

**Quality Improvement in Construction Activity (Case Study Approach)
using Vandermonde and Spline Interpolation Techniques**

by

Nur Hidayah binti Ngah

Supervisor

Dr. Noor Amila binti Wan Abdullah Zawawi

Co-supervisor

Mr. Samsul bin Ariffin

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

JANUARY 2012

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

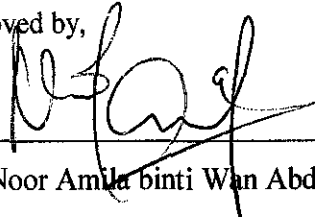
**Quality Improvement in Construction Activity (Case Study Approach)
using Vandermonde and Spline Interpolation Techniques**

by

Nur Hidayah binti Ngah

A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

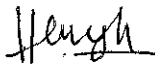


(Dr. Noor Amila binti Wan Abdullah Zawawi)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.



NUR HIDAYAH BINTI NGAH

ABSTRACT

There are two variables that are considered vital elements in any construction activities; cost and quality. Many misinterpret quality of products or services as what you see from the result of the project and how the product/ service being delivered to the client. In reality, the scope of quality involves the whole business model. In quality improvement effort, new methods are adopted namely Vandermonde and spline interpolation. Somehow these two methods are still new in construction industry as there is no established findings had been made. This study is continuity from Izzat (2011) whereby similar approach using Vandermonde and spline was adopted but with small-size case study and from that, some weakness had been identified particularly for Vandermonde interpolation. It is unable to portray clear break-even points in total cost's curve compared to spline interpolation because the data available was insufficient. Thus, the objective of this study is to show how Vandermonde and spline interpolation techniques can be effective quality management tools by using larger-scale case study compared to the previous one. Interpolations for curves are generated using MATLAB application. Both interpolation methods are expected to show better correlation between prevention, appraisal and failure costs and at the same time produce the optimal point of the total cost. The results show that spline can produce smoother and better-fitted curves compared to Vandermonde hence able to provide reliable break-even points. From the points obtained, the company can optimize investment and at the same time produce high quality products. By implementing this new quality model, the company also can monitor the curve's pattern of the project they are conducting and take immediate action whenever they notice the increasing pattern of failure cost.

ACKNOWLEDGEMENT

I would like to express my deepest gratitude towards Mohd. Asbi & Associates, especially to Ir. Ismail Mamat for assisting and providing useful data for this project. Not to forget the most important person behind this project which is my supervisor, Dr. Noor Amila binti Wan Abdullah Zawawi for aiding me through this whole project with excellent support and Mr. Mohd Izzat bin Mohamed Ishak as well as Mr. Samsul bin Ariffin for guiding me in the software part in order to understand the software further.

TABLE OF CONTENTS

CERTIFICATION OF APPROVAL.	i
CERTIFICATION OF ORIGINALITY.	ii
ABSTRACT	iii
ACKNOWLEDGEMENT.	iv
LIST OF FIGURES & TABLES	vi
CHAPTER 1: INTRODUCTION	1
1.1 Background.	1
1.2 Problem Statement	3
1.2.1 Problem Identification	3
1.2.2 Significant and Relevancy of the Project	4
1.3 Objective	6
1.4 Scope of Study	6
1.5 Feasibility of the Project	7
CHAPTER 2: LITERATURE REVIEW	8
2.1 Cost of Quality	8
2.2 Quality Management	12
2.3 PAF Modeling	16
2.4 Vandermonde Technique	17
2.5 Cubic Spline Approach	19
2.5.1 Cubic Spline Interpolant	19
2.5.2 Natural Spline (manually)	22
2.5.3 Automation.	25
2.5.4 Algorithm	28
2.6 Similar Case Study	30
CHAPTER 3: METHODOLOGY	32
3.1 Research Methodology	32
3.2 Gantt Chart	33
3.3 Data Required	33
3.4 Software Involved	34
3.5 Vandermonde Interpolation	35
3.6 Spline Interpolation	36
3.7 Details of Case Study	38
CHAPTER 4: RESULT AND DISCUSSION	39
4.1 Data Gathering and Analysis.	39
4.2 PAF Modeling	42
4.3 Vandermonde Interpolation	43
4.4 Spline Interpolation	48
4.5 Discussion	49
4.6 Comparing with Previous Study	51
CHAPTER 5: CONCLUSION AND RECOMMENDATION.	56
REFERENCES	58

