs of the next stages and KPI trends.

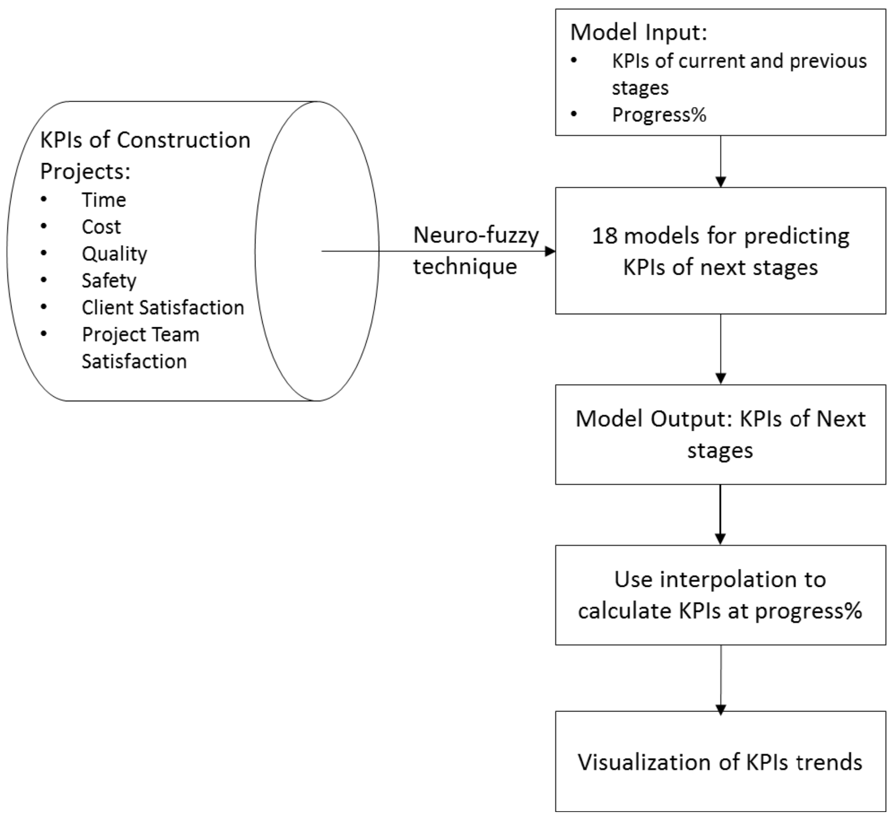

Figure 3-13: Model for predicting the KPIs of the next stages and KPI trends

3.5 PI Prediction Model

In this step, the KPIs predicted by the neuro-fuzzy technique are used to obtain the overall performance using a mathematical calculation, as shown in Equation 3-6. This mathematical calculation was done in the literature by Nassar and AbouRizk (2014) and Cha and Kim (2011). The values for the weights are determined using data by applying two different methods, the AHP and GA. The resulted weights of the KPIs depends on the location and the project type. The weights are generic for the same type and location of construction projects that use similar technologies. For example, if data are collected for building construction projects for a specific location, the resulted weights are generic only for building construction projects of that location.

$$\mathrm{PI} = w_1\mathrm{KPI}_1 + w_2\mathrm{KPI}_2 + w_3\mathrm{KPI}_3 + w_4\mathrm{KPI}_4 + w_5\mathrm{KPI}_5 + w_6\mathrm{KPI}_6 \quad 3\text{-}6$$

KPI_i: performance indicators w_i: weight of each indicator

During a construction project, the project manager collects the actual values for the selected six KPIs as the input to the model. Depending on the project's progress percentage, KPI values may be collected for the initial, middle or finishing stage of the project, as illustrated in Figure 3-14.

This collected data will be the model's input. After the data has been collected, the performance is predicted by the model, and the results of the model and the original plan should be compared. If a major deviation is found, an analysis should be performed to determine the cause of the deviation so that corrective actions can be selected to improve project performance. Therefore, this model enables managing the project performance by predicting project KPIs during three critical stages.

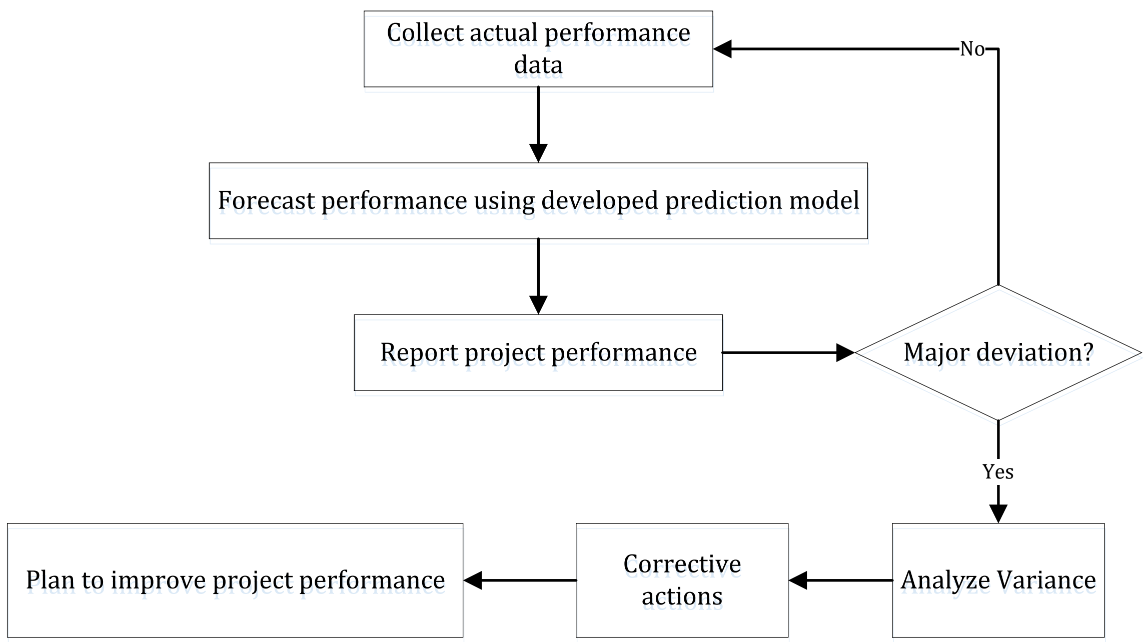

Figure 3-14: Steps for using the developed model

3.6 **Performance Optimization Model (POM) for selecting Corrective Action in Construction Projects**

Forecasting and monitoring the project performance indicator (PI) is very important in managing construction projects. When the deviation of actual vs. planned PI is faced, various corrective actions for the project activities may be considered for effective project performance control. Usually, numerous corrective actions are available to the activities of construction projects. However, evaluating all possible combinations of corrective actions and proposing an adequate corrective action plan is usually difficult in a timely and cost efficient manner (Nassar 2005). Additionally, various project aspects should be considered when providing an action plan to increase project performance, because one performance aspect cannot be improved independently of other aspects. The objective of this section is to develop a novel performance optimization model for selecting corrective actions to increase the overall project PI considering various project KPIs of construction projects. Also, the model is capable of optimizing a chosen KPI based on the user's request by selecting corrective actions.

The developed model can be applied to the initial and middle stage of the project. At these stages, the KPIs of the current and previous stages of the project will be used as the input. Developed models in Section 3.5 will be employed to predict the whole project KPIs and PI of the overall project.

There is not a standard or a commonly known value for the accepted PI of a construction project in the literature. Therefore, the acceptable PI value can be defined based on expert opinion for each project. In this research, the acceptable value of PI is assumed to be equal to the average of the project's PI in the collected data as calculated in Table 4-1.

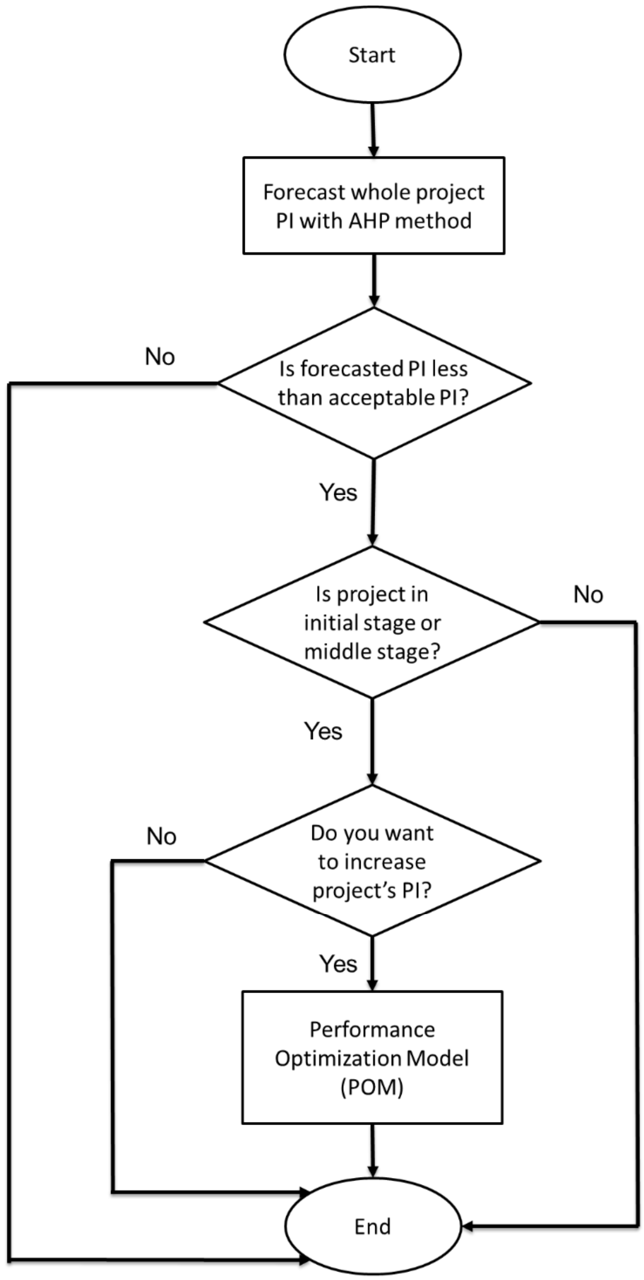

Figure 3-15: Performance Optimization Steps

The forecasted project PI is compared with the specified acceptable PI value. If the PI of the overall project is less than the specified acceptable value, the best scenario for the next stage could be found using the Performance Optimization Model (POM) (Figure 3-15). Additionally, the model will ask if the user prefers to optimize one specific KPI instead of the overall project PI. The POM component developed an optimized scenario. Figure 3-16 illustrates the flowchart of this process. First, the activities of the project to be completed during the next stage should be specified.

Also, a number of possible activity modes should be defined for each of the project activities for the next stage. Modes can represent different ways for resource allocation, construction or execution methods, or choice of different materials. These activity modes will impact the KPIs values of each activity. For each activity mode, six KPIs should be defined by experts that are cost, time, quality, safety, client satisfaction, and project team satisfaction. For instance, in one activity mode, the quality of activity could increase the time and cost of the project as well. A weight for each activity should also be defined by experts representing the importance of the activity performance in calculating the project KPIs of that stage. These weights will be employed to combine the KPIs of different activities (using weighted average) and calculate the project KPIs of that stage.

The best scenario is selected to maximize the overall project PI or project KPI using the GA method. In this research GA approach is used. The variable to be optimized is the scenario for choosing the activity modes of the next stage. The fitness function is the overall project PI. To calculate PI value, First, KPIs of next project stage (the stage for which the activity modes are defined) are calculated using the weighted average of KPIs of different activities. Neuro-fuzzy models described in section 3.3 are then used to calculate the KPIs of the whole project KPIs. Weights obtained from AHP method is then used to calculate the PI of the overall project.

GA is a powerful optimization algorithm which is based on defining genes and chromosomes. GA is specifically powerful when one tries to select among different features or modes. For example, Nassar (2005) and Zheng et al. (2005) applied GA to optimize the selection of activities for construction projects.

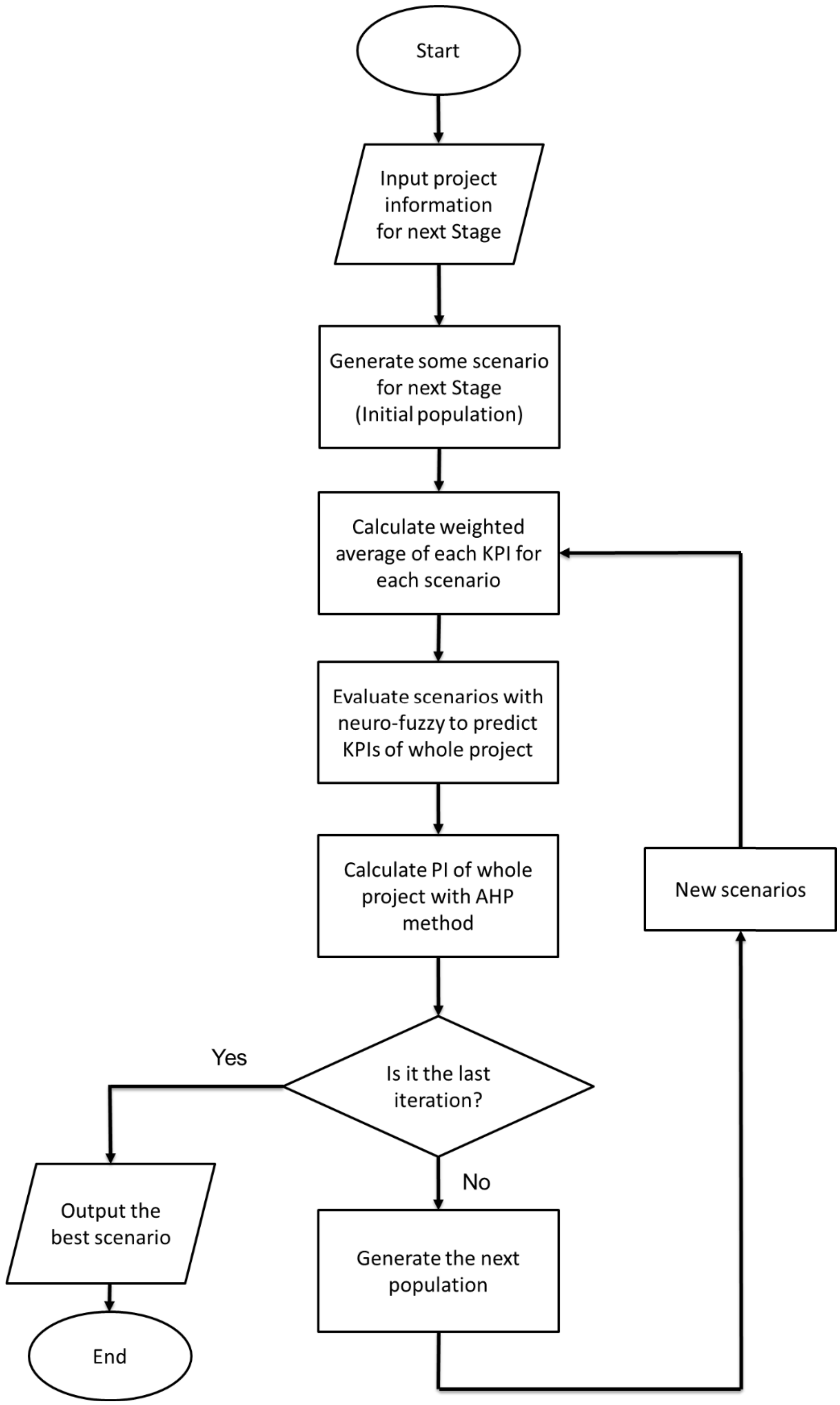

Figure 3-16: Performance Optimization Model (POM)

In the GA method, first, an initial population is generated by randomly generating some scenarios for the next stage. The fitness function is then applied to each of the scenarios. If the maximum number of iterations is not reached, crossover and mutation will be employed to generate a new population of scenarios. Otherwise, the best scenario is selected as the output of the POM.

It should be noted that the number of activities, activity modes, as well as the acceptable project PI value is flexible in the developed model. Therefore, these values are project dependent.

CHAPTER 4: DATA COLLECTION AND ANALYSIS

4.1 Chapter Overview

This Chapter describes the process of data collection as the first step for developing the models for predicting project performance. The data in this study were collected from experts . Two sets of questionnaires were designed. The first questionnaire was used to collect data from different projects. The second questionnaire was used to justify why six KPIs used in this research. Another 16 questionnaires are used in the next chapter to validate the model and to verify that the developed models work properly.

4.2 Questionnaires

In this research, two sets of questionnaires were sent to two different groups of experts. The first set was used to obtain the qualitative KPIs' amounts from different projects as well as whole project KPIs. The values of the 6 KPIs in three different stages of projects are used to develop and train the models. The second questionnaire was designed to select the six most important KPIs.

4.2.1 Questionnaire 1

To collect data on building construction projects, a questionnaire was designed and distributed to the owners of building construction projects in Tehran, Iran. Two-hundred questionnaires were distributed in 2017 to experts, of which 119 with consistent results were selected for analysis. All the responses were collected in two months. The questionnaire was designed in an online format on a Qualtrics website, a data collection platform. The questionnaire was designed based on the most important KPIs found in the literature. The experts were asked to qualitatively rank the performance of 6 KPIs in three stages in different construction projects. The questionnaire divided each project into three stages: an initial stage (0 to 30% physical progress), a middle stage (30% to 70% physical progress) and a finishing stage (70% to 100% physical progress). The first part of this questionnaire requests some general information from the respondents. The next part asks for information about the specific project that the questionnaire is being completed for, such as information about the project delivery method. The experts are then asked to rank the 6 KPIs' performance in each of the three stages of the project, as well as to rank the whole project's performance. In the end, there are some questions about any possible problems that the project has encountered. The data is collected using a 1 to 7 scale, where 1=Very Low, 2=Low, 3=Medium-Low, 4=Medium, 5=Medium-High, 6=High, 7=Very High (Dissanayake and Fayek 2008). The interpretation and the method for answering the questions are defined to the experts. For example, experts are asked to rank the time KPI based on its deviations from the original schedule. When Time (initial stage) is 1 or very low, it means that there is a time overrun in the initial stage of the project. Using quantitative scales allows soft computing methods to be applied to the qualitative data. The information is summarized in an excel table. Sample questions of the first questionnaire are shown in Figure 4-1. Complete questionnaire is available in Appendix A1.

In the initial stage (0 to 30% Physical Progress) of the project, what is the performance of each of the following indicator?

	Very Low	Low	Medium Low	Medium	Medium High	High	Very High
Cost	○	○	○	○	○	○	○
Time	○	○	○	○	○	○	○
Quality	○	○	○	○	○	○	○
Safety	○	○	○	○	○	○	○
Client Satisfaction	○	○	○	○	○	○	○
Project Team Satisfaction	○	○	○	○	○	○	○

In the middle stage (30% to 70% Physical Progress) of the project, what is the performance of each of the following indicator?

	Very Low	Low	Medium Low	Medium	Medium High	High	Very High
Cost	○	○	○	○	○	○	○
Time	○	○	○	○	○	○	○
Quality	○	○	○	○	○	○	○
Safety	○	○	○	○	○	○	○
Client Satisfaction	○	○	○	○	○	○	○
Project Team Satisfaction	○	○	○	○	○	○	○

In the finishing stage (70% to 100% Physical Progress) of the project, what is the performance of each of the following indicator?

	Very Low	Low	Medium Low	Medium	Medium High	High	Very High
Cost	○	○	○	○	○	○	○
Time	○	○	○	○	○	○	○
Quality	○	○	○	○	○	○	○
Safety	○	○	○	○	○	○	○
Client Satisfaction	○	○	○	○	○	○	○

Figure 4-1: Sample questions from KPIs amount questionnaire

Most of the experts who filled the questionnaires are active in the construction area and have 10 to 20 years of experience. Also, 70 percent of the projects are residential buildings, which is the research target. Data about the respondent's information is available in Appendix A3.

Sixty (60) percent of the collected projects have a major time delay, 61 percent of the collected projects have faced a sudden increase in prices during the project. Most of the projects belong to the private sector. This information is available in Appendix A3 using different charts.

Table 4-1 shows the statistical descriptions of all parameters included in the questionnaires' database**.** The quantities collected from the questionnaires are then used to train and develop a neuro-fuzzy model for predicting whole project KPIs and applying the AHP and GA methods for calculating the project PI.

Table 4-1: Statistics of collected data on building construction projects based on questionnaires

	Parameter	Min.	Max.	Mean	COV (%)
Initial stage	*Cost*	2.00	7.00	4.69	34.94
	Time	1.00	7.00	4.73	35.59
	Quality	3.00	7.00	5.65	18.02
	Safety	3.00	7.00	5.54	19.13
	Client satisfaction	3.00	7.00	5.66	17.02
	Project team satisfaction	3.00	7.00	5.53	16.04
Middle stage	*Cost*	2.00	7.00	4.95	23.70
	Time	1.00	7.00	5.08	24.52
	Quality	3.00	7.00	5.60	18.58
	Safety	3.00	7.00	5.26	19.48
	Client satisfaction	2.00	7.00	5.51	19.52
	Project team satisfaction	3.00	7.00	5.30	16.14
Finishing stage	*Cost*	2.00	7.00	5.27	23.04
	Time	2.00	7.00	5.14	27.99
	Quality	2.00	7.00	5.79	19.63
	Safety	2.00	7.00	5.53	21.72
	Client satisfaction	2.00	7.00	5.61	21.60
	Project team satisfaction	2.00	7.00	5.33	20.52
Whole project	*Cost*	2.00	7.00	4.98	23.70
	Time	2.00	7.00	4.76	26.56
	Quality	3.00	7.00	5.76	18.64
	Safety	3.00	7.00	5.42	20.51
	Client satisfaction	2.00	7.00	5.61	20.06
	Project team satisfaction	2.00	7.00	5.31	20.39
Performance indicator (PI)		3.00	7.00	5.29	17.02

Note: Very low=1, Low=2, Medium low=3, Medium=4, Medium high=5, High=6, Very high=7

4.2.2 Questionnaire 2

Questionnaire 2 was released in October 2017 and the results collected in three weeks. The questionnaire was designed in an online format on the Qualtrics website, a data collection platform.

These questionnaires were distributed to 34 experts and collected so that the results could be used to select the most important KPIs.

Questionnaire 2 has two main parts. In the first part, some general information is requested from the respondents. In the second part, respondents are requested to select and rank the importance of twenty KPIs according to seven qualitative levels. Figure 4-2 indicates sample questions from KPIs'selection questionnaire. The complete questionnaire is available in Appendix A2.


What is the importance of the KPIs during the whole projects?

	Very Low	Low	Medium Low	Medium	Medium High	High	Very High
Cost	O	O	O	O	O	O	O
Time	O	O	O	O	O	O	O
Quality (Technical Specification)	O	O	O	O	O	O	O
Safety	O	O	O	O	O	O	O
Client Satisfaction	O	O	O	O	O	O	O
Project Team Satisfaction	O	O	O	O	O	O	O
Productivity (Efficiency)	O	O	O	O	O	O	O
Environment	O	O	O	O	O	O	O
Profitability (Contractor)	O	O	O	O	O	O	O
User Satisfaction	O	O	O	O	O	O	O
Communication (Collaboration)	O	O	O	O	O	O	O
Rework and Defects	O	O	O	O	O	O	O
Information Management	O	O	O	O	O	O	O
Billing	O	O	O	O	O	O	O
Predictability (Time-Cost)	O	O	O	O	O	O	O

Figure 4-2: Sample questions from KPIs selection questionnaire

From the results, it was clear that the six first KPIs received 90 to 40 percent of the scores, but the seventh KPI had a score of 27, and the other KPIs had scores between 20 to 27 percent, as can be seen in Figure 4-3. With this tangible difference between KPI number 6 and the next-scoring KPI, it is logical to select the first 6 KPIs to develop the model. These six KPIs are cost, time, quality, safety, client satisfaction, and project team satisfaction. It can be concluded that the experts find the six first KPIs to be much more important than the others.

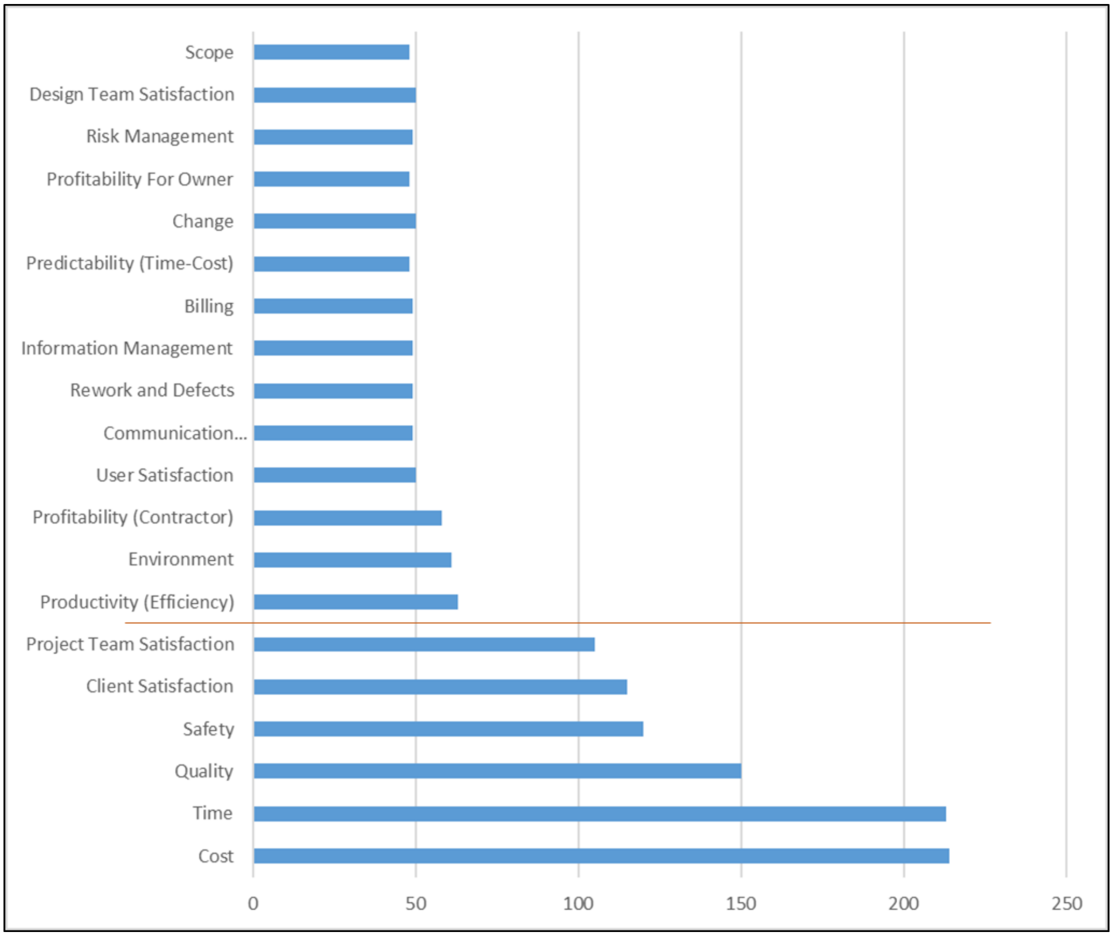

Figure 4-3: KPI scores from Questionnaire 2

CHAPTER 5: MODEL DEVELOPMENT AND IMPLEMENTATION

5.1 Chapter Overview

This chapter presents the implementation and model development of this research. The KPI prediction models are explained in Section 5.2. Both neuro-fuzzy and ANN techniques are applied to predict the KPIs. The neuro-fuzzy technique is implemented using two different clustering methods: FCM and subtractive clustering. A comparison between these two methods is performed at the end of that section to find the best model. Section 5.3 discusses KPI trend forecasting. This section includes two components: models to forecast the KPIs of the next stage and the visualization of KPIs trends. The model developed for predicting a project performance indicator (PI) is elaborated in section 5.4. In this section, AHP and GA methods are applied to define KPIs weights. Section 5.5 explains the model development for optimization of project PI based on KPIs using a genetic algorithm. A comparison of the results is performed to find the best method. Validation of the developed models is illustrated in Sections 5.6.

5.2 KPIs Prediction Models

In this research, A qualitative method is developed for measuring project performance. Then soft computing methods are then applied for forecasting the key performance indicators of a project. Three different techniques are applied, the neuro-fuzzy technique with FCM and with subtractive clustering, and the ANN method. The results of the different techniques are compared at the end of this section to select the best approach for predicting KPIs.

Figure 5-1 illustrates the whole process of the developed models that by having the key performance indicators (KPIs) of each stage, the model can forecast the KPIs of the whole project. In this figure, KPI i=1 to 6 are cost, time, quality, safety, client satisfaction, and project team satisfaction, respectively, and n=1 to 3 represents the initial, middle and finishing stages, respectively.

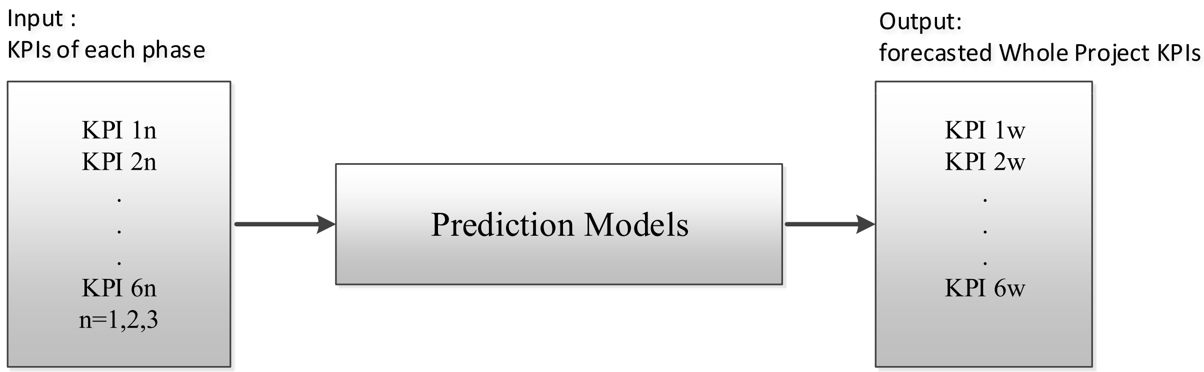

Figure 5-1: Inputs and outputs of KPIs prediction models

Measuring project performance in this research is based on the owner's viewpoint, and the focus is on DB (Design and Build) and DBB (Design Bid Build) Project Delivery Methods (PDM).

5.2.1 Neuro-Fuzzy Technique

As described in the methodology (section 3.3.1), this study develops a model that can forecast the performance of a project using KPIs by implementing the neuro-fuzzy technique in MATLAB using subtractive clustering and FCM clustering methods. To develop the model, data were collected by questionnaires in three phases of construction projects, for six KPIs. A large database containing the results of the building projects, assembled from extensive use of questionnaires, is used to develop the neuro-fuzzy models. The questionnaire is used for collecting data because of the difficulty in finding approximately one hundred case studies that have six KPIs in three stages of the project. As described in the previous chapters, the forecasting models were developed based on three stages. Six models are trained for each stage, and so 18 FIS models are trained to obtain the prediction model.

As can be seen in Figure 5-2, in the middle stage, 12 inputs are used to train the model, with one output. The finishing stage has 18 inputs and one output. The collected data are used to train the model to predict the six KPIs of the whole project.

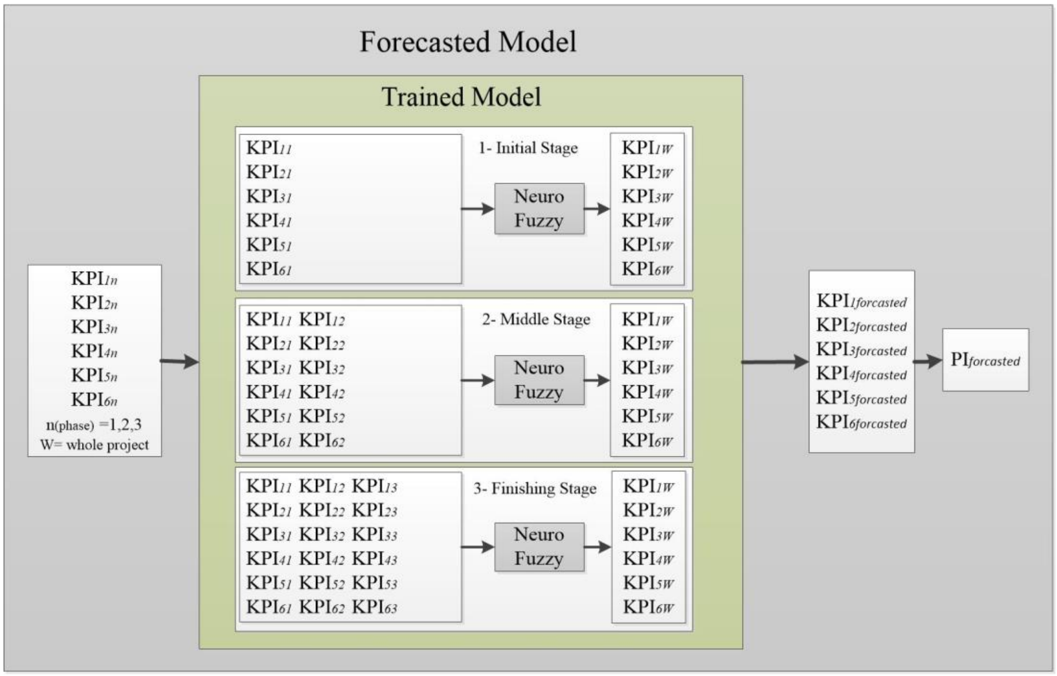

Figure 5-2: Trained and forecasted model

The subtractive Clustering method is applied as explained in the following. In developing a neuro-fuzzy model using subtractive clustering, the codes are written for generating the models and do not use the toolbox of MATLAB. The main reasons why the codes are written while generating the models is that first, the cluster radius amount is optimized, although by using toolbox the radius should be given by the user. Secondly, data division is not done randomly by the user to divide data to train and test data.

Figure 5-3 shows the general structure of our neuro-fuzzy model, and the Fuzzy logic designer window can be seen in Figure 5-4. Membership Function Editor is shown in Figure 5-5.

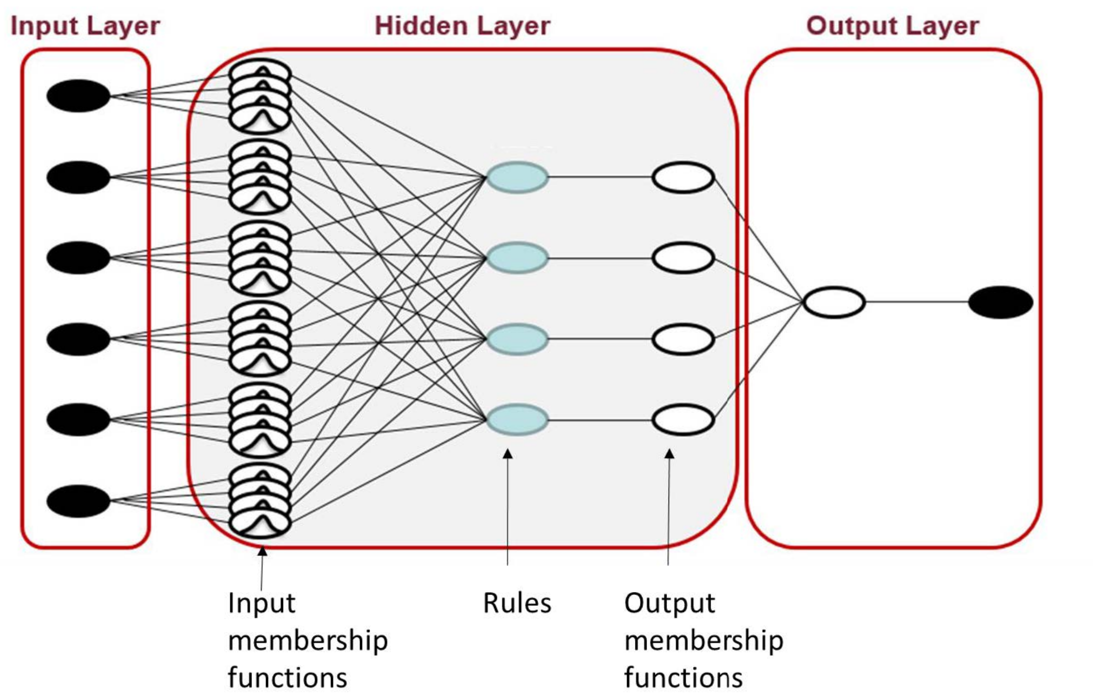

Figure 5-3: General structure of the Neuro-Fuzzy model

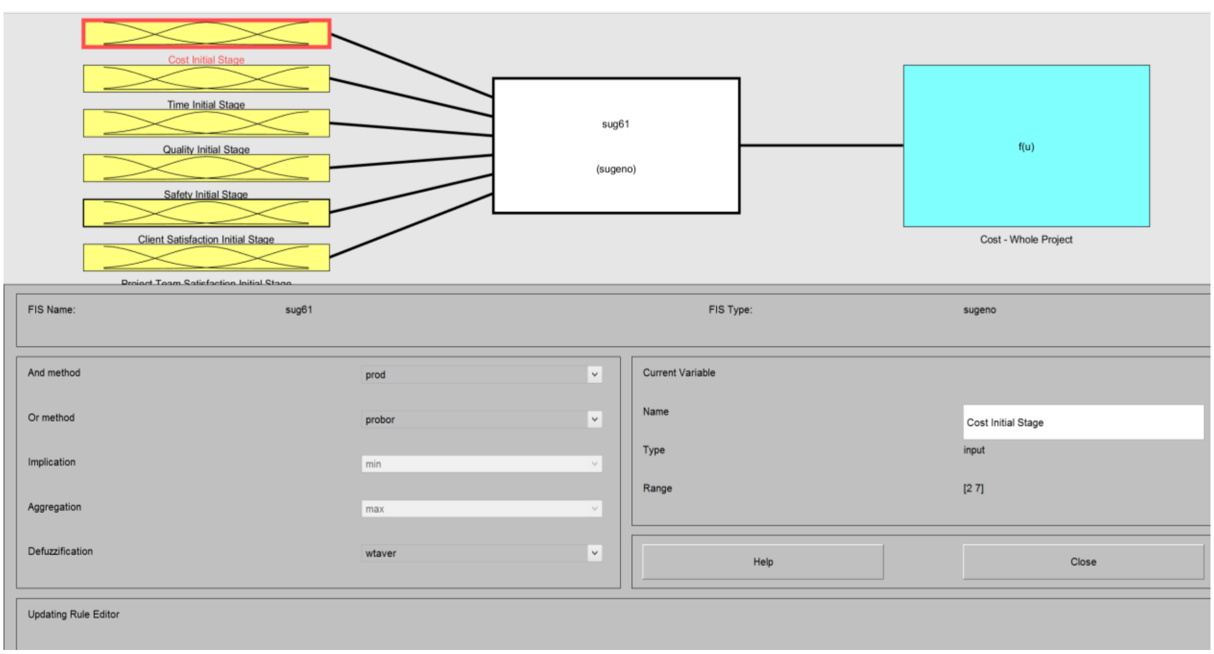

Figure 5-4: Fuzzy logic designer in the model developed using subtractive clustering

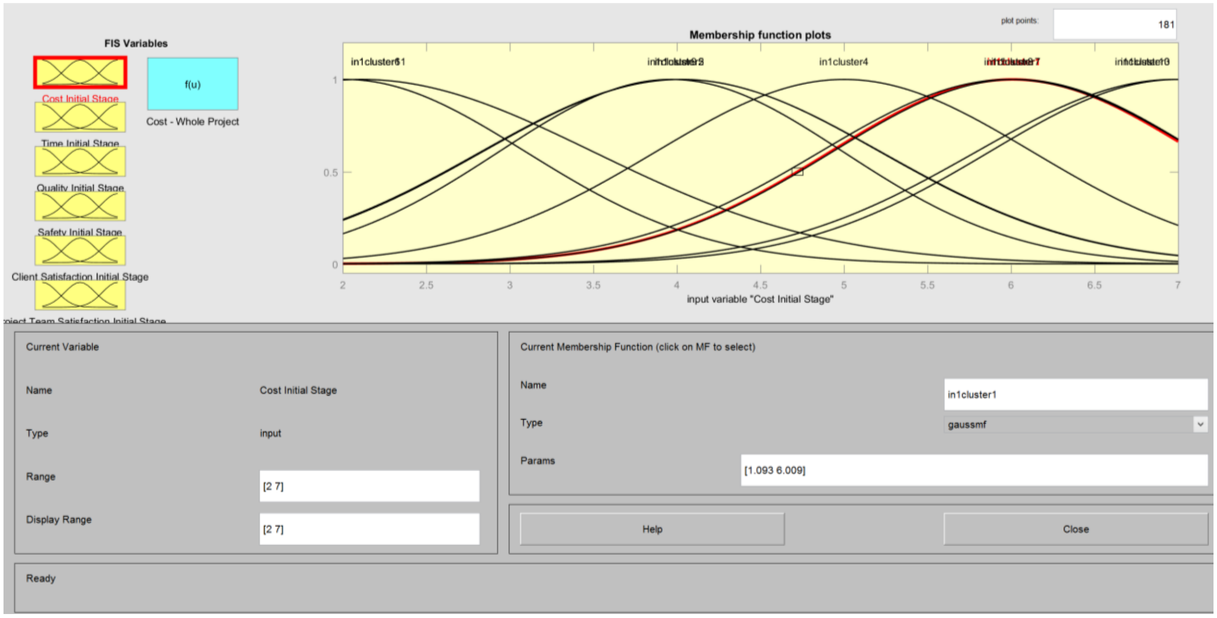

Figure 5-5: Membership Function Editor in the model developed using subtractive clustering

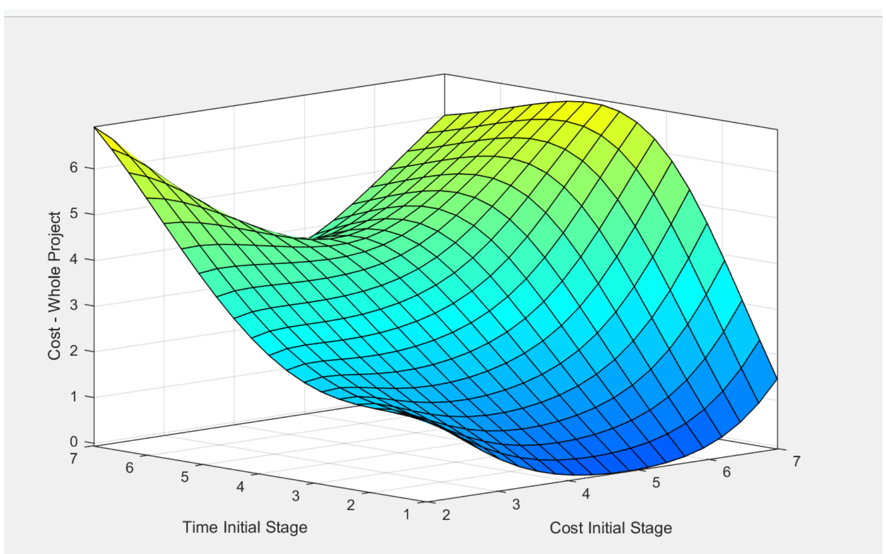

Figure 5-6: Surface Viewer in the model developed using subtractive clustering

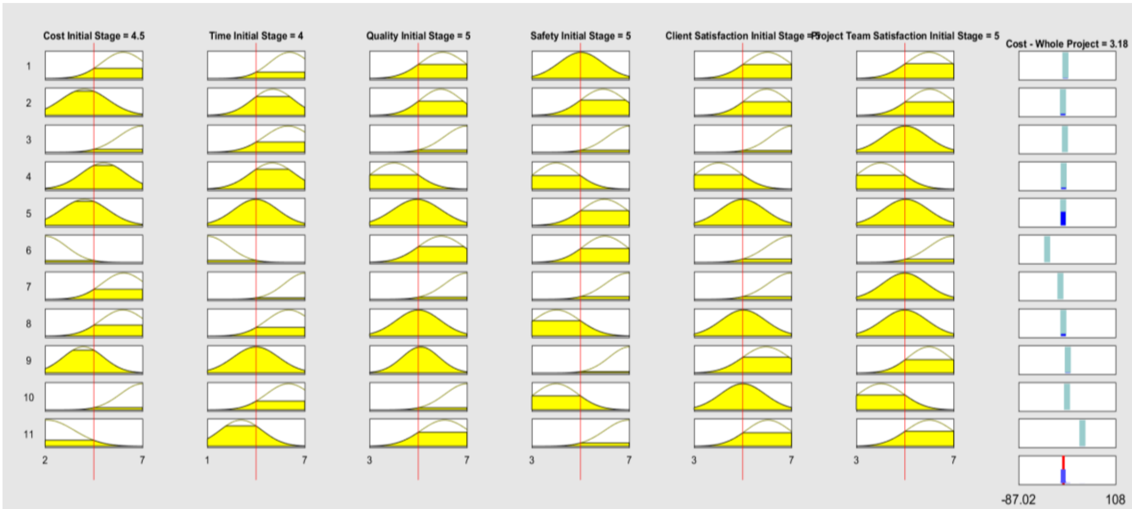

Figure 5-7: Rule viewer in the model developed using subtractive clustering

Figure 5-6 illustrates surface viewer of the model. All of the figures above are related to the neuro-fuzzy model of the initial stage using subtractive clustering. Figure 5-7 show rule viewer windows, respectively, in MATLAB. After generating the FIS, we train the FIS and can see the performance prediction result in Figure 5-8.

```
---
>>> From which Stage You Want Predicting The Whole Project KPIs?
>(Initial   stage:  0% to 30 % Physical Progress = Type 1)
>(Middle    stage: 30% to 70 % Physical Progress = Type 2)
>(Finishing stage: 70% to 100% Physical Progress = Type 3)
According to the description, the number to be entered:1
---
In the Initial Stage of the project, what is the performance of each of the following indicator?
(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very High=7)
Cost(Type 2 To 7) : 3
Time(Type 1 To 7) : 4
Quality(Type 3 To 7) : 5
Safety(Type 3 To 7) : 4
ClientSatisfaction(Type 3 To 7) : 5
ProjectTeamSatisfaction(Type 3 To 7) : 6
---

ans =
```

	Forecasted_KPIs_Of_The_Whole_Project
Cost	2.2577
Time	3.03
Quality	5.2933
Safety	5.1557
Client Satisfaction	5.1703
Project Team Satisfaction	6.22

Figure 5-8: Example of input and output of the forecasting model

First, the model is trained with the data from the questionnaire, and after that, the model uses to forecast the whole project KPIs for the other construction projects. The developed model includes 18 trained FIS.

The number of rules is calculated by subtractive clustering in a Sugeno-type of fuzzy inference system and then tuned by using the neuro-fuzzy technique. Figure 5-9 shows the rule description of the neuro-fuzzy model for predicting cost KPI using subtractive clustering in the initial stage which has six inputs and one output. As illustrated in this figure, 11 rules are generated for this neuro-fuzzy model. Similar neuro-fuzzy models are developed to predict the other 5 KPIs. This is because the fuzzy model (Sugeno type) is based on multiple inputs and only one output. The number of rules for predicting each of the KPIs using subtractive clustering approach is summarized in Table 5-1. This number of rules is the result of optimizing the radius value in subtractive clustering approach.