LIST OF FIGURES

Figure 1.1	Juran Triogy	2
Figure 2.1	The four stages of quality management	14
Figure 2.2	Results of TQM	15
Figure 2.3	Optimization of Quality and Cost	16
Figure 2.4	Natural cubic, quadratic and linear spline interpolation	24
Figure 3.1	Research methodology	32
Figure 3.2	Case study's area	38
Figure 4.1	PAF model of KP Perdana Fasa 1 (cost against quality)	42
Figure 4.2	Interpolation of prevention and appraisal, failure and total costs using 1 st order polynomial	43
Figure 4.3	Interpolation of prevention and appraisal, failure and total costs using 2 nd order polynomial	44
Figure 4.4	Interpolation of prevention and appraisal, failure and total costs using 3 rd order polynomial	44
Figure 4.5	Interpolation of prevention and appraisal, failure and total costs using 4 th order polynomial	45
Figure 4.6	Interpolation of prevention and appraisal, failure and total costs using 5 th order polynomial	45
Figure 4.7	Interpolation of prevention and appraisal, failure and total costs using 6 th order polynomial	46
Figure 4.8	Interpolation of prevention and appraisal, failure and total costs using 7 th order polynomial	46
Figure 4.9	Interpolation of prevention and appraisal, failure and total costs using 8 th order polynomial	47
Figure 4.10	Interpolation of prevention and appraisal, failure and total costs using spline method	48
Figure 4.11	Comparing Vandermonde's curves	52
Figure 4.12	Comparing Spline's curves	54

LIST OF TABLES

Table 1.1	Quality and Finance Parallels	2
Table 2.1	Comparison between Vandermonde and Spline Interpolation	30
Table 3.1	Research's Gantt Chart	33
Table 4.1	Total prevention, appraisal and failure cost	40
Table 4.2	Quality values	41
Table 4.3	Breakeven points and vertexes for Vandermonde curves	51
Table 4.4	Breakeven points and vertexes for Spline curves	53

CHAPTER 1

INTRODUCTION

1.1 Background

This study is very much related to project management as to control the overall quality performance of a project during construction would essentially need excellent project management planning. Project management can be defined as “the art of directing and coordinating human and material resources through the life of a project by using modern management techniques to achieve pre-determined goals of scope, cost, time, quality and participant satisfaction” (PMI, 2000). From this we know that the three main goals in any project constructions are to complete the project on time, to complete the project within budget and to complete the project with desired quality.

Dealing with quality problems can be similar to being lost. We do not know where we are. In quality improvement process, problem solvers need to know where they actually stand, what are the problems that occurring, and identify the causes of the problems before we can actually propose solutions to solve them. Quality improvement can be defined as a formal approach to the analysis of performance and systematic efforts to improve it (Duke University, 2005). There are numerous models that being developed in order to achieve desired goal, which is the improvement. Examples of these models are Total Quality Management (TQM), Juran’s Trilogy, Deming Cycle (Plan-Do-Check-Act) and lots more.

Joseph M. Juran (Juran, 1989), one of the quality gurus, defined quality as “fitness to purpose” where “fitness” is always defined by customers; such that providing a product (or in this case, a building) which provides an appropriate quality for the purpose for which it is intended. Figure 1.1 shows Quality Trilogy proposed by Juran that consist of Quality Planning, Quality Control and Quality Improvement. It is a universal approach

to quality that takes into account various hierarchy levels in the organization, various functions, various product lines, etc. (Tcherpokov, 2006).

In order to achieve good quality management, it requires quality actions to be planned out, improved and controlled. The process achieves control at one level of quality performance, and then plans are made to improve the performance on a project by project basis, using tools and techniques such as Pareto analysis. This activity eventually achieves breakthrough to an improved level, which is again controlled, to prevent any deterioration (www.dti.gov.uk).

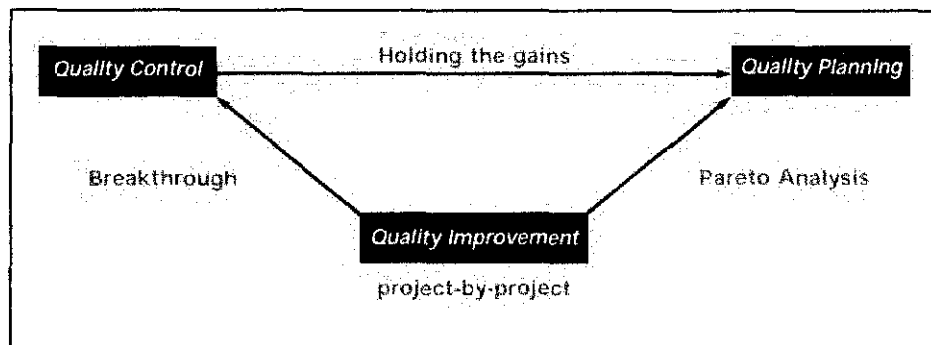


Figure 1.1: Juran Trilogy (www.dti.gov.uk)

The trilogy is not entirely “new”. If we look sideways at how people managing finance, we can notice some interesting parallels (Juran, 1989). Quality Trilogy does resemble the financial processes model as being shown in the figure below:

Quality and Finance Parallels		
Trilogy Processes		Financial processes
Quality planning	◊	Budgeting
Quality control	◊	Cost control; expense control
Quality improvement	◊	Cost reduction; profit improvement

Source: Adopted from Juran, J. M. (August 1988). “The quality trilogy: A universal approach to managing for quality”. *Quality Progress*, 19(8), 19-24

Table 1.1: Quality and Finance Parallels (Juran, 1989)

These financial processes consist of (Juran, Godfrey, 1999):

- i. **Financial planning:** Prepares the annual financial budget that defines the deeds to be done in the year ahead. It translates those deeds into money and determines the financial consequences of doing all those deeds. The final result establishes the financial goals for the organization and its various divisions and units.
- ii. **Financial control:** Evaluating actual financial performance, comparing this with the financial goals, and taking action on the difference- the accountant's "variance." There are numerous sub processes for financial control: cost control, expense control, inventory control, and so on.
- iii. **Financial improvement:** Improve financial results. It takes many forms: cost-reduction projects, new facilities to improve productivity, new product development to increase sales, acquisitions, joint ventures, and so on.

The financial analogy helps managers realize that they can manage for quality by using the same processes of planning, control, and improvement of the finance management. They are not required to change their conceptual approach as much of their previous training and experience in managing for finance is applicable to managing for quality (Juran, Godfrey, 1999).

1.2 Problem Statement

1.2.1 Problem Identification

Ironic as it may seem, an apparent problem with Quality Management is the word *quality* itself (McCabe, 1998). The construction industry is being viewed as one with poor quality emphasis (Yusof, Hakim, Saidin, Zakaria, Bakri, 2006) and rife with examples of substandard work, shoddy workmanship, cost overruns and project delays. Issues that arise from poor quality usually involve short piling, unsuitable use of materials (Vivian, Khoa, Hoang, 2008), construction personnel without proper training, insufficient reinforcement, etc. Quality problems in construction are having major impact on overall operational cost and need to be dealt with immediately and effectively in order to ensure it does not become an outbreak in the industry.

There are various methods, which have been used by organizations in construction industry to improve the quality. Many studies have been undertaken regarding the capability of properly implemented quality management systems to improve the ultimate project quality (Arditi & Gunaydin, 1997; Elghamrawy & Shibayama, 2008; Hellard, 1994; Jr et al., 1991; Wong & Fung, 1999). Mostly the studies conducted employing mainly two techniques: (1) Management Techniques, such as Quality Control, Quality Assurance and Total Quality Management (TQM) and (2) Statistical Techniques, such as Vandermonde, spline interpolation and Six Sigma (Vivian, Khoa, Hoang, 2008). Basically this study will focusing on both Vandermonde and spline methods of analysis.

Total Quality Management (TQM) is increasingly being adopted by construction companies nowadays as an initiative to solve quality problems in the construction industry and to meet the needs of the customer. However, construction firms have been continually struggling with its implementation (Yusof, Hakim, Saidin, Zakaria, Bakri, 2006) as TQM needs to be applied in every branch and at every level in the organization to ensure the effectiveness of this method.