In each modeling, the six KPIs of the initial stage are the input of the model, and one of each KPIs of the whole project is the output of the model. For example, in this Figure, six KPIs of the initial stage are the inputs, and the output is the cost of the whole project. This is done to train the model. So as the model is based on 6 KPIs, for initial stage, six models should be trained.

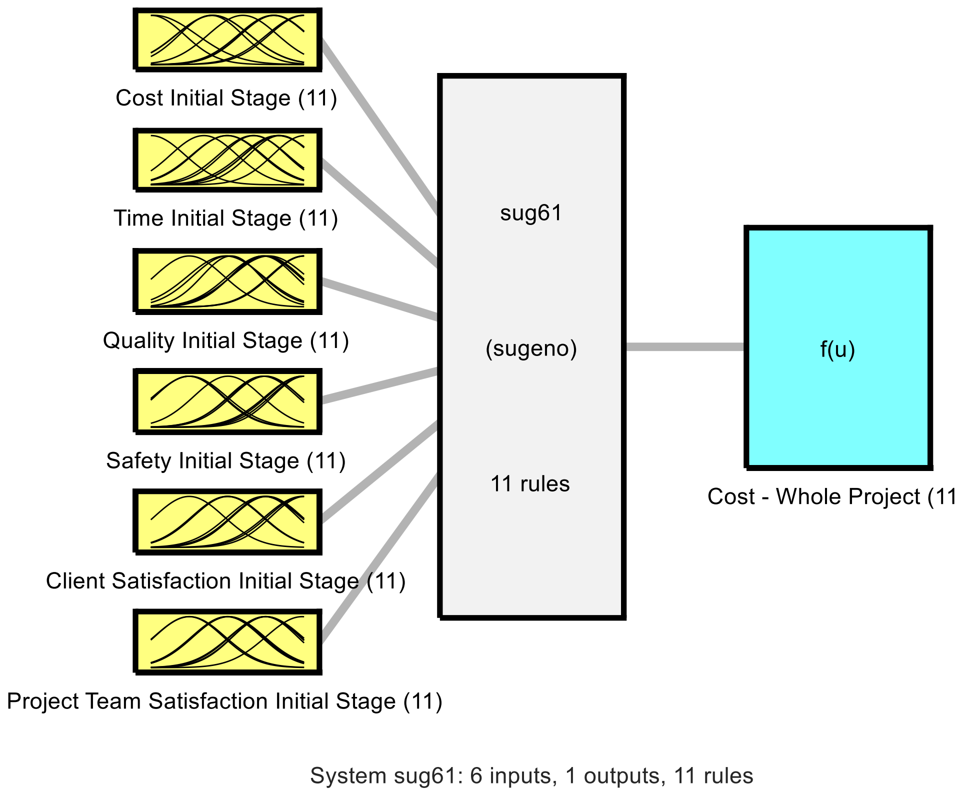

Figure 5-9: Neuro-fuzzy model using subtractive clustering in the initial stage

Table 5-1: Number of rules in neuro-fuzzy models developed using subtractive clustering method for the initial stage

Number	Model name	Input	Number of Rules	Output
1	MODEL11	6 KPIs of the initial stage	11	Cost indicator of the whole project
2	MODEL12	6 KPIs of the initial stage	14	Time indicator of the whole project
3	MODEL13	6 KPIs of the initial stage	22	Quality indicator of the whole project
4	MODEL14	6 KPIs of the initial stage	5	Safety indicator of the whole project
5	MODEL15	6 KPIs of the initial stage	5	Client satisfaction indicator of the whole project
6	MODEL16	6 KPIs of the initial stage	5	Project team Satisfaction indicator of the whole project

Fuzzy C-means (FCM) Clustering method is applied as illustrated in the following. In developing the neuro-fuzzy model using FCM, the codes written in generating the models. Function “genfis3” in MATLAB is employed to developed models using FCM technique. Eighteen neuro-fuzzy models are developed. The fuzzy logic designer is illustrated in Figure 5-10, and the membership function editor is shown in Figure 5-11. As illustrated in Figure 5-11, the number of membership functions is greater in the FCM approach compared with the subtractive clustering approach described in the previous section, resulting in a more complicated fuzzy rule-based system.

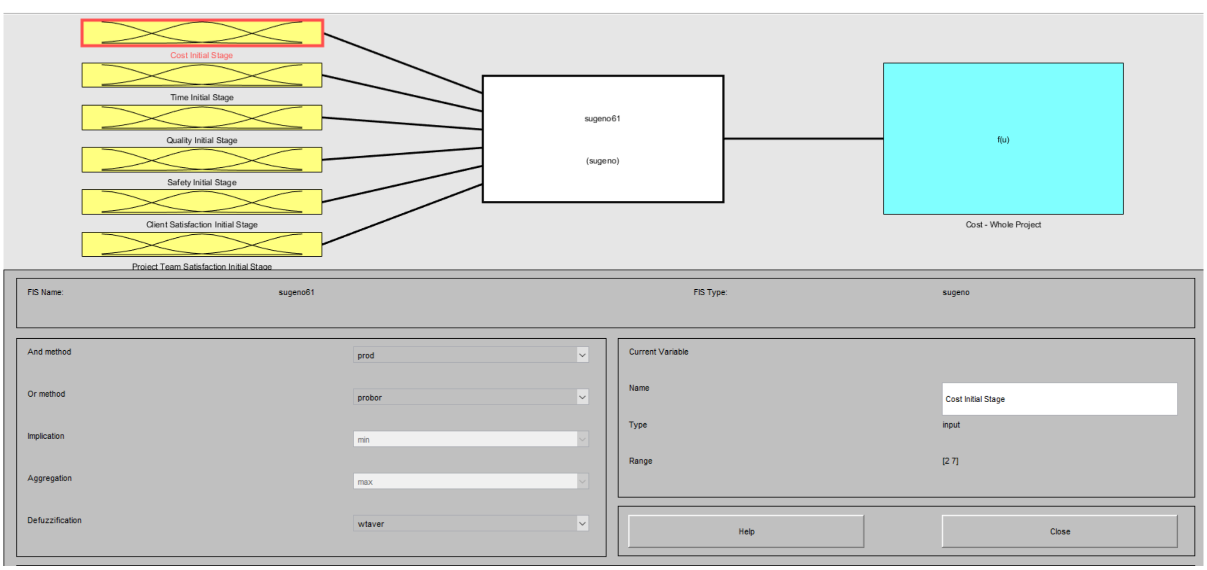

Figure 5-10: Fuzzy logic designer in the model developed using FCM

Figure 5-11: Membership Function Editor in the model developed using FCM

Figure 5-12 illustrates surface viewer of the model. All the figures are related to neuro-fuzzy for initial stage using FCM. Figure 5-13 show rule viewer windows in MATLAB. This figure shows an example of fuzzy rules developed in the MATLAB fuzzy inference system.

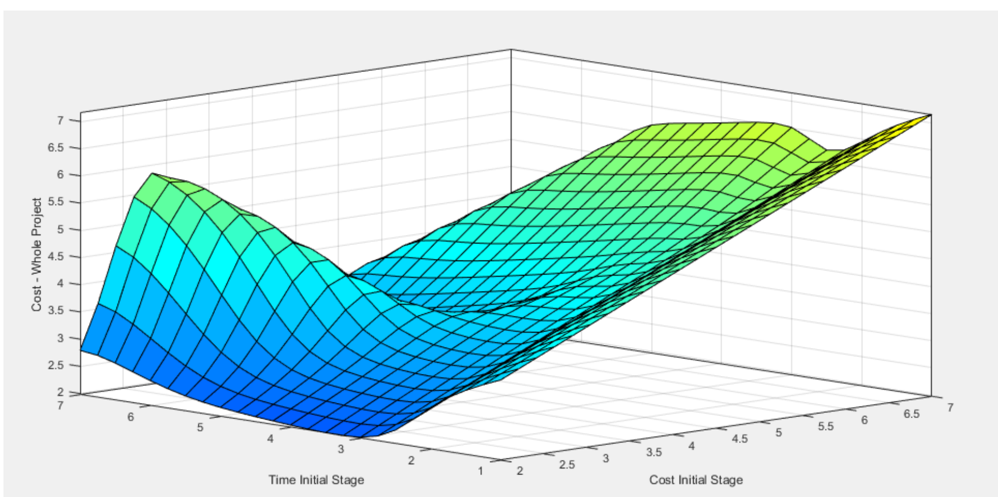

Figure 5-12: Surface Viewer in the model developed using FCM

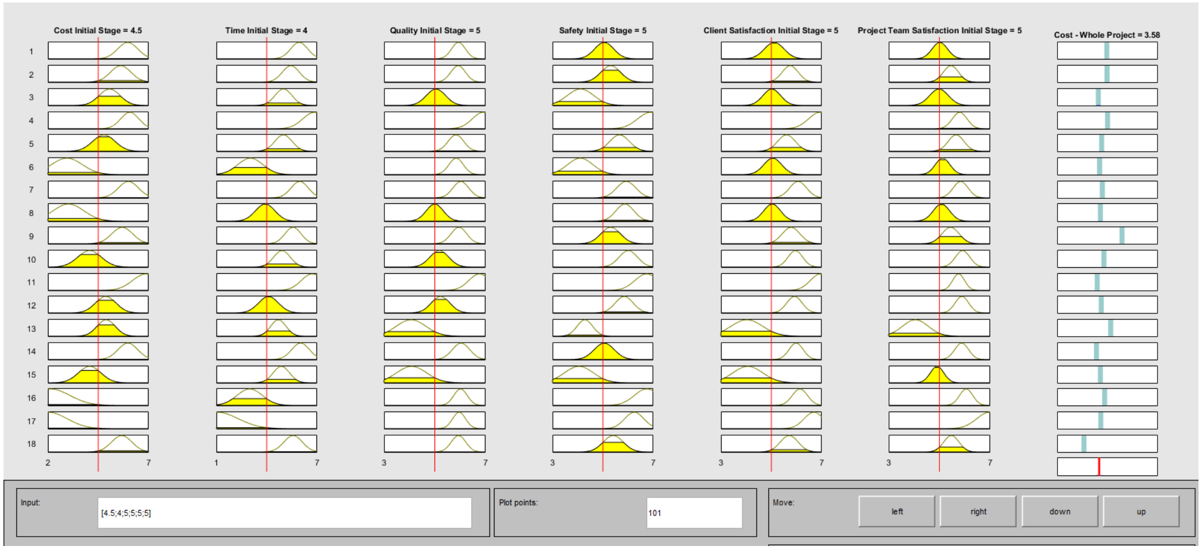

Figure 5-13: Rule viewer in the model developed using FCM

Figure 5-14 shows the rule description of the neuro-fuzzy model for predicting cost KPI using FCM in the initial stage, which has six inputs and one output. In this figure, six KPIs of the initial stage are the inputs, and the output is the cost of the whole project. Similar neuro-fuzzy models are developed to predict the other 5 KPIs. The number of rules for predicting each of the KPIs in the initial stage using FCM approach is summarized in Table 5-2. This number of rules is the result of optimizing the number of clusters in the FCM method.

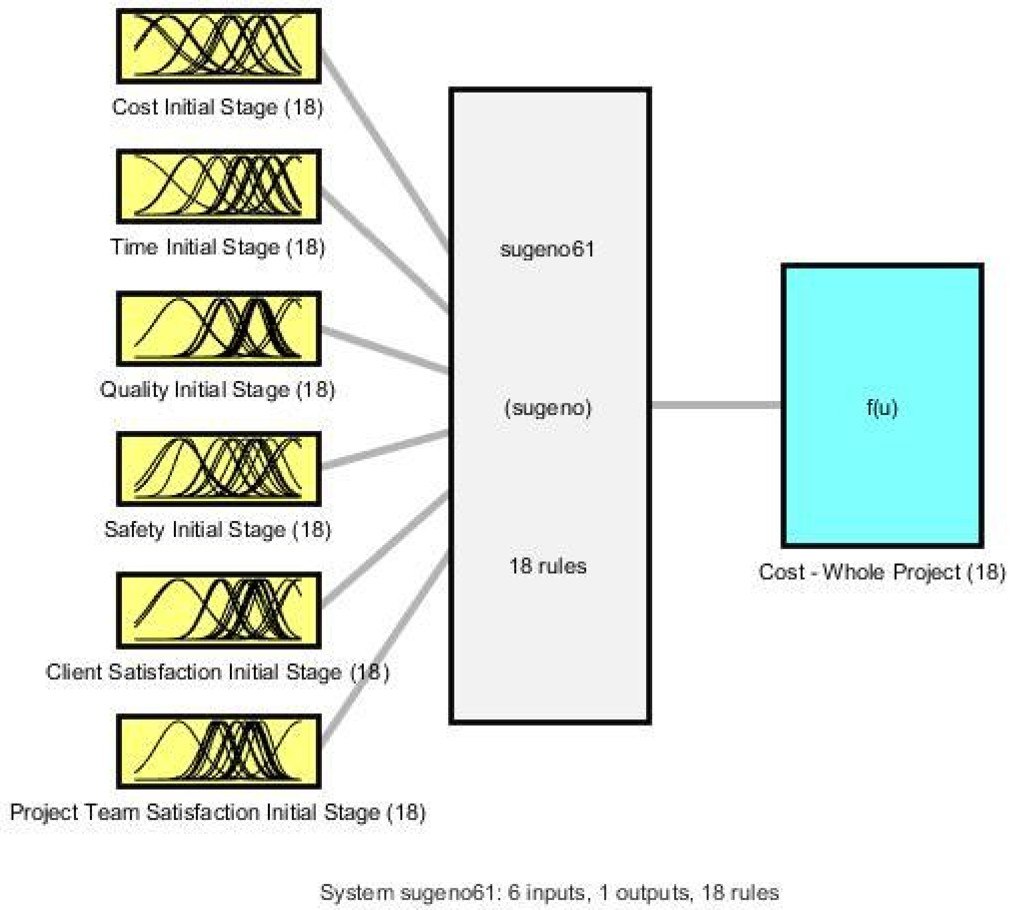

Figure 5-14: Neuro-fuzzy model using FCM in the initial stage

Table 5-2: Number of rules in neuro-fuzzy models developed using the FCM method for initial stage

Number	Model name	Input	Number of Rules	Output
1	MODEL11	6 KPIs of the initial stage	18	Cost indicator of the whole project
2	MODEL12	6 KPIs of the initial stage	21	Time indicator of the whole project
3	MODEL13	6 KPIs of the initial stage	44	Quality indicator of the whole project
4	MODEL14	6 KPIs of the initial stage	13	Safety indicator of the whole project
5	MODEL15	6 KPIs of the initial stage	23	Client satisfaction indicator of the whole project
6	MODEL16	6 KPIs of the initial stage	37	Project team Satisfaction indicator of the whole project

The models developed with the FCM technique are then compared with the models developed with subtractive clustering using validation data in Section 5.6.

5.2.2 ANN Technique

As described in the research methodology, the artificial neural network (ANN) technique is also applied to predict the KPIs of the whole project. Different numbers of neurons and training algorithms were used to find the best model for predicting the KPIs.

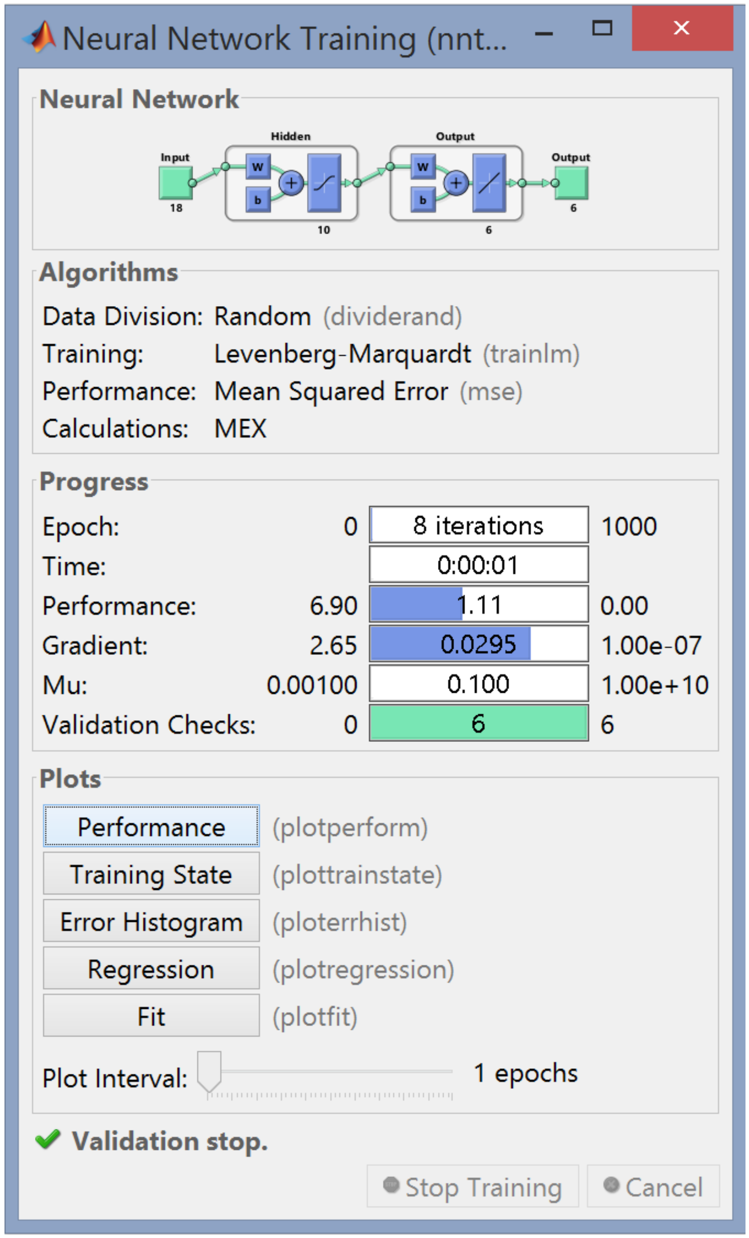

Figure 5-15: Sample structure of the neural network in MATLAB

The input of the developed models are 18 KPIs identified in the questionnaire in three stages, and the output of the model is the 6 KPIs of the whole project, as displayed in Figures 5-15 and 5-16.

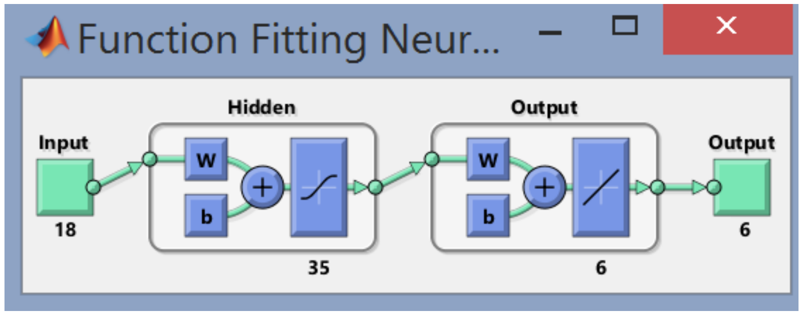

Figure 5-16: The structure of the neural network

Several ANN models were developed by changing the number of neurons. Also, three different algorithms are used for training models, namely: Levenberg–Marquardt (LM), Bayesian Regularization (BR), and Scaled Conjugate Gradient (SCG) algorithms. For each ANN model, ten different number of neurons (5, 10, 15, ..., 50) with the one hidden layer is tested. The performance of the models was evaluated based on different error values: R^2, MAE, RAE, RRSE,(Fanaei et al. 2018).

Figure 5-17 and Figure 5-18 represent the comparisons of MAE, R^2 between each of the ten models and three different algorithms LM, BR, and SCG. Also, the comparisons of other error measures including RAE, and RRSE is presented in Appendix C. As it is illustrated, among all errors, the model with 35 neurons when using BR algorithm has the lowest error value. Also, this model has the highest value for Coefficient of determination (R^2). This model has high accuracy forecast model which mean absolute error (MAE) is 0.059, and the amounts of RAE and RRSE are very small. Therefore, the BR model with 35 neurons has the best performance and is chosen as the final model for predicting the KPIs of the project.

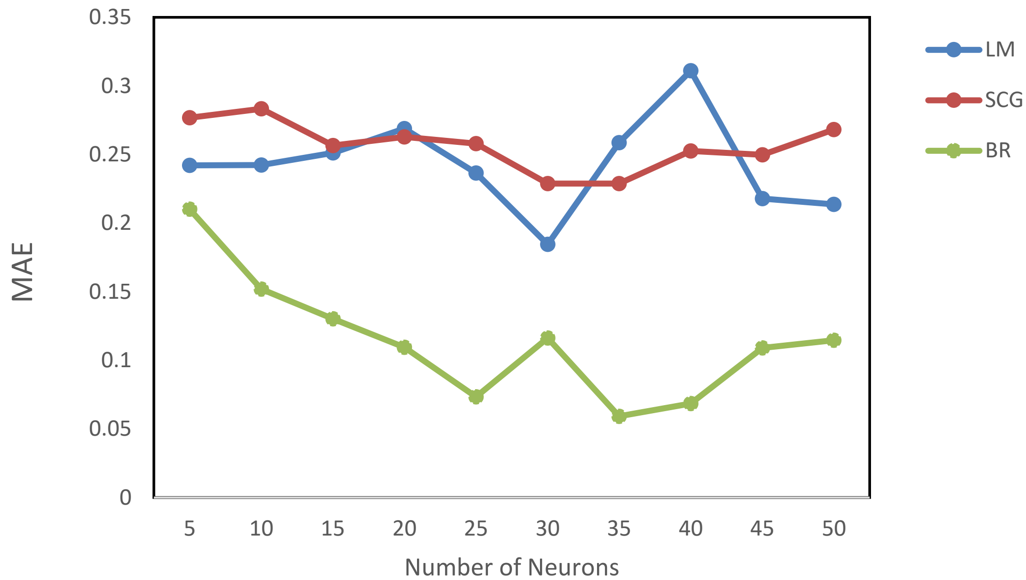

Figure 5-17: MAE values of ANN models

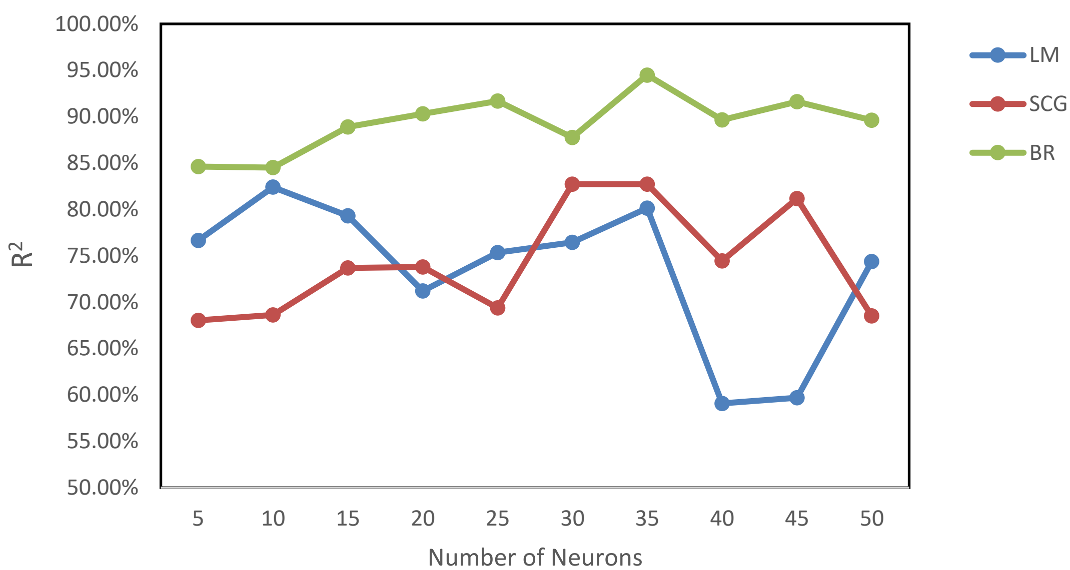

Figure 5-18: R^2 values of ANN models

Therefore, the BR model with 35 neurons is applied to the collected dataset for predicting the KPIs of building construction projects. Dataset has divided into 70% and 30% groups which are used for training and testing respectively.

The coefficient of determination values of training, testing phases are displayed in Figure 5-19. The horizontal axis and vertical axis show target versus output that are the KPIs here. The R^2 value of all data is displayed as well. The R^2 value is 99% which shows that the outputs are very close to the target values. Also, the overall value for R^2 is 0.93 (R=0.96) which is proof that the model is able to predict 93% of the outcomes accurately.

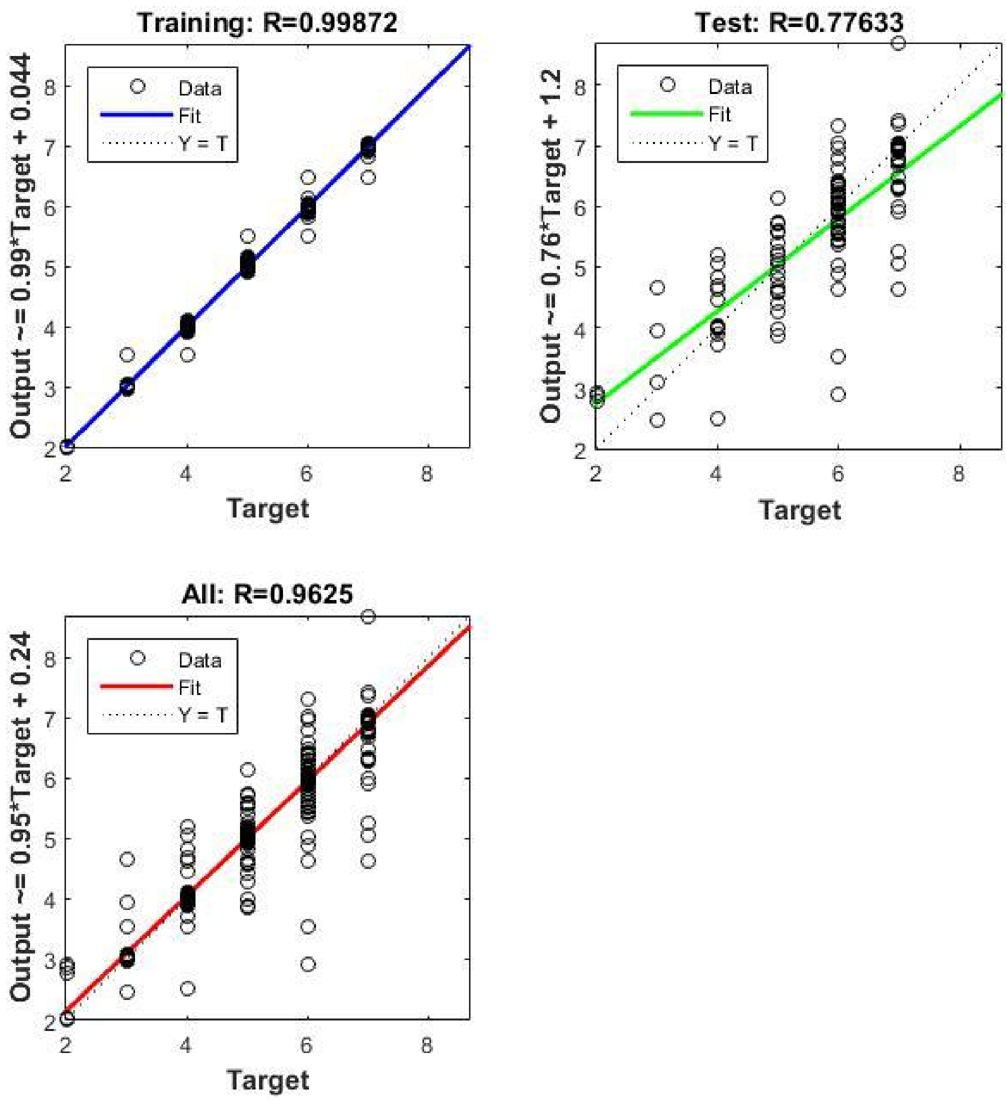

Figure 5-19: Coefficient of determination (R^2) values for the final model

5.3 KPIs Trend Forecasting Model

In this section, the process of model implementation and development for predicting KPIs of the next stage and at any project progress percentage is discussed in detail. The objective of this section is to develop models to predict the KPIs for building construction at any point during the project and to visualize the KPIs trends. The data collected for the different project stages of building construction projects in Tehran as discussed in the previous section are used to develop the models. First, the neuro-fuzzy technique is used to predict the KPIs of next stages based on the KPIs of previous stages. Second, the development of linear interpolation for predicting the KPIs at any progress percentage is elaborated, and the visualization of the project KPIs trend is discussed. Third, the user interface of the developed model is presented.

5.3.1 Next Stage KPIs Forecasting

The KPIs of the initial stage are used to predict the KPIs of the middle and the finishing stages. When a project is in the middle stage, the KPIs of the initial and middle stages are used to predict the KPIs of the finishing stage.

Eighteen models are developed using the neuro-fuzzy technique to predict the KPIs of the next stages. Table 5-3 shows the first six models, where the inputs are the KPIs of the initial stage, and the output is each of the KPIs of the middle stage. Table 5-4 indicates the results of the development of six models where the inputs are the KPIs of the initial stage, and the output is each of the KPIs of the finishing stage**.** Table 5-5 shows the neuro-fuzzy models where the inputs are the KPIs of the initial stage and the middle stage, and the output is each of the KPIs of the finishing stage. The model name MODEL*ijk* in the table means that the model is predicting the j^{th} KPI of the K^{th} stage and that the current stage of the project is *i*.

Table 5-3: Predicting KPIs of the middle stage from the initial stage

Model name	Input	Output	Train Error
MODEL112	Initial stage KPIs	Cost of middle stage	0.1940
MODEL122	Initial stage KPIs	Time of middle stage	0.2117
MODEL132	Initial stage KPIs	Quality of middle stage	0.2538
MODEL142	Initial stage KPIs	Safety of middle stage	0.2276
MODEL152	Initial stage KPIs	Client satisfaction of middle stage	0.1871
MODEL162	Initial stage KPIs	Project team Satisfaction of middle stage	0.1871

Table 5-4: Predicting KPIs of finishing stage from the initial stage

Model name	Input	Output	Train Error
MODEL113	Initial stage KPIs	Cost of finishing stage	0.2923
MODEL123	Initial stage KPIs	Time of finishing stage	0.3648
MODEL133	Initial stage KPIs	Quality of finishing stage	0.1755
MODEL143	Initial stage KPIs	Safety of finishing stage	0.2850
MODEL153	Initial stage KPIs	Client satisfaction of finishing stage	0.2699
MODEL163	Initial stage KPIs	Project team Satisfaction of finishing stage	0.2699

Table 5-5: Predicting KPIs of finishing stage from the middle and initial stages

Model name	Input	Output	Train Error
MODEL213	Initial and middle stage KPIs	Cost of finishing stage	0.0648
MODEL223	Initial and middle stage KPIs	Time of finishing stage	0.0917
MODEL233	Initial and middle stage KPIs	Quality of finishing stage	0.0000
MODEL243	Initial and middle stage KPIs	Safety of finishing stage	0.0648
MODEL253	Initial and middle stage KPIs	Client satisfaction of finishing stage	0.0648
MODEL263	Initial and middle stage KPIs	Project team Satisfaction of finishing stage	0.0648

As expected, the errors for predicting the KPIs in the middle stage is lower compared with the errors for predicting the KPIs in the initial stage. This is because the project is more advanced in the middle stage which will increase the predictive capabilities of the models

5.3.2 KPIs Trend Visualization

Developed prediction models are used to predict the KPIs at any progress% of the project using linear interpolation. Using the above prediction models, KPIs of initial, middle and finishing stages are available. For interpolation, the middle points of the range of each stage are assumed. Therefore, the points are as the following, (15% progress, initial stage KPIs), (50% progress, middle stage KPIs), and (85% progress, finishing stage KPIs). Linear interpolation is used to predict the KPIs of the project at any progress %. Codes are written to visualize the KPI trend. MATLAB function using "interp1" is used to perform linear interpolation on three available points. The input of this function is the progress %, and the output is the estimated KPIs associated with the progress percentage.

The above approach for predicting KPIs using interpolation is used to predict KPIs for the progress range between 15% to 100%. Interpolation is used to fit a curve on the predicted KPIs to better show the trend of each of the KPIs during the project. A user interface is developed to allow project managers to easily use the developed model. First, the questions regarding the current stage of the projects are asked. Then the user is asked to define the qualitative amount of KPIs in the current stage (and previous stages of the project if applicable). Figure 5-20 indicates an example of the user inputs for the project in the initial stage.

```
---
>>> From which Stage You Want Predicting The Project KPIs?
>(Initial   stage:  0% to 30 % Physical Progress = Type 1)
>(Middle    stage: 30% to 70 % Physical Progress = Type 2)
>(Finishing stage: 70% to 100% Physical Progress = Type 3)
According to the description, the number to be entered:1
---
In the Initial Stage of the project, what is the performance of each of the following indicators?
(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very High=7)
Cost(Type 2 To 7) : 6
Time(Type 1 To 7) : 5
Quality(Type 3 To 7) : 5
Safety(Type 3 To 7) : 4
ClientSatisfaction(Type 3 To 7) : 5
ProjectTeamSatisfaction(Type 3 To 7) : 5


---
Forcasted next stages

ans =
```

	Forecasted_KPIs_Of_Middle_Stage	Forecasted_KPIs_Of_Finishing_Stage
Cost	5.6059	4.94
Time	4.4695	4.3392
Quality	5.576	5.1568
Safety	4.3349	4.2754
Client Satisfaction	4.6864	4.5142
Project Team Satisfaction	4.8758	4.5086

```
(Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very High=7)
```

Figure 5-20: Example of input and output for predicting the KPIs of the next stages

The user interface will then develop its prediction for the KPIs of the next stages of the project. Afterwards, the model develops diagrams for each of the KPIs. In the plotted diagrams, the x-axis is the progress percentage of the project, ranging from 15% to 100%, and the y-axis is the predicted indicator. For example, Figure 5-21 illustrates the diagram for a safety indicator.

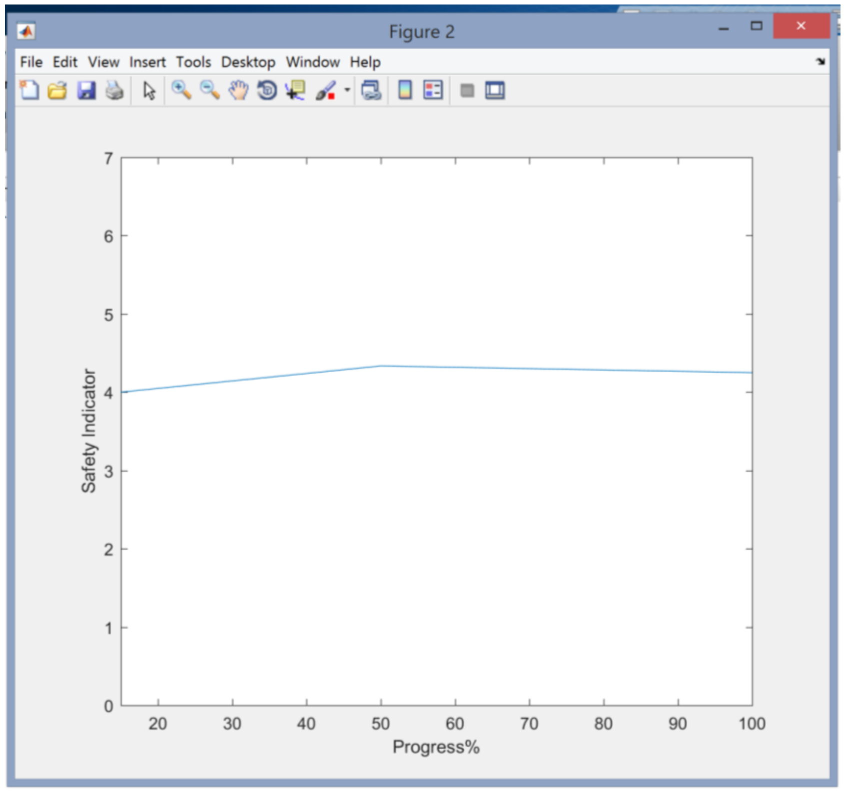

Figure 5-21: Sample diagram for the safety indicator trend

The user interface offers the capability to estimate the KPIs for a specific project percentage. The user should define a progress percentage between 15 to 100. An example of the output of the model is the predicted KPIs associated with the defined progress percentage, presented in Figure 5-22.

```
Would you like to get the KPIs for a specific progress percentage?
Y/N:'y'
Please type the progress percentage from  0 to 100:40

ans =

                                 KPIs_at_Specified_Progress
                                 __________________________

    Cost                         5.7185
    Time                         4.6211
    Quality                      5.4114
    Safety                       4.2392
    Client Satisfaction           4.776
    Project Team Satisfaction    4.9113

(Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very High=7)
```

Figure 5-22: Example of input and output for predicting the KPIs for a specific project progress percentage

In summary, in the developed model for predicting KPI trend, First, neuro-fuzzy are used to predict the KPIs of the next stages based on the KPIs of previous stages. Therefore, when the project is at the initial stage, the KPIs of the initial stage are used to predict the KPIs of the middle and finishing stages. At the middle stage, the KPIs of the initial and middle stage are used to predict the KPIs of the finishing stage. Using this method, at any point in a project, the KPIs of the initial, middle or finishing stage are either available or predicted. These three values are then used to predict the KPIs at different progress% of the project using linear interpolation. Also, plots are used to visualize KPIs trends for better analysis of the project.

5.4 **PI Prediction Model**

After predicting project KPIs using the neuro-fuzzy technique in the previous section, a model is developed to calculate the PI of the project. This model is based on the weighted sum of predicted KPIs as illustrated earlier in Equation 3-6. The weights of each KPI are calculated using both the AHP and GA methods. Figure 5-23 illustrate an example of the model output for the predicting Performance Indicator (PI) of a project.

```
---
>>> From which Stage You Want Predicting The Whole Project KPIs?
>(Initial   stage:  0% to 30 % Physical Progress = Type 1)
>(Middle    stage: 30% to 70 % Physical Progress = Type 2)
>(Finishing stage: 70% to 100% Physical Progress = Type 3)
According to the description, the number to be entered:1
---
In the Initial Stage of the project, what is the performance of each of the following indicator?
(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very High=7)
Cost(Type 2 To 7) : 3
Time(Type 1 To 7) : 4
Quality(Type 3 To 7) : 5
Safety(Type 3 To 7) : 4
ClientSatisfaction(Type 3 To 7) : 5
ProjectTeamSatisfaction(Type 3 To 7) : 6
---


ans =

                     Forecasted_Performance_Of_The_Whole_Project
                     ___________________________________________

    PI_AHP Method    4.8475
    PI_GA Method     4.9241

(Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very High=7)
>>
```

Figure 5-23: Example of the input and output for the PI prediction model

5.4.1 AHP Method

The AHP method is a methodology suggested for multi-criteria decision making (Saaty 1988). This method is able to derive priorities by ranking the different alternatives to a problem. AHP uses a pair-wise comparison matrix to rank different criteria. In this research, the AHP method is implemented in Microsoft Excel.

Questionnaires are utilized to calculate the weights of each KPI. The consistency ratio of each of the questionnaires is calculated according to Saaty (1988). From the 119 questionnaires returned, 35 questionnaires have acceptable consistency ratio of 10% or less (Saaty 1988). Each cell in the pair-wise comparison matrix in Table 5-6 is the average of the 35 pair-wise comparison matrixes that are developed earlier.

In the normalized matrix, each cell amount is calculated by dividing cell amounts by the sum of their columns. For defining the weight of each KPIs in Table 5-6, the average of each row is calculated.

Table 5-6: KPI weights from the AHP method

KPIs	Pair-Wise Comparison Matrix						Pair-Wise Comparison Matrix - Normalized						Weight Of KPIs using AHP
	Cost	*Time*	*Quality*	*Safety*	*Client Satisfaction*	*Project Team Satisfaction*	*Cost*	*Time*	*Quality*	*Safety*	*Client Satisfaction*	*Project Team Satisfaction*	
Cost	1.000	1.015	0.454	0.841	0.488	0.527	0.107	0.106	0.147	0.114	0.080	0.079	0.106
Time	0.986	1.000	0.393	0.897	0.515	0.499	0.106	0.104	0.128	0.122	0.084	0.075	0.103
Quality	2.205	2.544	1.000	2.502	2.394	2.394	0.236	0.265	0.325	0.340	0.392	0.360	0.320
Safety	1.190	1.115	0.400	1.000	0.912	0.986	0.128	0.116	0.130	0.136	0.149	0.148	0.134
Client Satisfaction	2.051	1.940	0.418	1.096	1.000	1.246	0.220	0.202	0.136	0.149	0.164	0.187	0.176
Project Team Satisfaction	1.898	2.002	0.418	1.015	0.803	1.000	0.203	0.208	0.136	0.138	0.131	0.150	0.161

The above results of the AHP method were derived from the data received in questionnaires distributed at building construction projects in Tehran, Iran. Therefore, the resulted weights are generic for the same location and project type.

In Table 5.6, the weight for quality is approximately 3 times the weights of other KPIs. This reflects the opinion of the owners who filled the questionnaires. It seems that quality is important for the owners in the marketing conditions of the location that the data are collected (Tehran). the economic depression may result in difficult competition conditions in which the quality has a major role in selling properties.

5.4.2 GA Method

The Genetic Algorithm (GA) method is used to optimize the weight of KPIs for two reasons: first, the GA method is a global optimization technique suggested by Holland that is suitable for complex and nonlinear problems (Holland 1975). Second, the GA approach has been successfully used for performance measurement optimization in the literature by and Nassar (2005). The main mechanism in GA is based on natural selection. In other words, the GA searches a population of potential solutions and keeps the best solutions for the generation of the next possible solutions.

The research applies the GA by writing codes in MATLAB, the flowchart of the steps is illustrated in Figure 5-24. As can be seen in the figure the shape of the mathematical formula for calculating the overall of the model is given to a method to define the fitness function. Equation 5-1 is the formula in which W_i, i=1,6 are the variables to be optimized. Where KPI_i is the performance indicators and w_i are the weights of each indicator.

$$\mathrm{PI} = w_1\mathrm{KPI}_1 + w_2\mathrm{KPI}_2 + w_3\mathrm{KPI}_3 + w_4\mathrm{KPI}_4 + w_5\mathrm{KPI}_5 + w_6\mathrm{KPI}_6 \quad 5\text{-}1$$

GA method optimizes the fitness function which is defined by the approach of the RMSE error of the questionnaire result and mathematical formula result. The questioner results are used as a dataset in the flowchart. The overall PI calculated by Equation 5-1 is compared with the PI of the dataset, and the RMSE error between the two values is used in the GA algorithm as the fitness value. The output of the GA method is the weights of the KPIs that as shown in table 5-7.

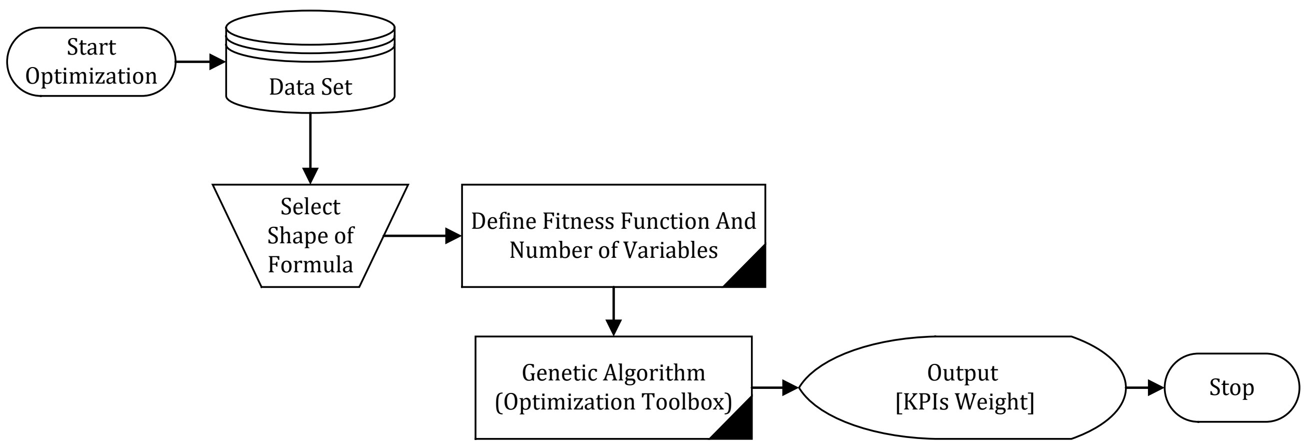

Figure 5-24: Flowchart of the GA method

Table 5-7: Weights of KPIs determined by the GA method

KPIs	Cost	Time	Quality	Safety	Client Satisfaction	Project Team Satisfaction
Weight of KPIs	0.027	0.193	0.292	0.100	0.062	0.327

The weights calculated using the AHP method are between 0.10 and 0.32. The smallest weight in the AHP is for time indicator, and the highest weight is for the quality indicator. On the other hand, the weights calculated using the GA method are between 0.02 and 0.32. The smallest weight in the GA is for the cost indicator, and the highest weight is for the project team satisfaction indicator. Overall, the weights calculated using the AHP method are closer to each other compared to the

GA method. The weights of KPIs is higher in the AHP method compared to GA method except for time and project team satisfaction indicators.

Next, by giving two different KPI weights to the model those from the GA and the AHP methods, two different results for overall project performance (PI) are calculated. The following sections will discuss which method performs better in predicting the PI.

5.4.3 Comparing the PI of the Model and the PI of the Questionnaire

This section compares the PI of the model using the AHP and GA methods with the questionnaire. In the initial stage diagram shown in Figure 5-25, the PIs predicted by the AHP and the GA methods by using the neuro-fuzzy modeling are compared to the PI obtained from the questionnaire. As the dots approach the diagonal line, it indicates that the model's predictions are more reliable.

Figure 5-25 shows that in the initial stage, the AHP method has a better prediction for getting PI compared to the questionnaire. Also, this figure compares the questionnaire results and predictions by the neuro-fuzzy model in the middle and finishing stage, respectively. In both stages, the scattered of the data set around the diagonal line is less for the AHP method than GA method.

Additionally, the coefficient of determination R^2 is calculated in each of the diagrams in Figure 5-25. R^2 is a coefficient for statistical analysis; an R^2 value of near 1 means very good fit while a value closer to 0 means poor fit (Dissanayake and Fayek 2008). As illustrated in the figures, the R^2 values are closer to 1 using the AHP method; thus, the AHP method performs slightly better as compared to the GA method. Comparing the questionnaire results and the neuro-fuzzy model predictions indicate that the data scatterings around the diagonal line are very similar in each stage. These comparisons show that the accuracy of the developed neuro-fuzzy models is quite satisfactory as the model predictions agree with the questionnaire data. However, the data scattered in the finishing stage are closer to the diagonal line compared to middle and initial stages. In other words, as one gets closer to the end of the project and the input parameters are more detailed, the accuracy of predicting the project PI also improves. Also, in Dissanayake and Fayek's (2008) results, the R^2 for predicting productivity using KPIs is equal to 0.95. In this research, the R^2 value in the finishing stage for AHP method is 0.93, which is very close to their reported value, showing the reasonable accuracy of the results.

Comparing the questionnaire results and predictions made by the neuro-fuzzy model indicates that the scattering of the data set around the diagonal line is very similar, which shows the good generalization of the model.

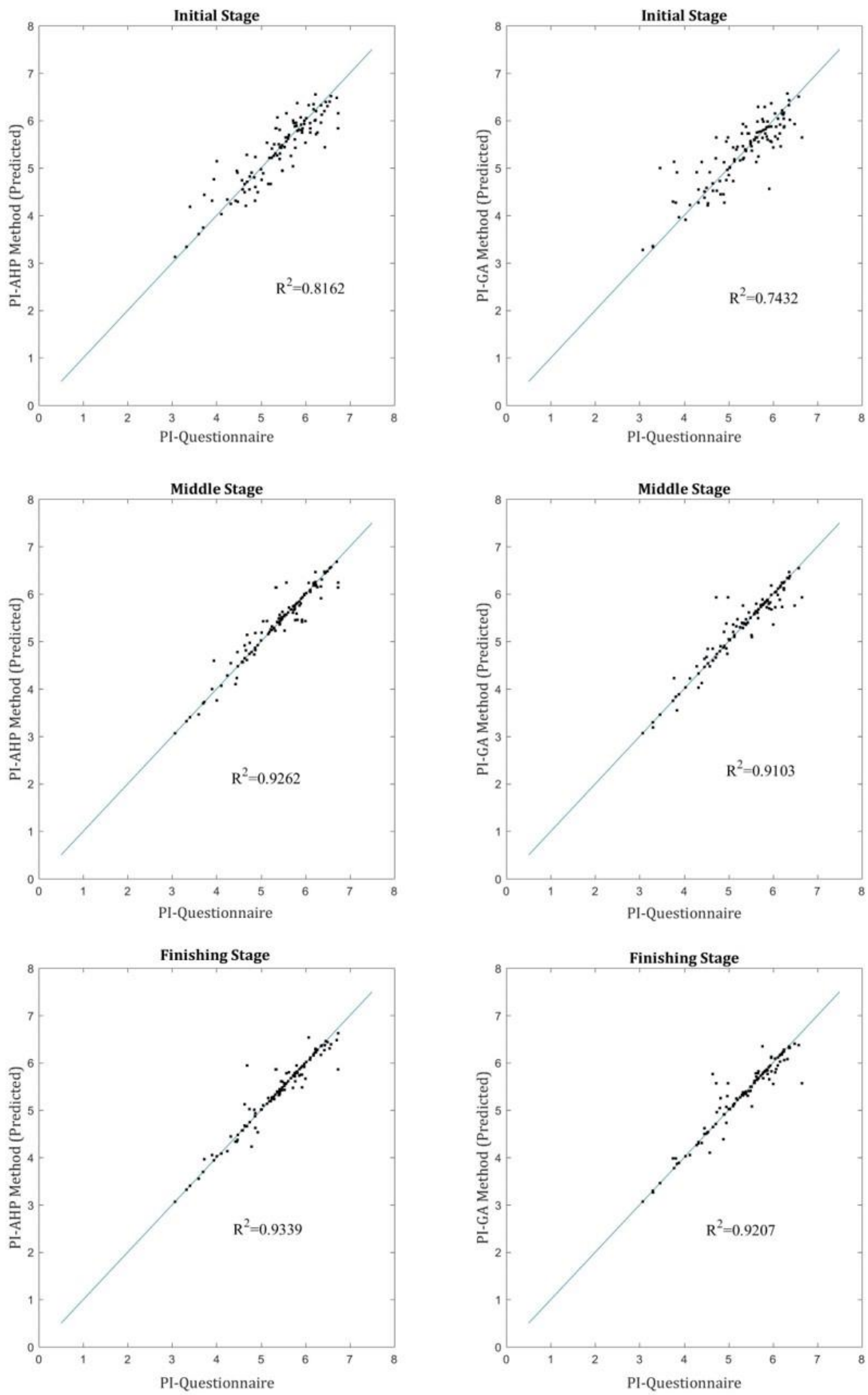

Figure 5-25: Comparison between PI of the model and PI of questionnaires in three stages

5.5 **Performance Optimization Model (POM) for selecting Corrective Action in Construction Projects**

Codes are written in MATLAB software to implement the developed model in section 3.6. The developed model offers a user interface to interact with the experts. After providing the overall project PI and whole project KPIs using the developed models in the previous section, the interface asks the experts if they would like to increase overall project PI or a selected KPI by providing different activity modes for the remaining of the project. When the user chooses to increase the overall project PI, the interface asks the user to fill the values in the excel file. The number of activities and their modes does not have any limitations. The number of activities as well as a number of activity modes are flexible and can be changed depending on the project. Different activity modes, as well as, KPIs of each activity mode should be entered by the user in an excel file. The activity modes represent the possible corrective actions to be applied to the project for improving performance. Modes can represent different ways for resource allocation, construction or execution methods, or choice of different materials. The codes for this optimization is presented in Appendix D4. After GA optimization, the user-interface defines a list for the proper activity modes of the project to increase the overall project PI as much as possible. It should be mentioned that the model is capable of optimizing each of KPIs separately if requested by the user. Also, the interface developed the forecasted KPIs and PI that will be achieved using the suggested activity modes. The option to change certain activity and certain modes (not all activities) for optimization are considered in the model because the number of modes for each activity is flexible. When the user does not want to change the modes of certain activities, only one mode should be defined for that activity. The PI and KPIs are optimized in two different examples of construction project. In the first examples, the impact of different project situations on PI optimization is discussed. In the second example, the developed model is applied on an example taken from the literature and the capability of the developed model on optimizing time and cost performance indicators is evaluated by comparing with the results in the literature.

5.5.1 PI Optimization Model

A model for PI optimization is developed for a real project adapted from Ghoddousi et al. (2013) to better illustrate the capabilities of the developed model. Figure 5-26 illustrates the CPM of this project. The CPM is divided into three stages: the initial stage, middle stage, and finishing stage based on the progress percentage of the project. Therefore, activities 1 to 10 are assumed to be in the initial stage, activities 11 to 26 are in the middle stage, and the finishing stage includes activities 27 to 37.

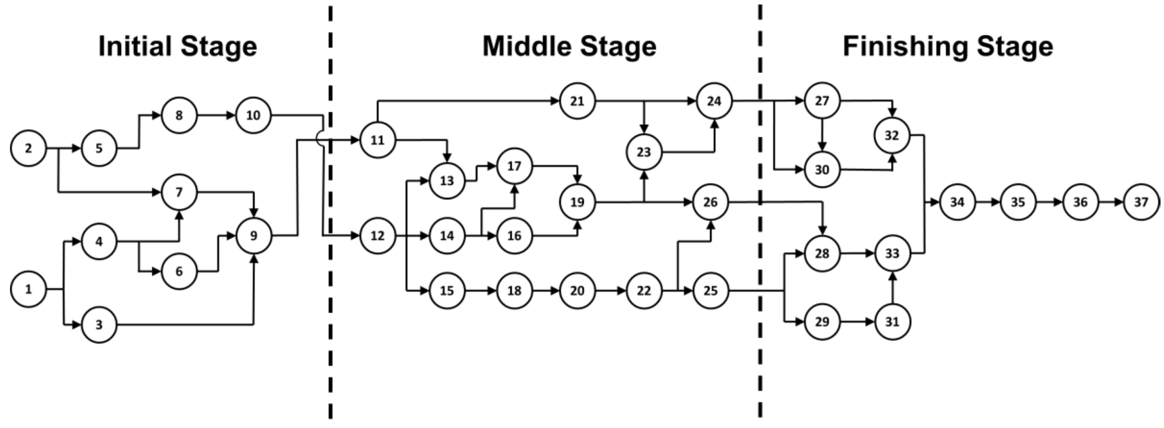

Figure 5-26: Project network activities of Case Study adapted from Ghoddousi et al. (2013)

Four situations are considered in the case study. In the first situation, the performance of the project is good, and the project is in the initial stage. The whole project KPIs and overall project PI are predicted by asking the user to define previous stage information as illustrated in Figure 5-27.

```
---
>>> From which Stage You Want Predicting The Whole Project KPIs?
>(Initial   stage:  0% to 30 % Physical Progress = Type 1)
>(Middle    stage: 30% to 70 % Physical Progress = Type 2)
>(Finishing stage: 70% to 100% Physical Progress = Type 3)
According to the description, the number to be entered:1
---
In the Initial Stage of the project, what is the performance of each of the following indicator?
(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very High=7)
Cost(Type 2 To 7) : 4
Time(Type 1 To 7) : 4
Quality(Type 3 To 7) : 5
Safety(Type 3 To 7) : 4
ClientSatisfaction(Type 3 To 7) : 5
ProjectTeamSatisfaction(Type 3 To 7) : 4
---
```

Figure 5-27: An example of the user interface for the initial stage and good situation

Then, weights obtained from the AHP method are employed to developed the overall project PI (Figure 5-28).

```
ans =

                                 Forecasted_KPIs_Of_The_Whole_Project
                                 ____________________________________

    Cost                                   1
    Time                              2.2734
    Quality                           5.3246
    Safety                            4.1649
    Client Satisfaction               5.5794
    Project Team Satisfaction         3.3933


ans =

                      Forecasted_Performance_Of_The_Whole_Project
                      ___________________________________________

    PI_AHP Method     4.1304
    PI_GA Method      3.6464

 (Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very High=7)
 ---

Your PI is lower than acceptable PI...Do you want to increase it? (Yes=1 No=0)1
---
Open the (Project Information for Middle Stage.xls)
and fill the KPIs values & weights for each activity then save and close it
When its done, press 1 and enter   1
```

Figure 5-28: An example of forecasted PI in the initial stage and in a good situation

If the calculated PI is greater than or equal to the acceptable PI value, the model shows acceptable performance and the program will not perform optimization. The acceptable PI value is assumed to be equal to 5.29 which is the average PI amount of the collected data in Table 4-1. On the other hand, if the overall PI is less than 5.29, the expert should determine a list of modes for the project activities in the middle the stage. Table 5-8 illustrates the information in the excel file that includes the list of activities, weight of each activity, the KPIs values of activity modes for the middle stage.

Table 5-8: An example of activity modes information in the excel file for the middle stage

(1=Very Low, 2=Low, 3=Medium-Low, 4=Medium, 5=Medium-High, 6=High, 7=Very High)

Activity	number of modes	Activity Weight (1 to 10)	Mode	Cost	Time	Quality	Safety	Client Satisfaction	Project Team Satisfaction
11	3	4	1	2	5	4	5	6	3
			2	3	4	5	5	5	3
			3	5	2	7	5	3	6
12	2	5	1	4	3	4	6	6	5
			2	2	1	5	3	6	3
13	3	2	1	6	5	7	4	7	5
			2	5	4	4	5	3	4
			3	4	2	5	6	4	7
14	1	3	1	2	4	3	3	2	4
15	3	6	1	2	5	3	6	7	3
			2	6	4	5	5	4	5
			3	3	2	4	3	3	4
16	4	5	1	5	3	5	3	2	5
			2	3	6	6	6	5	6
			3	5	5	4	5	4	3
			4	4	5	3	6	5	4
17	2	9	1	4	4	3	4	7	5
			2	2	2	5	4	4	5
18	3	1	1	6	6	4	7	6	6
			2	5	5	5	4	2	5
			3	7	4	6	5	3	4
19	5	10	1	4	2	4	6	5	7
			2	5	3	3	5	5	4
			3	6	6	5	4	4	4
			4	3	4	5	4	7	3
			5	4	2	3	7	6	3
20	3	3	1	3	5	7	4	4	7
			2	2	4	5	5	4	5
			3	4	2	6	6	5	6
21	3	5	1	5	5	6	5	2	5
			2	3	6	6	5	2	5
			3	4	4	6	4	3	4
22	4	4	1	5	5	5	4	2	5
			2	2	2	4	7	5	6
			3	6	7	3	4	4	5
			4	3	2	7	7	6	3
23	1	6	1	4	3	7	7	5	3
24	2	8	1	7	2	5	5	3	4
			2	6	5	3	3	6	5
25	3	2	1	5	6	4	6	5	7
			2	3	2	4	5	3	4
			3	4	4	6	3	5	3
26	5	4	1	5	1	3	3	4	5
			2	2	5	5	6	3	6
			3	4	3	3	5	6	5
			4	5	4	6	3	5	4
			5	3	5	3	4	6	4

Then the user completed the excel file, he/she should inform the program by pressing "1'. Then the model will suggest the best mode for each activity that optimizes the PI of the project using the GA method. The results are illustrated in Figure 5-29. The model also develops the iteration diagram for PI optimization (Figure 5-30).

```
Best Mode for Each Activity:
Activity  11  : Mode 3
Activity  12  : Mode 1
Activity  13  : Mode 2
Activity  14  : Mode 1
Activity  15  : Mode 2
Activity  16  : Mode 2
Activity  17  : Mode 1
Activity  18  : Mode 1
Activity  19  : Mode 3
Activity  20  : Mode 1
Activity  21  : Mode 1
Activity  22  : Mode 3
Activity  23  : Mode 1
Activity  24  : Mode 2
Activity  25  : Mode 1
Activity  26  : Mode 4

Optimum_Forecasted_PI_Of_The_Whole_Project =

    4.8581

---
---
```

Figure 5-29: An example of the user interface showing the optimization results of the model when the project is in the initial stage and good situation

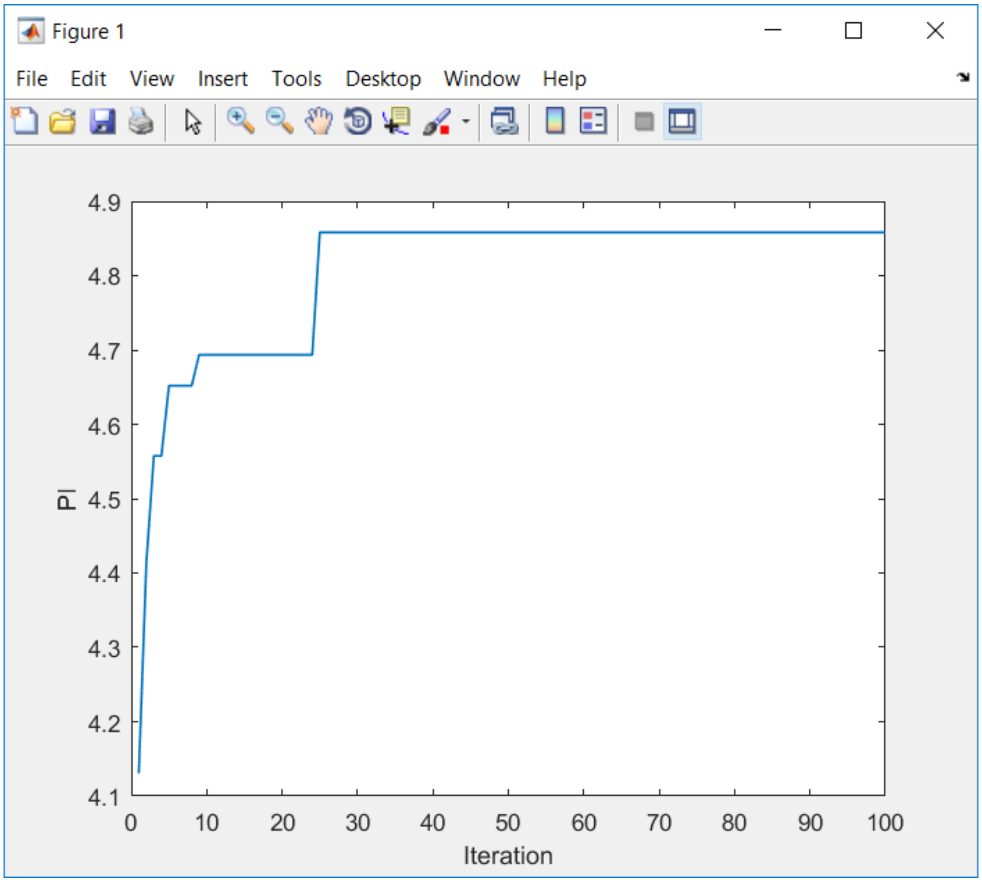

Figure 5-30: Iteration diagram of PI optimization using GA for the initial stage and good situation

In the second situation, an example is explained where the performance of the project is in a good situation, and the project is in the middle stage. The whole project KPIs and overall project PI are predicted by asking the user to determine previous stage information as illustrated in Figure 5-31. Then the project develops the overall project PI (Figure 5-32).

```
---
>>> From which Stage You Want Predicting The Whole Project KPIs?
>(Initial   stage:  0% to 30 % Physical Progress = Type 1)
>(Middle    stage: 30% to 70 % Physical Progress = Type 2)
>(Finishing stage: 70% to 100% Physical Progress = Type 3)
According to the description, the number to be entered:2
---
In the Initial Stage of the project, what is the performance of each of the following indicator?
(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very High=7)
Cost(Type 2 To 7) : 4
Time(Type 1 To 7) : 4
Quality(Type 3 To 7) : 5
Safety(Type 3 To 7) : 4
ClientSatisfaction(Type 3 To 7) : 5
ProjectTeamSatisfaction(Type 3 To 7) : 4
---
In the Middle Stage of the project, what is the performance of each of the following indicator?
(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very High=7)
Cost(Type 2 To 7) : 5
Time(Type 1 To 7) : 4
Quality(Type 3 To 7) : 4
Safety(Type 3 To 7) : 4
ClientSatisfaction(Type 2 To 7) : 4
ProjectTeamSatisfaction(Type 3 To 7) : 5
```

Figure 5-31: An example of the user interface for the middle stage and good situation

```
---

ans =

                              Forecasted_KPIs_Of_The_Whole_Project
                              ____________________________________

    Cost                      4.6472
    Time                      3.5815
    Quality                   3.8821
    Safety                    3.9681
    Client Satisfaction       3.8064
    Project Team Satisfaction 3.7114


ans =

                   Forecasted_Performance_Of_The_Whole_Project
                   ___________________________________________

    PI_AHP Method     3.903
    PI_GA Method     3.7981

(Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very High=7)

---
Your PI is lower than acceptable PI...Do you want to increase it? (Yes=1 No=0)1
---
Open the (Project Information for Finishing Stage.xls)
and fill the KPIs values & weights for each activity then save and close it
When its done, press 1 and enter   1
---
```

Figure 5-32: An example of forecasted PI in the middle stage and good situation

At this stage, the user is asked to determine the information about different activity modes in the excel file for the finishing stage. Table 5-9 illustrates the information in the excel file for the finishing stage.

Table 5-9: An example of activity modes information in the excel file for the finishing stage

(1=Very Low, 2=Low, 3=Medium-Low, 4=Medium, 5=Medium-High, 6=High, 7=Very High)

				Finishing Stage KPIs(1 to 7)					
Activity	number of modes	Activity Weight (1 to 10)	Mode	Cost	Time	Quality	Safety	Client Satisfaction	Project Team Satisfaction
27	1	4	1	5	3	2	2	2	3
28	3	5	1	3	3	2	6	2	7
			2	6	7	7	6	5	3
			3	3	2	6	7	4	2
29	2	3	1	4	6	4	7	6	4
			2	5	2	5	4	5	3
30	5	5	1	2	4	4	3	2	4
			2	7	3	7	6	5	7
			3	5	7	5	6	3	5
			4	3	5	4	6	3	5
			5	6	5	6	4	2	3
31	4	4	1	6	6	5	5	7	4
			2	4	3	3	4	5	6
			3	7	5	4	4	6	5
			4	3	5	2	6	6	5
32	2	2	1	3	7	5	5	3	4
			2	5	7	6	5	6	5
33	3	2	1	6	3	4	6	5	4
			2	3	4	7	5	2	7
			3	5	5	2	3	3	3
34	1	4	1	4	3	3	3	4	5
35	5	9	1	4	3	2	4	2	6
			2	6	3	4	7	5	3
			3	7	5	3	4	4	5
			4	3	3	5	7	6	5
			5	2	7	6	4	3	4
36	3	6	1	4	3	6	6	4	2
			2	5	4	4	5	5	7
			3	4	6	3	3	6	5
37	4	3	1	4	6	3	3	6	5
			2	5	7	4	2	6	3
			3	6	6	4	5	6	6
			4	7	5	6	4	5	6

When the user completed the excel file, the model will develop the best mode for each activity that optimizes the PI of the project using the GA method. The results are illustrated in Figure 5-33. The model also develops the iteration diagram for PI optimization (Figure 5-34).

```
Best Mode for Each Activity:
Activity  27  : Mode 1
Activity  28  : Mode 2
Activity  29  : Mode 1
Activity  30  : Mode 2
Activity  31  : Mode 1
Activity  32  : Mode 2
Activity  33  : Mode 2
Activity  34  : Mode 1
Activity  35  : Mode 3
Activity  36  : Mode 2
Activity  37  : Mode 4

Optimum_Forecasted_PI_Of_The_Whole_Project =

    4.5961
```

Figure 5-33: An example of user interface showing the optimization results of the model when the project is in the middle stage and good situation

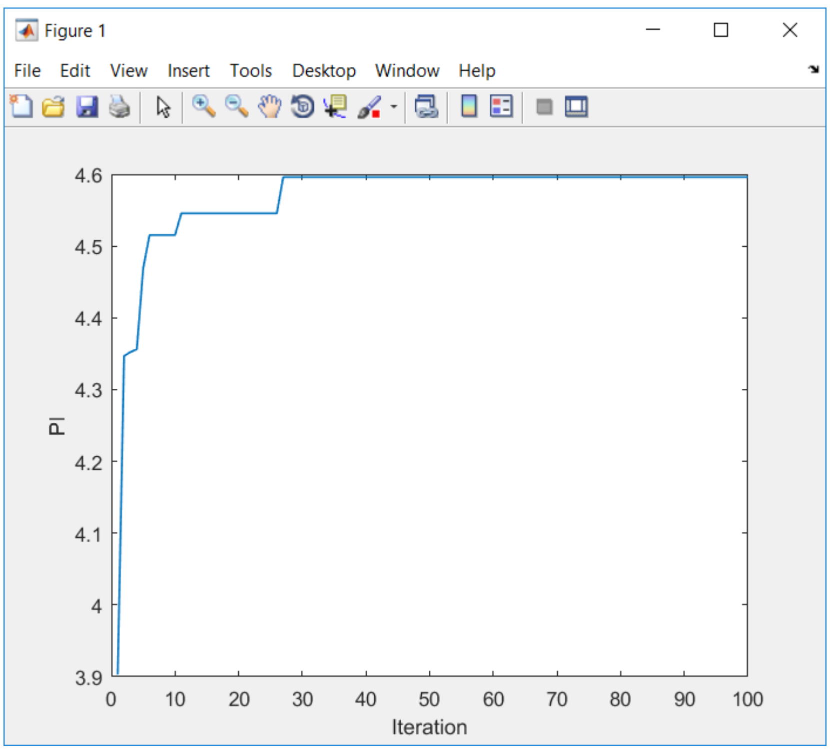

Figure 5-34: Iteration diagram of PI optimization using GA for the middle stage and good situation

In the thirds case, the performance of the project is in a bad situation, and the project is in the initial stage. The previous stage project KPIs are obtained from the user interface (Figure 5-35). Then, the model predicts the overall project PI (Figure 5-36).

```
---
>>> From which Stage You Want Predicting The Whole Project KPIs?
>(Initial   stage:  0% to 30 % Physical Progress = Type 1)
>(Middle    stage: 30% to 70 % Physical Progress = Type 2)
>(Finishing stage: 70% to 100% Physical Progress = Type 3)
According to the description, the number to be entered:1
---
In the Initial Stage of the project, what is the performance of each of the following indicator?
(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very High=7)
Cost(Type 2 To 7) : 2
Time(Type 1 To 7) : 2
Quality(Type 3 To 7) : 3
Safety(Type 3 To 7) : 3
ClientSatisfaction(Type 3 To 7) : 4
ProjectTeamSatisfaction(Type 3 To 7) : 3
---
```

Figure 5-35: An example of the user interface for the initial stage and bad situation

	Forecasted_KPIs_Of_The_Whole_Project
Cost	1
Time	2.4402
Quality	7
Safety	1
Client Satisfaction	2.5449
Project Team Satisfaction	2.7998

```
ans =
```

	Forecasted_Performance_Of_The_Whole_Project
PI_AHP Method	3.63
PI_GA Method	3.0776

Figure 5-36: An example of forecasted PI in the initial stage and bad situation

If overall forecasted PI is less than 5.29, the expert should determine a list of activity modes for different activities in the finishing the stage. Then the model will develop the best mode for each activity to optimizes the PI of the project. The results are illustrated in Figure 5-37. The model also illustrates the iteration diagram for PI optimization (Figure 5-38).

```
Best Mode for Each Activity:
Activity  11  : Mode 2
Activity  12  : Mode 1
Activity  13  : Mode 1
Activity  14  : Mode 1
Activity  15  : Mode 2
Activity  16  : Mode 1
Activity  17  : Mode 1
Activity  18  : Mode 1
Activity  19  : Mode 3
Activity  20  : Mode 2
Activity  21  : Mode 2
Activity  22  : Mode 3
Activity  23  : Mode 1
Activity  24  : Mode 2
Activity  25  : Mode 1
Activity  26  : Mode 2


Optimum_Forecasted_PI_Of_The_Whole_Project =

    4.4669

---
---
```

Figure 5-37: An example of user interface showing the optimization results of the model when the project is in the initial stage and bad situation

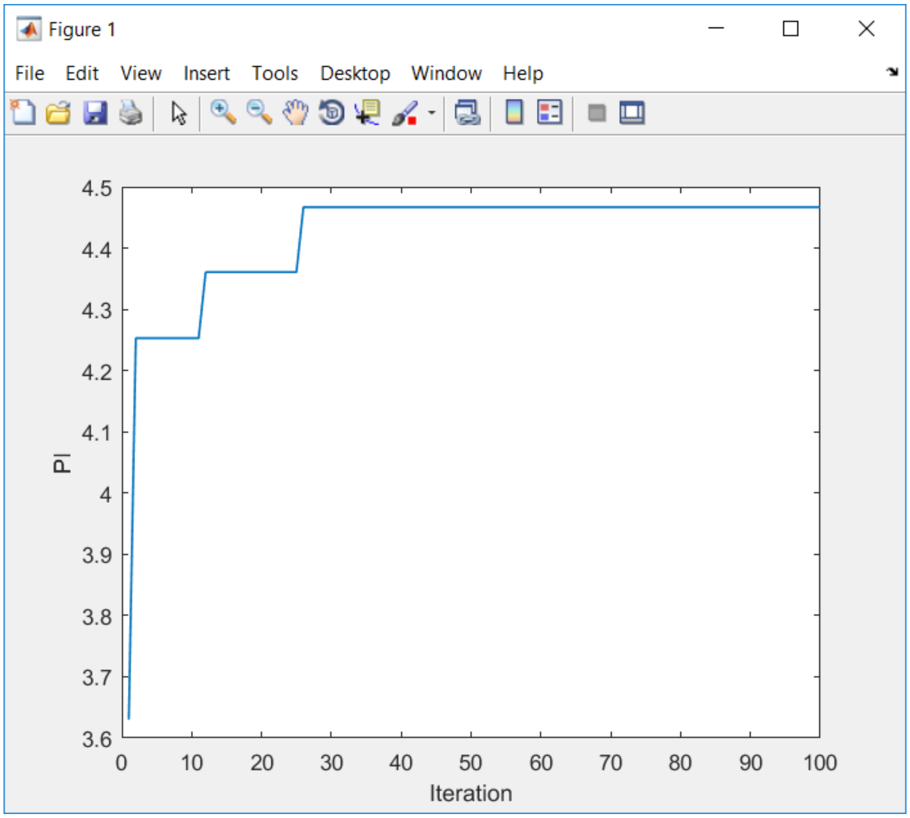

Figure 5-38: Iteration diagram of PI optimization using GA for the initial stage and bad situation

In the Last situation, an example is explained where the performance of the project is in a bad situation, and the project is in the middle stage. The whole project KPIs and overall project PI are predicted by asking the user to define previous stage information (Figure 5-39 and Figure 5-40).

```
---
>>> From which Stage You Want Predicting The Whole Project KPIs?
>(Initial   stage:  0% to 30 % Physical Progress = Type 1)
>(Middle    stage: 30% to 70 % Physical Progress = Type 2)
>(Finishing stage: 70% to 100% Physical Progress = Type 3)
According to the description, the number to be entered:2
---
In the Initial Stage of the project, what is the performance of each of the following indicator?
(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very High=7)
Cost(Type 2 To 7) : 2
Time(Type 1 To 7) : 2
Quality(Type 3 To 7) : 3
Safety(Type 3 To 7) : 3
ClientSatisfaction(Type 3 To 7) : 4
ProjectTeamSatisfaction(Type 3 To 7) : 3
---
In the Middle Stage of the project, what is the performance of each of the following indicator?
(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very High=7)
Cost(Type 2 To 7) : 3
Time(Type 1 To 7) : 2
Quality(Type 3 To 7) : 3
Safety(Type 3 To 7) : 3
ClientSatisfaction(Type 2 To 7) : 3
ProjectTeamSatisfaction(Type 3 To 7) : 4
```

Figure 5-39: An example of the user interface for the middle stage and bad situation

```
---

ans =

                                      Forecasted_KPIs_Of_The_Whole_Project
                                      ____________________________________

    Cost                              2.2388
    Time                              2.3999
    Quality                           3.1944
    Safety                             2.325
    Client Satisfaction               2.4121
    Project Team Satisfaction          2.391


ans =

                        Forecasted_Performance_Of_The_Whole_Project
                        ___________________________________________

    PI_AHP Method       2.6277
    PI_GA Method        2.5318

(Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very High=7)
```

```
---
Your PI is lower than acceptable PI...Do you want to increase it? (Yes=1 No=0)1
---
Open the (Project Information for Finishing Stage.xls)
and fill the KPIs values & weights for each activity then save and close it
When its done, press 1 and enter   1
```

Figure 5-40: An example of forecasted PI in the middle stage and bad situation

At this stage, the user defines the information about different activity modes in the excel file. When the user completed the excel file, the model will develop the best mode for each activity that optimizes the PI of the project using the GA method. The results are illustrated in Figure 5-41. The model also illustrates the iteration diagram for PI optimization (Figure 5-42).

```
Best Mode for Each Activity:
Activity  27  : Mode 1
Activity  28  : Mode 2
Activity  29  : Mode 1
Activity  30  : Mode 2
Activity  31  : Mode 1
Activity  32  : Mode 1
Activity  33  : Mode 1
Activity  34  : Mode 1
Activity  35  : Mode 2
Activity  36  : Mode 2
Activity  37  : Mode 4

Optimum_Forecasted_PI_Of_The_Whole_Project =

    3.5940
```

Figure 5-41: An example of user interface showing the optimization results of the model when the project is in the middle stage and bad situation

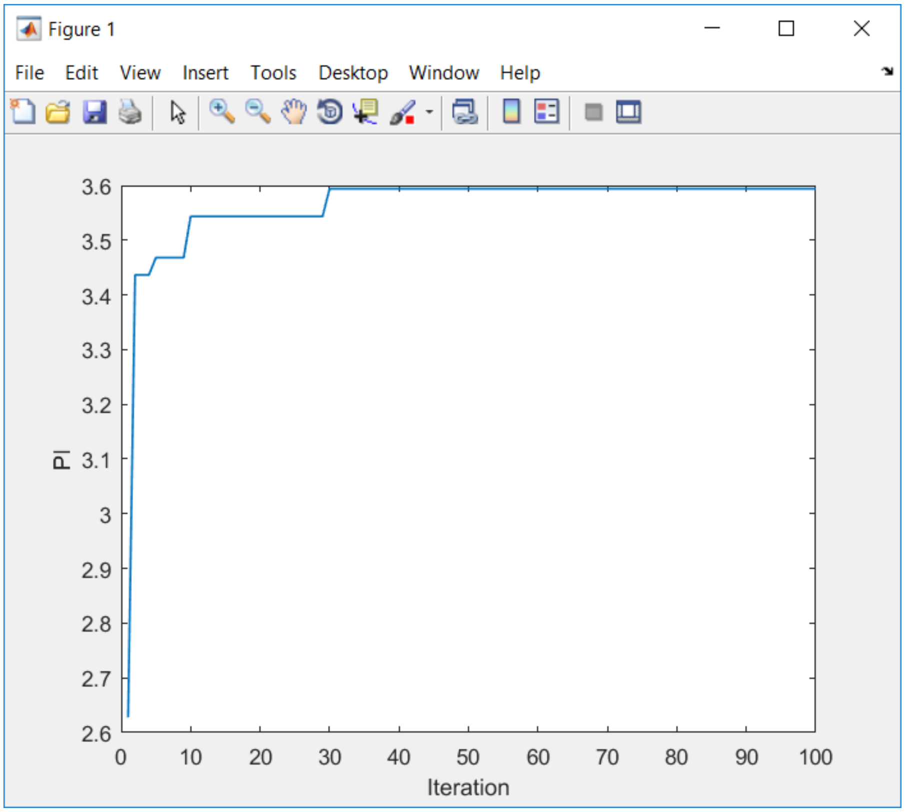

Figure 5-42: Iteration diagram of PI optimization using GA for the middle stage and bad situation

The results of the case study are analyzed to investigate the impact of time and the situation of the project on project performance. For example, “Good Situation” is considered for the case that the contractor’s quality is higher, and it is compared with “Bad Situation” in which contractor’s quality is lower. Also, the impact of timing of applying optimization in the initial and middle stage are compared.

Table 5-10: Summary of the results of four examples

	Good Situation		Bad Situation	
	PI predicted	PI optimized	PI predicted	PI optimized
Initial	4.13	4.86	3.63	4.46
Middle	3.9	4.6	2.63	3.6

Table 5-10 shows a summary of the results of the four examples described above. As it is expected, the results of the case study of the model indicate that the optimized PI value is greater when applying the POM in the initial stage compared to applying the POM in the middle stage as illustrates in Figure 5-43. The results highlight the importance of early decision making for performance optimization. It means if project managers try to improve performance with corrective action from the initial stage, they can achieve better results.

Moreover, when the project is in a better situation, for example, the project is performed with better contractors, in a specific stage, the optimized PI is closer to an acceptable range. As can be seen in Figure 5-43, when the project performs well from the beginning, the decision support system can give a better result and further improve the project.

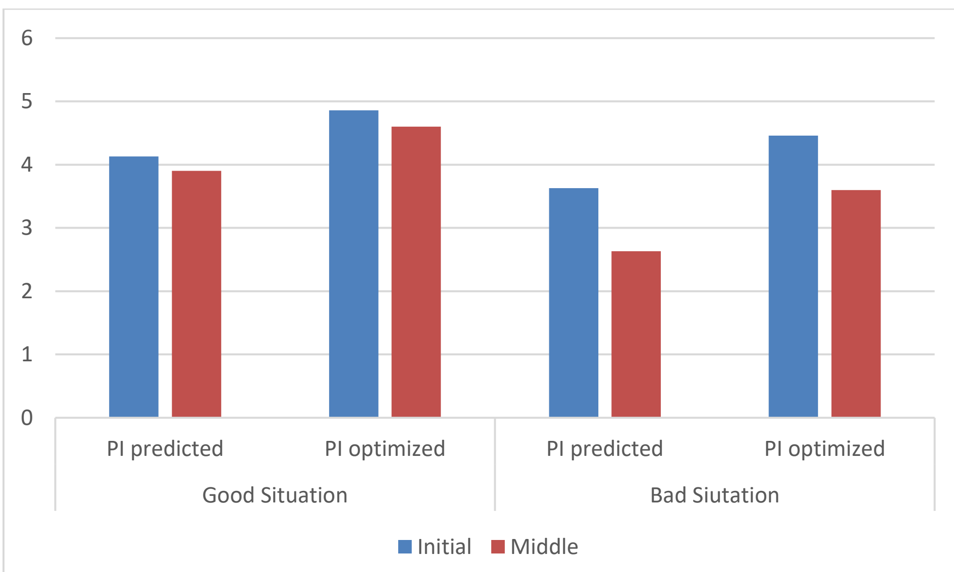

Figure 5-43: comparison if the result of four examples

5.5.2 Trade-off between Indicators

An example is taken from Toğan and Eirgash (2018) that includes 18 activities. The network with logical relationships of the activities is presented in Figure 5-44. For each of the activities, 3 to 5 activity modes are defined in Toğan and Eirgash (2018). In this example, the activity modes only include time and cost for performing the activities. Table 5-11 indicates the activities of this example as well as different modes. Additionally, the value of $1,500/day is adopted as an indirect cost rate for this example. This example is chosen to compare the results of the developed Performance Optimization Model (POM) with the results defined in Toğan and Eirgash (2018) where they optimized time and cost and given time-cost trade-off. They defined a multi-objective optimization model which is based on the Teaching-Learning Based Optimization (TLBO) incorporated with the Modified Adaptive Weight Approach (MAWA). Also three other optimization approaches have been applied on the same example which are MAWAGA (Zheng et al. 2005), MAWA-AS (Afshar et al. 2009) and MAWA-SGPU algorithms (Zhang and Ng 2012). In this section, the results of the POM approach will be compared with the results of all of these methods.

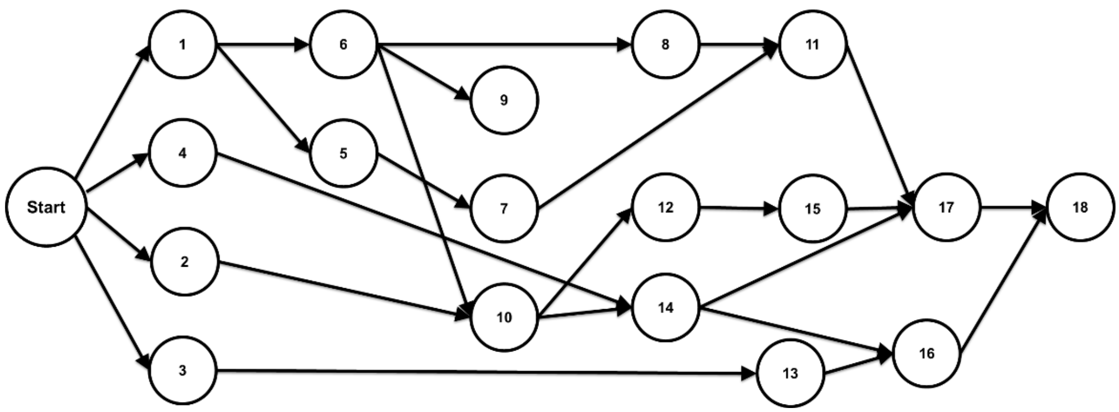

Figure 5-44: Project network activities of Case Study adapted from Toğan and Eirgash (2018)

Table 5-11: Activities of the case example and the activity modes (Toğan and Eirgash 2018)

		Mode 1		Mode 2		Mode 3		Mode 4		Mode 5	
Activity Number	Precedent Activity	Dur (day)	Direct Cost ($)	Dur (day)	Direct Cost ($)	Dur (day)	Direct Cost ($)	Dur (day)	Direct Cost ($)	Dur (day)	Direct Cost ($)
1	-	14	2400	15	2150	16	1900	21	1500	24	1200
2	-	15	3000	18	2400	20	1800	23	1500	25	1000
3	-	15	4500	22	4000	33	3200				
4	-	12	45000	16	35000	20	30000				
5	1	22	20000	24	17500	28	15000	30	10000		
6	1	14	40000	18	32000	24	18000				
7	5	9	30000	15	24000	18	22000				
8	6	14	220	15	215	16	200	21	208	24	120
9	6	15	300	18	240	20	180	23	150	25	100
10	2,6	15	450	22	400	33	320				
11	7,8	12	450	16	350	20	300				
12	5,9,10	22	2000	24	1750	28	1500	30	1000		
13	3	14	4000	18	3200	24	1800				
14	4,10	9	3000	15	2400	18	2200				
15	12	12	4500	16	3500						
16	13,14	20	3000	22	2000	24	1750	28	1500	30	1000
17	11,14,15	14	4000	18	3200	24	1800				
18	16,17	9	3000	15	2400	18	2200				

This example is used as the input to the developed model for optimizing project time and cost. However, our model only accepts qualitative KPIs and thus the cost and time values in Table 5-11 are mapped to qualitative values. To map the quantitative values to qualitative scale, for each activity, maximum to minimum time and cost values for different options are mapped to scale 1 to seven respectively. For the rest of the KPIs, the average value of an indicator which is four is used in the model. This is because the model developed by Toğan and Eirgash (2018) does not consider any other KPI except time and cost.

The developed POM developed in MATLAB is applied to the example to find the optimum time and cost indicators. After running the model, the developed model asks the user if he/she would like to optimize PI or KPI, and then asks which KPI should be optimized from the six possible KPIs. In this example the user could choose to optimize the time or cost indicators since these are the only available KPIs. Then the user should define the inputs of the model in an excel file containing the qualitative KPI values of different activity modes (Table 5-12). The interface is presented in Figure 5-45.

```
Do you want to increase PI or KPI ?  (PI=1  KPI=2)2
Which KPI do you want to increase?(Cost=1,Time=2,Quality=3,Safety=4,Client Satisfaction=5,Project Team Satisfaction=6)1
---
Open the (Project Information for All Stage.xls)
and fill the KPIs values & weights for each activity then save and close it
When its done, press 1 and enter   1
---
Optimizing Whole Project ...

Forecasted_Cost_Indicator_Of_The_Whole_Project =

    1.8970

---
```

Figure 5-45: The user interface for optimizing project time and cost

Table 5-12: The Excel file used as an input to POM

Activity	number of modes	Mode	All Stage KPIs					
			Type 2 to 7	Type 2 to 7	Type 2 to 7	Type 2 to 7	Type 2 to 7	Type 2 to 7
			Cost	Time	Quality	Safety	Client Satisfaction	Project Team Satisfaction
1	5	1	7	7	4	4	4	4
		2	6	6	4	4	4	4
		3	5	5	4	4	4	4
		4	4	4	4	4	4	4
		5	2	2	4	4	4	4
2	5	1	2	4	4	4	4	4
		2	4	4	4	4	4	4
		3	6	4	4	4	4	4
		4	6	4	4	4	4	4
		5	7	4	4	4	4	4
3	3	1	2	4	4	4	4	4
		2	4	4	4	4	4	4
		3	7	4	4	4	4	4
4	3	1	2	4	4	4	4	4
		2	4	4	4	4	4	4
		3	7	4	4	4	4	4
5	4	1	3	4	4	4	4	4
		2	4	4	4	4	4	4
		3	5	4	4	4	4	4
		4	6	4	4	4	4	4
6	3	1	4	7	4	4	4	4
		2	4	4	4	4	4	4
		3	5	2	4	4	4	4
7	3	1	2	4	4	4	4	4
		2	4	4	4	4	4	4
		3	7	4	4	4	4	4
8	5	1	3	4	4	4	4	4
		2	3	4	4	4	4	4
		3	4	4	4	4	4	4
		4	5	4	4	4	4	4
		5	6	4	4	4	4	4
9	5	1	2	4	4	4	4	4
		2	3	4	4	4	4	4
		3	4	4	4	4	4	4
		4	5	4	4	4	4	4
		5	7	4	4	4	4	4
10	3	1	7	7	4	4	4	4
		2	5	5	4	4	4	4
		3	2	2	4	4	4	4
11	3	1	2	4	4	4	4	4
		2	4	4	4	4	4	4
		3	7	4	4	4	4	4
12	4	1	7	7	4	4	4	4
		2	6	6	4	4	4	4
		3	3	3	4	4	4	4
		4	2	2	4	4	4	4
13	3	1	4	4	4	4	4	4
		2	5	4	4	4	4	4
		3	6	4	4	4	4	4
14	3	1	2	4	4	4	4	4
		2	4	4	4	4	4	4
		3	7	4	4	4	4	4
15	2	1	7	7	4	4	4	4
		2	2	2	4	4	4	4
16	5	1	2	4	4	4	4	4
		2	3	4	4	4	4	4
		3	3	4	4	4	4	4
		4	4	4	4	4	4	4
		5	7	4	4	4	4	4
17	3	1	7	7	4	4	4	4
		2	5	5	4	4	4	4
		3	2	2	4	4	4	4
18	3	1	7	7	4	4	4	4
		2	4	4	4	4	4	4
		3	2	2	4	4	4	4

The model will develop optimized KPIs value and the activity modes chosen based on the optimization. A sample output of the model is presented in Figure 5-46. The quantitative values of cost and duration of the project are calculated based on the chosen activity modes. For calculating the duration, the duration of the activities which are on the critical path are summed. For calculating the cost, the direct cost of each of the activities based on the chosen mode is summed and added to the indirect cost of the project. Also, the iteration diagram of the optimization process is illustrated in the developed program. A sample of this diagram is presented in Figure 5-47. Selected options and generated modes for 18 activities are given in Table 5-13.

```
Best Mode for Each Activity:
Activity  1  : Mode 1
Activity  2  : Mode 4
Activity  3  : Mode 3
Activity  4  : Mode 3
Activity  5  : Mode 4
Activity  6  : Mode 3
Activity  7  : Mode 3
Activity  8  : Mode 5
Activity  9  : Mode 2
Activity  10  : Mode 1
Activity  11  : Mode 3
Activity  12  : Mode 1
Activity  13  : Mode 2
Activity  14  : Mode 1
Activity  15  : Mode 1
Activity  16  : Mode 5
Activity  17  : Mode 1
Activity  18  : Mode 1


---
Optimum_Forecasted_Cost_Indicator_Of_The_Whole_Project= 4.1831

PI_Forecasted_Of_The_Whole_Project =

    3.5943

>> OUTPUT

Duration_Optimum_Day =

   110


Cost_Optimum_Dollar =

      273910
```

Figure 5-46: Sample output of the POM

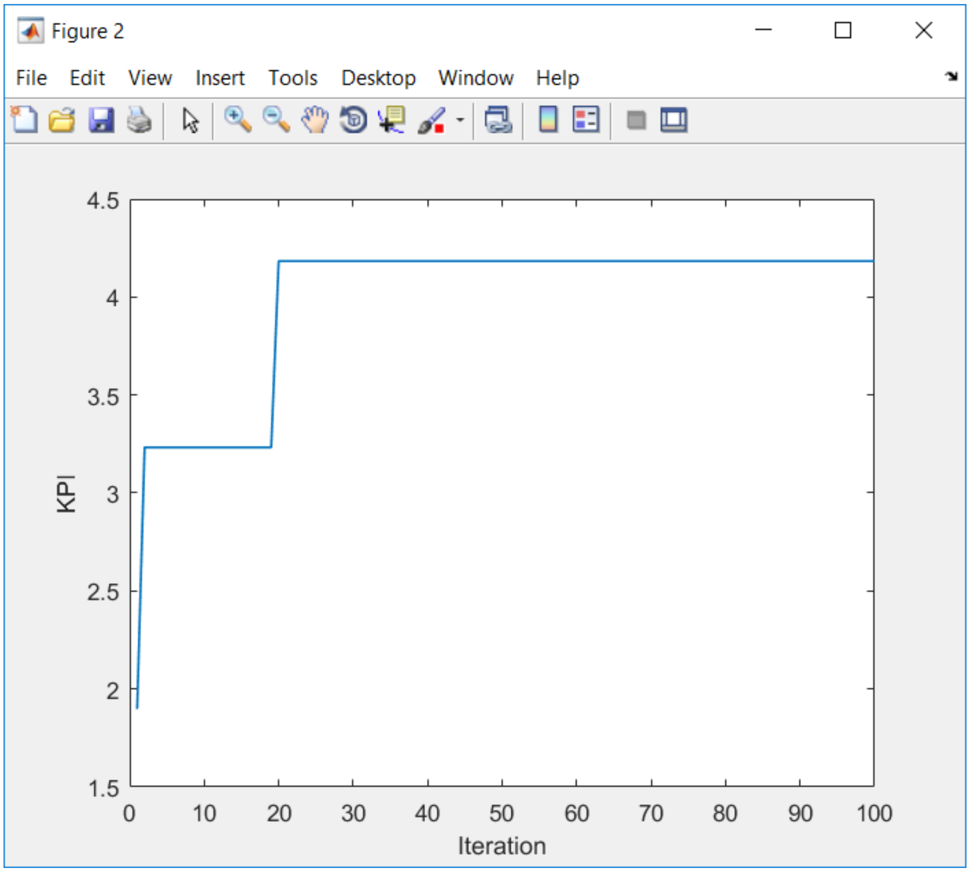

Figure 5-47: A sample iteration diagram

Table 5-13: Selected options and generated modes for 18 project activities

Plan	Duration (day)	Total Cost ($)	Activity																	
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
			Mode																	
1	100	288500	1	2	1	3	3	1	3	3	1	1	2	1	1	2	1	5	1	1
2	101	283020	1	4	3	3	4	1	3	1	1	1	2	1	2	2	1	2	1	1
3	104	280220	1	3	3	3	3	2	3	5	5	1	3	1	3	3	1	5	1	1
4	110	273910	1	4	2	2	4	3	2	5	2	1	2	1	2	2	1	4	1	1

The results of the developed model are compared with the results of four other methods solving the same example, which are MAWA-TLBO (Toğan and Eirgash 2018), MAWAGA (Zheng et al. 2005), MAWA-AS (Afshar et al. 2009) and MAWA-SGPU (Zhang and Ng 2012) algorithms. The companions of the results are demonstrated in Table 5-14.