So, that's leave us with the second approach; Statistical Techniques. By using Vandermonde and spline interpolation techniques, we need data such as cost invested in the process and customer satisfaction (complaints) on the quality of the products to develop the model. From the model generated, we can determine the optimal point of the total cost which is the sum of the prevention, appraisal and failure costs.

1.2.2 Significant and Relevancy of the Project

A study showed that by spending 1% more on prevention efforts, the failure costs of construction can be reduced from 2% to 10% (Roberts, 1991). Failure costs associated with cost after our product being handed over to the customer and there are some defects complained by the customer. When it reaches the customer, it also carried the reputation of the company as well. Low quality products will make the customers to have the bad perception on the reliability of the company itself. Hence the organizations should ensure the quality of their products are at best before being released to the customers.

We can achieve this by spending more on prevention activities (i.e. product inspection, grading, sorting, etc.) in order to make sure only high quality products reach the customer. The same situation applies for construction activities. At the end of the day we want the structure to be safe and stable for the users with long service life. Somehow to ensure we are doing the right job, we actually need to know how much exactly the amount that we need to invest and not just randomly guessing. Thus, we need to use Vandermonde and spline interpolation to locate the break-even points of the total costs.

Quality is important nowadays in order to create competitive advantage and increase profitability as in a real market, businesses stay ahead by offering products that are high in quality to customers. Returned customers are satisfied customers. If the customers are satisfied with the services or products that we give to them, they will come back to us. Increased in customer loyalty can bring cost savings to a company in at least six areas, which are (Griffin, 2003):

1. Reduced marketing costs (customer acquisition costs require more dollars).
2. Lower transaction costs such as contract negotiation and order processing.
3. Reduced customer turnover expenses (fewer lost customers to replace/no churning).
4. Increased cross selling success leading to larger share of customer.
5. More positive word of mouth.
6. Reduced failure costs.

Hence, the list of reasons why we need to improve the quality in our products and services become longer. This is when the importance of this study comes in. By knowing the right amount of cost we need to invest to improve the quality of our end products, we can increase the customer satisfaction, and at the same time less investment is possible to achieve this aim.

Relevant can be defined as being applicable to the matter at hand. This study is relevant to be carried out as it can contribute to the improvement of construction activities' performance as an overall. For the past years, companies keep spending huge amount of money and use lots of staffs' time in order for them to implement quality improvement

models in the organizations. Somehow so little of the models produce numerical solutions that actually more convenient for the organizations to do self-checking on how they are performing so far. Hence this study comes in handy as it can generate reliable solutions for quality improvement in the organizations.

1.3 Objective

The main objective of this study is to use the Vandermonde and spline interpolation techniques to best-fit the data collected from a construction company located in Malaysia.

Apart from that, other aims of this study are as follows:

- To develop an effective quality management tool.
- To show the location of the optimal point(s) in the total cost.
- To compare the performance Vandermonde and spline interpolation techniques.

1.4 Scope of Study

In this study, we only will be using MATLAB software to develop our cost vs. quality curves instead of other software such as Visual Basic in Excel. Coding method is used instead of others such as Simulink that use block diagram. Command that will be used for Vandermonde interpolation is “polyfit” meanwhile to generate spline interpolation, we use “spline” command. Data used to measure quality is from the complaints received which will be divided into oral and written format for each month. The data for quality is depending on the size of the case study that being used and large-scale of case study is preferred, then only we can produce better and accurate curves especially in Vandermonde interpolation. There will be limitation in this study as the data is obtained just from one case study and how the result will appear will based solely on the data that being provided.

1.5 Feasibility of the Project

Feasibility can be defined as the state or degree of being easily or conveniently done. In this case, is how convenient can this study being conducted. First of all, to conduct this study, what will we be needing are materials or data to be analyzed which obviously come from the construction activities as the title suggest, we want to improve the quality in construction. There are two components of the data which are:

1. Cost for each month (prevention cost, appraisal cost and failure cost) throughout the construction activities.
2. Number of complaints from R.E. regarding the problems that occurred to the buildings, in the form of non-compliance record (NCR) or verbal complaints that can be detected.

The data can be obtained from a local construction company and because for this time around, we targeted to use larger set of data, we are collaborating with a local construction company as they can provide us data of a completed project with construction time of around two to three years to be used in our study.