Table 5-14: Comparison of the results of different algorithms

Plan	MAWA-GA		MAWA-ACS-SGPU		MAWA-AS		MAWA-TLBO		POM	
	Time (day)	Cost ($)	Time (day)	Cost ($)	Time (day)	Cost ($)	Time (day)	Cost ($)	Time (day)	Cost ($)
1	100	287720	100	285400	100	286670	100	283420	100	288500
2	101	284020	101	282508	101	281300	101	281200	101	283020
3	104	280020	104	277200	104	277265	104	277170	104	280220
4	110	273720	110	273165	110	272265	110	273470	110	273910
Populations in an iteration	50		10		50		40		40	
Number of iterations to get the solutions	500		200		400		70		30	

It can be seen from Table 5-14 that the time and cost results for the case project using POM is either equal or very close to the results of other algorithms. Figure 5-48 represent Pareto front showing the result of time-cost trade-off for the developed algorithm and other algorithms. For example, for 101 days, the cost of solution resulted from POM is $283020, which is between the cost obtained using MAWA-GA and MAWA-ACS-SGPU algorithms.

Considering that the developed POM model is based on the qualitative values, its capability for providing results which are similar or close to quantitative algorithms indicates the ability of POM in the optimization of quantitative cases as well. Another main advantage of the POM is in its capability to deal, forecast, and optimize six KPI values that are mentioned in previous chapters. However, other algorithms are only able to deal with time and cost and can not consider other KPIs. In other words, the POM algorithm can compare six KPIs instead of two indicators.

Also, running the model several times, indicated that a solution is reached in less than 30 iterations (a sample is presented in Figure 5-47). In other words, the GA process proceeds without changing the optimum solution after 30 iterations. Therefore, population and generation number can be taken as 40 and 30 respectively. Although, the population size is the same as MAWA-TLBO (2018), the iteration number is smaller. The smaller values of iterations compared to other algorithms can be considered as an advantage of POM.

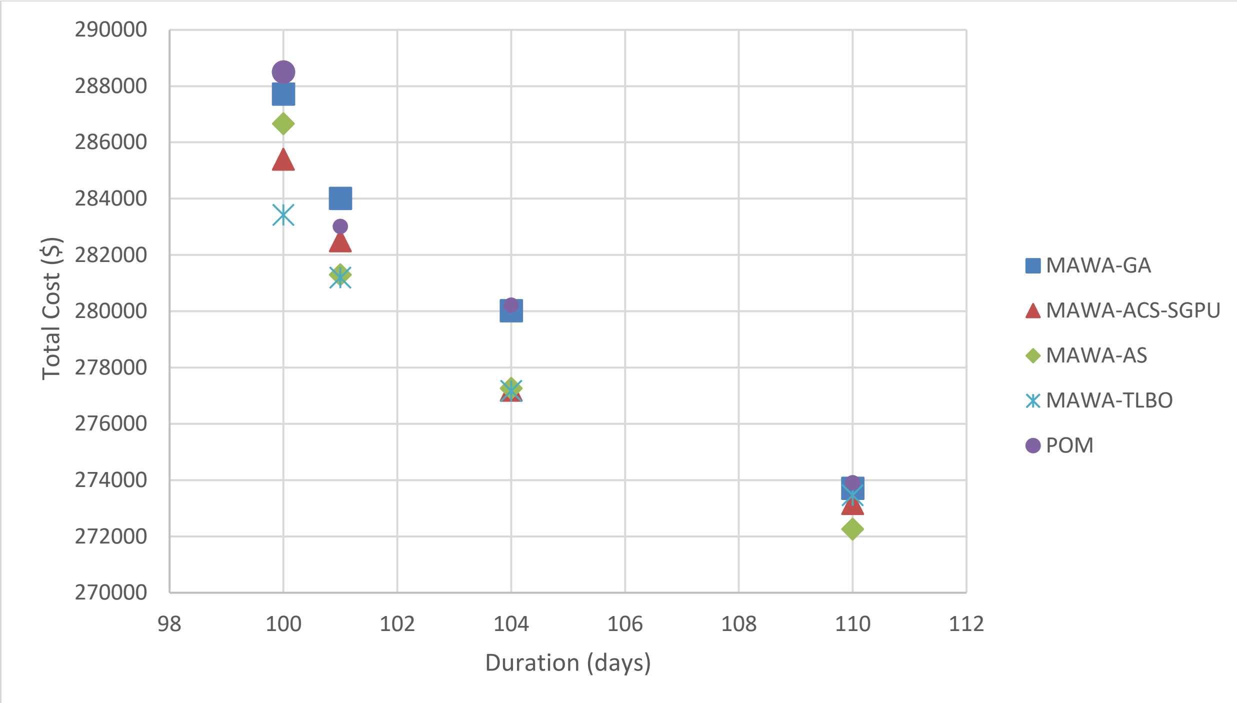

Figure 5-48: Comparison of Pareto Front results of different algorithms for 18 Activity

5.6 Validation

Sixteen questionnaires were used to obtain data from sixteen real projects to validate the model. First, the finishing stage KPIs of the developed models for all employed techniques: ANN and the neuro-fuzzy technique with subtractive clustering and FCM, are compared. The best method with the lowest error values is then chosen to predict the overall project PIs. The predicted PIs are also validated to show the practicality of the developed framework.

5.6.1 Validation of KPI Prediction models

In this section the comparisons of neuro-fuzzy and ANN techniques are developed. The outputs of the developed models for the finishing stage are compared with the actual data from the questionnaires. Tables 5-15 to 5-17 represent the output of these models and the four error measures, MAPE%, RAE, MAE and RRSE. In these tables, KPI1 to KPI6 are cost, time, quality, safety, client satisfaction, and project team satisfaction, respectively. The KPIs from the questionnaires were obtained from experts in the field, and the KPIs of the models were obtained from the models developed using ANN and neuro-fuzzy technique with subtractive clustering and FCM.

Table 5-15 shows validation results of KPI prediction models with the neuro-fuzzy technique using subtractive clustering for the finishing stage. The MAPE error for KPI3 is less than 20% showing a sound forecast. KPI1, KPI2, KPI5, and KPI6 have MAPE amount between 20% to 50% indicating a feasible forecast. Although, KPI4 has a MAPE around 50%. Table 5-16 illustrate the validation results of KPI prediction models with the neuro-fuzzy technique using FCM for the finishing stage. The results show that the MAPE for KPI1 and KPI3 and KPI4 is greater than 50% indicating an error forecast. On the other hand, KPI2, KPI5, and KPI6 have MAPE lower than 50% showing a feasible forecast. Table 5-17 represent validation results of KPIs prediction models with the neural network technique for the finishing stage. As shown in the table, the amount of MAPE for all KPI1, KPI2, KPI3, KPI5, and KPI6 is between 20% to 50% showing a feasible forecast. Although, MAPE of KPI4 is above 50%.

Table 5-15: Validation results of KPI prediction models with the neuro-fuzzy technique using subtractive clustering for the finishing stage (Continued)

No.	Finishing Stage					
	KPI1 Questionnaire	KPI1 Subtractive Clustering	KPI2 Questionnaire	KPI2 Subtractive Clustering	KPI3 Questionnaire	KPI3 Subtractive Clustering
1	6.00	5.02	6.00	4.43	6.00	5.46
2	7.00	6.49	6.00	7.57	7.00	5.47
3	7.00	4.92	6.00	4.13	6.00	7.04
4	6.00	4.74	5.00	4.02	6.00	5.01
5	6.00	4.68	6.00	4.53	6.00	5.74
6	1.00	3.12	7.00	4.94	7.00	6.15
7	6.00	4.46	6.00	3.62	6.00	5.25
8	6.00	4.74	6.00	4.36	5.00	4.86
9	7.00	5.08	6.00	5.39	6.00	4.90
10	4.00	5.33	6.00	4.66	7.00	5.80
11	7.00	3.89	6.00	3.35	5.00	6.09
12	6.00	5.08	4.00	4.18	5.00	6.02
13	3.00	3.43	3.00	3.46	4.00	4.13
14	3.00	4.03	3.00	2.98	3.00	3.79
15	3.00	3.85	3.00	4.97	3.00	4.76
16	7.00	4.04	4.00	3.76	7.00	5.09
	MAPE (%)	37.13%	MAPE (%)	24.55%	MAPE (%)	18.09%
	RAE	0.94	RAE	1.15	RAE	0.90
	MAE	1.48	MAE	1.31	MAE	0.94
	RRSE	0.91	RRSE	1.19	RRSE	0.84

No.	Finishing Stage					
	KPI4 Questionnaire	KPI4 Subtractive Clustering	KPI5 Questionnaire	KPI5 Subtractive Clustering	KPI6 Questionnaire	KPI6 Subtractive Clustering
1	4.00	4.44	6.00	5.12	6.00	5.54
2	6.00	6.13	6.00	7.45	6.00	6.04
3	1.00	4.77	6.00	6.70	6.00	6.36
4	6.00	4.26	4.00	4.74	4.00	4.73
5	6.00	4.75	4.00	5.92	6.00	5.67
6	3.00	4.53	7.00	4.72	7.00	5.15
7	3.00	3.91	6.00	4.31	6.00	4.46
8	3.00	4.10	6.00	4.71	6.00	4.75
9	4.00	4.48	5.00	5.52	5.00	5.21
10	2.00	4.42	7.00	5.40	5.00	5.97
11	4.00	5.78	5.00	5.95	3.00	6.02
12	3.00	4.21	5.00	5.13	4.00	5.21
13	4.00	3.33	4.00	3.03	4.00	3.55
14	3.00	3.72	3.00	3.41	3.00	3.94
15	3.00	3.61	3.00	4.48	3.00	3.82
16	4.00	4.19	5.00	3.67	5.00	4.14
	MAPE (%)	52.60%	MAPE (%)	22.95%	MAPE (%)	22.00%
	RAE	1.11	RAE	1.126	RAE	0.87
	MAE	1.18	MAE	1.144	MAE	0.94
	RRSE	1.10	RRSE	1.048	RRSE	0.95

Table 5-16: Validation results of KPI prediction models with the neuro-fuzzy technique using FCM for the finishing stage (Continued)

No.	Finishing Stage					
	KPI1 Questionnaire	KPI1 FCM model	KPI2 Questionnaire	KPI2 FCM model	KPI3 Questionnaire	KPI3 FCM model
1	6.00	2.96	6.00	4.53	6.00	14.28
2	7.00	7.45	6.00	7.65	7.00	10.16
3	7.00	6.64	6.00	5.16	6.00	3.13
4	6.00	4.98	5.00	5.30	6.00	3.62
5	6.00	4.23	6.00	5.68	6.00	6.17
6	1.00	1.09	7.00	5.85	7.00	0.89
7	6.00	3.21	6.00	3.73	6.00	6.84
8	6.00	3.04	6.00	5.28	5.00	4.62
9	7.00	4.36	6.00	4.14	6.00	5.44
10	4.00	4.51	6.00	4.66	7.00	6.76
11	7.00	2.54	6.00	3.76	5.00	8.81
12	6.00	3.93	4.00	4.77	5.00	7.43
13	3.00	6.20	3.00	5.36	4.00	10.09
14	3.00	8.15	3.00	3.60	3.00	1.93
15	3.00	8.08	3.00	6.47	3.00	8.12
16	7.00	4.05	4.00	4.02	7.00	13.43
	MAPE (%):	65.72%	MAPE (%):	29.30%	MAPE (%):	68.18%
	RAE	1.61	RAE	1.17	RAE	3.41
	MAE	2.53	MAE	1.34	MAE	3.57
	RRSE	1.60	RRSE	1.25	RRSE	3.64

No.	Finishing Stage					
	KPI4 Questionnaire	KPI4 FCM model	KPI5 Questionnaire	KPI5 FCM model	KPI6 Questionnaire	KPI6 FCM model
1	4.00	5.11	6.00	5.63	6.00	4.76
2	6.00	5.37	6.00	8.22	6.00	2.20
3	1.00	3.72	6.00	7.01	6.00	5.84
4	6.00	4.53	4.00	5.08	4.00	3.77
5	6.00	4.65	4.00	6.39	6.00	4.79
6	3.00	3.53	7.00	9.09	7.00	4.11
7	3.00	4.10	6.00	5.27	6.00	3.79
8	3.00	4.78	6.00	5.49	6.00	4.46
9	4.00	4.80	5.00	5.79	5.00	4.72
10	2.00	4.90	7.00	6.29	5.00	4.62
11	4.00	7.31	5.00	5.72	3.00	5.38
12	3.00	5.00	5.00	3.92	4.00	5.64
13	4.00	3.21	4.00	3.46	4.00	3.12
14	3.00	3.80	3.00	4.48	3.00	3.94
15	3.00	3.71	3.00	5.08	3.00	3.65
16	4.00	5.05	5.00	3.87	5.00	4.05
	MAPE (%):	55.06%	MAPE (%):	25.88%	MAPE (%):	27.73%
	RAE	1.36	RAE	1.17	RAE	1.24
	MAE	1.44	MAE	1.18	MAE	1.34
	RRSE	1.23	RRSE	1.11	RRSE	1.34

Table 5-17: Validation results of KPIs prediction models with the neural network technique for the finishing stage (Continued)

No.	Finishing Stage					
	KPI1 Questionnaire	KPI1 ANN model	KPI2 Questionnaire	KPI2 ANN model	KPI3 Questionnaire	KPI3 ANN model
1	6.00	5.01	6.00	6.46	6.00	5.02
2	7.00	5.57	6.00	6.28	7.00	6.22
3	7.00	4.58	6.00	6.95	6.00	6.13
4	6.00	6.89	5.00	5.84	6.00	6.28
5	6.00	3.48	6.00	6.74	6.00	6.53
6	1.00	3.01	7.00	5.68	7.00	6.47
7	6.00	6.99	6.00	5.73	6.00	6.67
8	6.00	6.43	6.00	6.64	5.00	6.35
9	7.00	5.99	6.00	6.41	6.00	6.45
10	4.00	4.51	6.00	6.38	7.00	5.97
11	7.00	5.53	6.00	5.27	5.00	6.54
12	6.00	6.32	4.00	5.73	5.00	6.67
13	3.00	5.78	3.00	5.09	4.00	5.15
14	3.00	4.25	3.00	4.62	3.00	4.39
15	3.00	5.23	3.00	6.05	3.00	5.37
16	7.00	6.89	4.00	6.61	7.00	5.32
	MAPE (%):	38.55%	MAPE (%):	28.16%	MAPE (%):	22.09%
	RAE	0.85	RAE	0.99	RAE	0.99
	MAE	1.34	MAE	1.13	MAE	1.03
	RRSE	0.85	RRSE	1.09	RRSE	0.93

	Finishing Stage					
No.	KPI4 Questionnaire	KPI4 ANN model	KPI5 Questionnaire	KPI5 ANN model	KPI6 Questionnaire	KPI6 ANN model
1	4.00	5.74	6.00	4.12	6.00	5.17
2	6.00	6.59	6.00	5.99	6.00	6.75
3	1.00	3.86	6.00	3.86	6.00	6.86
4	6.00	5.77	4.00	5.77	4.00	5.72
5	6.00	3.23	4.00	4.14	6.00	6.51
6	3.00	3.13	7.00	3.13	7.00	6.32
7	3.00	4.27	6.00	3.27	6.00	6.72
8	3.00	6.33	6.00	6.33	6.00	4.64
9	4.00	4.26	5.00	4.26	5.00	6.08
10	2.00	5.13	7.00	3.13	5.00	6.24
11	4.00	4.71	5.00	4.71	3.00	5.46
12	3.00	5.59	5.00	3.09	4.00	4.92
13	4.00	4.25	4.00	3.99	4.00	4.29
14	3.00	4.11	3.00	5.33	3.00	4.52
15	3.00	4.75	3.00	3.33	3.00	4.12
16	4.00	4.98	5.00	4.54	5.00	6.64
	MAPE (%):	58.76%	MAPE (%):	27.09%	MAPE (%):	26.00%
	RAE	1.39	RAE	1.40	RAE	1.03
	MAE	1.48	MAE	1.43	MAE	1.11
	RRSE	1.36	RRSE	1.57	RRSE	0.98

Table 5-18 presents the error values for the three different techniques. For error measures RAE, MAE, and RRSE, the error value of the ANN technique is slightly lower for predicting KPI1 and KPI2. However, these error values are lower using the subtractive clustering technique for predicting KPI 3, KPI 4, KPI 5, and KPI6. In all cases, the FCM technique produces poor predictive accuracy.

As indicated in this table, the MAPE% error is lower using the subtractive clustering technique in all six models. The MAPE% error ranges between 18% and 43%. According to Jia et al. (2015), MAPE values lower than 50% indicates a sound forecast. Therefore, the neuro-fuzzy technique using subtractive clustering is the only approach that has a sound forecast for predicting all 6 KPIs. Therefore, the neuro-fuzzy technique using subtractive clustering thus produces better results that are acceptable in predicting KPIs compared to the other techniques.

Table 5-18: Comparison of the errors on validation data for the different applied techniques

	Error of KPI1			Error of KPI2		
	ANN	subtractive clustering	FCM	ANN	subtractive clustering	FCM
MAPE (%):	38.55%	37.13%	65.72%	28.16%	24.55%	29.30%
RAE	0.85	0.94	1.61	0.99	1.15	1.17
MAE	1.34	1.48	2.53	1.13	1.31	1.34
RRSE	0.85	0.91	1.60	1.09	1.19	1.25

	Error of KPI3			Error of KPI4		
	ANN	subtractive clustering	FCM	ANN	subtractive clustering	FCM
MAPE (%):	22.09%	18.09%	68.18%	58.76%	42.60%	55.06%
RAE	0.99	0.90	3.41	1.39	1.11	1.36
MAE	1.03	0.94	3.57	1.48	1.18	1.44
RRSE	0.93	0.84	3.64	1.36	1.10	1.23

	Error of KPI5			Error of KPI6		
	ANN	subtractive clustering	FCM	ANN	subtractive clustering	FCM
MAPE (%):	27.09%	22.95%	25.88%	26.00%	22.00%	27.73%
RAE	1.40	1.12	1.17	1.03	0.87	1.24
MAE	1.43	1.14	1.18	1.11	0.94	1.34
RRSE	1.57	1.04	1.11	0.98	0.95	1.34

The results in this section also comply with the results in the literature. Comparing neuro-fuzzy and ANN outcome in inventory level forecasting demonstrates the advantage of neuro-fuzzy over ANN results and reveal that neuro-fuzzy gives a more precise prediction compared to ANN in this field (Paul et al. 2015). The study for prediction of back break in the open pit blasting uses multiple regression, ANN, and neuro-fuzzy models and the results show neuro-fuzzy has better results than ANN and multiple regression (Esmaeili et al. 2014). The literature demonstrates that the neuro-fuzzy technique gives a more precise prediction compared to other methods (Esmaeili et al. 2014; Paul et al. 2015).

In the construction area, Nilashi et al. (2017) applied machine learning techniques to develop a hybrid intelligent system for predicting heating and cooling loads of residential buildings. Adaptive Neuro-Fuzzy Inference System was compared with other techniques for predicting buildings' energy performance. The results indicate better prediction accuracy when using neuro-fuzzy..

5.6.2 PI Prediction Model Validation

The neuro-fuzzy technique using subtractive clustering has the lowest error values. Therefore, the project PI is calculated based on the KPIs predicted using the subtractive clustering technique and the results compared to the real data for validation. Tables 5-19 to 5-21 and figures 5-49 to 5-51 compares the performance indicator (PI) results that are predicted by the model with the PI from the 16 real projects that are not used in generating the model. The model performance was calculated by three questions that asked for the six KPIs at the three stages and obtains its results using the AHP and GA. The real project performance was obtained from the questionnaire in which the experts were asked for the performance of each of the six KPIs in whole projects. Then the PI of the questionnaire was calculated using the AHP and GA.

The error was calculated by the Mean Absolute Percentage Error (MAPE) and the Root Mean Square Error (RMSE) method in tables 5-19 to 5-21. The error results for the AHP method is lower than the GA method. For example, In the middle stage, the RMSE value for AHP is 0.96 and for GA is 1.01. Thus, the errors result also show that the model works better with the AHP method than with the GA method. Figures 5-49 to 5-51 also represent the results of the prediction of the model and compare them with the questionnaire. For each x-y value in these figures, the x-value represents the results of the questionnaire and y-value is the predicted result of the models. Therefore, in a perfect world, the x and y values should be equal and fall on the line presented in the figures 5-49 to 5-51. Thus, closer dots to the line indicate a better prediction of the model. As it is illustrated in the figures, the dots are closer to the line in the AHP method compared with GA. These results are compatible with the error results in tables 5-19 to 5-21.

Table 5-19: Comparison of the output of the model and questionnaire in the initial stage

	Initial Stage			
o.	PI (AHP) Question-naire	PI (AHP) Predicted	PI (GA) Question-naire	PI (GA) Predicted
1	4.63	4.66	5.81	4.72
2	6.42	6.59	6.33	6.21
3	1.00	1.18	5.53	1.00
4	4.63	4.66	5.04	4.72
5	5.13	5.59	5.88	5.08
6	3.37	3.79	6.45	3.77
7	4.82	3.85	5.71	6.15
8	4.63	4.66	5.41	4.72
9	4.62	4.66	5.44	4.48
10	4.63	4.66	5.58	4.72
11	5.66	5.56	4.50	6.23
12	5.16	4.38	4.31	5.01
13	1.00	1.00	3.78	1.00
14	4.79	4.89	3.00	4.87
15	4.79	4.89	3.00	4.87
16	6.20	6.30	5.35	6.32
	Mean:	0.9991	Mean:	1.4769
	COV (%):	9.36%	COV (%):	85.92%
	RMSE:	0.3574	RMSE:	1.7869
	MAPE (%):	5.52%	MAPE (%):	30.49%

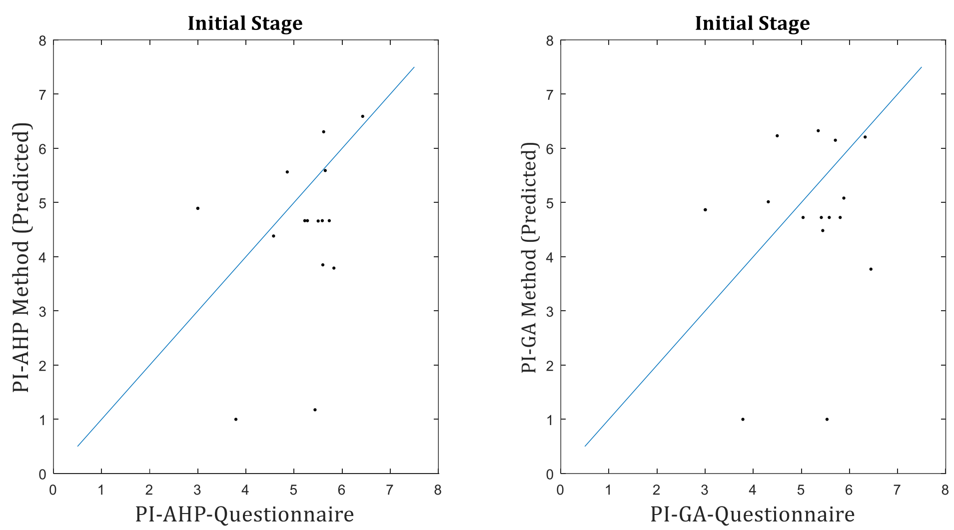

Figure 5-49: Comparing the predicted output of the model and questionnaire in the initial stage

Table 5-20: Comparison of the predicted output of the model and questionnaire in the middle stage

No.	Middle Stage: PI (AHP) Questionnaire	PI (AHP) Predicted	PI (GA) Questionnaire	PI (GA) Predicted
1	5.73	4.35	5.81	4.37
2	6.43	6.26	6.33	5.99
3	5.44	5.65	5.53	5.63
4	5.22	4.94	5.04	4.69
5	6.00	5.00	6.01	5.00
6	5.83	5.34	6.45	5.55
7	5.60	3.94	5.71	3.90
8	5.28	4.54	5.41	4.36
9	5.50	4.79	5.44	4.69
10	5.24	5.08	5.46	5.10
11	4.51	4.19	4.37	4.12
12	4.40	5.10	4.25	5.10
13	3.79	4.25	3.78	4.25
14	3.00	4.92	3.00	4.90
15	3.00	4.30	3.00	4.20
16	5.62	4.41	5.35	4.27
	Mean:	1.0520	Mean:	1.0691
	COV (%):	19.79%	COV (%):	20.23%
	RMSE:	0.9609	RMSE:	1.0111
	MAPE (%):	17.79%	MAPE (%):	18.85%

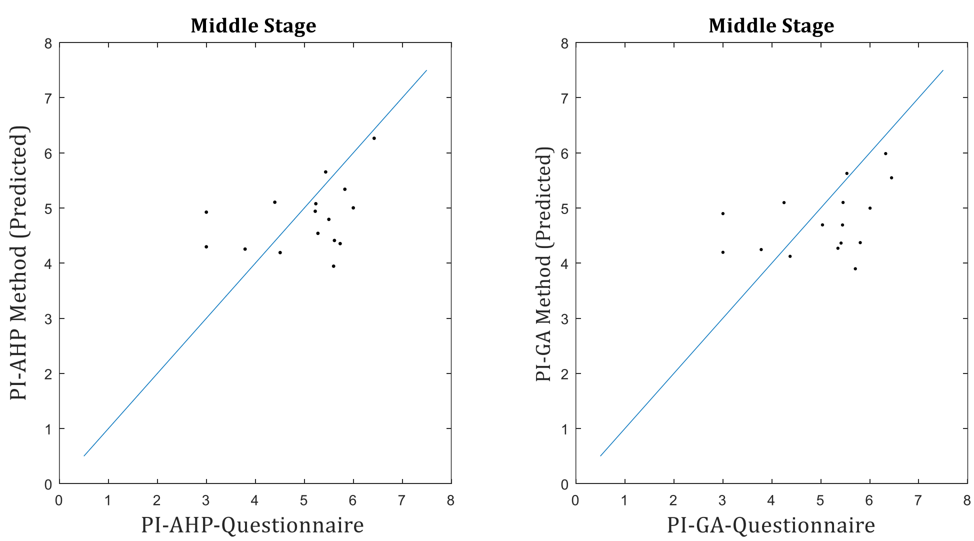

Figure 5-50: Comparing the predicted output of the model and questionnaire in the middle stage

Table 5-21: Comparison of the output of the model and questionnaire in the finishing stage

No.	Finishing Stage			
	PI (AHP) Question-naire	PI (AHP) Predicted	PI (GA) Question-naire	PI (GA) Predicted
1	5.73	5.12	5.81	5.16
2	6.43	6.32	6.33	6.29
3	5.44	6.04	5.53	5.96
4	5.22	4.69	5.04	4.63
5	5.65	5.39	5.88	5.37
6	5.83	5.07	6.45	5.26
7	5.60	4.53	5.71	4.47
8	5.28	4.65	5.41	4.64
9	5.50	5.07	5.44	5.10
10	5.59	5.41	5.58	5.46
11	4.86	5.50	4.50	5.44
12	4.57	5.20	4.31	5.14
13	3.79	3.59	3.78	3.65
14	3.00	3.68	3.00	3.66
15	3.00	4.33	3.00	4.34
16	5.62	4.32	5.35	4.32
	Mean:	1.0291	Mean:	1.0281
	COV (%):	15.00%	COV (%):	15.87%
	RMSE:	0.7158	RMSE:	0.7727
	MAPE (%):	13.48%	MAPE (%):	14.27%

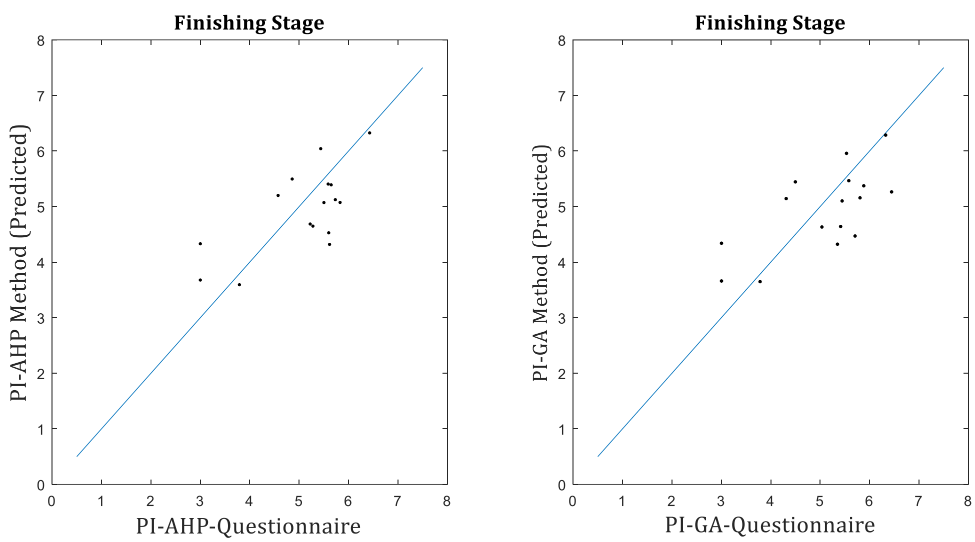

Figure 5-51: Comparing the predicted output of the model and questionnaire in the finishing stage

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Summary and Conclusion

Key Performance Indicators (KPIs) evaluate different projects aspects and are used to determine the health status of building projects. Therefore, by evaluating and predicting KPIs, monitoring and controlling project progress can be facilitated. A comprehensive literature review of the existing research is performed, highlighting the limitations of the previously developed models for forecasting project KPIs and overall project performance. First, limited work has been done on forecasting project performance using KPIs at the project level. Second, there has been little focus on dynamic performance measurement and forecasting during projects.

Based on the limitations mentioned above, this research is motivated to develop a framework for measuring and forecasting project KPIs and overall project performance indicator (PI). Because of different stakeholder investments and benefits, the first thing that needs to be defined is from whose viewpoint the performance is to be measured. A list of KPIs used in the literature at the project level was prepared, and their frequencies indicated. The first six KPIs were chosen due to the frequency of their use in the literature; they were used by approximately 50 percent of the studies. To further justify the selection of these six KPIs, a questionnaire was distributed among experts in the field. Based on the questionnaire responses, the first six KPIs got 40 to 90 percent of the score, with the seventh KPI receiving a score of only 27. Given the tangibly larger score ratio between KPI number six and seven in the questionnaire, the first six KPIs were chosen for model development. The selected KPIs are cost, time, quality, safety, client satisfaction, and project team satisfaction.

The KPIs of three critical project stages (initial, middle, and finishing) are used to predict the whole project KPIs using two main techniques: Artificial Neural Networks (ANN) and neuro-fuzzy models. In the ANN, the best model is selected by changing the number of neurons of the hidden layer. Neuro-fuzzy models are developed in two steps; first, initial Fuzzy Inference System (FIS) models are developed using both subtractive clustering and Fuzzy C-means (FCM). In subtractive clustering, the cluster radius is optimized to achieve optimum precision without overfitting. Next, the optimization of the initial FIS model is performed using ANN. In the neuro-fuzzy technique, 18 different models are developed, six models for each of the three critical project stages.

Also, this research develops a model for predicting the KPIs of the next stages and KPIs trends. First, neuro-fuzzy models are used to predict the KPIs of the next stages based on the KPIs of previous stages. Linear interpolation is then used to predict the KPIs at different progress% of the project. Graphic plots are also used to visualize KPIs trends for better analysis of a project.

The weighted sum of the project KPIs is then used to calculate the overall project Performance Indicator (PI). Two different methods were used to determine the weight for each of the indicators, the Analytical Hierarchy Process (AHP) and the Genetic Algorithm (GA) method. In the AHP, the relative importance of each indicator is determined based on paired comparisons in a matrix.

A Performance Optimization Model (POM) is also developed to optimize the overall project PI considering various project KPIs using GA. The developed model can be applied at the initial and middle stage of the project for selecting corrective action. If the overall PI of the project is less than the acceptable value, the best scenario for the next stage could be found using POM. Codes are written in MATLAB to implement performance optimization model for corrective action selection. The developed model allows a user interface to interact with the experts. Examples are employed to analyze the performance of the developed model showing improvement in the project PI. Also, the results highlight the importance of early decision making for performance optimization.

All KPIs were measured qualitatively by designing a questionnaire. The KPIs are measured qualitatively using a 1 to 7 scale for three critical project stages. The data in this study was collected from experts in construction companies in Tehran, Iran. Two sets of questionnaires were designed. The first questionnaire was used to collect data from different projects to run the model, and then the second questionnaire was used to justify the selected six KPIs used in this research. This research measures project performance from the owner's point of view.

Models are developed using the steps described above to forecast project performance using MATLAB software. ANN and neuro-fuzzy using both FCM and subtractive clustering, are used to develop models for predicting whole project KPIs. Models are also developed for predicting KPIs of the next stage.

To validate the model, questionnaires were designed to obtain information about 16 real projects. The errors of the three methods used for predicting KPIs, namely: ANN, neuro-fuzzy with FCM and neuro-fuzzy with subtractive clustering, were compared using different error calculation methods. The results indicate that the neuro-fuzzy technique using subtractive clustering performs better and has lower error values than the other two methods. The PIs obtained from the neuro-fuzzy technique with subtractive clustering (using the AHP and the GA approaches) and the PIs obtained from the questionnaire responses were compared. The results indicate that the AHP method performs better than the GA method. Also, the PIs resulted from the questionnaire and those calculated by the model are very similar.

This research develops a comprehensive framework to predict the KPIs of the next stages and for whole projects KPIs and PI. The key benefit of the developed framework is that it allows project managers to suggest timely corrective actions during a project to improve project performance. The developed framework is designed to be flexible and to be adaptable for other countries and other types of projects.

6.2 **Research Contributions**

6.2.1 Academic Contributions

The contributions of this research are as follows:

- Identification of the most important KPIs based on an extensive review of the literature and the responses to a designed questionnaire sent to professionals in the field.
- Development of a model to qualitatively measure and predict construction project KPIs by applying a neuro-fuzzy technique using two clustering methods: FCM and subtractive clustering. A methodology to optimize the cluster radius in developing a neuro-fuzzy model with subtractive clustering.
- Development of a model to predict the KPIs of next stages based on the current stage of a project and to estimate KPIs during a project based on the project progress percentage. Visualization of KPI trends during a project is also developed.
- Development of a KPI prediction model using an artificial neural network (ANN).
- Comparison of the results of the neuro-fuzzy and ANN to identify which of the following models can better predict the whole project KPIs.

- Development of a model for predicting the project performance indicator (PI) applying AHP and GA methods for defining KPI weights. A comparison of the results is performed to find the best method.
- Development of a novel project performance optimization model to suggest corrective actions based on project KPIs using GA.

6.2.2 Practical Contributions

- Development of a model to map six selected KPIs of three critical project stages to the whole project KPIs using a qualitative approach. Project stakeholders can predict the KPIs of the whole project, so they can forecast the status of future work and perform necessary corrective actions. This can help to improve the performance of the project.
- Facilitate and enhance progress reporting of construction projects by predicting project KPIs of next stages. Developed models can predict the KPIs of the next stages and KPIs at different progress% of the project. The research allows representing KPI trends for reporting purposes, as well.
- Providing the overall project performance (PI) as a thermometer representing the health status of the project. The weighted average of the whole project KPIs used to identify PI value.
- Developing a decision support system to optimize project performance by automatically selecting the best scenario among different available project activity modes.

6.3 Research Limitations

This research has some limitations that can be summarized as follows:

- Qualitative questioners have been used for collecting data for the KPIs even when these values are quantifiable (e.g., time and cost) due to the lack of access to the actual project data.
- The developed models divide projects into three stages, an initial stage (0 to 30 % physical progress), a middle stage (30% to 70 % physical progress) and a finishing stage (70% to 100 % physical progress).
- The user needs to manually enter the data for the six KPIs in a qualitative manner.

- The data for this model was collected for residential buildings in Tehran, Iran, so the model is only usable in this country and for this type of project. Also, the relative weights obtained through asking from participants are local which is one of this research limitations. The generalizability of the models can increase by increasing the number of data collected from construction projects.
- The developed model is based on the owners' point of view in DB and DBB delivery methods; the viewpoints of other stakeholders are not considered. The applicability of the neuro-fuzzy models is limited to the numerical range of the input parameters in the collected data. The developed neuro-fuzzy models are not capable of accepting input values that are out of this range.
- The performance optimization model developed an optimized scenario based on the information developed by experts. Therefore, the developed scenario is not necessarily the best scenario in all situations.

6.4 Future Work and Recommendations

The developed framework and its implementation achieved the suggested objectives of the research. However, some enhancements and extensions could improve the existing study:

- The developed framework for developing the performance prediction model could be applied to data collection in other locations or for other types of projects, that should be addressed in future research.
- The framework could be modified to encompass to the viewpoint of other stakeholders (this model only considers the owner's viewpoint).
- Another delivery method could be applied to this model, as this research only considers the DB and DBB delivery methods.
- Other methods for defining the weights in the calculation of overall project performance could be applied; this model only uses the AHP and GA for defining the weights.
- Using actual project data rather than using questionnaires for collecting some of the quantifiable KPIs (for example time and cost) would improve the accuracy of the developed model in future research.
- The model could be improved to automatically derive KPIs values as input to the model in any stage of a project based on project information instead of providing the KPIs values by

the project manager, making it more user-friendly. For example, the performance optimization model can be linked to the database of big companies that include the performance of each situation for different project activities. By linking the model to such a database, there is no need to define information to the model manually.

- The model could be extended to accept the whole input range for each KPI.
- The developed prediction model could be further validated by sending more questionnaires to additional experts.

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APPENDICES

Appendix A: Questionnaires

Appendix A1: Questionnaire 1- KPIs amount questionnaire

The KPIs amount questionnaire

This questionnaire wants to collect the Key Performance Indicators (KPIs) amount of existing projects. The findings of this questionnaire will be used in my PhD research under the supervision of Dr. Osama Moselhi at Concordia University. The findings are used on development of Neuro-Fuzzy models for forecasting the KPIs amount at different stage of project. It takes approximately 10 minutes to complete this questionnaire. The information collected will be used only for research purposes and will be treated strictly confidential. If you have questions regarding this study, you may contact Seyedeh Sara Fanaei, at sarafanaei@gmail.com or 514-663-8206.
Thank you in advance for your contribution to this study.

Enter your specifications:
(In the case of the project which have been most involved with that)

Name:	
Name of organization:	
Position at organization:	
Field of job:	
Years of experience:	
Type of the project:	
Name of the project:	
Email address:	

There are 6 KPIs that measured in three stages. The six KPIs are cost, time, quality, safety, client satisfaction, project team satisfaction. Three stages are initial stage (0 to 30% physical progress), middle stage (30% to 70% physical progress) and finishing stage (70% to 100% physical progress). You are requested to rank significance of these KPIs based on their relative importance in the first questions. The aims to score indicators based on their amount during each stage of project. If you would like to receive a copy of the findings of this questionnaire, please mark the appropriate box below the questionnaire wants to get the information from one of the real project that you have in mind.

please provide us with the project that you have the most information about it.

From With stage you start working in the project?

(Initial stage: 0 to 30% Physical Progress -- Middle stage: 30% to 70% Physical Progress -- Finishing stage: 70% to 100% Physical Progress)

Initial Stage

Middle Stage

Finishing Stage

What is the project delivery Method?

Design-Bid-Build (DBB) or Design-Award-Build (DAB)

DBB with Construction Management

Design-Build (DB) or Design-Construct

Design-Build-Operate-Maintain (DBOM)

Build-Operate-Transfer (BOT)

Integrated Project Delivery (IPD)

Other

What is the relative importance of each KPI in the project?

	(Very High)	(High)	(Medium High)	(Medium)	(Medium Low)	(Low)	(Very Low)	
Cost	O	O	O	O	O	O	O	Time
Cost	O	O	O	O	O	O	O	Quality
Cost	O	O	O	O	O	O	O	Safety
Cost	O	O	O	O	O	O	O	Client Satisfaction
Cost	O	O	O	O	O	O	O	Project Team Satisfaction
Time	O	O	O	O	O	O	O	Quality
Time	O	O	O	O	O	O	O	Safety
Time	O	O	O	O	O	O	O	Client Satisfaction
Time	O	O	O	O	O	O	O	Project Team Satisfaction
Quality	O	O	O	O	O	O	O	Safety
Quality	O	O	O	O	O	O	O	Client Satisfaction
Quality	O	O	O	O	O	O	O	Project Team Satisfaction

Safety	O	O	O	O	O	O	O	Client Satisfaction
Safety	O	O	O	O	O	O	O	Project Team Satisfaction
Client Satisfaction	O	O	O	O	O	O	O	Project Team Satisfaction

In the initial stage (0 to 30% Physical Progress) of the project, what is the performance of each of the following indicator?

	Very Low	Low	Medium Low	Medium	Medium High	High	Very High
Cost	O	O	O	O	O	O	O
Time	O	O	O	O	O	O	O
Quality	O	O	O	O	O	O	O
Safety	O	O	O	O	O	O	O
Client Satisfaction	O	O	O	O	O	O	O
Project Team Satisfaction	O	O	O	O	O	O	O

In the middle stage (30% to 70% Physical Progress) of the project, what is the performance of each of the following indicator?

	Very Low	Low	Medium Low	Medium	Medium High	High	Very High
Cost	O	O	O	O	O	O	O
Time	O	O	O	O	O	O	O
Quality	O	O	O	O	O	O	O
Safety	O	O	O	O	O	O	O
Client Satisfaction	O	O	O	O	O	O	O
Project Team Satisfaction	O	O	O	O	O	O	O

In the finishing stage (70% to 100% Physical Progress) of the project, what is the performance of each of the following indicator?

	Very Low	Low	Medium Low	Medium	Medium High	High	Very High
Cost	O	O	O	O	O	O	O
Time	O	O	O	O	O	O	O
Quality	O	O	O	O	O	O	O
Safety	O	O	O	O	O	O	O
Client Satisfaction	O	O	O	O	O	O	O

Project Team Satisfaction	O	O	O	O	O	O	O

With considering the whole project, what is the performance of each of the following indicator?

	Very Low	Low	Medium Low	Medium	Medium High	High	Very High
Cost	O	O	O	O	O	O	O
Time	O	O	O	O	O	O	O
Quality	O	O	O	O	O	O	O
Safety	O	O	O	O	O	O	O
Client Satisfaction	O	O	O	O	O	O	O
Project Team Satisfaction	O	O	O	O	O	O	O

With considering the whole project, what is the total project performance with containg 6 KPIs?

	Very Low	Low	Medium Low	Medium	Medium High	High	Very High
Total Performance	O	O	O	O	O	O	O

Is the project face the major delay in time?

Yes

No

Does the project have problem in providing money?

Yes

No

Does the project face the sudden increase in prices?

Yes

No

Is the project have been in private or public sector?

Private

Public

Do you want to receive a copy of findings?

Yes

No

Further Details ...

Appendix A2: Questionnaire 2- KPIs' selection questionnaire

KPIs Selection

This questionnaire wants to select the most significant Key Performance Indicators (KPIs) of existing Papers. The findings of this questionnaire will be used in my PhD research under the supervision of Dr. Osama Moselhi at Concordia University. The findings are used on select the most important KPIs from quantity results. It takes approximately 5 minutes to complete this questionnaire. The information collected will be used only for research purposes and will be treated strictly confidential. If you have questions regarding this study, you may contact Seyedeh Sara Fanaei, at sarafanaei@gmail.com or 514-663-8206.
Thank you in advance for your contribution to this study.

Enter your specifications:
(In the case of the project which have been most involved with that)

Name:

Name of organization:

Position at organization:

Years of experience:

Type of the project:

What is the importance of the KPIs during the whole projects?

	Very Low	Low	Medium Low	Medium	Medium High	High	Very High
Cost	O	O	O	O	O	O	O
Time	O	O	O	O	O	O	O
Quality (Technical Specification)	O	O	O	O	O	O	O
Safety	O	O	O	O	O	O	O
Client Satisfaction	O	O	O	O	O	O	O
Project Team Satisfaction	O	O	O	O	O	O	O
Productivity (Efficiency)	O	O	O	O	O	O	O
Environment	O	O	O	O	O	O	O
Profitability (Contractor)	O	O	O	O	O	O	O
User Satisfaction	O	O	O	O	O	O	O
Communication (Collaboration)	O	O	O	O	O	O	O
Rework and Defects	O	O	O	O	O	O	O
Information Management	O	O	O	O	O	O	O
Billing	O	O	O	O	O	O	O
Predictability (Time-Cost)	O	O	O	O	O	O	O

	Very Low	Low	Medium Low	Medium	Medium High	High	Very High
Change	O	O	O	O	O	O	O
Profitability For Owner	O	O	O	O	O	O	O
Risk Management	O	O	O	O	O	O	O
Design Team Satisfaction	O	O	O	O	O	O	O
Scope	O	O	O	O	O	O	O

Appendix A3: Respondent's information

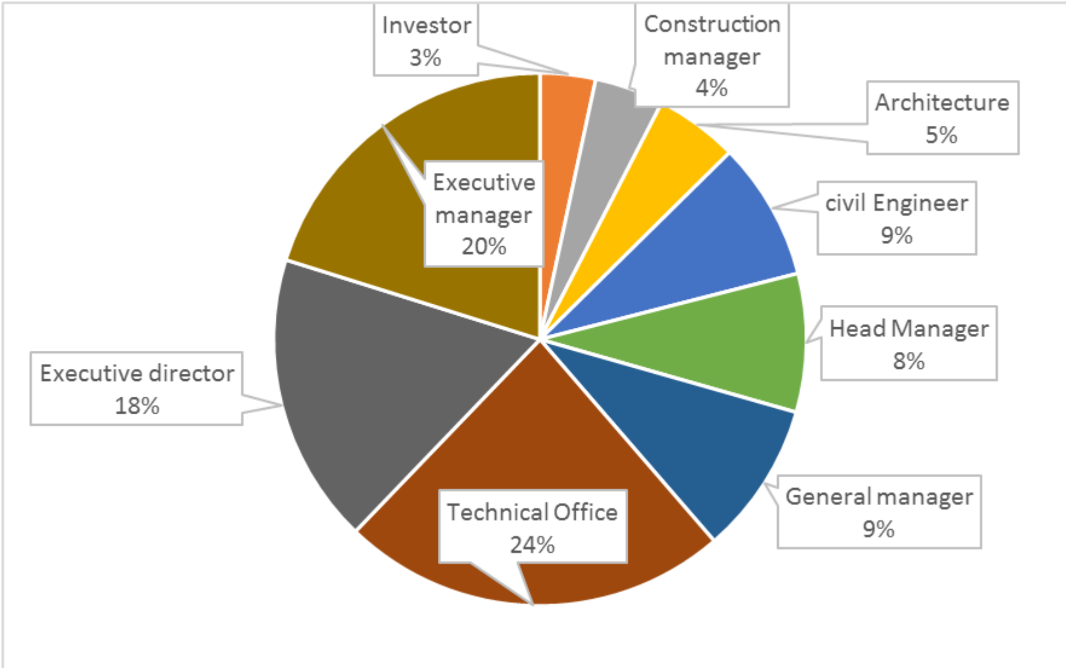

Figure A-1: Position of experts at their organization

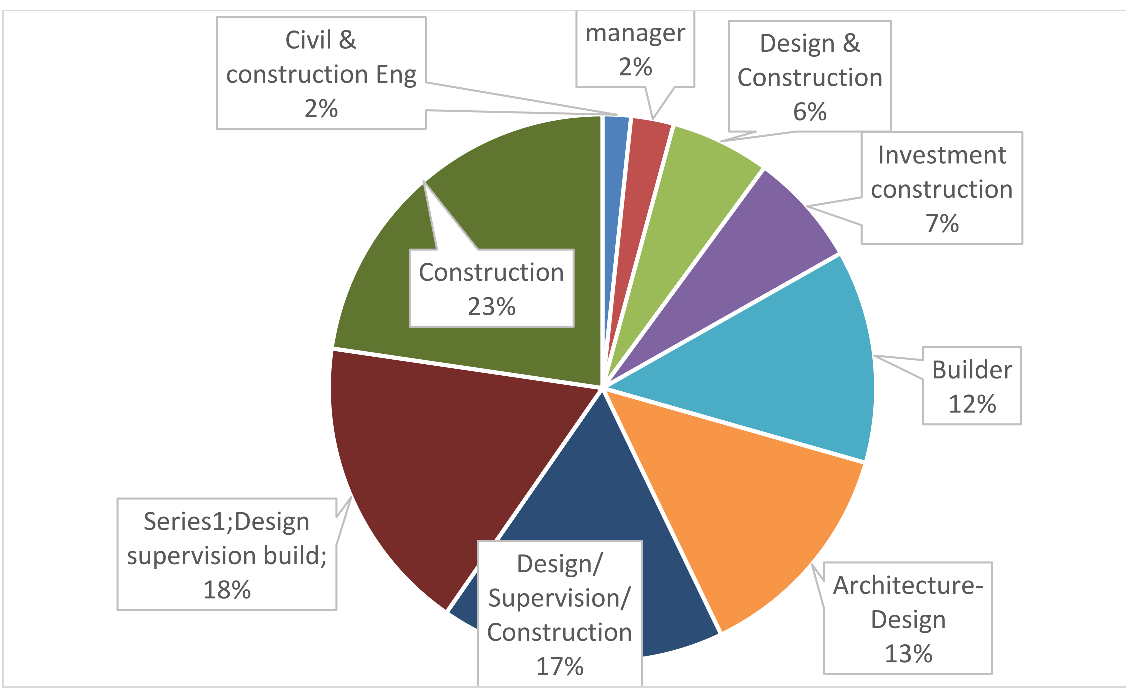

Figure A-2: Experts' field of job

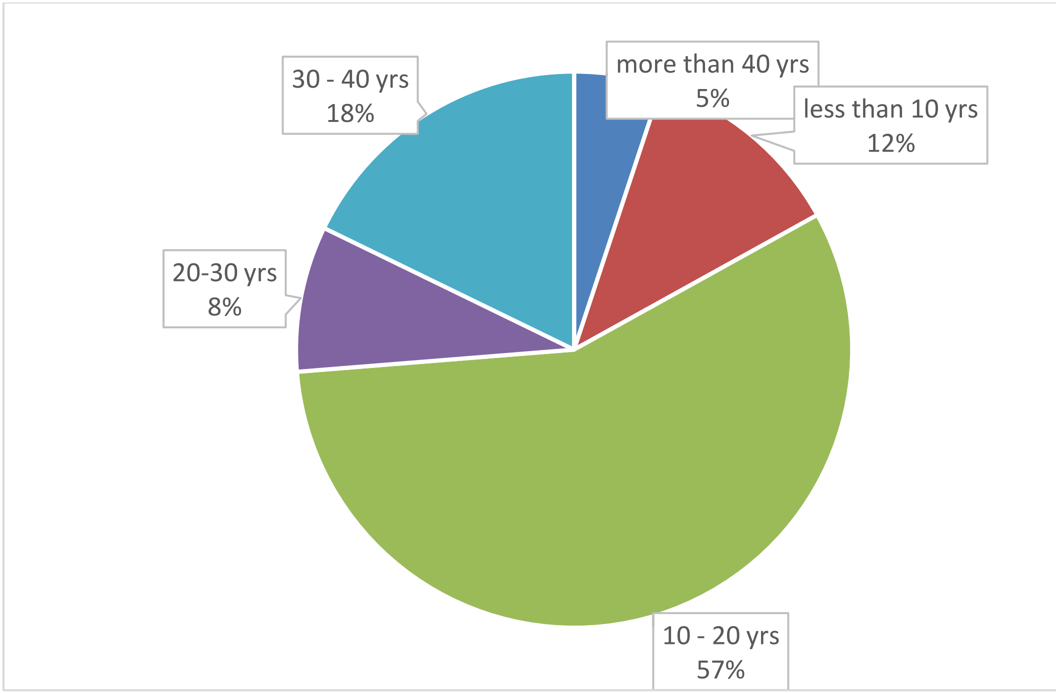

Figure A-3: Experts' years of experience

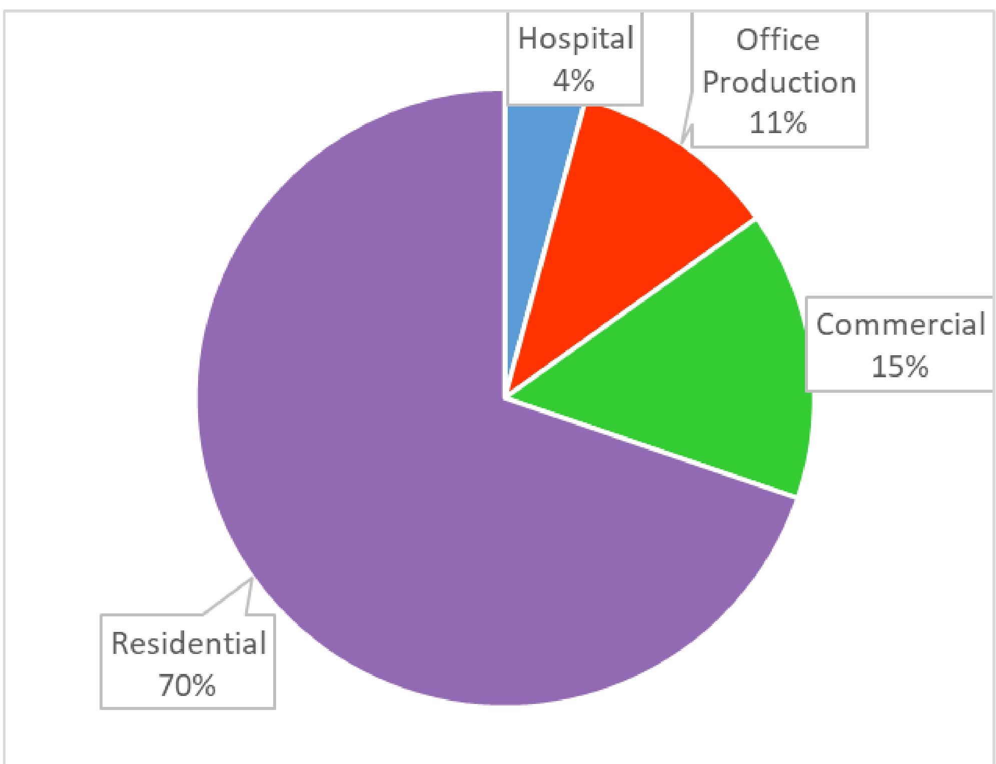

Figure A-4: Type of the projects under consideration

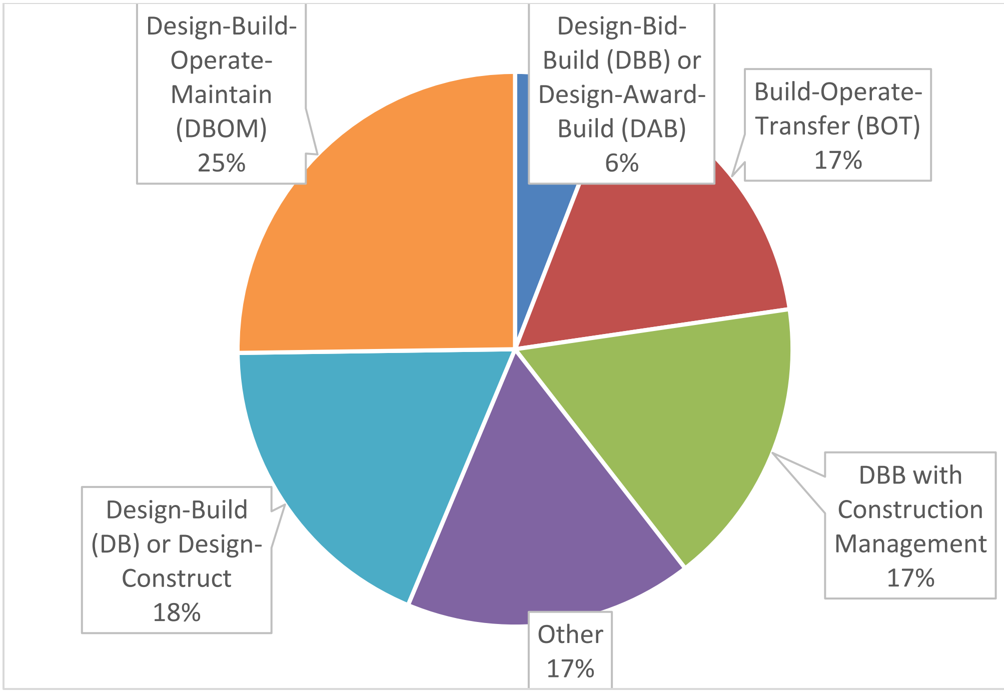

Figure A-5: Project delivery method

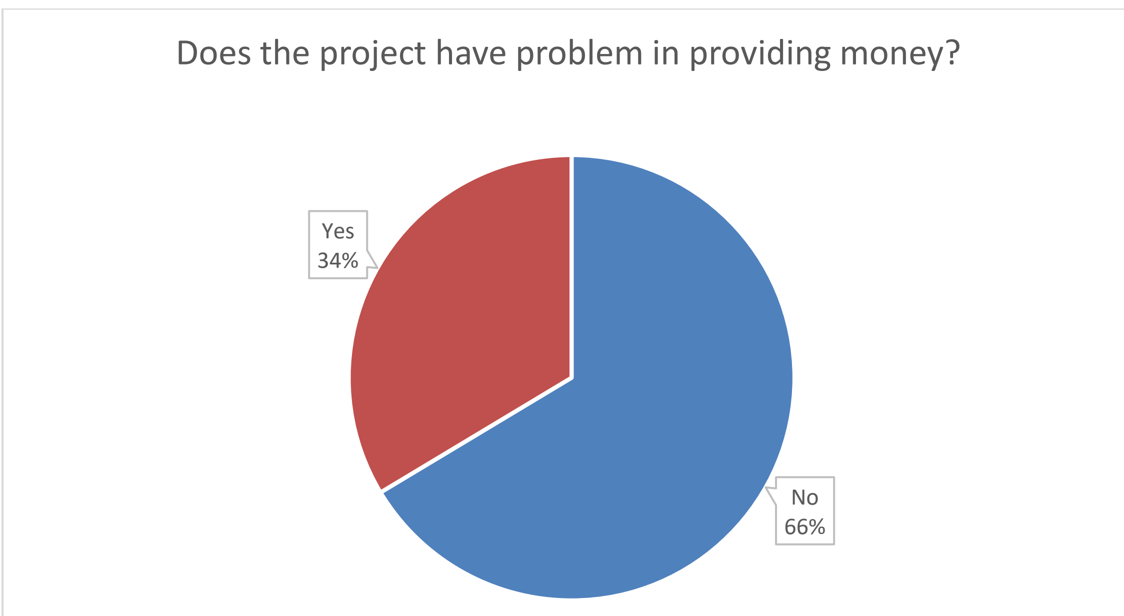

Figure A-6: Have a problem in providing money

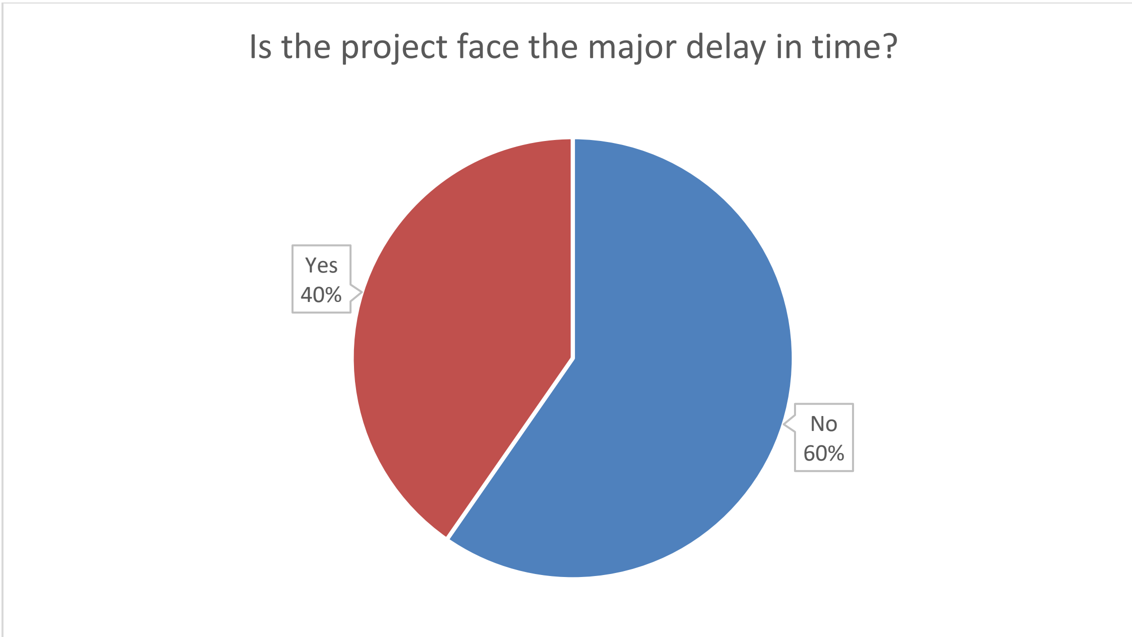

Figure A-7: Have a major delay in time

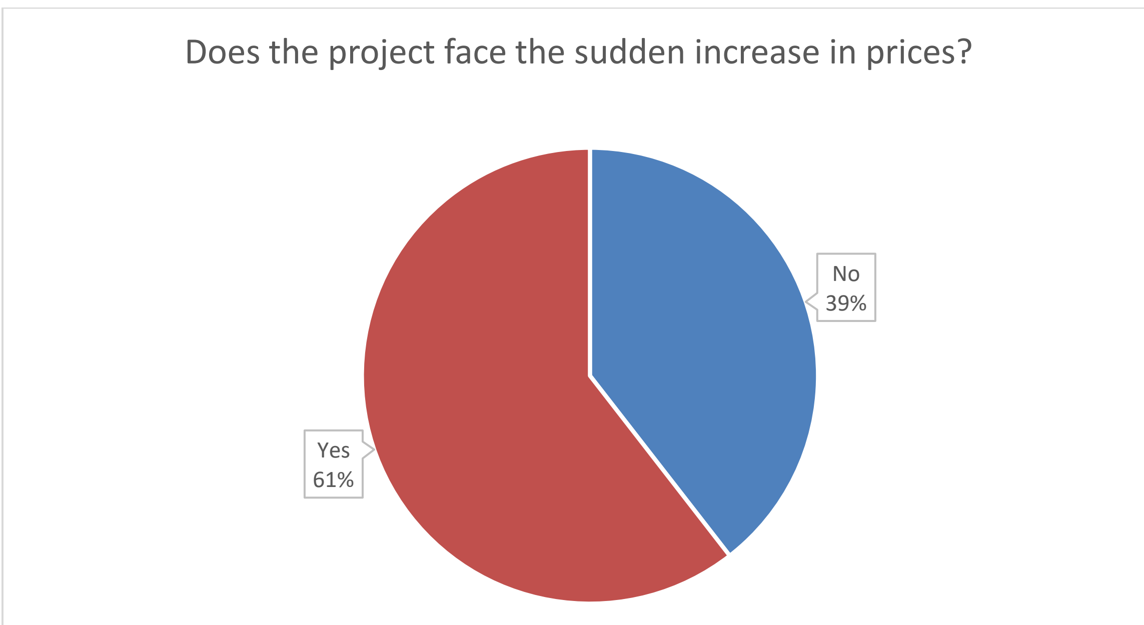

Figure A-8: Have a sudden increase in prices

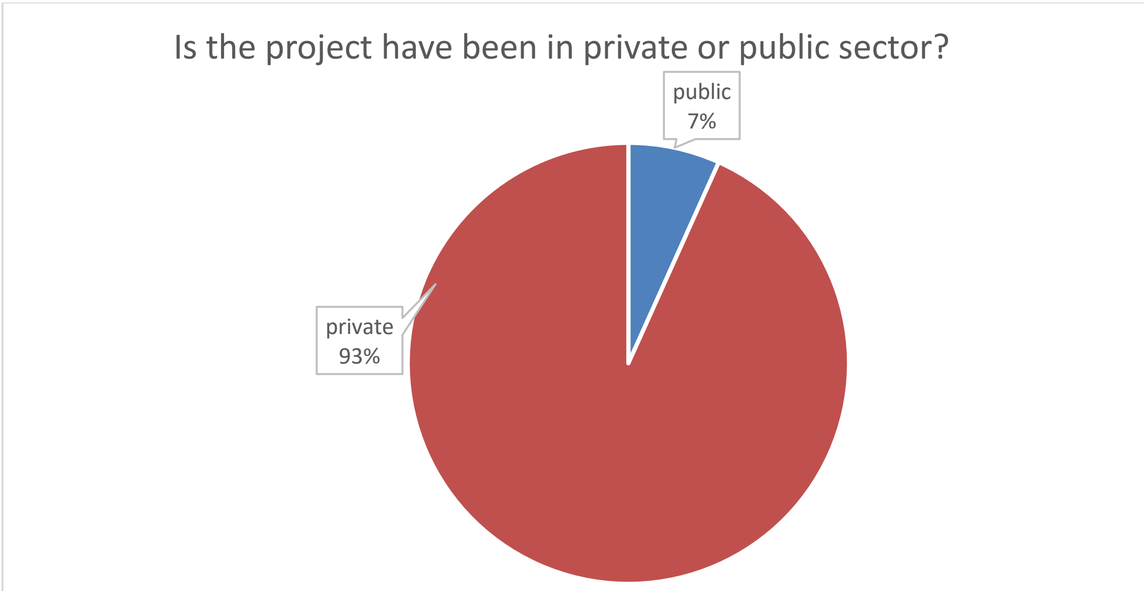

Figure A-9: Project belong to the private or public sector

Appendix B: Information About Collected Data

No.	Name of organiza-tion:	Position at organi-zation:	Field of job:	Years of experi-ence:	Type of the pro-ject:	Name of the project:	Email address:	Web Site
1	Bam group	Bam central office	Investment construction	8	Residential	Bam e Nasrin	-	http://www.bamgroup.ir/fa/
2	Bam group	Bam central office	Investment construction	8	Residential	Bam e Alborz	-	http://www.bamgroup.ir/fa/
3	Bam group	Bam central office	Investment construction	8	Office	Bam central office	-	http://www.bamgroup.ir/fa/
4	Bam group	Bam central office	Investment construction	8	Residential	Bam e niavaran	-	http://www.bamgroup.ir/fa/
5	Bam group	Bam central office	Investment construction	8	Residential	Bame jamshidieh	-	http://www.bamgroup.ir/fa/
6	Bam group	Bam central office	Investment construction	8	Commerical - Office	Bam Brand Center	-	http://www.bamgroup.ir/fa/
7	Bam group	Bam central office	Investment construction	8	Residential	Bam e mehmandous	-	http://www.bamgroup.ir/fa/
8	Bam group	Bam central office	Investment construction	8	Commerical - Office	Bam IT Center	-	http://www.bamgroup.ir/fa/
9	Dooranshahr consulting Engineers	Head Manager	Architecture-Design	25	Residential	Resalat Residental Complex (Tehran)	Dooranshahr@yahoo.com	-
10	Dooranshahr consulting Engineers	Head Manager	Architecture-Design	25	Residential	Jame-Jam Residental complex of islamshahr	Dooranshahr@yahoo.com	-
11	Dooranshahr consulting Engineers	Head Manager	Architecture-Design	25	Residential	Noor Residental complex (Tehran)	Dooranshahr@yahoo.com	-
12	Dooranshahr consulting Engineers	Head Manager	Architecture-Design	25	Residential	Amir kabir residental complex (semnan)	Dooranshahr@yahoo.com	-
13	Dooranshahr consulting Engineers	Head Manager	Architecture-Design	25	Residential	Golha Residental complex of maragheh	Dooranshahr@yahoo.com	-
14	-	-	Civil engineer	7	Commerical	Niavaran	Amiranamiran@gmail.com	-

No.	Name of organization:	Position at organization:	Field of job:	Years of experience:	Type of the project:	Name of the project:	Email address:	Web Site
15	-	-	Civil engineer	7	Commerical & Residential	Mehregan	Amirana-miran@gmail.com	-
16	Diplomat	Executive manager	Construction	15	Residential	Sarrafha diplomat residental complex	diplomat-co@yahoo.com	http://dbg-co.com/
17	Diplomat	Executive manager	Construction	38	Office	Banafsheh office complex	-	http://dbg-co.com/
18	Diplomat	Executive manager	Construction	15	Residential	Darya residental	diplomat-co@yahoo.com	http://dbg-co.com/
19	Diplomat	Executive manager	Construction	15	Residential	Farmaniyeh Diplomat	diplomat-co@yahoo.com	http://dbg-co.com/
20	Diplomat	Executive manager	Construction	15	Residential	Elahiyeh Diplomat	diplomat-co@yahoo.com	http://dbg-co.com/
21	Diplomat	Executive manager	Construction	15	Residential	Vardavard Diplomat	diplomat-co@yahoo.com	http://dbg-co.com/
22	Diplomat	Executive manager	Construction	15	Residential	Velenjak 3 Diplomat	diplomat-co@yahoo.com	http://dbg-co.com/
23	Diplomat	Executive manager	Construction	15	Residential	Velenjak 6 Diplomat	diplomat-co@yahoo.com	http://dbg-co.com/
24	Diplomat	Executive manager	Construction	15	Residential	Kaj Diplomat	diplomat-co@yahoo.com	http://dbg-co.com/
25	Diplomat	Executive manager	Construction	15	Residential	Sasan Diplomat	diplomat-co@yahoo.com	http://dbg-co.com/
26	Diplomat	Executive manager	Construction	15	Residential	Borje Abi	diplomat-co@yahoo.com	http://dbg-co.com/
27	Diplomat	Executive manager	Construction	15	Residential	Narenjestan Diplomat	diplomat-co@yahoo.com	http://dbg-co.com/
28	Diplomat	Executive manager	Construction	15	Residential	Raazi residental tower	diplomat-co@yahoo.com	http://dbg-co.com/
29	Diplomat	Executive manager	Construction	15	Commerical	Boroujerd yaghout commerical center	diplomat-co@yahoo.com	http://dbg-co.com/
30	Diplomat	Executive manager	Construction	15	Residential	Saadat abad 15th st complex	diplomat-co@yahoo.com	http://dbg-co.com/
31	Diplomat	Executive manager	Construction	15	Residential	Morvarid complex	diplomat-co@yahoo.com	http://dbg-co.com/

No.	Name of organization:	Position at organization:	Field of job:	Years of experience:	Type of the project:	Name of the project:	Email address:	Web Site
32	Diplomat	Executive manager	Construction	15	Residential	Saadat abad 4th st complex	diplomat-co@yahoo.com	http://dbg-co.com/
33	Diplomat	Executive manager	Construction	15	Residential	Kamraniyeh Residental	diplomat-co@yahoo.com	http://dbg-co.com/
34	Diplomat	Executive manager	Construction	15	Residential	Golestan residental	diplomat-co@yahoo.com	http://dbg-co.com/
35	Diplomat	Executive manager	Construction	15	Residential	Diplomat central office	diplomat-co@yahoo.com	http://dbg-co.com/
36	Diplomat	Executive manager	Construction	15	Residential	Zaferaniyeh Diplomat residential complex	diplomat-co@yahoo.com	http://dbg-co.com/
37	Diplomat	Executive manager	Construction	15	Residential	Arya residential tower	diplomat-co@yahoo.com	http://dbg-co.com/
38	Diplomat	Executive manager	Construction	15	Residential	Goldasht villa	diplomat-co@yahoo.com	http://dbg-co.com/
39	Diplomat	Executive manager	Construction	15	Residential	Dizin Villa	diplomat-co@yahoo.com	http://dbg-co.com/
40	Diplomat	Executive manager	Construction	15	Residential	Lavasan Villa	diplomat-co@yahoo.com	http://dbg-co.com/
41	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Residential	Darus	h-beshnam@yahoo.com	-
42	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Commerical - Office	Zafar	h-beshnam@yahoo.com	-
43	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Residential	Dezashib	h-beshnam@yahoo.com	-
44	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Residential	Heravi	h-beshnam@yahoo.com	-
45	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Commerical - Office	Amaar	h-beshnam@yahoo.com	-
46	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Residential	Pasdaran	h-beshnam@yahoo.com	-

No.	Name of organization:	Position at organization:	Field of job:	Years of experience:	Type of the project:	Name of the project:	Email address:	Web Site
47	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Residential	Aghdasieh	h-beshnam@yahoo.com	-
48	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Residential	Abshar	h-beshnam@yahoo.com	-
49	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Residential	Chizar	h-beshnam@yahoo.com	-
50	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Residential	Mobasher	h-beshnam@yahoo.com	-
51	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Commerical	Bazar Ozgol	h-beshnam@yahoo.com	-
52	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Residential	Asef	h-beshnam@yahoo.com	-
53	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Office Production	Pardis	h-beshnam@yahoo.com	-
54	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Residential	Farhang	h-beshnam@yahoo.com	-
55	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Commerical - Office	Erfan	h-beshnam@yahoo.com	-
56	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Residential	Jamaran	h-beshnam@yahoo.com	-
57	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Residential	Nahvi	h-beshnam@yahoo.com	-
58	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Residential	Bagh Ferdos	h-beshnam@yahoo.com	-

No.	Name of organization:	Position at organization:	Field of job:	Years of experience:	Type of the project:	Name of the project:	Email address:	Web Site
59	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Residential	Ozgol	h-beshnam@yahoo.com	-
60	Khest Bartar	Technical Office	Design/ Supervision/ Construction	15	Residential	Kurosh	h-beshnam@yahoo.com	-
61	Hamkaran Omran Arzesh	Head Office	Architecture	43	Residential	Tabriz sister	n_boushehri@yahoo.com	www.hozco.net
62	Hamkaran Omran Arzesh	Head Office	Architecture	43	Residential	sobhan Project	n_boushehri@yahoo.com	www.hozco.net
63	Hamkaran Omran Arzesh	Head Office	Architecture	43	Residential	Rezieh Ghadimeh navaei	n_boushehri@yahoo.com	www.hozco.net
64	Hamkaran Omran Arzesh	Head Office	Architecture	43	Residential	Bijan siasi	n_boushehri@yahoo.com	www.hozco.net
65	Hamkaran Omran Arzesh	Head Office	Architecture	43	Residential	Shadli residental	n_boushehri@yahoo.com	www.hozco.net
66	Hands Construction	civil Engineer	Builder/ Designer	32	Residential complex	Kohsar #25	Davidsahih@yahoo.com	www.handsiran.com/index.htm
67	Hands Construction	civil Engineer	Builder	28	Residential	Mehran residential project	Handscoinc@gmail.com	www.handsiran.com/index.htm
68	Hands Construction	Construction manager	manager	31	Residential	Rose building	Alensahih@yahoo.com	www.handsiran.com/index.htm
69	Hands Construction	Civil Engineer	Designer	29	Residential	Dehghan residential project	Handscoinc2@gmail.com	www.handsiran.com/index.htm
70	Hands Construction	Civil Engineer	Builder/ Designer	32	Residential	Sasan Tower	Davidsahih@yahoo.com	www.handsiran.com/index.htm
71	Hands Construction	Civil Engineer	Builder	28	Residential	Sepidkouh residential tower	Handscoinc@gmail.com	www.handsiran.com/index.htm
72	Hands Construction	Construction manager and electrical engneer	Electrical engineer	32	Residential	Razi (2)	Jhonsahih@yahoo.com	www.handsiran.com/index.htm
73	Hands Construction	Architecture	Builder/ Designer	35	Commerical	Galleria Shopping center	Hamidsahih@Gmail.com	www.handsiran.com/index.htm

No.	Name of organization:	Position at organization:	Field of job:	Years of experience:	Type of the project:	Name of the project:	Email address:	Web Site
74	Hands Construction	Construction manager and electrical engneer	Electrical engineer	32	Residential	Shirkouh tower	Jhonsahih@yahoo.com	www.handsiran.com/index.htm
75	Hands Construction	Construction manager	Builder/ Designer	31	Residential	Razi (1)	Alensahih@yahoo.com	www.handsiran.com/index.htm
76	Hands Construction	Construction manager	Builder/ superviser	31	Residential	Mehman Doust residential	Alensahih@yahoo.com	www.handsiran.com/index.htm
77	Hands Construction	civil Engineer	Builder	5	Residential	Razi (4)	Handscoinc2@gmail.com	www.handsiran.com/index.htm
78	Hands Construction	Architecture	Builder/ Designer	9	Residential	Razi (5)	Handscoinc2@gmail.com	www.handsiran.com/index.htm
79	Hands Construction	Architecture	Builder/ Designer	14	Residential	Razi karimi	Handscoinc2@gmail.com	www.handsiran.com/index.htm
80	Hands Construction	civil Engineer	Builder/ Designer	6	Residential	Baghestan residential building	Handscoinc2@gmail.com	www.handsiran.com/index.htm
81	Hands Construction	Architecture	Builder	55	Residential	Yarmohammadi residential	Handscoinc2@gmail.com	www.handsiran.com/index.htm
82	Hands Construction	civil Engineer	Builder/ Designer	16	Residential	Neshat residential building	Handscoinc2@gmail.com	www.handsiran.com/index.htm
83	Hands Construction	civil Engineer	Designer	30	Office	Beneton Office building	Davidsahih@yahoo.com	www.handsiran.com/index.htm
84	Hands Construction	civil Engineer	Builder/ Designer	30	Commerical	Emam Hassan	Davidsahih@yahoo.com	www.handsiran.com/index.htm
85	Hands Construction	Architecture	Builder/ Designer	35	Residential	Behesht Tower	Hamidsahih@Gmail.com	www.handsiran.com/index.htm
86	Tarh_o_Sazeh	General manager	Design & Construction	40	Commerical & Residential	Negine Reza Commerical center	T_sazeh@yahoo.com	-
87	Tarh_o_Sazeh	General manager	Design & Construction	40	Commerical center	Adineh commerical center At Chaloos	T_sazeh@yahoo.com	-

No.	Name of organization:	Position at organization:	Field of job:	Years of experience:	Type of the project:	Name of the project:	Email address:	Web Site
88	Tarh_o_Sazeh	General manager	Design & Construction	40	Commerical	Adineh commerical center at tonekabon	T_sazeh@yahoo.com	-
89	Tarh_o_Sazeh	General manager	Design & Construction	40	Commerical Center	Goldis center	T_sazeh@yahoo.com	-
90	Tarh_o_Sazeh	General manager	Design & Construction	40	Commerical	Boustan commerical center	T_sazeh@yahoo.com	-
91	Tarh_o_Sazeh	General manager	Design & Construction	40	Commerical Center	City computer center	T_sazeh@yahoo.com	-
92	Tarh_o_Sazeh	General manager	Design & Construction	40	Commerical Center	Milad Center (Karaj)	T_sazeh@yahoo.com	-
93	Rezvan Co	Investor	Civil & construction Eng	7	Commerical & sport center	Rezvan Center	T_sazeh@yahoo.com	-
94	Tandis center	Investor	Civil & construction Eng	45	Commerical	Tandis commerical center	T_sazeh@yahoo.com	-
95	Tarh_o_Sazeh	General manager	Architectural	40	Commerical	Kian commerical center	T_sazeh@yahoo.com	-
96	Tarh_o_Sazeh	General manager	Architectural	40	Commerical	Kourosh shoping center	T_sazeh@yahoo.com	-
97	Tarh_o_Sazeh	General manager	Architectural	40	Commerical	Lashgarak	T_sazeh@yahoo.com	-
98	Tarh_o_Sazeh	General manager	Architectural	40	Commerical	Zendegui commerical center	T_sazeh@yahoo.com	-
99	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Amir	arseszhav@gmail.com	www.arseszhav.com
100	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Negin	arseszhav@gmail.com	www.arseszhav.com
101	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Shahran-Mahsa	arseszhav@gmail.com	www.arseszhav.com
102	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Solmaz	arseszhav@gmail.com	www.arseszhav.com

No.	Name of organization:	Position at organization:	Field of job:	Years of experience:	Type of the project:	Name of the project:	Email address:	Web Site
103	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Daros	arseszhav@gmail.com	www.arseszhav.com
104	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Janat Abad	arseszhav@gmail.com	www.arseszhav.com
105	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Amir Building	arseszhav@gmail.com	www.arseszhav.com
106	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Armaghan	arseszhav@gmail.com	www.arseszhav.com
107	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Sara Building	arseszhav@gmail.com	www.arseszhav.com
108	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Alborz	arseszhav@gmail.com	www.arseszhav.com
109	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Keyhan	arseszhav@gmail.com	www.arseszhav.com
110	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Nastaran	arseszhav@gmail.com	www.arseszhav.com
111	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Aghaghia	arseszhav@gmail.com	www.arseszhav.com
112	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Afra	arseszhav@gmail.com	www.arseszhav.com
113	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Nazanin	arseszhav@gmail.com	www.arseszhav.com
114	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Nastaran	arseszhav@gmail.com	www.arseszhav.com

No.	Name of organization:	Position at organization:	Field of job:	Years of experience:	Type of the project:	Name of the project:	Email address:	Web Site
115	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Azadi	arseszhav@gmail.com	www.arseszhav.com
116	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Elnaz	arseszhav@gmail.com	www.arseszhav.com
117	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Ardestani	arseszhav@gmail.com	www.arseszhav.com
118	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Niavaran	arseszhav@gmail.com	www.arseszhav.com
119	Arseszhav	Executive director	Design-Supervision-Build	20	Residential	Raz	arseszhav@gmail.com	www.arseszhav.com

Appendix C: Neural Network Training Errors

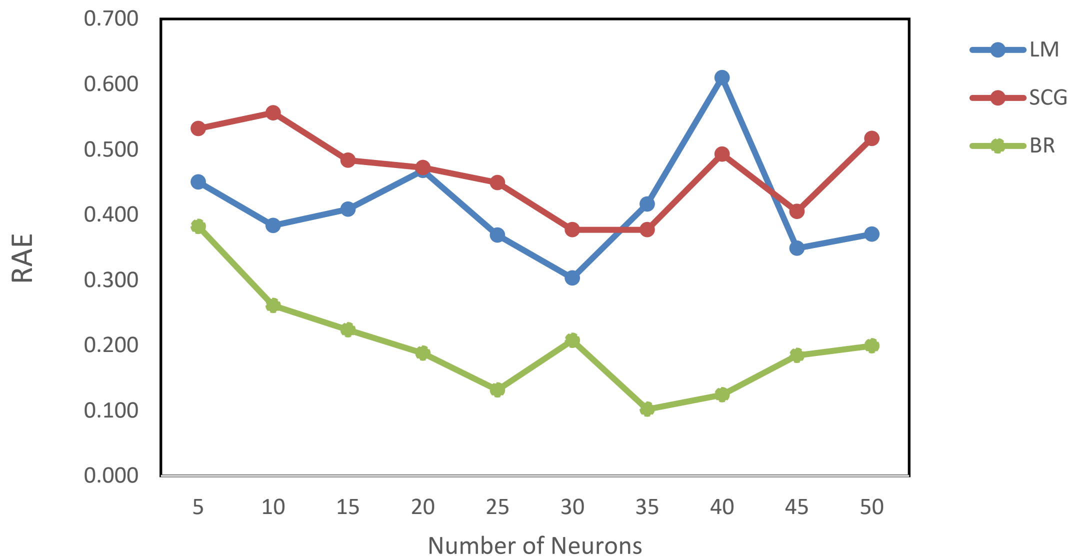

Figure C-1: RAE values of ANN models

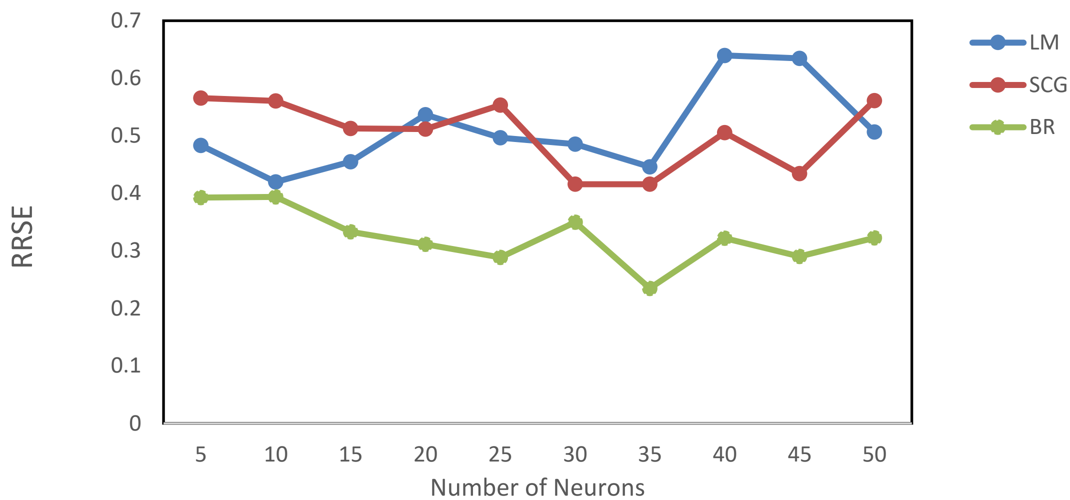

Figure C-2: RRSE values of ANN models

Appendix D: Coding

Appendix D1: Neuro-Fuzzy coding

- **Create_Model**

```
tic
clc;
clear all
```

- **Input dataset from excel file to Matlab**

```
Data11 = xlsread('Questionnaire - Results-951024','Data11');
Data12 = xlsread('Questionnaire - Results-951024','Data12');
Data13 = xlsread('Questionnaire - Results-951024','Data13');
Data14 = xlsread('Questionnaire - Results-951024','Data14');
Data15 = xlsread('Questionnaire - Results-951024','Data15');
Data16 = xlsread('Questionnaire - Results-951024','Data16');
Data21 = xlsread('Questionnaire - Results-951024','Data21');
Data22 = xlsread('Questionnaire - Results-951024','Data22');
Data23 = xlsread('Questionnaire - Results-951024','Data23');
Data24 = xlsread('Questionnaire - Results-951024','Data24');
Data25 = xlsread('Questionnaire - Results-951024','Data25');
Data26 = xlsread('Questionnaire - Results-951024','Data26');
Data31 = xlsread('Questionnaire - Results-951024','Data31');
Data32 = xlsread('Questionnaire - Results-951024','Data32');
Data33 = xlsread('Questionnaire - Results-951024','Data33');
Data34 = xlsread('Questionnaire - Results-951024','Data34');
Data35 = xlsread('Questionnaire - Results-951024','Data35');
Data36 = xlsread('Questionnaire - Results-951024','Data36');
```

- **Train ANFIS models**

```
ANFIS11 = Trained_ANFIS(Data11);
pause(1)
ANFIS12 = Trained_ANFIS(Data12);
pause(1)
ANFIS13 = Trained_ANFIS(Data13);
pause(1)
ANFIS14 = Trained_ANFIS(Data14);
pause(1)
ANFIS15 = Trained_ANFIS(Data15);
pause(1)
ANFIS16 = Trained_ANFIS(Data16);
pause(1)

ANFIS21 = Trained_ANFIS(Data21);
pause(1)
ANFIS22 = Trained_ANFIS(Data22);
pause(1)
ANFIS23 = Trained_ANFIS(Data23);
pause(1)
ANFIS24 = Trained_ANFIS(Data24);
pause(1)
```

```
ANFIS25 = Trained_ANFIS(Data25);
pause(1)
ANFIS26 = Trained_ANFIS(Data26);
pause(1)

ANFIS31 = Trained_ANFIS(Data31);
pause(1)
ANFIS32 = Trained_ANFIS(Data32);
pause(1)
ANFIS33 = Trained_ANFIS(Data33);
pause(1)
ANFIS34 = Trained_ANFIS(Data34);
pause(1)
ANFIS35 = Trained_ANFIS(Data35);
pause(1)
ANFIS36 = Trained_ANFIS(Data36);
pause(1)
```

- **Save ANFIS models to use in using_model code**

```
save('ANFIS11','ANFIS11');
save('ANFIS12','ANFIS12');
save('ANFIS13','ANFIS13');
save('ANFIS14','ANFIS14');
save('ANFIS15','ANFIS15');
save('ANFIS16','ANFIS16');

save('ANFIS21','ANFIS21');
save('ANFIS22','ANFIS22');
save('ANFIS23','ANFIS23');
save('ANFIS24','ANFIS24');
save('ANFIS25','ANFIS25');
save('ANFIS26','ANFIS26');

save('ANFIS31','ANFIS31');
save('ANFIS32','ANFIS32');
save('ANFIS33','ANFIS33');
save('ANFIS34','ANFIS34');
save('ANFIS35','ANFIS35');
save('ANFIS36','ANFIS36');


toc
```