Secondly, to analyze the data obtained, we will use MATLAB application to generate the curves from the numbers by implementing Vandermonde and spline interpolation techniques. Since Universiti Teknologi PETRONAS (UTP) has registered MATLAB software available for use, this would not be an issue anymore. From the MATLAB software used, we will determine the best-fit curves that can be produced by both method and identify the break-even points on the curves. From economic perspective, a break-even point defines an investment that will generate a positive return and can be determined graphically or with simple mathematics (Gutierrez & Dalsted, 2010).

The next step in this is to analyze the results after we run them on MATLAB and finalize the findings. From this explanation, we can be assured that this study is possible to be completed within two semesters of study as long as we have the right data and the right tools to begin with.

CHAPTER 2

LITERATURE REVIEW

2.1 Cost of Quality

Cost of Quality (COQ) is usually understood as the sum of conformance plus non-conformance costs, where cost of conformance is the price paid for prevention of poor quality (e.g. inspection and quality appraisal) and cost of non-conformance is the cost of poor quality caused by product and service failure (e.g. rework and returns) (Schiffauerova, Thomson, 2006). To make it simpler, the costs associated with quality are divided into two categories: costs associated with improving quality (prevention costs and appraisal costs) and cost due to poor quality (failure costs). Most COQ models are based on the PAF classification (Dale, Plunket, 1995). The objective of a COQ system is to find the level of quality that minimizes total cost of quality. The terms used in PAF modeling is prevention cost, appraisal cost and quality failure cost. These terms are defined as follows (Liu, Cui, Meng, Pan, 2008):

1. Prevention Cost: costs associated with the design, implementation and maintenance of the total quality management system. The costs are planned and are incurred before actual operation.
2. Appraisal Cost: costs associated with the supplier's and customer's evaluation of purchased materials, processes, intermediates, products and services to according to the specified requirements.
3. Quality Failure Cost can be divided into two types:
 - a) Internal failure costs: costs occur when the work fail to reach designed quality standards and are detected before transfer to customer takes place.
 - b) External failure costs: costs occur when products or services fail to reach design quality standards but are not detected until after transfer to the customer.

$$\text{Total Cost} = \text{Cost of Failures} + \text{Cost of Prevention and Appraisal}$$

To further understand all three types of cost mentioned above, examples for each cost in companies operation are being listed below (Juran, Godfrey, 1999):

Prevention Cost:

- i. **Quality planning:** Activities that create overall quality plan.
- ii. **New-products review:** Reliability engineering associated with launching of new design.
- iii. **Process planning:** Process capability studies, inspection planning associated with manufacturing and service processes.
- iv. **Process control:** In-process inspection and test to determine the status of the process.
- v. **Quality audits:** Evaluating the execution of activities in the overall quality plan.
- vi. **Supplier quality evaluation:** Evaluating supplier quality activities prior to supplier selection, auditing the activities during the contract, and associated effort with suppliers.
- vii. **Training:** Preparing and conducting quality-related training programs.

**Note that prevention costs are costs of special planning, review and analysis activities for quality and do not include basic activities such as product design, process design, process maintenance, and customer service.

Appraisal Cost:

- i. **Incoming inspection and test:** Determining the quality of purchased product (by inspection on receipt, at the source or by surveillance).
- ii. **In-process inspection and test:** In-process evaluation of conformance to requirements.
- iii. **Final inspection & test:** Evaluation of conformance to requirements for product acceptance.
- iv. **Document review:** Examination of paperwork to be sent to customer.
- v. **Balancing:** Examination of various accounts to assure internal consistency.
- vi. **Product quality audits:** Performing quality audits on in-process or finished products.

- vii. **Maintaining accuracy of test equipment:** Keeping measuring instruments and equipment in calibration.
- viii. **Inspection on materials and services:** Inspect materials and supplies and test work (e.g., x-ray film) and services (e.g., electric power) where significant.
- ix. **Evaluation of stocks:** Test products in field storage or in stock to evaluate degradation.