- **Trained_ Neuro-fuzzy using Subtractive Clustering**

```
function [ANFIS] = Trained_ANFIS(Data)

%% Load Data
format short                                    % Short scientific notation,
with 4 digits after the decimal point

[Train_Dataset,Test_Dataset]=Data_Division(Data);  % Using Data_Division func-
tion
```

```
Input_Exp_Train  = Train_Dataset(:,1:end-1);      % Train Inputs (Experimental)
Output_Exp_Train = Train_Dataset(:,end);          % Train Output (Experimental)

Input_Exp_Test   = Test_Dataset(:,1:end-1);        % Test Inputs (Experimental)
Output_Exp_Test  = Test_Dataset(:,end);            % Test Output (Experimental)

%% Select the initial FIS model

    step=0;
    Results = zeros(1001,4);
for Cluster_Radius = 0:0.001:1    % Notice: Need at least two rules for ANFIS
learning!

    step = step + 1;                    % It is a counter
    disp('Please wait ...');
    disp(step);

% Generate Fuzzy Inference System structure from data using subtractive clus-
tering (Sugeno-type-Linear)
  Initial_FIS = genfis2(Input_Exp_Train,Output_Exp_Train,Cluster_Radius);

   Output_Model_Train = evalfis(Input_Exp_Train,Initial_FIS);              %
Train Output (FIS model)
   Output_Model_Test  = evalfis(Input_Exp_Test,Initial_FIS);               %
Test  Output (FIS model)
   Output_Model_Total    =    evalfis([Input_Exp_Train;    Input_Exp_Test],Ini-
tial_FIS); % Total Output (FIS model)

   [Cov_Train,~,~,~] = Error( Output_Exp_Train,Output_Model_Train);
   [Cov_Test ,~,~,~] = Error( Output_Exp_Test,Output_Model_Test);
   [Cov_Total,~,~,~]   =   Error(   [Output_Exp_Train;   Output_Exp_Test],Out-
put_Model_Total);
   Results(step,:)=[Cluster_Radius    abs(Cov_Test-Cov_Train)    abs(Cov_Total-
Cov_Test) abs(Cov_Total-Cov_Train)];

end

   Sort_Results = sortrows(Results,2);  % sort the results matrix based on the
columns specified in the COVs column

for i = 1:size(Sort_Results,1)     % Compare initial FIS model to select final
initial FIS model that must be used in ANFIS
    if  Sort_Results(i,2) <= 2 &&...
        Sort_Results(i,3) <= 2 &&...
        Sort_Results(i,4) <= 2

        Final_Cluster_Radius = Sort_Results(i,1);

        % Save the final cluster radius for using in the final initial FIS model
        save('Final_Cluster_Radius','Final_Cluster_Radius')

        break;

    elseif Sort_Results(i,2) <= 2.5 &&...
```

```
            Sort_Results(i,3) <= 2.5 &&...
            Sort_Results(i,4) <= 2.5
            Final_Cluster_Radius = Sort_Results(i,1);

            % Save the final cluster radius for using in the final initial FIS
model
            save('Final_Cluster_Radius','Final_Cluster_Radius')

            break;
    elseif Sort_Results(i,2) <= 3 &&...
            Sort_Results(i,3) <= 3 &&...
            Sort_Results(i,4) <= 3
            Final_Cluster_Radius = Sort_Results(i,1);

            % Save the final cluster radius for using in the final initial FIS
model
            save('Final_Cluster_Radius','Final_Cluster_Radius')

            break;
    elseif Sort_Results(i,2) <= 3.5 &&...
            Sort_Results(i,3) <= 3.5 &&...
            Sort_Results(i,4) <= 3.5
            Final_Cluster_Radius = Sort_Results(i,1);

            % Save the final cluster radius for using in the final initial FIS
model
            save('Final_Cluster_Radius','Final_Cluster_Radius')

            break;
    elseif Sort_Results(i,2) <= 4 &&...
            Sort_Results(i,3) <= 4 &&...
            Sort_Results(i,4) <= 4
            Final_Cluster_Radius = Sort_Results(i,1);

            % Save the final cluster radius for using in the final initial FIS
model
            save('Final_Cluster_Radius','Final_Cluster_Radius')

            break;
    elseif Sort_Results(i,2) <= 4.5 &&...
            Sort_Results(i,3) <= 4.5 &&...
            Sort_Results(i,4) <= 4.5
            Final_Cluster_Radius = Sort_Results(i,1);

            % Save the final cluster radius for using in the final initial FIS
model
            save('Final_Cluster_Radius','Final_Cluster_Radius')

            break;
    elseif Sort_Results(i,2) <= 5 &&...
            Sort_Results(i,3) <= 5 &&...
            Sort_Results(i,4) <= 5
            Final_Cluster_Radius = Sort_Results(i,1);
```

```
            % Save the final cluster radius for using in the final initial FIS
model
            save('Final_Cluster_Radius','Final_Cluster_Radius')

            break;
        elseif Sort_Results(i,2) <= 5.5 &&...
            Sort_Results(i,3) <= 5.5 &&...
            Sort_Results(i,4) <= 5.5
            Final_Cluster_Radius = Sort_Results(i,1);

            % Save the final cluster radius for using in the final initial FIS
model
            save('Final_Cluster_Radius','Final_Cluster_Radius')

            break;
        elseif Sort_Results(i,2) <= 6 &&...
            Sort_Results(i,3) <= 6 &&...
            Sort_Results(i,4) <= 6
            Final_Cluster_Radius = Sort_Results(i,1);

            % Save the final cluster radius for using in the final initial FIS
model
            save('Final_Cluster_Radius','Final_Cluster_Radius')

            break;
        elseif Sort_Results(i,2) <= 6.5 &&...
            Sort_Results(i,3) <= 6.5 &&...
            Sort_Results(i,4) <= 6.5
            Final_Cluster_Radius = Sort_Results(i,1);

            % Save the final cluster radius for using in the final initial FIS
model
            save('Final_Cluster_Radius','Final_Cluster_Radius')

            break;
        elseif Sort_Results(i,2) <= 7 &&...
            Sort_Results(i,3) <= 7 &&...
            Sort_Results(i,4) <= 7
            Final_Cluster_Radius = Sort_Results(i,1);

            % Save the final cluster radius for using in the final initial FIS
model
            save('Final_Cluster_Radius','Final_Cluster_Radius')

            break;
        elseif Sort_Results(i,2) <= 7.5 &&...
            Sort_Results(i,3) <= 7.5 &&...
            Sort_Results(i,4) <= 7.5
            Final_Cluster_Radius = Sort_Results(i,1);

            % Save the final cluster radius for using in the final initial FIS
model
            save('Final_Cluster_Radius','Final_Cluster_Radius')

            break;
```

```
    elseif Sort_Results(i,2) <= 8 &&...
           Sort_Results(i,3) <= 8 &&...
           Sort_Results(i,4) <= 8
           Final_Cluster_Radius = Sort_Results(i,1);

           % Save the final cluster radius for using in the final initial FIS
model
           save('Final_Cluster_Radius','Final_Cluster_Radius')

           break;
    elseif Sort_Results(i,2) <= 8.5 &&...
           Sort_Results(i,3) <= 8.5 &&...
           Sort_Results(i,4) <= 8.5
           Final_Cluster_Radius = Sort_Results(i,1);

           % Save the final cluster radius for using in the final initial FIS
model
           save('Final_Cluster_Radius','Final_Cluster_Radius')

           break;
    elseif Sort_Results(i,2) <= 9 &&...
           Sort_Results(i,3) <= 9 &&...
           Sort_Results(i,4) <= 9
           Final_Cluster_Radius = Sort_Results(i,1);

           % Save the final cluster radius for using in the final initial FIS
model
           save('Final_Cluster_Radius','Final_Cluster_Radius')

           break;
    elseif Sort_Results(i,2) <= 9.5 &&...
           Sort_Results(i,3) <= 9.5 &&...
           Sort_Results(i,4) <= 9.5
           Final_Cluster_Radius = Sort_Results(i,1);

           % Save the final cluster radius for using in the final initial FIS
model
           save('Final_Cluster_Radius','Final_Cluster_Radius')

           break;
    elseif Sort_Results(i,2) <= 10 &&...
           Sort_Results(i,3) <= 10 &&...
           Sort_Results(i,4) <= 10
           Final_Cluster_Radius = Sort_Results(i,1);

           % Save the final cluster radius for using in the final initial FIS
model
           save('Final_Cluster_Radius','Final_Cluster_Radius')

           break;
    end

end
```

```
%% Create ANFIS Structure

 % The final cluster Radius from compare algorithm
   load('Final_Cluster_Radius.mat')

 % Create initial FIS with final cluster radius (sugeno-Linear with Subtractive
Clustering)
   Initial_FIS   =   genfis2(Input_Exp_Train,Output_Exp_Train,Final_Cluster_Ra-
dius);

 % ANFIS Options
                % Training Options
                  MaxEpoch=100;
                  ErrorGoal=0;
                  InitialStepSize=0.01;
                  StepSizeDecRate=0.9;
                  StepSizeIncRate=1.1;
                  TrainOptions=[MaxEpoch  ErrorGoal  InitialStepSize  StepSiz-
eDecRate StepSizeIncRate];

                % Display Options
                  ShowAnfisInformation=true;
                  ShowError=true;
                  ShowStepSize=true;
                  ShowFinalResult=true;
                  DisplayOptions=[ShowAnfisInformation  ShowError  ShowStepSize
ShowFinalResult];

                % Training Algorithm - Select Training Algorithm
                  %TrainAlgorithm=0;   % BP
                  TrainAlgorithm=1;    % Hybrid LS-BP
% ANIFS works
 [~,~,~,ANFIS,~]   =   anfis(Train_Dataset,Initial_FIS,TrainOptions,DisplayOp-
tions, Test_Dataset,TrainAlgorithm);

End
```

- **Trained_ Neuro-fuzzy using FCM**

```
function [ANFIS] = Trained_ANFIS(Data)

%% Load Data
format short                                      % Short scientific notation,
with 4 digits after the decimal point

[Train_Dataset,Test_Dataset]=Data_Division(Data);  % Using Data_Division func-
tion

Input_Exp_Train  = Train_Dataset(:,1:end-1);      % Train Inputs (Experimental)
Output_Exp_Train = Train_Dataset(:,end);          % Train Output (Experimental)

Input_Exp_Test   = Test_Dataset(:,1:end-1);        % Test Inputs (Experimental)
Output_Exp_Test  = Test_Dataset(:,end);            % Test Output (Experimental)
```

```
%% Select the initial FIS model

    step=0;
    Results = zeros(50,4);
for nCluster = 1:50
    step = step + 1;                   % It is a counter
    disp('Please wait ...');
    disp(step);

% Generate Fuzzy Inference System structure from data using FCM (Sugeno-type-
Linear)
  Initial_FIS = genfis3(Input_Exp_Train,Output_Exp_Train,'sugeno',nCluster);

   Output_Model_Train = evalfis(Input_Exp_Train,Initial_FIS);              %
Train Output (FIS model)
   Output_Model_Test  = evalfis(Input_Exp_Test,Initial_FIS);               %
Test  Output (FIS model)
   Output_Model_Total    =    evalfis([Input_Exp_Train;    Input_Exp_Test],Ini-
tial_FIS); % Total Output (FIS model)

   [Cov_Train,~,~,~] = Error( Output_Exp_Train,Output_Model_Train);
   [Cov_Test ,~,~,~] = Error( Output_Exp_Test,Output_Model_Test);
   [Cov_Total,~,~,~]   =   Error(   [Output_Exp_Train;   Output_Exp_Test],Out-
put_Model_Total);
   Results(step,:)=[nCluster  abs(Cov_Test-Cov_Train)  abs(Cov_Total-Cov_Test)
abs(Cov_Total-Cov_Train)];

end

   Sort_Results = sortrows(Results,2);  % sort the results matrix based on the
columns specified in the COVs column

for i = 1:size(Sort_Results,1)     % Compare initial FIS model to select final
initial FIS model that must be used in ANFIS
    if  Sort_Results(i,2) <= 2 &&...
        Sort_Results(i,3) <= 2 &&...
        Sort_Results(i,4) <= 2

        Final_Cluster_number = Sort_Results(i,1);

        % Save the final cluster number for using in the final initial FIS model
        save('Final_Cluster_number','Final_Cluster_number')

        break;

    elseif Sort_Results(i,2) <= 2.5 &&...
           Sort_Results(i,3) <= 2.5 &&...
           Sort_Results(i,4) <= 2.5
           Final_Cluster_number = Sort_Results(i,1);

           % Save the final cluster number for using in the final initial FIS
model
           save('Final_Cluster_number','Final_Cluster_number')

           break;
    elseif Sort_Results(i,2) <= 3 &&...
           Sort_Results(i,3) <= 3 &&...
```

```
            Sort_Results(i,4) <= 3
            Final_Cluster_number = Sort_Results(i,1);

            % Save the final cluster number for using in the final initial FIS
model
            save('Final_Cluster_number','Final_Cluster_number')

            break;
        elseif Sort_Results(i,2) <= 3.5 &&...
            Sort_Results(i,3) <= 3.5 &&...
            Sort_Results(i,4) <= 3.5
            Final_Cluster_number = Sort_Results(i,1);

            % Save the final cluster number for using in the final initial FIS
model
            save('Final_Cluster_number','Final_Cluster_number')

            break;
        elseif Sort_Results(i,2) <= 4 &&...
            Sort_Results(i,3) <= 4 &&...
            Sort_Results(i,4) <= 4
            Final_Cluster_number = Sort_Results(i,1);

            % Save the final cluster number for using in the final initial FIS
model
            save('Final_Cluster_number','Final_Cluster_number')

            break;
        elseif Sort_Results(i,2) <= 4.5 &&...
            Sort_Results(i,3) <= 4.5 &&...
            Sort_Results(i,4) <= 4.5
            Final_Cluster_number = Sort_Results(i,1);

            % Save the final cluster number for using in the final initial FIS
model
            save('Final_Cluster_number','Final_Cluster_number')

            break;
        elseif Sort_Results(i,2) <= 5 &&...
            Sort_Results(i,3) <= 5 &&...
            Sort_Results(i,4) <= 5
            Final_Cluster_number = Sort_Results(i,1);

            % Save the final cluster number for using in the final initial FIS
model
            save('Final_Cluster_number','Final_Cluster_number')

            break;
        elseif Sort_Results(i,2) <= 5.5 &&...
            Sort_Results(i,3) <= 5.5 &&...
            Sort_Results(i,4) <= 5.5
            Final_Cluster_number = Sort_Results(i,1);

            % Save the final cluster number for using in the final initial FIS
model
            save('Final_Cluster_number','Final_Cluster_number')
```

```
            break;
    elseif Sort_Results(i,2) <= 6 &&...
            Sort_Results(i,3) <= 6 &&...
            Sort_Results(i,4) <= 6
            Final_Cluster_number = Sort_Results(i,1);

            % Save the final cluster number for using in the final initial FIS
model
            save('Final_Cluster_number','Final_Cluster_number')

            break;
    elseif Sort_Results(i,2) <= 6.5 &&...
            Sort_Results(i,3) <= 6.5 &&...
            Sort_Results(i,4) <= 6.5
            Final_Cluster_number = Sort_Results(i,1);

            % Save the final cluster number for using in the final initial FIS
model
            save('Final_Cluster_number','Final_Cluster_number')

            break;
    elseif Sort_Results(i,2) <= 7 &&...
            Sort_Results(i,3) <= 7 &&...
            Sort_Results(i,4) <= 7
            Final_Cluster_number = Sort_Results(i,1);

            % Save the final cluster number for using in the final initial FIS
model
            save('Final_Cluster_number','Final_Cluster_number')

            break;
    elseif Sort_Results(i,2) <= 7.5 &&...
            Sort_Results(i,3) <= 7.5 &&...
            Sort_Results(i,4) <= 7.5
            Final_Cluster_number = Sort_Results(i,1);

            % Save the final cluster number for using in the final initial FIS
model
            save('Final_Cluster_number','Final_Cluster_number')

            break;
    elseif Sort_Results(i,2) <= 8 &&...
            Sort_Results(i,3) <= 8 &&...
            Sort_Results(i,4) <= 8
            Final_Cluster_number = Sort_Results(i,1);

            % Save the final cluster number for using in the final initial FIS
model
            save('Final_Cluster_number','Final_Cluster_number')

            break;
    elseif Sort_Results(i,2) <= 8.5 &&...
            Sort_Results(i,3) <= 8.5 &&...
            Sort_Results(i,4) <= 8.5
            Final_Cluster_number = Sort_Results(i,1);
```

```
            % Save the final cluster number for using in the final initial FIS
model
            save('Final_Cluster_number','Final_Cluster_number')

            break;
    elseif Sort_Results(i,2) <= 9 &&...
            Sort_Results(i,3) <= 9 &&...
            Sort_Results(i,4) <= 9
            Final_Cluster_number = Sort_Results(i,1);

            % Save the final cluster number for using in the final initial FIS
model
            save('Final_Cluster_number','Final_Cluster_number')

            break;
    elseif Sort_Results(i,2) <= 9.5 &&...
            Sort_Results(i,3) <= 9.5 &&...
            Sort_Results(i,4) <= 9.5
            Final_Cluster_number = Sort_Results(i,1);

            % Save the final cluster number for using in the final initial FIS
model
            save('Final_Cluster_number','Final_Cluster_number')

            break;
    elseif Sort_Results(i,2) <= 25 &&...
            Sort_Results(i,3) <= 25 &&...
            Sort_Results(i,4) <= 25
            Final_Cluster_number = Sort_Results(i,1);

            % Save the final cluster number for using in the final initial FIS
model
            save('Final_Cluster_number','Final_Cluster_number')

            break;
    end

end


%% Create ANFIS Structure

 % The final cluster Radius from compare algorithm
   load('Final_Cluster_number.mat')

 % Create initial FIS with final cluster number (sugeno-Linear with FCM)
   Initial_FIS = genfis3(Input_Exp_Train,Output_Exp_Train,'sugeno',Final_Clus-
ter_number);

 % ANFIS Options
                % Training Options
                  MaxEpoch=100;
                  ErrorGoal=0;
                  InitialStepSize=0.01;
                  StepSizeDecRate=0.9;
                  StepSizeIncRate=1.1;
```

```
                  TrainOptions=[MaxEpoch  ErrorGoal  InitialStepSize  StepSiz-
eDecRate StepSizeIncRate];

                % Display Options
                  ShowAnfisInformation=true;
                  ShowError=true;
                  ShowStepSize=true;
                  ShowFinalResult=true;
                  DisplayOptions=[ShowAnfisInformation  ShowError  ShowStepSize
ShowFinalResult];

                % Training Algorithm - Select Training Algorithm
                  %TrainAlgorithm=0;   % BP
                  TrainAlgorithm=1;    % Hybrid LS-BP
% ANIFS works
 [~,~,~,ANFIS,~]   =   anfis(Train_Dataset,Initial_FIS,TrainOptions,DisplayOp-
tions,Test_Dataset,TrainAlgorithm);

end
```

- **Error**

```
function [Cov, Mean, RMSE, MAPE ] = Error(Output_EXP,Output_Model)

         Errors=Output_EXP-Output_Model;
       % Mean Squared Error
         MSE=mean(Errors(:).^2);
       % Root Mean Squared Error
         RMSE=sqrt(MSE);
         yi=abs(Errors(:))./Output_EXP(:);
       % Mean Absolute Percentage Error
         MAPE=(mean(yi(:)))*100;

         xi=Output_EXP./Output_Model;
         Mean=mean(xi(:));
       % Coefficient Of Variation
         Cov=((sqrt(mean((xi(:)-Mean).^2)))/Mean)*100;

End
```

- **Data_ Division**

```
function [TrainData,TestData] = Data_Division(Data)

%% Data Division

Data = unique(Data,'rows');
Number_Of_Total_Data = size(Data,1); % Number of case studies (Rows)
Percentage_Of_Train = 70;          % Percentage of Training data (approximately)

for i=1:10000                          % Infinite repetition to achieve results

% Train (Random selection a specified Percentage of the total dataset)
```

```
   acceptRatio = ceil (0.01 * Percentage_Of_Train * Number_Of_Total_Data);
   TRrand = unique(randsample(Number_Of_Total_Data,acceptRatio));

% Max & min Of case studies from each columns (Parameters)
  [maximum.Cost ,maximum.Position]=max(Data);
  [minimum.Cost ,minimum.Position]=min(Data);
% Index Of max & min Position
  maxmin_position = unique([maximum.Position,minimum.Position]);

% Training data with max and min parameters
  Trainplus=unique([TRrand;maxmin_position']);
  TrainData(1:size(Trainplus,1),:)=Data(Trainplus(1:size(Trainplus,1),1),:);
  TrainData = unique(TrainData,'rows');

% Testing data = [Total Data]-[Train Data]
  TestData = setdiff(Data,TrainData,'rows');  % returns the rows from Data that
are not in TrainData
  TestData = unique(TestData,'rows');

% Statistical Check (std,mean,range)

   % Standard deviation for each column of dataset
     stdTrain=std(TrainData);
     stdTest=std(TestData);

   % Mean for each column of dataset
     meanTrain=mean(TrainData);
     meanTest=mean(TestData);

   % Range for each column of dataset
     rangeTrain=range(TrainData);
     rangeTest=range(TestData);

   if      (abs(stdTrain  (1,:)-stdTest  (1,:)))/stdTrain  (1,:) <= 0.1 ...
        && (abs(meanTrain (1,:)-meanTest (1,:)))/meanTrain (1,:) <= 0.1 ...
        && (abs(rangeTrain(1,:)-rangeTest(1,:)))/rangeTrain(1,:) <= 0.1

    break;
   end

end
   save('TrainData','TrainData');  % Save TrainData
   save('TestData','TestData');    % Save TestData

end
```

- **Using _Model**

```
clc;
clear all
format short
```

- **Load ANFIS models**

```
load('ANFIS11.mat')
ANFIS11.input(1,1).name = 'Cost Initial Stage';
ANFIS11.input(1,2).name = 'Time Initial Stage';
ANFIS11.input(1,3).name = 'Quality Initial Stage';
ANFIS11.input(1,4).name = 'Safety Initial Stage';
ANFIS11.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS11.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS11.output(1,1).name = 'Cost - Whole Project';

load('ANFIS12.mat')
ANFIS12.input(1,1).name = 'Cost Initial Stage';
ANFIS12.input(1,2).name = 'Time Initial Stage';
ANFIS12.input(1,3).name = 'Quality Initial Stage';
ANFIS12.input(1,4).name = 'Safety Initial Stage';
ANFIS12.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS12.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS12.output(1,1).name = 'Time - Whole Project';

load('ANFIS13.mat')
ANFIS13.input(1,1).name = 'Cost Initial Stage';
ANFIS13.input(1,2).name = 'Time Initial Stage';
ANFIS13.input(1,3).name = 'Quality Initial Stage';
ANFIS13.input(1,4).name = 'Safety Initial Stage';
ANFIS13.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS13.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS13.output(1,1).name = 'Quality - Whole Project';

load('ANFIS14.mat')
ANFIS14.input(1,1).name = 'Cost Initial Stage';
ANFIS14.input(1,2).name = 'Time Initial Stage';
ANFIS14.input(1,3).name = 'Quality Initial Stage';
ANFIS14.input(1,4).name = 'Safety Initial Stage';
ANFIS14.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS14.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS14.output(1,1).name = 'Safety - Whole Project';

load('ANFIS15.mat')
ANFIS15.input(1,1).name = 'Cost Initial Stage';
ANFIS15.input(1,2).name = 'Time Initial Stage';
ANFIS15.input(1,3).name = 'Quality Initial Stage';
ANFIS15.input(1,4).name = 'Safety Initial Stage';
ANFIS15.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS15.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS15.output(1,1).name = 'Client Satisfaction - Whole Project';

load('ANFIS16.mat')
ANFIS16.input(1,1).name = 'Cost Initial Stage';
ANFIS16.input(1,2).name = 'Time Initial Stage';
ANFIS16.input(1,3).name = 'Quality Initial Stage';
ANFIS16.input(1,4).name = 'Safety Initial Stage';
ANFIS16.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS16.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS16.output(1,1).name = 'Project Team Satisfaction - Whole Project';
```

```
load('ANFIS21.mat')
ANFIS21.input(1,1).name = 'Cost Initial Stage';
ANFIS21.input(1,2).name = 'Time Initial Stage';
ANFIS21.input(1,3).name = 'Quality Initial Stage';
ANFIS21.input(1,4).name = 'Safety Initial Stage';
ANFIS21.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS21.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS21.input(1,7).name = 'Cost Middle Stage';
ANFIS21.input(1,8).name = 'Time Middle Stage';
ANFIS21.input(1,9).name = 'Quality Middle Stage';
ANFIS21.input(1,10).name = 'Safety Middle Stage';
ANFIS21.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS21.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS21.output(1,1).name = 'Cost - Whole Project';

load('ANFIS22.mat')
ANFIS22.input(1,1).name = 'Cost Initial Stage';
ANFIS22.input(1,2).name = 'Time Initial Stage';
ANFIS22.input(1,3).name = 'Quality Initial Stage';
ANFIS22.input(1,4).name = 'Safety Initial Stage';
ANFIS22.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS22.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS22.input(1,7).name = 'Cost Middle Stage';
ANFIS22.input(1,8).name = 'Time Middle Stage';
ANFIS22.input(1,9).name = 'Quality Middle Stage';
ANFIS22.input(1,10).name = 'Safety Middle Stage';
ANFIS22.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS22.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS22.output(1,1).name = 'Time - Whole Project';

load('ANFIS23.mat')
ANFIS23.input(1,1).name = 'Cost Initial Stage';
ANFIS23.input(1,2).name = 'Time Initial Stage';
ANFIS23.input(1,3).name = 'Quality Initial Stage';
ANFIS23.input(1,4).name = 'Safety Initial Stage';
ANFIS23.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS23.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS23.input(1,7).name = 'Cost Middle Stage';
ANFIS23.input(1,8).name = 'Time Middle Stage';
ANFIS23.input(1,9).name = 'Quality Middle Stage';
ANFIS23.input(1,10).name = 'Safety Middle Stage';
ANFIS23.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS23.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS23.output(1,1).name = 'Quality - Whole Project';

load('ANFIS24.mat')
ANFIS24.input(1,1).name = 'Cost Initial Stage';
ANFIS24.input(1,2).name = 'Time Initial Stage';
ANFIS24.input(1,3).name = 'Quality Initial Stage';
ANFIS24.input(1,4).name = 'Safety Initial Stage';
ANFIS24.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS24.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS24.input(1,7).name = 'Cost Middle Stage';
ANFIS24.input(1,8).name = 'Time Middle Stage';
ANFIS24.input(1,9).name = 'Quality Middle Stage';
ANFIS24.input(1,10).name = 'Safety Middle Stage';
```

```
ANFIS24.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS24.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS24.output(1,1).name = 'Safety - Whole Project';

load('ANFIS25.mat')
ANFIS25.input(1,1).name = 'Cost Initial Stage';
ANFIS25.input(1,2).name = 'Time Initial Stage';
ANFIS25.input(1,3).name = 'Quality Initial Stage';
ANFIS25.input(1,4).name = 'Safety Initial Stage';
ANFIS25.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS25.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS25.input(1,7).name = 'Cost Middle Stage';
ANFIS25.input(1,8).name = 'Time Middle Stage';
ANFIS25.input(1,9).name = 'Quality Middle Stage';
ANFIS25.input(1,10).name = 'Safety Middle Stage';
ANFIS25.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS25.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS25.output(1,1).name = 'Client Satisfaction - Whole Project';

load('ANFIS26.mat')
ANFIS26.input(1,1).name = 'Cost Initial Stage';
ANFIS26.input(1,2).name = 'Time Initial Stage';
ANFIS26.input(1,3).name = 'Quality Initial Stage';
ANFIS26.input(1,4).name = 'Safety Initial Stage';
ANFIS26.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS26.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS26.input(1,7).name = 'Cost Middle Stage';
ANFIS26.input(1,8).name = 'Time Middle Stage';
ANFIS26.input(1,9).name = 'Quality Middle Stage';
ANFIS26.input(1,10).name = 'Safety Middle Stage';
ANFIS26.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS26.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS26.output(1,1).name = 'Project Team Satisfaction - Whole Project';


load('ANFIS31.mat')
ANFIS31.input(1,1).name = 'Cost Initial Stage';
ANFIS31.input(1,2).name = 'Time Initial Stage';
ANFIS31.input(1,3).name = 'Quality Initial Stage';
ANFIS31.input(1,4).name = 'Safety Initial Stage';
ANFIS31.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS31.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS31.input(1,7).name = 'Cost Middle Stage';
ANFIS31.input(1,8).name = 'Time Middle Stage';
ANFIS31.input(1,9).name = 'Quality Middle Stage';
ANFIS31.input(1,10).name = 'Safety Middle Stage';
ANFIS31.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS31.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS31.input(1,13).name = 'Cost Finishing Stage';
ANFIS31.input(1,14).name = 'Time Finishing Stage';
ANFIS31.input(1,15).name = 'Quality Finishing Stage';
ANFIS31.input(1,16).name = 'Safety Finishing Stage';
ANFIS31.input(1,17).name = 'Client Satisfaction Finishing Stage';
ANFIS31.input(1,18).name = 'Project Team Satisfaction Finishing Stage';
ANFIS31.output(1,1).name = 'Cost - Whole Project';
```

```
load('ANFIS32.mat')
ANFIS32.input(1,1).name = 'Cost Initial Stage';
ANFIS32.input(1,2).name = 'Time Initial Stage';
ANFIS32.input(1,3).name = 'Quality Initial Stage';
ANFIS32.input(1,4).name = 'Safety Initial Stage';
ANFIS32.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS32.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS32.input(1,7).name = 'Cost Middle Stage';
ANFIS32.input(1,8).name = 'Time Middle Stage';
ANFIS32.input(1,9).name = 'Quality Middle Stage';
ANFIS32.input(1,10).name = 'Safety Middle Stage';
ANFIS32.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS32.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS32.input(1,13).name = 'Cost Finishing Stage';
ANFIS32.input(1,14).name = 'Time Finishing Stage';
ANFIS32.input(1,15).name = 'Quality Finishing Stage';
ANFIS32.input(1,16).name = 'Safety Finishing Stage';
ANFIS32.input(1,17).name = 'Client Satisfaction Finishing Stage';
ANFIS32.input(1,18).name = 'Project Team Satisfaction Finishing Stage';
ANFIS32.output(1,1).name = 'Time - Whole Project';

load('ANFIS33.mat')
ANFIS33.input(1,1).name = 'Cost Initial Stage';
ANFIS33.input(1,2).name = 'Time Initial Stage';
ANFIS33.input(1,3).name = 'Quality Initial Stage';
ANFIS33.input(1,4).name = 'Safety Initial Stage';
ANFIS33.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS33.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS33.input(1,7).name = 'Cost Middle Stage';
ANFIS33.input(1,8).name = 'Time Middle Stage';
ANFIS33.input(1,9).name = 'Quality Middle Stage';
ANFIS33.input(1,10).name = 'Safety Middle Stage';
ANFIS33.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS33.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS33.input(1,13).name = 'Cost Finishing Stage';
ANFIS33.input(1,14).name = 'Time Finishing Stage';
ANFIS33.input(1,15).name = 'Quality Finishing Stage';
ANFIS33.input(1,16).name = 'Safety Finishing Stage';
ANFIS33.input(1,17).name = 'Client Satisfaction Finishing Stage';
ANFIS33.input(1,18).name = 'Project Team Satisfaction Finishing Stage';
ANFIS33.output(1,1).name = 'Quality - Whole Project';

load('ANFIS34.mat')
ANFIS34.input(1,1).name = 'Cost Initial Stage';
ANFIS34.input(1,2).name = 'Time Initial Stage';
ANFIS34.input(1,3).name = 'Quality Initial Stage';
ANFIS34.input(1,4).name = 'Safety Initial Stage';
ANFIS34.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS34.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS34.input(1,7).name = 'Cost Middle Stage';
ANFIS34.input(1,8).name = 'Time Middle Stage';
ANFIS34.input(1,9).name = 'Quality Middle Stage';
ANFIS34.input(1,10).name = 'Safety Middle Stage';
ANFIS34.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS34.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS34.input(1,13).name = 'Cost Finishing Stage';
```

```
ANFIS34.input(1,14).name = 'Time Finishing Stage';
ANFIS34.input(1,15).name = 'Quality Finishing Stage';
ANFIS34.input(1,16).name = 'Safety Finishing Stage';
ANFIS34.input(1,17).name = 'Client Satisfaction Finishing Stage';
ANFIS34.input(1,18).name = 'Project Team Satisfaction Finishing Stage';
ANFIS34.output(1,1).name = 'Safety - Whole Project';

load('ANFIS35.mat')
ANFIS35.input(1,1).name = 'Cost Initial Stage';
ANFIS35.input(1,2).name = 'Time Initial Stage';
ANFIS35.input(1,3).name = 'Quality Initial Stage';
ANFIS35.input(1,4).name = 'Safety Initial Stage';
ANFIS35.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS35.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS35.input(1,7).name = 'Cost Middle Stage';
ANFIS35.input(1,8).name = 'Time Middle Stage';
ANFIS35.input(1,9).name = 'Quality Middle Stage';
ANFIS35.input(1,10).name = 'Safety Middle Stage';
ANFIS35.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS35.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS35.input(1,13).name = 'Cost Finishing Stage';
ANFIS35.input(1,14).name = 'Time Finishing Stage';
ANFIS35.input(1,15).name = 'Quality Finishing Stage';
ANFIS35.input(1,16).name = 'Safety Finishing Stage';
ANFIS35.input(1,17).name = 'Client Satisfaction Finishing Stage';
ANFIS35.input(1,18).name = 'Project Team Satisfaction Finishing Stage';
ANFIS35.output(1,1).name = 'Client Satisfaction - Whole Project';

load('ANFIS36.mat')
ANFIS36.input(1,1).name = 'Cost Initial Stage';
ANFIS36.input(1,2).name = 'Time Initial Stage';
ANFIS36.input(1,3).name = 'Quality Initial Stage';
ANFIS36.input(1,4).name = 'Safety Initial Stage';
ANFIS36.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS36.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS36.input(1,7).name = 'Cost Middle Stage';
ANFIS36.input(1,8).name = 'Time Middle Stage';
ANFIS36.input(1,9).name = 'Quality Middle Stage';
ANFIS36.input(1,10).name = 'Safety Middle Stage';
ANFIS36.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS36.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS36.input(1,13).name = 'Cost Finishing Stage';
ANFIS36.input(1,14).name = 'Time Finishing Stage';
ANFIS36.input(1,15).name = 'Quality Finishing Stage';
ANFIS36.input(1,16).name = 'Safety Finishing Stage';
ANFIS36.input(1,17).name = 'Client Satisfaction Finishing Stage';
ANFIS36.input(1,18).name = 'Project Team Satisfaction Finishing Stage';
ANFIS36.output(1,1).name = 'Project Team Satisfaction - Whole Project';
```

- **Get inputs from user for calculation KPIs & PI**

```
disp('---')
disp('')
disp('>>> From which Stage You Want Predicting The Whole Project KPIs?')
disp('>(Initial   stage:  0% to 30 % Physical Progress = Type 1)')
disp('>(Middle    stage: 30% to 70 % Physical Progress = Type 2)')
```

```
disp('>(Finishing stage: 70% to 100% Physical Progress = Type 3)')
Stage=input('According to the description, the number to be entered:');

if     Stage==1
disp('---')
disp('')
disp('In the Initial Stage of the project, what is the performance of each of the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6 Very High=7)')
CostInitialStage = input('Cost(Type 2 To 7) : ');
if CostInitialStage(1,1)>7 | CostInitialStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

TimeInitialStage = input('Time(Type 1 To 7) : ');
if TimeInitialStage(1,1)>7 | TimeInitialStage(1,1)<1
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

QualityInitialStage = input('Quality(Type 3 To 7) : ');
if QualityInitialStage(1,1)>7 | QualityInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

SafetyInitialStage = input('Safety(Type 3 To 7) : ');
if SafetyInitialStage(1,1)>7 | SafetyInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionInitialStage = input('ClientSatisfaction(Type 3 To 7) : ');
if    ClientSatisfactionInitialStage(1,1)>7    |    ClientSatisfactionInitial-
Stage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionInitialStage = input('ProjectTeamSatisfaction(Type 3 To 7) : ');
if    ProjectTeamSatisfactionInitialStage(1,1)>7    |    ProjectTeamSatisfac-
tionInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

InitialStage=[CostInitialStage TimeInitialStage QualityInitialStage SafetyIni-
tialStage  ClientSatisfactionInitialStage  ProjectTeamSatisfactionInitialStage
];
```

- **Predict KPIs of middle Stage with KPIs of initial Stage**

```
In1=[InitialStage];
KPIf1 = evalfis(In1,ANFIS11);
KPIf2 = evalfis(In1,ANFIS12);
KPIf3 = evalfis(In1,ANFIS13);
KPIf4 = evalfis(In1,ANFIS14);
KPIf5 = evalfis(In1,ANFIS15);
KPIf6 = evalfis(In1,ANFIS16);
KPI1tof=[KPIf1 KPIf2 KPIf3 KPIf4 KPIf5 KPIf6];

for i=1:6
if KPI1tof(1,i) > 7
    KPI1tof(1,i)=7;
else if KPI1tof(1,i) < 1
        KPI1tof(1,i)=1;
    end
end
end

disp('---')
disp('')
Name = {'Cost';'Time';'Quality';'Safety';'Client Satisfaction';'Project Team
Satisfaction'};
Forecasted_KPIs_Of_The_Whole_Project                                          =
[KPI1tof(1,1);KPI1tof(1,2);KPI1tof(1,3);KPI1tof(1,4);KPI1tof(1,5);KPI1tof(1,6
)];
table(Forecasted_KPIs_Of_The_Whole_Project,'RowNames',Name)

PI_AHP =  (0.106*KPI1tof(1,1) + 0.103*KPI1tof(1,2) +...
              0.320*KPI1tof(1,3) + 0.134*KPI1tof(1,4) +...
              0.176*KPI1tof(1,5) + 0.161*KPI1tof(1,6));
PI_GA  =  (0.026*KPI1tof(1,1) + 0.237*KPI1tof(1,2) +...
              0.196*KPI1tof(1,3) + 0.228*KPI1tof(1,4) +...
              0.012*KPI1tof(1,5) + 0.301*KPI1tof(1,6));
Name = {'PI_AHP Method';'PI_GA Method'};
Forecasted_Performance_Of_The_Whole_Project = [PI_AHP;PI_GA];
table(Forecasted_Performance_Of_The_Whole_Project,'RowNames',Name)


disp('(Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very
High=7)')


elseif Stage==2

disp('---')
disp('')
disp('In the Initial Stage of the project, what is the performance of each of
the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostInitialStage = input('Cost(Type 2 To 7) : ');
if CostInitialStage(1,1)>7 | CostInitialStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end
```

```
TimeInitialStage = input('Time(Type 1 To 7) : ');
if TimeInitialStage(1,1)>7 | TimeInitialStage(1,1)<1
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

QualityInitialStage = input('Quality(Type 3 To 7) : ');
if QualityInitialStage(1,1)>7 | QualityInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

SafetyInitialStage = input('Safety(Type 3 To 7) : ');
if SafetyInitialStage(1,1)>7 | SafetyInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionInitialStage = input('ClientSatisfaction(Type 3 To 7) : ');
if    ClientSatisfactionInitialStage(1,1)>7    |    ClientSatisfactionInitial-
Stage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionInitialStage = input('ProjectTeamSatisfaction(Type 3 To
7) : ');
if    ProjectTeamSatisfactionInitialStage(1,1)>7    |    ProjectTeamSatisfac-
tionInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

InitialStage=[CostInitialStage TimeInitialStage QualityInitialStage SafetyIni-
tialStage  ClientSatisfactionInitialStage  ProjectTeamSatisfactionInitialStage
];

disp('---')
disp('')
disp('In the Middle Stage of the project, what is the performance of each of
the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostMiddleStage = input('Cost(Type 2 To 7) : ');
if CostMiddleStage(1,1)>7 | CostMiddleStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

TimeMiddleStage = input('Time(Type 1 To 7) : ');
if TimeMiddleStage(1,1)>7 | TimeMiddleStage(1,1)<1
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end
```

```
QualityMiddleStage = input('Quality(Type 3 To 7) : ');
if QualityMiddleStage(1,1)>7 | QualityMiddleStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

SafetyMiddleStage = input('Safety(Type 3 To 7) : ');
if SafetyMiddleStage(1,1)>7 | SafetyMiddleStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionMiddleStage = input('ClientSatisfaction(Type 2 To 7) : ');
if ClientSatisfactionMiddleStage(1,1)>7 | ClientSatisfactionMiddleStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionMiddleStage = input('ProjectTeamSatisfaction(Type 3 To
7) : ');
if  ProjectTeamSatisfactionMiddleStage(1,1)>7  |  ProjectTeamSatisfactionMid-
dleStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

MiddleStage=[CostMiddleStage  TimeMiddleStage  QualityMiddleStage  SafetyMid-
dleStage ClientSatisfactionMiddleStage ProjectTeamSatisfactionMiddleStage ];
```

- **Predict KPIs of finishing stage with KPIs of initial and middle stages**

```
In2=[InitialStage MiddleStage];
KPIf1 = evalfis(In2,ANFIS21);
KPIf2 = evalfis(In2,ANFIS22);
KPIf3 = evalfis(In2,ANFIS23);
KPIf4 = evalfis(In2,ANFIS24);
KPIf5 = evalfis(In2,ANFIS25);
KPIf6 = evalfis(In2,ANFIS26);
KPI12tof=[KPIf1 KPIf2 KPIf3 KPIf4 KPIf5 KPIf6];


for i=1:6
if KPI12tof(1,i) > 7
    KPI12tof(1,i)=7;
else if KPI12tof(1,i) < 1
        KPI12tof(1,i)=1;
    end
end
end

disp('---')
disp('')
Name  = {'Cost';'Time';'Quality';'Safety';'Client  Satisfaction';'Project  Team
Satisfaction'};
```

```
Forecasted_KPIs_Of_The_Whole_Project                                           =
[KPI12tof(1,1);KPI12tof(1,2);KPI12tof(1,3);KPI12tof(1,4);KPI12tof(1,5);KPI12t
of(1,6)];
table(Forecasted_KPIs_Of_The_Whole_Project,'RowNames',Name)

PI_AHP =  (0.106*KPI12tof(1,1) + 0.103*KPI12tof(1,2) +...
                0.320*KPI12tof(1,3) + 0.134*KPI12tof(1,4) +...
                0.176*KPI12tof(1,5) + 0.161*KPI12tof(1,6));
PI_GA  =  (0.026*KPI12tof(1,1) + 0.237*KPI12tof(1,2) +...
                0.196*KPI12tof(1,3) + 0.228*KPI12tof(1,4) +...
                0.012*KPI12tof(1,5) + 0.301*KPI12tof(1,6));
Name = {'PI_AHP Method';'PI_GA Method'};
Forecasted_Performance_Of_The_Whole_Project = [PI_AHP;PI_GA];
table(Forecasted_Performance_Of_The_Whole_Project,'RowNames',Name)

disp('(Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very
High=7)')

elseif Stage==3

disp('---')
disp('')
disp('In the Initial Stage of the project, what is the performance of each of
the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostInitialStage = input('Cost(Type 2 To 7) : ');
if CostInitialStage(1,1)>7 | CostInitialStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

TimeInitialStage = input('Time(Type 1 To 7) : ');
if TimeInitialStage(1,1)>7 | TimeInitialStage(1,1)<1
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

QualityInitialStage = input('Quality(Type 3 To 7) : ');
if QualityInitialStage(1,1)>7 | QualityInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

SafetyInitialStage = input('Safety(Type 3 To 7) : ');
if SafetyInitialStage(1,1)>7 | SafetyInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionInitialStage = input('ClientSatisfaction(Type 3 To 7) : ');
if    ClientSatisfactionInitialStage(1,1)>7    |    ClientSatisfactionInitial-
Stage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
```

```
end

ProjectTeamSatisfactionInitialStage = input('ProjectTeamSatisfaction(Type 3 To
7) : ');
if   ProjectTeamSatisfactionInitialStage(1,1)>7   |   ProjectTeamSatisfac-
tionInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

InitialStage=[CostInitialStage TimeInitialStage QualityInitialStage SafetyIni-
tialStage  ClientSatisfactionInitialStage  ProjectTeamSatisfactionInitialStage
];

disp('---')
disp('')
disp('In the Middle Stage of the project, what is the performance of each of
the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostMiddleStage = input('Cost(Type 2 To 7) : ');
if CostMiddleStage(1,1)>7 | CostMiddleStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

TimeMiddleStage = input('Time(Type 1 To 7) : ');
if TimeMiddleStage(1,1)>7 | TimeMiddleStage(1,1)<1
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

QualityMiddleStage = input('Quality(Type 3 To 7) : ');
if QualityMiddleStage(1,1)>7 | QualityMiddleStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

SafetyMiddleStage = input('Safety(Type 3 To 7) : ');
if SafetyMiddleStage(1,1)>7 | SafetyMiddleStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionMiddleStage = input('ClientSatisfaction(Type 2 To 7) : ');
if ClientSatisfactionMiddleStage(1,1)>7 | ClientSatisfactionMiddleStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionMiddleStage = input('ProjectTeamSatisfaction(Type 3 To
7) : ');
if  ProjectTeamSatisfactionMiddleStage(1,1)>7  |  ProjectTeamSatisfactionMid-
dleStage(1,1)<3
   error('MyComponent:incorrectType',...
```

```
       'Error. \nInputs must be in range, Try Again ...')
end

MiddleStage=[CostMiddleStage  TimeMiddleStage  QualityMiddleStage  SafetyMid-
dleStage ClientSatisfactionMiddleStage ProjectTeamSatisfactionMiddleStage ];

disp('---')
disp('')
disp('In the Finishing Stage of the project, what is the performance of each of
the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostFinishingStage = input('Cost(Type 2 To 7) : ');
if CostFinishingStage(1,1)>7 | CostFinishingStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

TimeFinishingStage = input('Time(Type 2 To 7) : ');
if TimeFinishingStage(1,1)>7 | TimeFinishingStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

QualityFinishingStage = input('Quality(Type 2 To 7) : ');
if QualityFinishingStage(1,1)>7 | QualityFinishingStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

SafetyFinishingStage = input('Safety(Type 2 To 7) : ');
if SafetyFinishingStage(1,1)>7 | SafetyFinishingStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionFinishingStage = input('ClientSatisfaction(Type 2 To 7) : ');
if   ClientSatisfactionFinishingStage(1,1)>7   |   ClientSatisfactionFinish-
ingStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionFinishingStage = input('ProjectTeamSatisfaction(Type 2
To 7) : ');
if ProjectTeamSatisfactionFinishingStage(1,1)>7 | ProjectTeamSatisfactionFin-
ishingStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

FinishingStage=[CostFinishingStage  TimeFinishingStage  QualityFinishingStage
SafetyFinishingStage ClientSatisfactionFinishingStage ProjectTeamSatisfaction-
FinishingStage ];
```

- **Predict KPIs of whole project with KPIs of initial, middle and finishing stages**

```
In3=[InitialStage MiddleStage FinishingStage];
KPIf1 = evalfis(In3,ANFIS31);
KPIf2 = evalfis(In3,ANFIS32);
KPIf3 = evalfis(In3,ANFIS33);
KPIf4 = evalfis(In3,ANFIS34);
KPIf5 = evalfis(In3,ANFIS35);
KPIf6 = evalfis(In3,ANFIS36);
KPI123tof=[KPIf1 KPIf2 KPIf3 KPIf4 KPIf5 KPIf6];

for i=1:6
if KPI123tof(1,i) > 7
    KPI123tof(1,i)=7;
else if KPI123tof(1,i) < 1
        KPI123tof(1,i)=1;
    end
end
end

disp('---')
disp('')
Name  =  {'Cost';'Time';'Quality';'Safety';'Client  Satisfaction';'Project  Team
Satisfaction'};
Forecasted_KPIs_Of_The_Whole_Project                                          =
[KPI123tof(1,1);KPI123tof(1,2);KPI123tof(1,3);KPI123tof(1,4);KPI123tof(1,5);K
PI123tof(1,6)];
table(Forecasted_KPIs_Of_The_Whole_Project,'RowNames',Name)
```

- **Calculating PI using AHP and GA method**

```
PI_AHP =  (0.106*KPI123tof(1,1) + 0.103*KPI123tof(1,2) +...
                0.320*KPI123tof(1,3) + 0.134*KPI123tof(1,4) +...
                0.176*KPI123tof(1,5) + 0.161*KPI123tof(1,6));

PI_GA  =  (0.026*KPI123tof(1,1) + 0.237*KPI123tof(1,2) +...
                0.196*KPI123tof(1,3) + 0.228*KPI123tof(1,4) +...
                0.012*KPI123tof(1,5) + 0.301*KPI123tof(1,6));
Name = {'PI_AHP Method';'PI_GA Method'};
Forecasted_Performance_Of_The_Whole_Project = [PI_AHP;PI_GA];
table(Forecasted_Performance_Of_The_Whole_Project,'RowNames',Name)

disp('(Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very
High=7)')

else

    disp('--')
    disp('')
    disp('Notice!!!')
    disp('Please Type Correct Number...')
end
```

Appendix D2: Genetic Algorithm codes

- **GA_ Optimization**

```
close all;
clear all;
clc;
format short
%% Load Data

load('Data.mat')
load('TrainData.mat')
load('TestData.mat')

%% Genetic Algorithm (GA) - Optimization Tool
    options = gaoptimset;
%  Modify options setting  (It could be changed with user expert)

    options = gaoptimset(options,'PopulationType', 'doubleVector');
    options = gaoptimset(options,'PopInitRange', [0;1]);
    options = gaoptimset(options,'PopulationSize',50);
    options = gaoptimset(options,'CreationFcn', @gacreationlinearfeasible);
    options = gaoptimset(options,'EliteCount', 2);
    options = gaoptimset(options,'CrossoverFraction', 0.8);
    options = gaoptimset(options,'MigrationDirection', 'forward');
    options = gaoptimset(options,'MigrationInterval', 20);
    options = gaoptimset(options,'MigrationFraction', 0.2);
    options = gaoptimset(options,'Generations', 10000);
    options = gaoptimset(options,'TimeLimit', Inf);
    options = gaoptimset(options,'FitnessLimit', -Inf);
    options = gaoptimset(options,'StallGenLimit', 100);
    options = gaoptimset(options,'StallTimeLimit', Inf);
    options = gaoptimset(options,'TolFun', 1e-6 );
    options = gaoptimset(options,'FitnessScalingFcn', {@fitscalingrank});
    options = gaoptimset(options,'SelectionFcn', {@selectionstochunif});
    options = gaoptimset(options,'CrossoverFcn', {@crossoverscattered});
    options = gaoptimset(options,'MutationFcn', @mutationadaptfeasible);
    options = gaoptimset(options,'HybridFcn', {  @fminsearch [] });
    options = gaoptimset(options,'Display', 'diagnose');



    [Final_points,~,~,~,~,~]=ga(@FitnessFunction,6,options);

    disp(' ')
    disp(' ')
    disp(' Constant parameters from function')
    Final_points = abs(Final_points./(sum(abs(Final_points))))
    save('Final_points');
    Percentage_Of_TrainData = (size(TrainData,1)/size(Data,1))*100
    Percentage_Of_TestData = (size(TestData,1)/size(Data,1))*100
```

- Fitness Function

```
Function [ RMSE ] = FitnessFunction(X)

    load('TrainData.mat')              % Load Train dataset
    load('TestData.mat')               % Load Test dataset
    TotalData = [TrainData;TestData];  % Total dataset
    DataInUse = TrainData;             % The Data is used in optimization

     for i=1:size(DataInUse,1)

       % Output from experimental
         Output_Exp(i,1)  = DataInUse(i,end);

       % Output from function
         Output_Model(i,1)= X(1)*DataInUse(i,1)+...
                            X(2)*DataInUse(i,2)+...
                            X(3)*DataInUse(i,3)+...
                            X(4)*DataInUse(i,4)+...
                            X(5)*DataInUse(i,5)+...
                            X(6)*DataInUse(i,6);
         Errors(i,1)      = abs(Output_Exp(i,1)-Output_Model(i,1));
     end

    MSE  = mean(Errors(:,1).^2);    % Calculate MSE
    RMSE = sqrt(MSE);               % Calculate RMSE,RMSE must be optimized

End
```

Appendix D3: Predicting KPIs of Next Stage

```
tic
clc;
clear all

StagesData = xlsread('Stages','Sheet1');

%%Read Data to predict stage 2 from stage 1
Data112=StagesData(:,[1:6,7]);
Data122=StagesData(:,[1:6,8]);
Data132=StagesData(:,[1:6,9]);
Data142=StagesData(:,[1:6,10]);
Data152=StagesData(:,[1:6,11]);
Data162=StagesData(:,[1:6,12]);

%models to predict stage 2 from 1
[ANFIS112,TrainError]= Trained_ANFIS_Mine(Data112);
writefis(ANFIS112,'ANFIS112.fis');
disp('ANFIS112 saved')
error=[TrainError(end)];


[ANFIS122,TrainError]= Trained_ANFIS_Mine(Data122);
writefis(ANFIS122,'ANFIS122.fis');
disp('ANFIS122 saved')
error=[error;TrainError(end)];


[ANFIS132,TrainError]= Trained_ANFIS_Mine(Data132);
writefis(ANFIS132,'ANFIS132.fis');
disp('ANFIS132 saved')
error=[error;TrainError(end)];

[ANFIS142,TrainError]= Trained_ANFIS_Mine(Data142);
writefis(ANFIS142,'ANFIS142.fis');
disp('ANFIS142 saved')
error=[error;TrainError(end)];

[ANFIS152,TrainError]= Trained_ANFIS_Mine(Data152);
writefis(ANFIS152,'ANFIS152.fis');
disp('ANFIS152 saved')
error=[error;TrainError(end)];

[ANFIS162,TrainErrorr]= Trained_ANFIS_Mine(Data162);
writefis(ANFIS162,'ANFIS162.fis');
disp('ANFIS162 saved')
error=[error;TrainError(end)];
```

```
%Read Data to predict stage 3 from stage 1
Data113=StagesData(:,[1:6,13]);
Data123=StagesData(:,[1:6,14]);
Data133=StagesData(:,[1:6,15]);
Data143=StagesData(:,[1:6,16]);
Data153=StagesData(:,[1:6,17]);
Data163=StagesData(:,[1:6,18]);

%models to predict stage 3 from 1
[ANFIS113,TrainError]= Trained_ANFIS_Mine(Data113);
writefis(ANFIS113,'ANFIS113.fis');
disp('ANFIS113 saved')
error=[TrainError(end)];


[ANFIS123,TrainError]= Trained_ANFIS_Mine(Data123);
writefis(ANFIS123,'ANFIS123.fis');
disp('ANFIS123 saved')
error=[error;TrainError(end)];


[ANFIS133,TrainError]= Trained_ANFIS_Mine(Data133);
writefis(ANFIS133,'ANFIS133.fis');
disp('ANFIS133 saved')
error=[error;TrainError(end)];

[ANFIS143,TrainError]= Trained_ANFIS_Mine(Data143);
writefis(ANFIS143,'ANFIS143.fis');
disp('ANFIS143 saved')
error=[error;TrainError(end)];

[ANFIS153,TrainError]= Trained_ANFIS_Mine(Data153);
writefis(ANFIS153,'ANFIS153.fis');
disp('ANFIS153 saved')
error=[error;TrainError(end)];

[ANFIS163,TrainErrorr]= Trained_ANFIS_Mine(Data163);
writefis(ANFIS163,'ANFIS163.fis');
disp('ANFIS163 saved')
error=[error;TrainError(end)];
```

```
%Read Data to predict stage 3 from stage 2
Data213=StagesData(:,[1:12,13]);
Data223=StagesData(:,[1:12,14]);
Data233=StagesData(:,[1:12,15]);
Data243=StagesData(:,[1:12,16]);
Data253=StagesData(:,[1:12,17]);
Data263=StagesData(:,[1:12,18]);

%models to predict stage 3 from 2
[ANFIS213,TrainError]= Trained_ANFIS_Mine(Data213);
writefis(ANFIS213,'ANFIS213.fis');
disp('ANFIS213 saved')
error=[TrainError(end)];


[ANFIS223,TrainError]= Trained_ANFIS_Mine(Data223);
writefis(ANFIS223,'ANFIS223.fis');
disp('ANFIS223 saved')
error=[error;TrainError(end)];


[ANFIS233,TrainError]= Trained_ANFIS_Mine(Data233);
writefis(ANFIS233,'ANFIS233.fis');
disp('ANFIS233 saved')
error=[error;TrainError(end)];

[ANFIS243,TrainError]= Trained_ANFIS_Mine(Data243);
writefis(ANFIS243,'ANFIS243.fis');
disp('ANFIS243 saved')
error=[error;TrainError(end)];

[ANFIS253,TrainError]= Trained_ANFIS_Mine(Data253);
writefis(ANFIS253,'ANFIS253.fis');
disp('ANFIS253 saved')
error=[error;TrainError(end)];

[ANFIS263,TrainErrorr]= Trained_ANFIS_Mine(Data263);
writefis(ANFIS263,'ANFIS263.fis');
disp('ANFIS263 saved')
error=[error;TrainError(end)];
```

- **User interface for predicting KPIs of next stage and plotting KPIs trend**

```
clc;
clear all
format short
```

- **Read ANFIS models**

```
ANFIS112=readfis('ANFIS112.fis');
ANFIS122=readfis('ANFIS122.fis');
ANFIS132=readfis('ANFIS132.fis');
ANFIS142=readfis('ANFIS142.fis');
ANFIS152=readfis('ANFIS152.fis');
ANFIS162=readfis('ANFIS162.fis');

ANFIS113=readfis('ANFIS113.fis');
ANFIS123=readfis('ANFIS123.fis');
ANFIS133=readfis('ANFIS133.fis');
ANFIS143=readfis('ANFIS143.fis');
ANFIS153=readfis('ANFIS153.fis');
ANFIS163=readfis('ANFIS163.fis');

ANFIS213=readfis('ANFIS213.fis');
ANFIS223=readfis('ANFIS223.fis');
ANFIS233=readfis('ANFIS233.fis');
ANFIS243=readfis('ANFIS243.fis');
ANFIS253=readfis('ANFIS253.fis');
ANFIS263=readfis('ANFIS263.fis');


disp('---')
disp('')
disp('>>> From which Stage You Want Predicting The Project KPIs?')
disp('>(Initial   stage:  0% to 30 % Physical Progress = Type 1)')
disp('>(Middle    stage: 30% to 70 % Physical Progress = Type 2)')
disp('>(Finishing stage: 70% to 100% Physical Progress = Type 3)')
Stage=input('According to the description, the number to be entered:');
```

- **Enter KPIs for each stage**

```
if     Stage==1
disp('---')
disp('')
disp('In the Initial Stage of the project, what is the performance of each of
the following indicators?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostInitialStage = input('Cost(Type 2 To 7) : ');
if CostInitialStage(1,1)>7 | CostInitialStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

TimeInitialStage = input('Time(Type 1 To 7) : ');
if TimeInitialStage(1,1)>7 | TimeInitialStage(1,1)<1
```

```
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

QualityInitialStage = input('Quality(Type 3 To 7) : ');
if QualityInitialStage(1,1)>7 | QualityInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

SafetyInitialStage = input('Safety(Type 3 To 7) : ');
if SafetyInitialStage(1,1)>7 | SafetyInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionInitialStage = input('ClientSatisfaction(Type 3 To 7) : ');
if    ClientSatisfactionInitialStage(1,1)>7    |    ClientSatisfactionInitial-
Stage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionInitialStage = input('ProjectTeamSatisfaction(Type 3 To
7) : ');
if    ProjectTeamSatisfactionInitialStage(1,1)>7    |    ProjectTeamSatisfac-
tionInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

InitialStage=[CostInitialStage TimeInitialStage QualityInitialStage SafetyIni-
tialStage  ClientSatisfactionInitialStage  ProjectTeamSatisfactionInitialStage
];
```

- **Predict KPIs of middle stage with KPIs of initial stage**

```
In1=InitialStage;

KPIf1S2 = evalfis(In1,ANFIS112);
KPIf2S2 = evalfis(In1,ANFIS122);
KPIf3S2 = evalfis(In1,ANFIS132);
KPIf4S2 = evalfis(In1,ANFIS142);
KPIf5S2 = evalfis(In1,ANFIS152);
KPIf6S2 = evalfis(In1,ANFIS162);

KPIf1S3 = evalfis(In1,ANFIS113);
KPIf2S3 = evalfis(In1,ANFIS123);
KPIf3S3 = evalfis(In1,ANFIS133);
KPIf4S3 = evalfis(In1,ANFIS143);
KPIf5S3 = evalfis(In1,ANFIS153);
KPIf6S3 = evalfis(In1,ANFIS163);


ForcastedOfStage2=[KPIf1S2 KPIf2S2 KPIf3S2 KPIf4S2 KPIf5S2 KPIf6S2];
ForcastedOfStage3=[KPIf1S3 KPIf2S3 KPIf3S3 KPIf4S3 KPIf5S3 KPIf6S3];
```

```
for i=1:6
if ForcastedOfStage2(1,i) > 7
    ForcastedOfStage2(1,i)=7;
else if ForcastedOfStage2(1,i) < 1
        ForcastedOfStage2(1,i)=1;
    end
end
end

for i=1:6
if ForcastedOfStage3(1,i) > 7
    ForcastedOfStage3(1,i)=7;
else if ForcastedOfStage3(1,i) < 1
        ForcastedOfStage3(1,i)=1;
    end
end
end

disp('---')
disp('')


disp('Forcasted next stages')

Name = {'Cost';'Time';'Quality';'Safety';'Client Satisfaction';'Project Team
Satisfaction'};
Forecasted_KPIs_Of_Middle_Stage=ForcastedOfStage2';
Forecasted_KPIs_Of_Finishing_Stage=ForcastedOfStage3';
table(Forecasted_KPIs_Of_Middle_Stage,Forecasted_KPIs_Of_Finish-
ing_Stage,'RowNames',Name)
disp('(Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very
High=7)')
Stage1= InitialStage;
Stage2=ForcastedOfStage2;
Stage3=ForcastedOfStage3;
elseif Stage==2

disp('---')
disp('')
disp('In the Initial Stage of the project, what is the performance of each of
the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostInitialStage = input('Cost(Type 2 To 7) : ');
if CostInitialStage(1,1)>7 | CostInitialStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

TimeInitialStage = input('Time(Type 1 To 7) : ');
if TimeInitialStage(1,1)>7 | TimeInitialStage(1,1)<1
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

QualityInitialStage = input('Quality(Type 3 To 7) : ');
```

```
if QualityInitialStage(1,1)>7 | QualityInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

SafetyInitialStage = input('Safety(Type 3 To 7) : ');
if SafetyInitialStage(1,1)>7 | SafetyInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionInitialStage = input('ClientSatisfaction(Type 3 To 7) : ');
if    ClientSatisfactionInitialStage(1,1)>7    |    ClientSatisfactionInitial-
Stage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionInitialStage = input('ProjectTeamSatisfaction(Type 3 To
7) : ');
if    ProjectTeamSatisfactionInitialStage(1,1)>7    |    ProjectTeamSatisfac-
tionInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

InitialStage=[CostInitialStage TimeInitialStage QualityInitialStage SafetyIni-
tialStage  ClientSatisfactionInitialStage  ProjectTeamSatisfactionInitialStage
];

disp('---')
disp('')
disp('In the Middle Stage of the project, what is the performance of each of
the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostMiddleStage = input('Cost(Type 2 To 7) : ');
if CostMiddleStage(1,1)>7 | CostMiddleStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

TimeMiddleStage = input('Time(Type 1 To 7) : ');
if TimeMiddleStage(1,1)>7 | TimeMiddleStage(1,1)<1
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

QualityMiddleStage = input('Quality(Type 3 To 7) : ');
if QualityMiddleStage(1,1)>7 | QualityMiddleStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

SafetyMiddleStage = input('Safety(Type 3 To 7) : ');
if SafetyMiddleStage(1,1)>7 | SafetyMiddleStage(1,1)<3
   error('MyComponent:incorrectType',...
```

```
        'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionMiddleStage = input('ClientSatisfaction(Type 2 To 7) : ');
if ClientSatisfactionMiddleStage(1,1)>7 | ClientSatisfactionMiddleStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionMiddleStage = input('ProjectTeamSatisfaction(Type 3 To
7) : ');
if  ProjectTeamSatisfactionMiddleStage(1,1)>7  |  ProjectTeamSatisfactionMid-
dleStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

MiddleStage=[CostMiddleStage  TimeMiddleStage  QualityMiddleStage  SafetyMid-
dleStage ClientSatisfactionMiddleStage ProjectTeamSatisfactionMiddleStage ];
```

- **Predict KPIs of finishing stage with KPIs of initial and middle stages**

```
In2=[InitialStage MiddleStage];

KPIf1S3=evalfis(In2,ANFIS213);
KPIf2S3=evalfis(In2,ANFIS223);
KPIf3S3=evalfis(In2,ANFIS233);
KPIf4S3=evalfis(In2,ANFIS243);
KPIf5S3=evalfis(In2,ANFIS253);
KPIf6S3=evalfis(In2,ANFIS263);

KPIS3=[KPIf1S3 KPIf2S3 KPIf3S3 KPIf4S3 KPIf5S3 KPIf6S3];



for i=1:6
if KPIS3(1,i) > 7
    KPIS3(1,i)=7;
else if KPIS3(1,i) < 1
        KPIS3(1,i)=1;
    end
end
end
Stage1=InitialStage;
Stage2=MiddleStage;
Stage3=KPIS3;
disp('---');
Name  =  {'Cost';'Time';'Quality';'Safety';'Client  Satisfaction';'Project  Team
Satisfaction'};
Forecasted_KPIs_Of_Stage3=KPIS3';
table(Forecasted_KPIs_Of_Stage3,'RowNames',Name)
disp('(Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very
High=7)')


elseif Stage==3
```

```
disp('---')
disp('')
disp('In the Initial Stage of the project, what is the performance of each of
the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostInitialStage = input('Cost(Type 2 To 7) : ');
if CostInitialStage(1,1)>7 | CostInitialStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

TimeInitialStage = input('Time(Type 1 To 7) : ');
if TimeInitialStage(1,1)>7 | TimeInitialStage(1,1)<1
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

QualityInitialStage = input('Quality(Type 3 To 7) : ');
if QualityInitialStage(1,1)>7 | QualityInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

SafetyInitialStage = input('Safety(Type 3 To 7) : ');
if SafetyInitialStage(1,1)>7 | SafetyInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionInitialStage = input('ClientSatisfaction(Type 3 To 7) : ');
if    ClientSatisfactionInitialStage(1,1)>7    |    ClientSatisfactionInitial-
Stage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionInitialStage = input('ProjectTeamSatisfaction(Type 3 To
7) : ');
if    ProjectTeamSatisfactionInitialStage(1,1)>7    |    ProjectTeamSatisfac-
tionInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

InitialStage=[CostInitialStage TimeInitialStage QualityInitialStage SafetyIni-
tialStage  ClientSatisfactionInitialStage  ProjectTeamSatisfactionInitialStage
];

disp('---')
disp('')
disp('In the Middle Stage of the project, what is the performance of each of
the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostMiddleStage = input('Cost(Type 2 To 7) : ');
```

```
if CostMiddleStage(1,1)>7 | CostMiddleStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

TimeMiddleStage = input('Time(Type 1 To 7) : ');
if TimeMiddleStage(1,1)>7 | TimeMiddleStage(1,1)<1
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

QualityMiddleStage = input('Quality(Type 3 To 7) : ');
if QualityMiddleStage(1,1)>7 | QualityMiddleStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

SafetyMiddleStage = input('Safety(Type 3 To 7) : ');
if SafetyMiddleStage(1,1)>7 | SafetyMiddleStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionMiddleStage = input('ClientSatisfaction(Type 2 To 7) : ');
if ClientSatisfactionMiddleStage(1,1)>7 | ClientSatisfactionMiddleStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionMiddleStage = input('ProjectTeamSatisfaction(Type 3 To 
7) : ');
if  ProjectTeamSatisfactionMiddleStage(1,1)>7  |  ProjectTeamSatisfactionMid-
dleStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

MiddleStage=[CostMiddleStage  TimeMiddleStage  QualityMiddleStage  SafetyMid-
dleStage ClientSatisfactionMiddleStage ProjectTeamSatisfactionMiddleStage ];

disp('---')
disp('')
disp('In the Finishing Stage of the project, what is the performance of each of 
the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6 
Very High=7)')
CostFinishingStage = input('Cost(Type 2 To 7) : ');
if CostFinishingStage(1,1)>7 | CostFinishingStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

TimeFinishingStage = input('Time(Type 2 To 7) : ');
if TimeFinishingStage(1,1)>7 | TimeFinishingStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end
```

```
QualityFinishingStage = input('Quality(Type 2 To 7) : ');
if QualityFinishingStage(1,1)>7 | QualityFinishingStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

SafetyFinishingStage = input('Safety(Type 2 To 7) : ');
if SafetyFinishingStage(1,1)>7 | SafetyFinishingStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionFinishingStage = input('ClientSatisfaction(Type 2 To 7) : ');
if   ClientSatisfactionFinishingStage(1,1)>7   |   ClientSatisfactionFinish-
ingStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionFinishingStage = input('ProjectTeamSatisfaction(Type 2
To 7) : ');
if ProjectTeamSatisfactionFinishingStage(1,1)>7 | ProjectTeamSatisfactionFin-
ishingStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

FinishingStage=[CostFinishingStage  TimeFinishingStage  QualityFinishingStage
SafetyFinishingStage ClientSatisfactionFinishingStage ProjectTeamSatisfaction-
FinishingStage ];

Stage1=InitialStage;
Stage2=MiddleStage;
Stage3=FinishingStage;




else

    disp('--')
    disp('')
    disp('Notice!!!')
    disp('Please Type Correct Number...')
end

disp('Drawing diagrams');
Name = {'Cost';'Time';'Quality';'Safety';'Client Satisfaction';'Project Team
Satisfaction'};

Progress=[.15,0.5,0.85];
KPI_Of_Stages=[Stage1;Stage2;Stage3];

xi=0:0.05:1;
interpolatedKPIStages=zeros(6,length(xi));
```

```
for ID=1:6
figure(ID)

yi=interp1(Progress,KPI_Of_Stages(:,ID),xi ,'linear','extrap');

for i=1:length(yi)
    if yi(i)<1
        yi(i)=1;
    elseif yi(i)>7
        yi(i)=7;
    end
    interpolatedKPIStages(ID,i)=yi(i);
end
plot(xi*100,yi);
axis([15,100,0,7])
xlabel('Progress%')
ylabel(strcat(Name(ID),' Indicator'))

end

figure(8)
plot(xi*100,interpolatedKPIStages);
axis([15,100,0,7])
legend(Name);
xlabel('Progress%')
ylabel('Key Performance Indicators')

ask=true;
disp('Would you like to get the KPIs for a specific progress percentage?')
Asking=input('Y/N:');
if Asking=='N'|| Asking=='n'
    ask=false;
end
while(ask)
    inputProgress=input('Please type the progress percentage from  0 to 100:');
    if inputProgress<0 || inputProgress>100
        disp('Wrong input')
    else
        ProgressKPI(1)=interp1(Progress,KPI_Of_Stages(:,1),inputProgress/100
,'linear','extrap');
        ProgressKPI(2)=interp1(Progress,KPI_Of_Stages(:,2),inputProgress/100
,'linear','extrap');
        ProgressKPI(3)=interp1(Progress,KPI_Of_Stages(:,3),inputProgress/100
,'linear','extrap');
        ProgressKPI(4)=interp1(Progress,KPI_Of_Stages(:,4),inputProgress/100
,'linear','extrap');
        ProgressKPI(5)=interp1(Progress,KPI_Of_Stages(:,5),inputProgress/100
,'linear','extrap');
        ProgressKPI(6)=interp1(Progress,KPI_Of_Stages(:,6),inputProgress/100
,'linear','extrap');
        KPIs_at_Specified_Progress=ProgressKPI';
        table(KPIs_at_Specified_Progress,'RowNames',Name)
        disp('(Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
    end
    disp('Would you like to get the KPIs for another specific progress%?')
    Asking=input('Y/N:');
```

```
    if Asking~='Y' && Asking~='y'
       ask=false;
    end
end
```

Appendix D4: Performance Optimization Model (POM) for selecting Corrective Action in Construction Projects

- **Optimizing PI of next stage**

```
clear BestPI
clear BestCost
close all
```

- **Loading ANFIS models**

```
load('ANFIS11.mat')
load('ANFIS12.mat')
load('ANFIS13.mat')
load('ANFIS14.mat')
load('ANFIS15.mat')
load('ANFIS16.mat')
load('ANFIS21.mat')
load('ANFIS22.mat')
load('ANFIS23.mat')
load('ANFIS24.mat')
load('ANFIS25.mat')
load('ANFIS26.mat')
load('ANFIS31.mat')
load('ANFIS32.mat')
load('ANFIS33.mat')
load('ANFIS34.mat')
load('ANFIS35.mat')
load('ANFIS36.mat')

%%
Set GA Parameters

Maximum_Iterations=100;                    %Maxmimum Iterations for GA

Population_Size=20;                        %Population for each Iteration

pc=0.5;                                    %Percentage of CrossOver

NumberOfParents=2*round(pc*Population_Size/2);

pm=0.5;                                    %Percentage of Mutation

NumberOfMutants=round(pm*Population_Size);
```

- **Optimizing middle stage**

```
if Optimizing==2

disp('Optimizing Middle Stage ...');

C_Cost=0.106;
```

```
C_Time=0.103;
C_Quality=0.320;
C_Safety=0.134;
C_ClientSatisfaction=0.176;
C_ProjectTeamSatisfaction=0.161;

Coefficients=[C_Cost,C_Time,C_Quality,C_Safety,C_ClientSatisfaction,C_Pro-
jectTeamSatisfaction];

KPI_InitialStage=InitialStage;

KPI_13=KPI_InitialStage;

KPI_Predict_Whole=[evalfis(KPI_13,ANFIS11)    evalfis(KPI_13,ANFIS12)    eval-
fis(KPI_13,ANFIS13)   evalfis(KPI_13,ANFIS14)   evalfis(KPI_13,ANFIS15)   eval-
fis(KPI_13,ANFIS16)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

Forecasted_PI_Of_The_Whole_Project=PI_Predict_Whole
disp('---');
BestPI(1)=PI_Predict_Whole;
```

- **Import data from excel to MATLAB**

```
DATA=xlsread('Project Information for Middle Stage.xlsx');

NumberOfActivities=DATA(1,1);

NameOfActivities=DATA(:,2);

NameOfActivities(isnan(NameOfActivities))=[];

ActivitiesMode=DATA(:,3);

ActivitiesMode(isnan(ActivitiesMode))=[];

ActivitiesWeight=DATA(:,4);

ActivitiesWeight(isnan(ActivitiesWeight))=[];
```

- **Optimization with GA**

```
Gene=NumberOfActivities;

Chromosome=[1 Gene];
```

```
GeneMin=ones([1,NumberOfActivities]);

for i=1:NumberOfActivities

    GeneMax(i)=ActivitiesMode(i);

end


%%

X.Position=[];
X.PI=[];

pop=repmat(X,Population_Size,1);

for i=1:Population_Size

    for j=1:Gene

    pop(i).Position(j)=randi([GeneMin(j),GeneMax(j)]);

    end

  %%
  x=pop(i).Position;

  for j=1:Gene

      if j==1

      KPI_Activies_MiddleStage(j,:)=DATA(x(j),6:11);

      else

      KPI_Activies_MiddleStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_MiddleStage(o,:)=ActivitiesWeight(o)*KPI_Activies_MiddleStage(o,:);
end


KPI_MiddleStage=sum(KPI_MiddleStage)/sum(ActivitiesWeight);

KPI=round([KPI_13 KPI_MiddleStage]);
```

- **Predict KPIs of the whole project**

```
KPI_Predict_Whole=[evalfis(KPI,ANFIS21)  evalfis(KPI,ANFIS22)  evalfis(KPI,AN-
FIS23) evalfis(KPI,ANFIS24) evalfis(KPI,ANFIS25) evalfis(KPI,ANFIS26)];
```

```
for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
elseif KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
end
end
```

- **Calculate PI of the whole project**

```
PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);
pop(i).PI=PI_Predict_Whole;

end

PI=[pop.PI];
[PI, SortOrder]=sort(PI);
pop=pop(SortOrder);
BestSol=pop(end);

BestCost=zeros(Maximum_Iterations,1);

for iterations=2:Maximum_Iterations

    popc=repmat(X,NumberOfParents/2,2);

    for k=1:NumberOfParents/2

%% Choose Parents for GA

        i1=randi([1,Population_Size]);
        p1=pop(i1);
        i2=randi([1,Population_Size]);
        p2=pop(i2);

%% CrossOver (SinglePoint)

           c=randi(Gene-1,1);

           popc(k,1).Position=[p1.Position(1:c),p2.Position(c+1:end)];
           popc(k,2).Position=[p2.Position(1:c),p1.Position(c+1:end)];

    %%
    x=popc(k,1).Position;

  for j=1:Gene

      if j==1

      KPI_Activies_MiddleStage(j,:)=DATA(x(j),6:11);

      else

      KPI_Activies_MiddleStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);
```

```
      end

  end

for o=1:Gene
    KPI_MiddleStage(o,:)=ActivitiesWeight(o)*KPI_Activies_MiddleStage(o,:);
end

KPI_MiddleStage=sum(KPI_MiddleStage)/sum(ActivitiesWeight);

KPI=round([KPI_13 KPI_MiddleStage]);

KPI_Predict_Whole=[evalfis(KPI,ANFIS21)  evalfis(KPI,ANFIS22)  evalfis(KPI,AN-
FIS23) evalfis(KPI,ANFIS24) evalfis(KPI,ANFIS25) evalfis(KPI,ANFIS26)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

popc(k,1).PI=PI_Predict_Whole;
%%

    x=popc(k,2).Position;

  for j=1:Gene

      if j==1

      KPI_Activies_MiddleStage(j,:)=DATA(x(j),6:11);

      else

      KPI_Activies_MiddleStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_MiddleStage(o,:)=ActivitiesWeight(o)*KPI_Activies_MiddleStage(o,:);
end

KPI_MiddleStage=sum(KPI_MiddleStage)/sum(ActivitiesWeight);

KPI=round([KPI_13 KPI_MiddleStage]);

KPI_Predict_Whole=[evalfis(KPI,ANFIS21)  evalfis(KPI,ANFIS22)  evalfis(KPI,AN-
FIS23) evalfis(KPI,ANFIS24) evalfis(KPI,ANFIS25) evalfis(KPI,ANFIS26)];
```

```
for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

popc(k,2).PI=PI_Predict_Whole;

    end

    popc=popc(:);

%% Mutation

    popm=repmat(X,NumberOfMutants,1);

    for k=1:NumberOfMutants


        i=randi([1 Population_Size]);
        p=pop(i);

        I=randi([1,Gene]);

        NumberOfActivitiesMode_Mutate=ActivitiesMode(I);

        popm(k).Position=p.Position;

        MaxGene_Mutate=GeneMax(I);

        if MaxGene_Mutate==1

            popm(k).Position(I)=p.Position(I);

        else

            Modes=1:NumberOfActivitiesMode_Mutate;

            Modes(Modes==p.Position(I))=[];

            n=numel(Modes);
            d=randi([1,n],1);

            popm(k).Position(I)=d;

        end


        %%
    x=popm(k).Position;
```

```
  for j=1:Gene

      if j==1

      KPI_Activies_MiddleStage(j,:)=DATA(x(j),6:11);

      else

      KPI_Activies_MiddleStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_MiddleStage(o,:)=ActivitiesWeight(o)*KPI_Activies_MiddleStage(o,:);
end

KPI_MiddleStage=sum(KPI_MiddleStage)/sum(ActivitiesWeight);

KPI=round([KPI_13 KPI_MiddleStage]);

KPI_Predict_Whole=[evalfis(KPI,ANFIS21)  evalfis(KPI,ANFIS22)  evalfis(KPI,AN-
FIS23) evalfis(KPI,ANFIS24) evalfis(KPI,ANFIS25) evalfis(KPI,ANFIS26)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

popm(k).PI=PI_Predict_Whole;
    end


    pop=[pop
         popc
         popm];


    PI=[pop.PI];
    [PI, SortOrder]=sort(PI);
    pop=pop(SortOrder);
    pop(1).Position;

    pop=pop(end-Population_Size:end);

%% Find the best solution in each iteration

    BestSol=pop(end);
```

```
    BestPI(iterations)=BestSol.PI;

%     disp(['Iteration ' num2str(iterations) ': Best PI = ' num2str(BestPI(it-
erations))]);

end

BestModes=BestSol.Position;

%%
    x=BestModes;

  for j=1:Gene

      if j==1

      KPI_Activies_MiddleStage(j,:)=DATA(x(j),6:11);

      else

      KPI_Activies_MiddleStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_MiddleStage(o,:)=ActivitiesWeight(o)*KPI_Activies_MiddleStage(o,:);
end

KPI_MiddleStage=sum(KPI_MiddleStage)/sum(ActivitiesWeight);

KPI=round([KPI_13 KPI_MiddleStage]);

KPI_Predict_Whole=[evalfis(KPI,ANFIS21)  evalfis(KPI,ANFIS22)  evalfis(KPI,AN-
FIS23) evalfis(KPI,ANFIS24) evalfis(KPI,ANFIS25) evalfis(KPI,ANFIS26)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole_Optimum=sum(Coefficients.*KPI_Predict_Whole);
Optimum_Forecasted_PI_Of_The_Whole_Project=PI_Predict_Whole_Optimum;
```

- **Display outputs**

```
if Optimum_Forecasted_PI_Of_The_Whole_Project>=BestPI(1)

    BestPI(BestPI<BestPI(1))=BestPI(1);
```

```
disp('Best Mode for Each Activity:');

for i=1:NumberOfActivities
```

- **Display best action plans**

```
disp(['Activity  ',num2str(NameOfActivities(i)),'  : Mode ',  num2str(Best-
Modes(i))]);

end


%%
figure;
semilogy(BestPI,'LineWidth',1);
plot(BestPI,'LineWidth',1);
xlabel('Iteration');
ylabel('PI');

Optimum_Forecasted_PI_Of_The_Whole_Project

else

    disp('Please Continue the same way');

end
```

- **Optimizing finishing stage**

```
elseif Optimizing==3

disp('Optimizing Finishing Stage ...');

C_Cost=0.106;
C_Time=0.103;
C_Quality=0.320;
C_Safety=0.134;
C_ClientSatisfaction=0.176;
C_ProjectTeamSatisfaction=0.161;

Coefficients=[C_Cost,C_Time,C_Quality,C_Safety,C_ClientSatisfaction,C_Pro-
jectTeamSatisfaction];

KPI_InitialStage=InitialStage;
KPI_MiddleStage=MiddleStage;

KPI_23=[KPI_InitialStage KPI_MiddleStage];

KPI_Predict_Whole=[evalfis(KPI_23,ANFIS21)   evalfis(KPI_23,ANFIS22)   eval-
fis(KPI_23,ANFIS23)  evalfis(KPI_23,ANFIS24)  evalfis(KPI_23,ANFIS25)  eval-
fis(KPI_23,ANFIS26)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
```

```
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

Forecasted_PI_Of_The_Whole_Project=PI_Predict_Whole
disp('---');
BestPI(1)=PI_Predict_Whole;
```

- **Import data from excel to MATLAB**

```
DATA=xlsread('Project Information for Finishing Stage.xlsx');

NumberOfActivities=DATA(1,1);

NameOfActivities=DATA(:,2);

NameOfActivities(isnan(NameOfActivities))=[];

ActivitiesMode=DATA(:,3);

ActivitiesMode(isnan(ActivitiesMode))=[];

ActivitiesWeight=DATA(:,4);

ActivitiesWeight(isnan(ActivitiesWeight))=[];
```

- **Optimization with GA**

```
Gene=NumberOfActivities;

Chromosome=[1 Gene];

GeneMin=ones([1,NumberOfActivities]);

for i=1:NumberOfActivities

    GeneMax(i)=ActivitiesMode(i);

end



%%

X.Position=[];
X.PI=[];

pop=repmat(X,Population_Size,1);

for i=1:Population_Size
```

```
    for j=1:Gene

    pop(i).Position(j)=randi([GeneMin(j),GeneMax(j)]);

    end

  %%
  x=pop(i).Position;

  for j=1:Gene

      if j==1

      KPI_Activies_FinishingStage(j,:)=DATA(x(j),6:11);

      else


      KPI_Activies_FinishingStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_FinishingStage(o,:)=ActivitiesWeight(o)*KPI_Activies_Finish-
ingStage(o,:);
end

KPI_FinishingStage=sum(KPI_FinishingStage)/sum(ActivitiesWeight);

KPI=round([KPI_23 KPI_FinishingStage]);
```

- **Predict KPIs of the whole project**

```
KPI_Predict_Whole=[evalfis(KPI,ANFIS31)  evalfis(KPI,ANFIS32)  evalfis(KPI,AN-
FIS33) evalfis(KPI,ANFIS34) evalfis(KPI,ANFIS35) evalfis(KPI,ANFIS36)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
elseif KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
end
end
```

- **Calculate PI of the whole project**

```
PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

pop(i).PI=PI_Predict_Whole;

end

PI=[pop.PI];
```

```
[PI, SortOrder]=sort(PI);
pop=pop(SortOrder);
BestSol=pop(end);

BestCost=zeros(Maximum_Iterations,1);

for iterations=2:Maximum_Iterations

    popc=repmat(X,NumberOfParents/2,2);

    for k=1:NumberOfParents/2

%% Choose Parents for CrossOver

        i1=randi([1,Population_Size]);
        p1=pop(i1);
        i2=randi([1,Population_Size]);
        p2=pop(i2);

%% CrossOver(SinglePoint)

           c=randi(Gene-1,1);

           popc(k,1).Position=[p1.Position(1:c),p2.Position(c+1:end)];
           popc(k,2).Position=[p2.Position(1:c),p1.Position(c+1:end)];

    %%
    x=popc(k,1).Position;

  for j=1:Gene

      if j==1

      KPI_Activies_FinishingStage(j,:)=DATA(x(j),6:11);

      else

      KPI_Activies_FinishingStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_FinishingStage(o,:)=ActivitiesWeight(o)*KPI_Activies_Finish-
ingStage(o,:);
end

KPI_FinishingStage=sum(KPI_FinishingStage)/sum(ActivitiesWeight);

KPI=round([KPI_23 KPI_FinishingStage]);


KPI_Predict_Whole=[evalfis(KPI,ANFIS31)  evalfis(KPI,ANFIS32)  evalfis(KPI,AN-
FIS33) evalfis(KPI,ANFIS34) evalfis(KPI,ANFIS35) evalfis(KPI,ANFIS36)];
```

```
for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end


PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

popc(k,1).PI=PI_Predict_Whole;
%%

    x=popc(k,2).Position;

  for j=1:Gene

      if j==1

      KPI_Activies_FinishingStage(j,:)=DATA(x(j),6:11);

      else

      KPI_Activies_FinishingStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_FinishingStage(o,:)=ActivitiesWeight(o)*KPI_Activies_Finish-
ingStage(o,:);
end

KPI_FinishingStage=sum(KPI_FinishingStage)/sum(ActivitiesWeight);

KPI=round([KPI_23 KPI_FinishingStage]);

%% Predict KPIs of the whole project for Crossovered population

KPI_Predict_Whole=[evalfis(KPI,ANFIS31)  evalfis(KPI,ANFIS32)  evalfis(KPI,AN-
FIS33) evalfis(KPI,ANFIS34) evalfis(KPI,ANFIS35) evalfis(KPI,ANFIS36)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

%% Predict PI of whole project for Crossovered population
```

```
PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

popc(k,2).PI=PI_Predict_Whole;

    end

    popc=popc(:);

%% Mutation

    popm=repmat(X,NumberOfMutants,1);

    for k=1:NumberOfMutants


        i=randi([1 Population_Size]);
        p=pop(i);

        I=randi([1,Gene]);

        NumberOfActivitiesMode_Mutate=ActivitiesMode(I);

        popm(k).Position=p.Position;

        MaxGene_Mutate=GeneMax(I);

        if MaxGene_Mutate==1

            popm(k).Position(I)=p.Position(I);

        else

            Modes=1:NumberOfActivitiesMode_Mutate;

            Modes(Modes==p.Position(I))=[];

            n=numel(Modes);
            d=randi([1,n],1);

            popm(k).Position(I)=d;

        end


        %%
    x=popm(k).Position;

  for j=1:Gene

      if j==1

      KPI_Activies_FinishingStage(j,:)=DATA(x(j),6:11);

      else

      KPI_Activies_FinishingStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);
```

```
      end

  end

for o=1:Gene
    KPI_FinishingStage(o,:)=ActivitiesWeight(o)*KPI_Activies_Finish-
ingStage(o,:);
end

KPI_FinishingStage=sum(KPI_FinishingStage)/sum(ActivitiesWeight);

KPI=round([KPI_23 KPI_FinishingStage]);

%% Predict KPIs of the whole project for mutated population

KPI_Predict_Whole=[evalfis(KPI,ANFIS31)  evalfis(KPI,ANFIS32)  evalfis(KPI,AN-
FIS33) evalfis(KPI,ANFIS34) evalfis(KPI,ANFIS35) evalfis(KPI,ANFIS36)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

%% Calculate KPIs of the whole project for mutated population

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

popm(k).PI=PI_Predict_Whole;
    end


    pop=[pop
         popc
         popm];


    PI=[pop.PI];
    [PI, SortOrder]=sort(PI);
    pop=pop(SortOrder);
    pop(1).Position;

    pop=pop(end-Population_Size:end);

%% Find the best solution in each iteration

    BestSol=pop(end);

    BestPI(iterations)=BestSol.PI;

%     disp(['Iteration ' num2str(iterations) ': Best PI = ' num2str(BestPI(it-
erations))]);
```

```
end

BestModes=BestSol.Position;

%%
    x=BestModes;

  for j=1:Gene

      if j==1

      KPI_Activies_FinishingStage(j,:)=DATA(x(j),6:11);

      else

      KPI_Activies_FinishingStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_FinishingStage(o,:)=ActivitiesWeight(o)*KPI_Activies_Finish-
ingStage(o,:);
end

KPI_FinishingStage=sum(KPI_FinishingStage)/sum(ActivitiesWeight);

KPI=round([KPI_23 KPI_FinishingStage]);

KPI_Predict_Whole=[evalfis(KPI,ANFIS31)  evalfis(KPI,ANFIS32)  evalfis(KPI,AN-
FIS33) evalfis(KPI,ANFIS34) evalfis(KPI,ANFIS35) evalfis(KPI,ANFIS36)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole_Optimum=sum(Coefficients.*KPI_Predict_Whole);
Optimum_Forecasted_PI_Of_The_Whole_Project=PI_Predict_Whole_Optimum;
```

- **Display output**

```
if Optimum_Forecasted_PI_Of_The_Whole_Project>=BestPI(1)

    BestPI(BestPI<BestPI(1))=BestPI(1);

disp('Best Mode for Each Activity:');
```

- **Display best action plans**

```
for i=1:NumberOfActivities

disp(['Activity   ',num2str(NameOfActivities(i)),'   : Mode  ',   num2str(Best-
Modes(i))]);

end

%%
figure;
semilogy(BestPI,'LineWidth',1);
plot(BestPI,'LineWidth',1);
xlabel('Iteration');
ylabel('PI');

Optimum_Forecasted_PI_Of_The_Whole_Project

else

    disp('Please Continue the same way');

end

end
```

- **Using Model**

```
clc;
clear all
format short
```

- **Loading ANFIS models**

```
load('ANFIS11.mat')
ANFIS11.input(1,1).name = 'Cost Initial Stage';
ANFIS11.input(1,2).name = 'Time Initial Stage';
ANFIS11.input(1,3).name = 'Quality Initial Stage';
ANFIS11.input(1,4).name = 'Safety Initial Stage';
ANFIS11.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS11.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS11.output(1,1).name = 'Cost - Whole Project';

load('ANFIS12.mat')
ANFIS12.input(1,1).name = 'Cost Initial Stage';
ANFIS12.input(1,2).name = 'Time Initial Stage';
ANFIS12.input(1,3).name = 'Quality Initial Stage';
ANFIS12.input(1,4).name = 'Safety Initial Stage';
ANFIS12.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS12.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS12.output(1,1).name = 'Time - Whole Project';
```

```
load('ANFIS13.mat')
ANFIS13.input(1,1).name = 'Cost Initial Stage';
ANFIS13.input(1,2).name = 'Time Initial Stage';
ANFIS13.input(1,3).name = 'Quality Initial Stage';
ANFIS13.input(1,4).name = 'Safety Initial Stage';
ANFIS13.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS13.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS13.output(1,1).name = 'Quality - Whole Project';

load('ANFIS14.mat')
ANFIS14.input(1,1).name = 'Cost Initial Stage';
ANFIS14.input(1,2).name = 'Time Initial Stage';
ANFIS14.input(1,3).name = 'Quality Initial Stage';
ANFIS14.input(1,4).name = 'Safety Initial Stage';
ANFIS14.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS14.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS14.output(1,1).name = 'Safety - Whole Project';

load('ANFIS15.mat')
ANFIS15.input(1,1).name = 'Cost Initial Stage';
ANFIS15.input(1,2).name = 'Time Initial Stage';
ANFIS15.input(1,3).name = 'Quality Initial Stage';
ANFIS15.input(1,4).name = 'Safety Initial Stage';
ANFIS15.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS15.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS15.output(1,1).name = 'Client Satisfaction - Whole Project';

load('ANFIS16.mat')
ANFIS16.input(1,1).name = 'Cost Initial Stage';
ANFIS16.input(1,2).name = 'Time Initial Stage';
ANFIS16.input(1,3).name = 'Quality Initial Stage';
ANFIS16.input(1,4).name = 'Safety Initial Stage';
ANFIS16.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS16.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS16.output(1,1).name = 'Project Team Satisfaction - Whole Project';


load('ANFIS21.mat')
ANFIS21.input(1,1).name = 'Cost Initial Stage';
ANFIS21.input(1,2).name = 'Time Initial Stage';
ANFIS21.input(1,3).name = 'Quality Initial Stage';
ANFIS21.input(1,4).name = 'Safety Initial Stage';
ANFIS21.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS21.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS21.input(1,7).name = 'Cost Middle Stage';
ANFIS21.input(1,8).name = 'Time Middle Stage';
ANFIS21.input(1,9).name = 'Quality Middle Stage';
ANFIS21.input(1,10).name = 'Safety Middle Stage';
ANFIS21.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS21.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS21.output(1,1).name = 'Cost - Whole Project';

load('ANFIS22.mat')
ANFIS22.input(1,1).name = 'Cost Initial Stage';
ANFIS22.input(1,2).name = 'Time Initial Stage';
ANFIS22.input(1,3).name = 'Quality Initial Stage';
ANFIS22.input(1,4).name = 'Safety Initial Stage';
```

```
ANFIS22.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS22.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS22.input(1,7).name = 'Cost Middle Stage';
ANFIS22.input(1,8).name = 'Time Middle Stage';
ANFIS22.input(1,9).name = 'Quality Middle Stage';
ANFIS22.input(1,10).name = 'Safety Middle Stage';
ANFIS22.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS22.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS22.output(1,1).name = 'Time - Whole Project';

load('ANFIS23.mat')
ANFIS23.input(1,1).name = 'Cost Initial Stage';
ANFIS23.input(1,2).name = 'Time Initial Stage';
ANFIS23.input(1,3).name = 'Quality Initial Stage';
ANFIS23.input(1,4).name = 'Safety Initial Stage';
ANFIS23.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS23.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS23.input(1,7).name = 'Cost Middle Stage';
ANFIS23.input(1,8).name = 'Time Middle Stage';
ANFIS23.input(1,9).name = 'Quality Middle Stage';
ANFIS23.input(1,10).name = 'Safety Middle Stage';
ANFIS23.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS23.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS23.output(1,1).name = 'Quality - Whole Project';

load('ANFIS24.mat')
ANFIS24.input(1,1).name = 'Cost Initial Stage';
ANFIS24.input(1,2).name = 'Time Initial Stage';
ANFIS24.input(1,3).name = 'Quality Initial Stage';
ANFIS24.input(1,4).name = 'Safety Initial Stage';
ANFIS24.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS24.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS24.input(1,7).name = 'Cost Middle Stage';
ANFIS24.input(1,8).name = 'Time Middle Stage';
ANFIS24.input(1,9).name = 'Quality Middle Stage';
ANFIS24.input(1,10).name = 'Safety Middle Stage';
ANFIS24.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS24.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS24.output(1,1).name = 'Safety - Whole Project';

load('ANFIS25.mat')
ANFIS25.input(1,1).name = 'Cost Initial Stage';
ANFIS25.input(1,2).name = 'Time Initial Stage';
ANFIS25.input(1,3).name = 'Quality Initial Stage';
ANFIS25.input(1,4).name = 'Safety Initial Stage';
ANFIS25.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS25.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS25.input(1,7).name = 'Cost Middle Stage';
ANFIS25.input(1,8).name = 'Time Middle Stage';
ANFIS25.input(1,9).name = 'Quality Middle Stage';
ANFIS25.input(1,10).name = 'Safety Middle Stage';
ANFIS25.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS25.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS25.output(1,1).name = 'Client Satisfaction - Whole Project';

load('ANFIS26.mat')
ANFIS26.input(1,1).name = 'Cost Initial Stage';
```

```
ANFIS26.input(1,2).name = 'Time Initial Stage';
ANFIS26.input(1,3).name = 'Quality Initial Stage';
ANFIS26.input(1,4).name = 'Safety Initial Stage';
ANFIS26.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS26.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS26.input(1,7).name = 'Cost Middle Stage';
ANFIS26.input(1,8).name = 'Time Middle Stage';
ANFIS26.input(1,9).name = 'Quality Middle Stage';
ANFIS26.input(1,10).name = 'Safety Middle Stage';
ANFIS26.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS26.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS26.output(1,1).name = 'Project Team Satisfaction - Whole Project';


load('ANFIS31.mat')
ANFIS31.input(1,1).name = 'Cost Initial Stage';
ANFIS31.input(1,2).name = 'Time Initial Stage';
ANFIS31.input(1,3).name = 'Quality Initial Stage';
ANFIS31.input(1,4).name = 'Safety Initial Stage';
ANFIS31.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS31.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS31.input(1,7).name = 'Cost Middle Stage';
ANFIS31.input(1,8).name = 'Time Middle Stage';
ANFIS31.input(1,9).name = 'Quality Middle Stage';
ANFIS31.input(1,10).name = 'Safety Middle Stage';
ANFIS31.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS31.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS31.input(1,13).name = 'Cost Finishing Stage';
ANFIS31.input(1,14).name = 'Time Finishing Stage';
ANFIS31.input(1,15).name = 'Quality Finishing Stage';
ANFIS31.input(1,16).name = 'Safety Finishing Stage';
ANFIS31.input(1,17).name = 'Client Satisfaction Finishing Stage';
ANFIS31.input(1,18).name = 'Project Team Satisfaction Finishing Stage';
ANFIS31.output(1,1).name = 'Cost - Whole Project';

load('ANFIS32.mat')
ANFIS32.input(1,1).name = 'Cost Initial Stage';
ANFIS32.input(1,2).name = 'Time Initial Stage';
ANFIS32.input(1,3).name = 'Quality Initial Stage';
ANFIS32.input(1,4).name = 'Safety Initial Stage';
ANFIS32.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS32.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS32.input(1,7).name = 'Cost Middle Stage';
ANFIS32.input(1,8).name = 'Time Middle Stage';
ANFIS32.input(1,9).name = 'Quality Middle Stage';
ANFIS32.input(1,10).name = 'Safety Middle Stage';
ANFIS32.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS32.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS32.input(1,13).name = 'Cost Finishing Stage';
ANFIS32.input(1,14).name = 'Time Finishing Stage';
ANFIS32.input(1,15).name = 'Quality Finishing Stage';
ANFIS32.input(1,16).name = 'Safety Finishing Stage';
ANFIS32.input(1,17).name = 'Client Satisfaction Finishing Stage';
ANFIS32.input(1,18).name = 'Project Team Satisfaction Finishing Stage';
ANFIS32.output(1,1).name = 'Time - Whole Project';

load('ANFIS33.mat')
```

```
ANFIS33.input(1,1).name = 'Cost Initial Stage';
ANFIS33.input(1,2).name = 'Time Initial Stage';
ANFIS33.input(1,3).name = 'Quality Initial Stage';
ANFIS33.input(1,4).name = 'Safety Initial Stage';
ANFIS33.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS33.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS33.input(1,7).name = 'Cost Middle Stage';
ANFIS33.input(1,8).name = 'Time Middle Stage';
ANFIS33.input(1,9).name = 'Quality Middle Stage';
ANFIS33.input(1,10).name = 'Safety Middle Stage';
ANFIS33.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS33.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS33.input(1,13).name = 'Cost Finishing Stage';
ANFIS33.input(1,14).name = 'Time Finishing Stage';
ANFIS33.input(1,15).name = 'Quality Finishing Stage';
ANFIS33.input(1,16).name = 'Safety Finishing Stage';
ANFIS33.input(1,17).name = 'Client Satisfaction Finishing Stage';
ANFIS33.input(1,18).name = 'Project Team Satisfaction Finishing Stage';
ANFIS33.output(1,1).name = 'Quality - Whole Project';

load('ANFIS34.mat')
ANFIS34.input(1,1).name = 'Cost Initial Stage';
ANFIS34.input(1,2).name = 'Time Initial Stage';
ANFIS34.input(1,3).name = 'Quality Initial Stage';
ANFIS34.input(1,4).name = 'Safety Initial Stage';
ANFIS34.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS34.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS34.input(1,7).name = 'Cost Middle Stage';
ANFIS34.input(1,8).name = 'Time Middle Stage';
ANFIS34.input(1,9).name = 'Quality Middle Stage';
ANFIS34.input(1,10).name = 'Safety Middle Stage';
ANFIS34.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS34.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS34.input(1,13).name = 'Cost Finishing Stage';
ANFIS34.input(1,14).name = 'Time Finishing Stage';
ANFIS34.input(1,15).name = 'Quality Finishing Stage';
ANFIS34.input(1,16).name = 'Safety Finishing Stage';
ANFIS34.input(1,17).name = 'Client Satisfaction Finishing Stage';
ANFIS34.input(1,18).name = 'Project Team Satisfaction Finishing Stage';
ANFIS34.output(1,1).name = 'Safety - Whole Project';

load('ANFIS35.mat')
ANFIS35.input(1,1).name = 'Cost Initial Stage';
ANFIS35.input(1,2).name = 'Time Initial Stage';
ANFIS35.input(1,3).name = 'Quality Initial Stage';
ANFIS35.input(1,4).name = 'Safety Initial Stage';
ANFIS35.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS35.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS35.input(1,7).name = 'Cost Middle Stage';
ANFIS35.input(1,8).name = 'Time Middle Stage';
ANFIS35.input(1,9).name = 'Quality Middle Stage';
ANFIS35.input(1,10).name = 'Safety Middle Stage';
ANFIS35.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS35.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS35.input(1,13).name = 'Cost Finishing Stage';
ANFIS35.input(1,14).name = 'Time Finishing Stage';
ANFIS35.input(1,15).name = 'Quality Finishing Stage';
```

```
ANFIS35.input(1,16).name = 'Safety Finishing Stage';
ANFIS35.input(1,17).name = 'Client Satisfaction Finishing Stage';
ANFIS35.input(1,18).name = 'Project Team Satisfaction Finishing Stage';
ANFIS35.output(1,1).name = 'Client Satisfaction - Whole Project';

load('ANFIS36.mat')
ANFIS36.input(1,1).name = 'Cost Initial Stage';
ANFIS36.input(1,2).name = 'Time Initial Stage';
ANFIS36.input(1,3).name = 'Quality Initial Stage';
ANFIS36.input(1,4).name = 'Safety Initial Stage';
ANFIS36.input(1,5).name = 'Client Satisfaction Initial Stage';
ANFIS36.input(1,6).name = 'Project Team Satisfaction Initial Stage';
ANFIS36.input(1,7).name = 'Cost Middle Stage';
ANFIS36.input(1,8).name = 'Time Middle Stage';
ANFIS36.input(1,9).name = 'Quality Middle Stage';
ANFIS36.input(1,10).name = 'Safety Middle Stage';
ANFIS36.input(1,11).name = 'Client Satisfaction Middle Stage';
ANFIS36.input(1,12).name = 'Project Team Satisfaction Middle Stage';
ANFIS36.input(1,13).name = 'Cost Finishing Stage';
ANFIS36.input(1,14).name = 'Time Finishing Stage';
ANFIS36.input(1,15).name = 'Quality Finishing Stage';
ANFIS36.input(1,16).name = 'Safety Finishing Stage';
ANFIS36.input(1,17).name = 'Client Satisfaction Finishing Stage';
ANFIS36.input(1,18).name = 'Project Team Satisfaction Finishing Stage';
ANFIS36.output(1,1).name = 'Project Team Satisfaction - Whole Project';


disp('---')
disp('')

disp('>>> From which Stage You Want Predicting The Whole Project KPIs?')
disp('>(Initial   stage:  0% to 30 % Physical Progress = Type 1)')
disp('>(Middle    stage: 30% to 70 % Physical Progress = Type 2)')
disp('>(Finishing stage: 70% to 100% Physical Progress = Type 3)')
```

- **Enter KPIs for each stage**

```
Stage=input('According to the description, the number to be entered:');

if     Stage==1
disp('---')
disp('')
disp('In the Initial Stage of the project, what is the performance of each of
the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostInitialStage = input('Cost(Type 2 To 7) : ');
if CostInitialStage(1,1)>7 | CostInitialStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

TimeInitialStage = input('Time(Type 1 To 7) : ');
if TimeInitialStage(1,1)>7 | TimeInitialStage(1,1)<1
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
```

```
end

QualityInitialStage = input('Quality(Type 3 To 7) : ');
if QualityInitialStage(1,1)>7 | QualityInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

SafetyInitialStage = input('Safety(Type 3 To 7) : ');
if SafetyInitialStage(1,1)>7 | SafetyInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionInitialStage = input('ClientSatisfaction(Type 3 To 7) : ');
if    ClientSatisfactionInitialStage(1,1)>7    |    ClientSatisfactionInitial-
Stage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionInitialStage = input('ProjectTeamSatisfaction(Type 3 To
7) : ');
if    ProjectTeamSatisfactionInitialStage(1,1)>7    |    ProjectTeamSatisfac-
tionInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

InitialStage=[CostInitialStage TimeInitialStage QualityInitialStage SafetyIni-
tialStage  ClientSatisfactionInitialStage  ProjectTeamSatisfactionInitialStage
];
```

- **Predict KPIs of middle stage with KPIs of initial stage**

```
In1=[InitialStage];
KPIf1 = evalfis(In1,ANFIS11);
KPIf2 = evalfis(In1,ANFIS12);
KPIf3 = evalfis(In1,ANFIS13);
KPIf4 = evalfis(In1,ANFIS14);
KPIf5 = evalfis(In1,ANFIS15);
KPIf6 = evalfis(In1,ANFIS16);
KPI1tof=[KPIf1 KPIf2 KPIf3 KPIf4 KPIf5 KPIf6];

for i=1:6
if KPI1tof(1,i) > 7
    KPI1tof(1,i)=7;
else if KPI1tof(1,i) < 1
        KPI1tof(1,i)=1;
    end
end
end

% KPI1tof=round(KPI1tof);
disp('---')
disp('')
```

```
Name = {'Cost';'Time';'Quality';'Safety';'Client Satisfaction';'Project Team
Satisfaction'};
Forecasted_KPIs_Of_The_Whole_Project                                          =
[KPI1tof(1,1);KPI1tof(1,2);KPI1tof(1,3);KPI1tof(1,4);KPI1tof(1,5);KPI1tof(1,6
)];
table(Forecasted_KPIs_Of_The_Whole_Project,'RowNames',Name)

PI_AHP =  (0.106*KPI1tof(1,1) + 0.103*KPI1tof(1,2) +...
                0.320*KPI1tof(1,3) + 0.134*KPI1tof(1,4) +...
                0.176*KPI1tof(1,5) + 0.161*KPI1tof(1,6));
PI_GA  =  (0.026*KPI1tof(1,1) + 0.237*KPI1tof(1,2) +...
                0.196*KPI1tof(1,3) + 0.228*KPI1tof(1,4) +...
                0.012*KPI1tof(1,5) + 0.301*KPI1tof(1,6));
Name = {'PI_AHP Method';'PI_GA Method'};
Forecasted_Performance_Of_The_Whole_Project = [PI_AHP;PI_GA];
table(Forecasted_Performance_Of_The_Whole_Project,'RowNames',Name)


disp('(Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very
High=7)')


elseif Stage==2

disp('---')
disp('')
disp('In the Initial Stage of the project, what is the performance of each of
the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostInitialStage = input('Cost(Type 2 To 7) : ');
if CostInitialStage(1,1)>7 | CostInitialStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

TimeInitialStage = input('Time(Type 1 To 7) : ');
if TimeInitialStage(1,1)>7 | TimeInitialStage(1,1)<1
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

QualityInitialStage = input('Quality(Type 3 To 7) : ');
if QualityInitialStage(1,1)>7 | QualityInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

SafetyInitialStage = input('Safety(Type 3 To 7) : ');
if SafetyInitialStage(1,1)>7 | SafetyInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionInitialStage = input('ClientSatisfaction(Type 3 To 7) : ');
if    ClientSatisfactionInitialStage(1,1)>7    |    ClientSatisfactionInitial-
Stage(1,1)<3
```

```
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionInitialStage = input('ProjectTeamSatisfaction(Type 3 To
7) : ');
if    ProjectTeamSatisfactionInitialStage(1,1)>7    |    ProjectTeamSatisfac-
tionInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

InitialStage=[CostInitialStage TimeInitialStage QualityInitialStage SafetyIni-
tialStage  ClientSatisfactionInitialStage  ProjectTeamSatisfactionInitialStage
];

disp('---')
disp('')
disp('In the Middle Stage of the project, what is the performance of each of
the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostMiddleStage = input('Cost(Type 2 To 7) : ');
if CostMiddleStage(1,1)>7 | CostMiddleStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

TimeMiddleStage = input('Time(Type 1 To 7) : ');
if TimeMiddleStage(1,1)>7 | TimeMiddleStage(1,1)<1
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

QualityMiddleStage = input('Quality(Type 3 To 7) : ');
if QualityMiddleStage(1,1)>7 | QualityMiddleStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

SafetyMiddleStage = input('Safety(Type 3 To 7) : ');
if SafetyMiddleStage(1,1)>7 | SafetyMiddleStage(1,1)<3
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionMiddleStage = input('ClientSatisfaction(Type 2 To 7) : ');
if ClientSatisfactionMiddleStage(1,1)>7 | ClientSatisfactionMiddleStage(1,1)<2
   error('MyComponent:incorrectType',...
       'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionMiddleStage = input('ProjectTeamSatisfaction(Type 3 To
7) : ');
if  ProjectTeamSatisfactionMiddleStage(1,1)>7  |  ProjectTeamSatisfactionMid-
dleStage(1,1)<3
   error('MyComponent:incorrectType',...
```

```
       'Error. \nInputs must be in range, Try Again ...')
end

MiddleStage=[CostMiddleStage  TimeMiddleStage  QualityMiddleStage  SafetyMid-
dleStage ClientSatisfactionMiddleStage ProjectTeamSatisfactionMiddleStage ];
```

- **Predict KPIs of finishing stage with KPIs of initial and middle stages**

```
In2=[InitialStage MiddleStage];
KPIf1 = evalfis(In2,ANFIS21);
KPIf2 = evalfis(In2,ANFIS22);
KPIf3 = evalfis(In2,ANFIS23);
KPIf4 = evalfis(In2,ANFIS24);
KPIf5 = evalfis(In2,ANFIS25);
KPIf6 = evalfis(In2,ANFIS26);
KPI12tof=[KPIf1 KPIf2 KPIf3 KPIf4 KPIf5 KPIf6];


for i=1:6
if KPI12tof(1,i) > 7
    KPI12tof(1,i)=7;
else if KPI12tof(1,i) < 1
        KPI12tof(1,i)=1;
    end
end
end

% KPI12tof=round(KPI12tof);
disp('---')
disp('')
Name = {'Cost';'Time';'Quality';'Safety';'Client Satisfaction';'Project Team
Satisfaction'};
Forecasted_KPIs_Of_The_Whole_Project                                         =
[KPI12tof(1,1);KPI12tof(1,2);KPI12tof(1,3);KPI12tof(1,4);KPI12tof(1,5);KPI12t
of(1,6)];
table(Forecasted_KPIs_Of_The_Whole_Project,'RowNames',Name)

PI_AHP =  (0.106*KPI12tof(1,1) + 0.103*KPI12tof(1,2) +...
                0.320*KPI12tof(1,3) + 0.134*KPI12tof(1,4) +...
                0.176*KPI12tof(1,5) + 0.161*KPI12tof(1,6));
PI_GA  =  (0.026*KPI12tof(1,1) + 0.237*KPI12tof(1,2) +...
                0.196*KPI12tof(1,3) + 0.228*KPI12tof(1,4) +...
                0.012*KPI12tof(1,5) + 0.301*KPI12tof(1,6));
Name = {'PI_AHP Method';'PI_GA Method'};
Forecasted_Performance_Of_The_Whole_Project = [PI_AHP;PI_GA];
table(Forecasted_Performance_Of_The_Whole_Project,'RowNames',Name)

disp('(Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very
High=7)')

elseif Stage==3

disp('---')
disp('')
disp('In the Initial Stage of the project, what is the performance of each of
the following indicator?')
```

```
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostInitialStage = input('Cost(Type 2 To 7) : ');
if CostInitialStage(1,1)>7 | CostInitialStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

TimeInitialStage = input('Time(Type 1 To 7) : ');
if TimeInitialStage(1,1)>7 | TimeInitialStage(1,1)<1
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

QualityInitialStage = input('Quality(Type 3 To 7) : ');
if QualityInitialStage(1,1)>7 | QualityInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

SafetyInitialStage = input('Safety(Type 3 To 7) : ');
if SafetyInitialStage(1,1)>7 | SafetyInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionInitialStage = input('ClientSatisfaction(Type 3 To 7) : ');
if    ClientSatisfactionInitialStage(1,1)>7    |    ClientSatisfactionInitial-
Stage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionInitialStage = input('ProjectTeamSatisfaction(Type 3 To
7) : ');
if    ProjectTeamSatisfactionInitialStage(1,1)>7    |    ProjectTeamSatisfac-
tionInitialStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

InitialStage=[CostInitialStage TimeInitialStage QualityInitialStage SafetyIni-
tialStage  ClientSatisfactionInitialStage  ProjectTeamSatisfactionInitialStage
];

disp('---')
disp('')
disp('In the Middle Stage of the project, what is the performance of each of
the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostMiddleStage = input('Cost(Type 2 To 7) : ');
if CostMiddleStage(1,1)>7 | CostMiddleStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end
```

```
TimeMiddleStage = input('Time(Type 1 To 7) : ');
if TimeMiddleStage(1,1)>7 | TimeMiddleStage(1,1)<1
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

QualityMiddleStage = input('Quality(Type 3 To 7) : ');
if QualityMiddleStage(1,1)>7 | QualityMiddleStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

SafetyMiddleStage = input('Safety(Type 3 To 7) : ');
if SafetyMiddleStage(1,1)>7 | SafetyMiddleStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionMiddleStage = input('ClientSatisfaction(Type 2 To 7) : ');
if ClientSatisfactionMiddleStage(1,1)>7 | ClientSatisfactionMiddleStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionMiddleStage = input('ProjectTeamSatisfaction(Type 3 To
7) : ');
if  ProjectTeamSatisfactionMiddleStage(1,1)>7  |  ProjectTeamSatisfactionMid-
dleStage(1,1)<3
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

MiddleStage=[CostMiddleStage  TimeMiddleStage  QualityMiddleStage  SafetyMid-
dleStage ClientSatisfactionMiddleStage ProjectTeamSatisfactionMiddleStage ];

disp('---')
disp('')
disp('In the Finishing Stage of the project, what is the performance of each of
the following indicator?')
disp('(Type Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6
Very High=7)')
CostFinishingStage = input('Cost(Type 2 To 7) : ');
if CostFinishingStage(1,1)>7 | CostFinishingStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

TimeFinishingStage = input('Time(Type 2 To 7) : ');
if TimeFinishingStage(1,1)>7 | TimeFinishingStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

QualityFinishingStage = input('Quality(Type 2 To 7) : ');
if QualityFinishingStage(1,1)>7 | QualityFinishingStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
```

```
end

SafetyFinishingStage = input('Safety(Type 2 To 7) : ');
if SafetyFinishingStage(1,1)>7 | SafetyFinishingStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ClientSatisfactionFinishingStage = input('ClientSatisfaction(Type 2 To 7) : ');
if    ClientSatisfactionFinishingStage(1,1)>7    |    ClientSatisfactionFinish-
ingStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

ProjectTeamSatisfactionFinishingStage = input('ProjectTeamSatisfaction(Type 2
To 7) : ');
if ProjectTeamSatisfactionFinishingStage(1,1)>7 | ProjectTeamSatisfactionFin-
ishingStage(1,1)<2
   error('MyComponent:incorrectType',...
        'Error. \nInputs must be in range, Try Again ...')
end

FinishingStage=[CostFinishingStage  TimeFinishingStage  QualityFinishingStage
SafetyFinishingStage ClientSatisfactionFinishingStage ProjectTeamSatisfaction-
FinishingStage ];
```

- **Predict KPIs of the whole project with KPIs of initial, middle and finishing Stages**

```
In3=[InitialStage MiddleStage FinishingStage];
KPIf1 = evalfis(In3,ANFIS31);
KPIf2 = evalfis(In3,ANFIS32);
KPIf3 = evalfis(In3,ANFIS33);
KPIf4 = evalfis(In3,ANFIS34);
KPIf5 = evalfis(In3,ANFIS35);
KPIf6 = evalfis(In3,ANFIS36);
KPI123tof=[KPIf1 KPIf2 KPIf3 KPIf4 KPIf5 KPIf6];

for i=1:6
if KPI123tof(1,i) > 7
    KPI123tof(1,i)=7;
else if KPI123tof(1,i) < 1
        KPI123tof(1,i)=1;
    end
end
end

% KPI123tof=round(KPI123tof);
disp('---')
disp('')
Name = {'Cost';'Time';'Quality';'Safety';'Client Satisfaction';'Project Team
Satisfaction'};
Forecasted_KPIs_Of_The_Whole_Project                                          =
[KPI123tof(1,1);KPI123tof(1,2);KPI123tof(1,3);KPI123tof(1,4);KPI123tof(1,5);K
PI123tof(1,6)];
table(Forecasted_KPIs_Of_The_Whole_Project,'RowNames',Name)
```

- **Calculating PI with AHP and GA Methods**

```
PI_AHP =  (0.106*KPI123tof(1,1) + 0.103*KPI123tof(1,2) +...
                0.320*KPI123tof(1,3) + 0.134*KPI123tof(1,4) +...
                0.176*KPI123tof(1,5) + 0.161*KPI123tof(1,6));


PI_GA  =  (0.026*KPI123tof(1,1) + 0.237*KPI123tof(1,2) +...
                0.196*KPI123tof(1,3) + 0.228*KPI123tof(1,4) +...
                0.012*KPI123tof(1,5) + 0.301*KPI123tof(1,6));
Name = {'PI_AHP Method';'PI_GA Method'};
Forecasted_Performance_Of_The_Whole_Project = [PI_AHP;PI_GA];
table(Forecasted_Performance_Of_The_Whole_Project,'RowNames',Name)

disp('(Very Low=1  Low=2  Medium Low=3  Medium=4  Medium High=5  High=6  Very
High=7)')

else

    disp('--')
    disp('')
    disp('Notice!!!')
    disp('Please Type Correct Number...')
end
```

- **Optimizing next stage PI or KPIs**

```
answer=input('Do you want to increase PI or KPI ?  (PI=1  KPI=2)');

if answer==1

disp('---')
```

- **Compare to acceptable PI**

```
if PI_AHP>=5.29
disp('Your PI is more than acceptable PI')
disp('---')
elseif PI_AHP<5.29 && Stage==1
optimization=input('Your PI is lower than acceptable PI...Do you want to in-
crease it? (Yes=1 No=0)');
disp('---')
if optimization
    disp('Open the (Project Information for Middle Stage.xls) ');
    disp('and fill the KPIs values & weights for each activity then save and
close it');
    StartOptimizationStage2=input('When its done, press 1 and enter   ');
    disp('---')

    if StartOptimizationStage2
```

- **Run Performance Optimization Model (POM) and optimize indicators**

```
        Optimizing=2;

        Unlimited

    end
end
elseif PI_AHP<5.29 && Stage==2
optimization=input('Your PI is lower than acceptable PI...Do you want to in-
crease it? (Yes=1 No=0)');
disp('---')
if optimization
    disp('Open the (Project Information for Finishing Stage.xls) ');
    disp('and fill the KPIs values & weights for each activity then save and
close it');
    StartOptimizationStage3=input('When its done, press 1 and enter   ');
    disp('---')

    Optimizing=3;

    if StartOptimizationStage3



      Optimizing=3;

        Unlimited

    end
end

end

disp('---')
disp('---')

elseif answer==2

   answer2=input('Which  KPI  do  you  want  to  increase?(Cost=1,Time=2,Qual-
ity=3,Safety=4,Client Satisfaction=5,Project Team Satisfaction=6)');

   disp('---')

if  Stage==1

    disp('Open the (Project Information for Middle Stage.xls) ');
    disp('and fill the KPIs values & weights for each activity then save and
close it');
    StartOptimizationStage2=input('When its done, press 1 and enter   ');
    disp('---')

    if StartOptimizationStage2

        Optimizing=2;
```

```
        Optimize_KPI

    end
elseif  Stage==2

    disp('Open the (Project Information for Finishing Stage.xls) ');
    disp('and fill the KPIs values & weights for each activity then save and
close it');
    StartOptimizationStage3=input('When its done, press 1 and enter   ');
    disp('---')

    Optimizing=3;

    if StartOptimizationStage3

        Optimizing=3;

        Optimize_KPI

    end


end

disp('---')
disp('---')



end
```

- **Optimize_KPIs**
- **Optimizing next stage KPIs**

```
clear BestPI

clear BestCost
close all
```

- **Loading Anfis models**

```
load('ANFIS11.mat')
load('ANFIS12.mat')
load('ANFIS13.mat')
load('ANFIS14.mat')
load('ANFIS15.mat')
load('ANFIS16.mat')
load('ANFIS21.mat')
load('ANFIS22.mat')
load('ANFIS23.mat')
load('ANFIS24.mat')
load('ANFIS25.mat')
load('ANFIS26.mat')
load('ANFIS31.mat')
load('ANFIS32.mat')
load('ANFIS33.mat')
load('ANFIS34.mat')
load('ANFIS35.mat')
load('ANFIS36.mat')

%% Set GA Parameters
Maximum_Iterations=100;

Population_Size=40;

pc=0.5;

NumberOfParents=2*round(pc*Population_Size/2);

pm=0.5;

NumberOfMutants=round(pm*Population_Size);
```

- **Optimizing middle stage indicators**

```
if Optimizing==2

disp('Optimizing Middle Stage ...');

C_Cost=0.106;
C_Time=0.103;
C_Quality=0.320;
C_Safety=0.134;
C_ClientSatisfaction=0.176;
```

```
C_ProjectTeamSatisfaction=0.161;

Coefficients=[C_Cost,C_Time,C_Quality,C_Safety,C_ClientSatisfaction,C_Pro-
jectTeamSatisfaction];

KPI_InitialStage=InitialStage;

KPI_13=KPI_InitialStage;

KPI_Predict_Whole=[evalfis(KPI_13,ANFIS11)    evalfis(KPI_13,ANFIS12)    eval-
fis(KPI_13,ANFIS13)   evalfis(KPI_13,ANFIS14)   evalfis(KPI_13,ANFIS15)   eval-
fis(KPI_13,ANFIS16)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

if answer2==1
Forecasted_Cost_Indicator_Of_The_Whole_Project=KPI_Predict_Whole(answer2)

elseif answer2==2
Forecasted_Time_Indicator_Of_The_Whole_Project=KPI_Predict_Whole(answer2)

elseif answer2==3
Forecasted_Quality_Indicator_Of_The_Whole_Project=KPI_Predict_Whole(answer2)

elseif answer2==4
Forecasted_Safety_Indicator_Of_The_Whole_Project=KPI_Predict_Whole(answer2)

elseif answer2==5
Forecasted_ClientSatisfaction_Indicator_Of_The_Whole_Project=KPI_Pre-
dict_Whole(answer2)

elseif answer2==6
Forecasted_ProjectTeamSatisfaction_Indicator_Of_Whole_Project=KPI_Pre-
dict_Whole(answer2)

end
disp('---');

    BestKPI(1)=KPI_Predict_Whole(answer2);

KPI_at_the_first=KPI_Predict_Whole;
PI_at_the_first=PI_Predict_Whole;
```

- **Import data from excel to MATLAB**

```
DATA=xlsread('Project Information for Middle Stage.xlsx');
```

```
NumberOfActivities=DATA(1,1);

NameOfActivities=DATA(:,2);

NameOfActivities(isnan(NameOfActivities))=[];

ActivitiesMode=DATA(:,3);

ActivitiesMode(isnan(ActivitiesMode))=[];

ActivitiesWeight=DATA(:,4);

ActivitiesWeight(isnan(ActivitiesWeight))=[];
```

- **Optimization with GA**

```
Gene=NumberOfActivities;

Chromosome=[1 Gene];

GeneMin=ones([1,NumberOfActivities]);

for i=1:NumberOfActivities

    GeneMax(i)=ActivitiesMode(i);

end


%%

X.Position=[];
X.KPI=[];

pop=repmat(X,Population_Size,1);

for i=1:Population_Size

    for j=1:Gene

    pop(i).Position(j)=randi([GeneMin(j),GeneMax(j)]);

    end

  %%
  x=pop(i).Position;

  for j=1:Gene

      if j==1

      KPI_Activies_MiddleStage(j,:)=DATA(x(j),6:11);

      else
```

```
      KPI_Activies_MiddleStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_MiddleStage(o,:)=ActivitiesWeight(o)*KPI_Activies_MiddleStage(o,:);
end

KPI_MiddleStage=sum(KPI_MiddleStage)/sum(ActivitiesWeight);

KPI=round([KPI_13 KPI_MiddleStage]);

KPI_Predict_Whole=[evalfis(KPI,ANFIS21)  evalfis(KPI,ANFIS22)  evalfis(KPI,AN-
FIS23) evalfis(KPI,ANFIS24) evalfis(KPI,ANFIS25) evalfis(KPI,ANFIS26)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
elseif KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
end
end

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);


pop(i).KPI=KPI_Predict_Whole(answer2);


end

KPII=[pop.KPI];
[KPII, SortOrder]=sort(KPII);
pop=pop(SortOrder);
BestSol=pop(end);

BestCost=zeros(Maximum_Iterations,1);

for iterations=2:Maximum_Iterations

    popc=repmat(X,NumberOfParents/2,2);

    for k=1:NumberOfParents/2
%% Choose Parents for GA

        i1=randi([1,Population_Size]);
        p1=pop(i1);
        i2=randi([1,Population_Size]);
        p2=pop(i2);

%% CrossOver (SinglePoint)

           c=randi(Gene-1,1);
```

```
            popc(k,1).Position=[p1.Position(1:c),p2.Position(c+1:end)];
            popc(k,2).Position=[p2.Position(1:c),p1.Position(c+1:end)];

    %%
    x=popc(k,1).Position;

  for j=1:Gene

      if j==1

      KPI_Activies_MiddleStage(j,:)=DATA(x(j),6:11);

      else

      KPI_Activies_MiddleStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_MiddleStage(o,:)=ActivitiesWeight(o)*KPI_Activies_MiddleStage(o,:);
end

KPI_MiddleStage=sum(KPI_MiddleStage)/sum(ActivitiesWeight);

KPI=round([KPI_13 KPI_MiddleStage]);

KPI_Predict_Whole=[evalfis(KPI,ANFIS21)  evalfis(KPI,ANFIS22)  evalfis(KPI,AN-
FIS23) evalfis(KPI,ANFIS24) evalfis(KPI,ANFIS25) evalfis(KPI,ANFIS26)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

popc(k,1).KPI=KPI_Predict_Whole(answer2);

%%

    x=popc(k,2).Position;

  for j=1:Gene

      if j==1

      KPI_Activies_MiddleStage(j,:)=DATA(x(j),6:11);

      else
```

```
      KPI_Activies_MiddleStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_MiddleStage(o,:)=ActivitiesWeight(o)*KPI_Activies_MiddleStage(o,:);
end

KPI_MiddleStage=sum(KPI_MiddleStage)/sum(ActivitiesWeight);

KPI=round([KPI_13 KPI_MiddleStage]);

KPI_Predict_Whole=[evalfis(KPI,ANFIS21)  evalfis(KPI,ANFIS22)  evalfis(KPI,AN-
FIS23) evalfis(KPI,ANFIS24) evalfis(KPI,ANFIS25) evalfis(KPI,ANFIS26)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

popc(k,2).KPI=KPI_Predict_Whole(answer2);

    end

    popc=popc(:);

%% Mutation

    popm=repmat(X,NumberOfMutants,1);

    for k=1:NumberOfMutants


        i=randi([1 Population_Size]);
        p=pop(i);

        I=randi([1,Gene]);

        NumberOfActivitiesMode_Mutate=ActivitiesMode(I);

        popm(k).Position=p.Position;

        MaxGene_Mutate=GeneMax(I);

        if MaxGene_Mutate==1

            popm(k).Position(I)=p.Position(I);
```

```
        else

            Modes=1:NumberOfActivitiesMode_Mutate;

            Modes(Modes==p.Position(I))=[];

            n=numel(Modes);
            d=randi([1,n],1);

            popm(k).Position(I)=d;

        end


        %%
    x=popm(k).Position;

  for j=1:Gene

      if j==1

      KPI_Activies_MiddleStage(j,:)=DATA(x(j),6:11);

      else

      KPI_Activies_MiddleStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_MiddleStage(o,:)=ActivitiesWeight(o)*KPI_Activies_MiddleStage(o,:);
end

KPI_MiddleStage=sum(KPI_MiddleStage)/sum(ActivitiesWeight);

KPI=round([KPI_13 KPI_MiddleStage]);

KPI_Predict_Whole=[evalfis(KPI,ANFIS21)  evalfis(KPI,ANFIS22)  evalfis(KPI,AN-
FIS23) evalfis(KPI,ANFIS24) evalfis(KPI,ANFIS25) evalfis(KPI,ANFIS26)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

popm(k).KPI=KPI_Predict_Whole(answer2);

    end
```

```
    pop=[pop
         popc
         popm];


    KPII=[pop.KPI];
    [KPII, SortOrder]=sort(KPII);
    pop=pop(SortOrder);
    pop(1).Position;

    pop=pop(end-Population_Size:end);

    BestSol=pop(end);

    BestKPI(iterations)=BestSol.KPI;

%     disp(['Iteration ' num2str(iterations) ': Best PI = ' num2str(BestPI(it-
erations))]);

end

BestModes=BestSol.Position;

%%
    x=BestModes;

  for j=1:Gene

      if j==1

      KPI_Activies_MiddleStage(j,:)=DATA(x(j),6:11);

      else

      KPI_Activies_MiddleStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_MiddleStage(o,:)=ActivitiesWeight(o)*KPI_Activies_MiddleStage(o,:);
end

KPI_MiddleStage=sum(KPI_MiddleStage)/sum(ActivitiesWeight);

KPI=round([KPI_13 KPI_MiddleStage]);

KPI_Predict_Whole=[evalfis(KPI,ANFIS21)  evalfis(KPI,ANFIS22)  evalfis(KPI,AN-
FIS23) evalfis(KPI,ANFIS24) evalfis(KPI,ANFIS25) evalfis(KPI,ANFIS26)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
```

```
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole_Optimum=sum(Coefficients.*KPI_Predict_Whole);

Optimum_Forecasted_Intended_KPI_Of_The_Whole_Project=KPI_Predict_Whole(an-
swer2);
```

- **Display output**

```
if Optimum_Forecasted_Intended_KPI_Of_The_Whole_Project>BestKPI(1)

    BestKPI(BestKPI<BestKPI(1))=BestKPI(1);

disp('Best Mode for Each Activity:');
```

- **Display best action plans**

```
for i=1:NumberOfActivities

disp(['Activity   ',num2str(NameOfActivities(i)),'   : Mode  ',   num2str(Best-
Modes(i))]);

end


%%
figure;
semilogy(BestKPI,'LineWidth',1);
plot(BestKPI,'LineWidth',1);
xlabel('Iteration');
ylabel('KPI');

disp('---')

if answer2==1
disp(['Optimum_Forecasted_Cost_Indicator_Of_The_Whole_Project= ',num2str(Opti-
mum_Forecasted_Intended_KPI_Of_The_Whole_Project)])

elseif answer2==2
disp(['Optimum_Forecasted_Time_Indicator_Of_The_Whole_Project= ',num2str(Opti-
mum_Forecasted_Intended_KPI_Of_The_Whole_Project)])

elseif answer2==3
disp(['Optimum_Forecasted_Quality_Indicator_Of_The_Whole_Project=
',num2str(Optimum_Forecasted_Intended_KPI_Of_The_Whole_Project)])

elseif answer2==4
disp(['Optimum_Forecasted_Safety_Indicator_Of_The_Whole_Project= ',num2str(Op-
timum_Forecasted_Intended_KPI_Of_The_Whole_Project)])

elseif answer2==5
```

```
disp(['Optimum_Forecasted_ClientSatisfaction_Indicator_Of_The_Whole_Project=
',num2str(Optimum_Forecasted_Intended_KPI_Of_The_Whole_Project)])

elseif answer2==6
disp(['Optimum_Forecasted_ProjectTeamSatisfaction_Indicator_Of_The_Whole_Pro-
ject= ',num2str(Optimum_Forecasted_Intended_KPI_Of_The_Whole_Project)])

end

PI_Forecasted_Of_The_Whole_Project=PI_Predict_Whole_Optimum

else

    disp('Please Continue the same way');

end
```

- **Optimizing finishing stage indicators**

```
elseif Optimizing==3

disp('Optimizing Finishing Stage ...');

C_Cost=0.106;
C_Time=0.103;
C_Quality=0.320;
C_Safety=0.134;
C_ClientSatisfaction=0.176;
C_ProjectTeamSatisfaction=0.161;

Coefficients=[C_Cost,C_Time,C_Quality,C_Safety,C_ClientSatisfaction,C_Pro-
jectTeamSatisfaction];

KPI_InitialStage=InitialStage;
KPI_MiddleStage=MiddleStage;

KPI_23=[KPI_InitialStage KPI_MiddleStage];

KPI_Predict_Whole=[evalfis(KPI_23,ANFIS21)    evalfis(KPI_23,ANFIS22)    eval-
fis(KPI_23,ANFIS23)   evalfis(KPI_23,ANFIS24)   evalfis(KPI_23,ANFIS25)   eval-
fis(KPI_23,ANFIS26)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

if answer2==1
Forecasted_Cost_Indicator_Of_The_Whole_Project=KPI_Predict_Whole(answer2)
```

```
elseif answer2==2
Forecasted_Time_Indicator_Of_The_Whole_Project=KPI_Predict_Whole(answer2)

elseif answer2==3
Forecasted_Quality_Indicator_Of_The_Whole_Project=KPI_Predict_Whole(answer2)

elseif answer2==4
Forecasted_Safety_Indicator_Of_The_Whole_Project=KPI_Predict_Whole(answer2)

elseif answer2==5
Forecasted_ClientSatisfaction_Indicator_Of_The_Whole_Project=KPI_Pre-
dict_Whole(answer2)

elseif answer2==6
Forecasted_ProjectTeamSatisfaction_Indicator_Of_Whole_Project=KPI_Pre-
dict_Whole(answer2)

end

disp('---');
BestKPI(1)=KPI_Predict_Whole(answer2);

KPI_at_the_first=KPI_Predict_Whole;
PI_at_the_first=PI_Predict_Whole;

%%
```

- **Import data from excel to MATLAB**

```
DATA=xlsread('Project Information for Finishing Stage.xlsx');

NumberOfActivities=DATA(1,1);

NameOfActivities=DATA(:,2);

NameOfActivities(isnan(NameOfActivities))=[];

ActivitiesMode=DATA(:,3);

ActivitiesMode(isnan(ActivitiesMode))=[];

ActivitiesWeight=DATA(:,4);

ActivitiesWeight(isnan(ActivitiesWeight))=[];
```

- **Optimization with GA**

```
Gene=NumberOfActivities;

Chromosome=[1 Gene];

GeneMin=ones([1,NumberOfActivities]);

for i=1:NumberOfActivities

    GeneMax(i)=ActivitiesMode(i);
```

```
end


%%

X.Position=[];
X.KPI=[];

pop=repmat(X,Population_Size,1);

for i=1:Population_Size

    for j=1:Gene

    pop(i).Position(j)=randi([GeneMin(j),GeneMax(j)]);

    end

  %%
  x=pop(i).Position;

  for j=1:Gene

      if j==1

      KPI_Activies_FinishingStage(j,:)=DATA(x(j),6:11);

      else


      KPI_Activies_FinishingStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_FinishingStage(o,:)=ActivitiesWeight(o)*KPI_Activies_Finish-
ingStage(o,:);
end

KPI_FinishingStage=sum(KPI_FinishingStage)/sum(ActivitiesWeight);

KPI=round([KPI_23 KPI_FinishingStage]);

KPI_Predict_Whole=[evalfis(KPI,ANFIS31)  evalfis(KPI,ANFIS32)  evalfis(KPI,AN-
FIS33) evalfis(KPI,ANFIS34) evalfis(KPI,ANFIS35) evalfis(KPI,ANFIS36)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
elseif KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
end
```

```
end

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

pop(i).KPI=KPI_Predict_Whole(answer2);

end

KPII=[pop.KPI];
[KPII, SortOrder]=sort(KPII);
pop=pop(SortOrder);
BestSol=pop(end);

BestCost=zeros(Maximum_Iterations,1);

for iterations=2:Maximum_Iterations

    popc=repmat(X,NumberOfParents/2,2);

    for k=1:NumberOfParents/2
%% Choose Parents for CrossOver

        i1=randi([1,Population_Size]);
        p1=pop(i1);
        i2=randi([1,Population_Size]);
        p2=pop(i2);

%% CrossOver (SinglePoint)

           c=randi(Gene-1,1);

           popc(k,1).Position=[p1.Position(1:c),p2.Position(c+1:end)];
           popc(k,2).Position=[p2.Position(1:c),p1.Position(c+1:end)];

    %%
    x=popc(k,1).Position;

  for j=1:Gene

      if j==1

      KPI_Activies_FinishingStage(j,:)=DATA(x(j),6:11);

      else

      KPI_Activies_FinishingStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_FinishingStage(o,:)=ActivitiesWeight(o)*KPI_Activies_Finish-
ingStage(o,:);
end
```

```
KPI_FinishingStage=sum(KPI_FinishingStage)/sum(ActivitiesWeight);

KPI=round([KPI_23 KPI_FinishingStage]);

KPI_Predict_Whole=[evalfis(KPI,ANFIS31)  evalfis(KPI,ANFIS32)  evalfis(KPI,AN-
FIS33) evalfis(KPI,ANFIS34) evalfis(KPI,ANFIS35) evalfis(KPI,ANFIS36)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

popc(k,1).KPI=KPI_Predict_Whole(answer2);

%%

    x=popc(k,2).Position;

  for j=1:Gene

      if j==1

      KPI_Activies_FinishingStage(j,:)=DATA(x(j),6:11);

      else

      KPI_Activies_FinishingStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_FinishingStage(o,:)=ActivitiesWeight(o)*KPI_Activies_Finish-
ingStage(o,:);
end

KPI_FinishingStage=sum(KPI_FinishingStage)/sum(ActivitiesWeight);

KPI=round([KPI_23 KPI_FinishingStage]);

KPI_Predict_Whole=[evalfis(KPI,ANFIS31)  evalfis(KPI,ANFIS32)  evalfis(KPI,AN-
FIS33) evalfis(KPI,ANFIS34) evalfis(KPI,ANFIS35) evalfis(KPI,ANFIS36)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
```

```
end
end

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

popc(k,2).KPI=KPI_Predict_Whole(answer2);

    end

    popc=popc(:);

%% Mutation

    popm=repmat(X,NumberOfMutants,1);

    for k=1:NumberOfMutants


        i=randi([1 Population_Size]);
        p=pop(i);

        I=randi([1,Gene]);

        NumberOfActivitiesMode_Mutate=ActivitiesMode(I);

        popm(k).Position=p.Position;

        MaxGene_Mutate=GeneMax(I);

        if MaxGene_Mutate==1

            popm(k).Position(I)=p.Position(I);

        else

            Modes=1:NumberOfActivitiesMode_Mutate;

            Modes(Modes==p.Position(I))=[];

            n=numel(Modes);
            d=randi([1,n],1);

            popm(k).Position(I)=d;

        end


        %%
    x=popm(k).Position;

  for j=1:Gene

      if j==1

      KPI_Activies_FinishingStage(j,:)=DATA(x(j),6:11);

      else
```

```
      KPI_Activies_FinishingStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_FinishingStage(o,:)=ActivitiesWeight(o)*KPI_Activies_Finish-
ingStage(o,:);
end

KPI_FinishingStage=sum(KPI_FinishingStage)/sum(ActivitiesWeight);

KPI=round([KPI_23 KPI_FinishingStage]);

KPI_Predict_Whole=[evalfis(KPI,ANFIS31)  evalfis(KPI,ANFIS32)  evalfis(KPI,AN-
FIS33) evalfis(KPI,ANFIS34) evalfis(KPI,ANFIS35) evalfis(KPI,ANFIS36)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole=sum(Coefficients.*KPI_Predict_Whole);

popm(k).KPI=KPI_Predict_Whole(answer2);

    end


    pop=[pop
         popc
         popm];


    KPII=[pop.KPI];
    [KPII, SortOrder]=sort(KPII);
    pop=pop(SortOrder);
    pop(1).Position;

    pop=pop(end-Population_Size:end);

    BestSol=pop(end);

    BestKPI(iterations)=BestSol.KPI;

%     disp(['Iteration ' num2str(iterations) ': Best PI = ' num2str(BestPI(it-
erations))]);

end
```

```
BestModes=BestSol.Position;

%%
    x=BestModes;

  for j=1:Gene

      if j==1

      KPI_Activies_FinishingStage(j,:)=DATA(x(j),6:11);

      else

      KPI_Activies_FinishingStage(j,:)=DATA(sum(ActivitiesMode(1:j-
1))+x(j),6:11);

      end

  end

for o=1:Gene
    KPI_FinishingStage(o,:)=ActivitiesWeight(o)*KPI_Activies_Finish-
ingStage(o,:);
end

KPI_FinishingStage=sum(KPI_FinishingStage)/sum(ActivitiesWeight);

KPI=round([KPI_23 KPI_FinishingStage]);

KPI_Predict_Whole=[evalfis(KPI,ANFIS31)  evalfis(KPI,ANFIS32)  evalfis(KPI,AN-
FIS33) evalfis(KPI,ANFIS34) evalfis(KPI,ANFIS35) evalfis(KPI,ANFIS36)];

for j=1:6
if KPI_Predict_Whole(1,j) > 7
    KPI_Predict_Whole(1,j)=7;
else if KPI_Predict_Whole(1,j) < 1
        KPI_Predict_Whole(1,j)=1;
    end
end
end

PI_Predict_Whole_Optimum=sum(Coefficients.*KPI_Predict_Whole);


Optimum_Forecasted_Intended_KPI_Of_The_Whole_Project=KPI_Predict_Whole(an-
swer2);
```

- **Display output**

```
if Optimum_Forecasted_Intended_KPI_Of_The_Whole_Project>BestKPI(1)

    BestKPI(BestKPI<BestKPI(1))=BestKPI(1);

disp('Best Mode for Each Activity:');
```

- **Display best action plans**

```
for i=1:NumberOfActivities

disp(['Activity   ',num2str(NameOfActivities(i)),'   : Mode ',   num2str(Best-
Modes(i))]);

end


%% Plot
figure;
semilogy(BestKPI,'LineWidth',1);
plot(BestKPI,'LineWidth',1);
xlabel('Iteration');
ylabel('KPI');

disp('---')

if answer2==1
disp(['Optimum_Forecasted_Cost_Indicator_Of_The_Whole_Project= ',num2str(Opti-
mum_Forecasted_Intended_KPI_Of_The_Whole_Project)])

elseif answer2==2
disp(['Optimum_Forecasted_Time_Indicator_Of_The_Whole_Project= ',num2str(Opti-
mum_Forecasted_Intended_KPI_Of_The_Whole_Project)])

elseif answer2==3
disp(['Optimum_Forecasted_Quality_Indicator_Of_The_Whole_Project=
',num2str(Optimum_Forecasted_Intended_KPI_Of_The_Whole_Project)])

elseif answer2==4
disp(['Optimum_Forecasted_Safety_Indicator_Of_The_Whole_Project= ',num2str(Op-
timum_Forecasted_Intended_KPI_Of_The_Whole_Project)])

elseif answer2==5
disp(['Optimum_Forecasted_ClientSatisfaction_Indicator_Of_The_Whole_Project=
',num2str(Optimum_Forecasted_Intended_KPI_Of_The_Whole_Project)])

elseif answer2==6
disp(['Optimum_Forecasted_ProjectTeamSatisfaction_Indicator_Of_The_Whole_Pro-
ject= ',num2str(Optimum_Forecasted_Intended_KPI_Of_The_Whole_Project)])

end

PI_Forecasted_Of_The_Whole_Project=PI_Predict_Whole_Optimum

else

    disp('Please Continue the same way');

end

end

KPIs_Predicted_After_Optimization=KPI_Predict_Whole;
```