**Note that industries use a variety of terms for “appraisal,” e.g., checking, balancing, reconciliation, review.

Quality Failure Cost:

a) Internal Failure Costs

➤ Failure to meet customer requirements and needs:

- i. **Scrap:** Labor, material, and overhead on defective product that cannot economically be repaired.
- ii. **Rework:** Correcting defectives in physical products or errors in service products.
- iii. **Lost/ missing information:** Retrieving information that should be supplied.
- iv. **Failure analysis:** Analyzing nonconforming goods/ services to determine causes.
- v. **One hundred percent sorting inspection:** Finding defective units in product lots which contain unacceptably high levels of defectives.
- vi. **Re-inspection, retest:** Done on products that have undergone rework.
- vii. **Changing processes:** Modifying manufacturing/ service processes to correct deficiencies.
- viii. **Redesign of hardware:** Changing designs of hardware to correct deficiencies.
- ix. **Redesign of software:** Changing designs of software to correct deficiencies.

- x. **Downgrading:** The difference between the normal selling price and the reduced price due to quality reasons.

**Note that other terms used for scrap are spoilage, defectives, etc.

➤ Cost of inefficient processes:

- i. **Variability of product characteristics:** Losses occur even conforming product.
- ii. **Unplanned downtime of equipment:** Loss of capacity equipment due to failures.
- iii. **Inventory shrinkage:** Loss due to difference between actual & recorded inventory amounts.
- iv. **Variation of process characteristics from “best practice”:** Losses due to cycle time & costs of processes as compared to best practices to provide same output.
- v. **Non-value-added activities:** Redundant operations, sorting inspections & other non-value added activities.

** Note that a value-added activity increases the usefulness of a product to the customer; a non-value-added activity does not.

b) External Failure Costs

➤ Failure to meet customer requirements and needs:

- i. **Warranty charges:** The costs involved in replacing or making repairs to products that are still within the warranty period.
- ii. **Complaint adjustment:** The costs of investigation and adjustment of justified complaints attributable to defective product or installation.
- iii. **Returned material:** The costs associated with receipt and replacement of defective product received from the field.
- iv. **Allowances:** The costs of concessions made to customers due to substandard products accepted by the customer as is or to conforming product that does not meet customer needs.

- v. **Penalties due to poor quality:** Applies to goods or services delivered or to internal processes such as late payment of an invoice resulting in a lost discount for paying on time.
 - vi. **Rework on support operations:** Correcting errors on billing and other processes.
 - vii. **Revenue losses in support operations:** An example is the failure to collect on receivables from some customers.
- Lost opportunities for sales revenue:
- i. **Customer defections:** Profit margin on current revenue lost due to customers who switch for reasons of quality. An important example of this category is current contracts that are canceled due to quality.
 - ii. **New customers lost because of quality:** Profit on potential customers lost due to poor quality.
 - iii. **New customers lost because of lack of capability to meet customer needs:** Profit on potential revenue lost because of inadequate processes to meet customer needs.

2.2 Quality Management

Definition of quality management base on ISO 8402 is “all activities of the overall management function that determine the quality policy, objectives and responsibilities, and implement them by means such as quality planning, quality control, quality assurance and quality improvement, within the quality system”. In construction, quality had become major issue as it is commonly being associated with poor development activities such that many costumers already experienced quality problems related to development that they already agree to invest their money on. Therefore, we should find a way to minimize the quality problems on our buildings by identifying where we can improve the level of quality and at the same time maximizing the cost.

Dale, Boaden and Lascelles (1994) come out with four stages of quality management which are:

- a) **Inspection:** BS EN ISO 8402 define it as “activity such as measuring, examining, testing or gauging one or more characteristics of an entity and comparing these results with specified requirements in order to establish whether conformity is achieved for each characteristic”.
- b) **Quality Control (QC):** Often regarded as an extension of inspection. BS EN ISO 8402 defined it as “operational techniques and activities that are used to fulfill requirements for quality”.
- c) **Quality Assurance (QA):** Dale, Boaden and Lascelles (1994) regarded QA as “in a detection or ‘fire-fighting’ environment, the emphasis is on product, procedures and or service deliverables and the downstream producing and delivery process”.
- d) **Total Quality Management (TQM):** An integrative philosophy of management for continuously improving the quality of products and processes (Ahire, 1997). TQM is a customer focused approach that aims to satisfy the customer by providing the best quality product at lowest price possible. It is a company-wide strategy that involves everyone in the organization.

Inspection and QC are operating in detection mode aiming to find problems that had occurred. Meanwhile QA and TQM aim to reduce and ultimately avoid problems from occurring (McCabe, 1998).

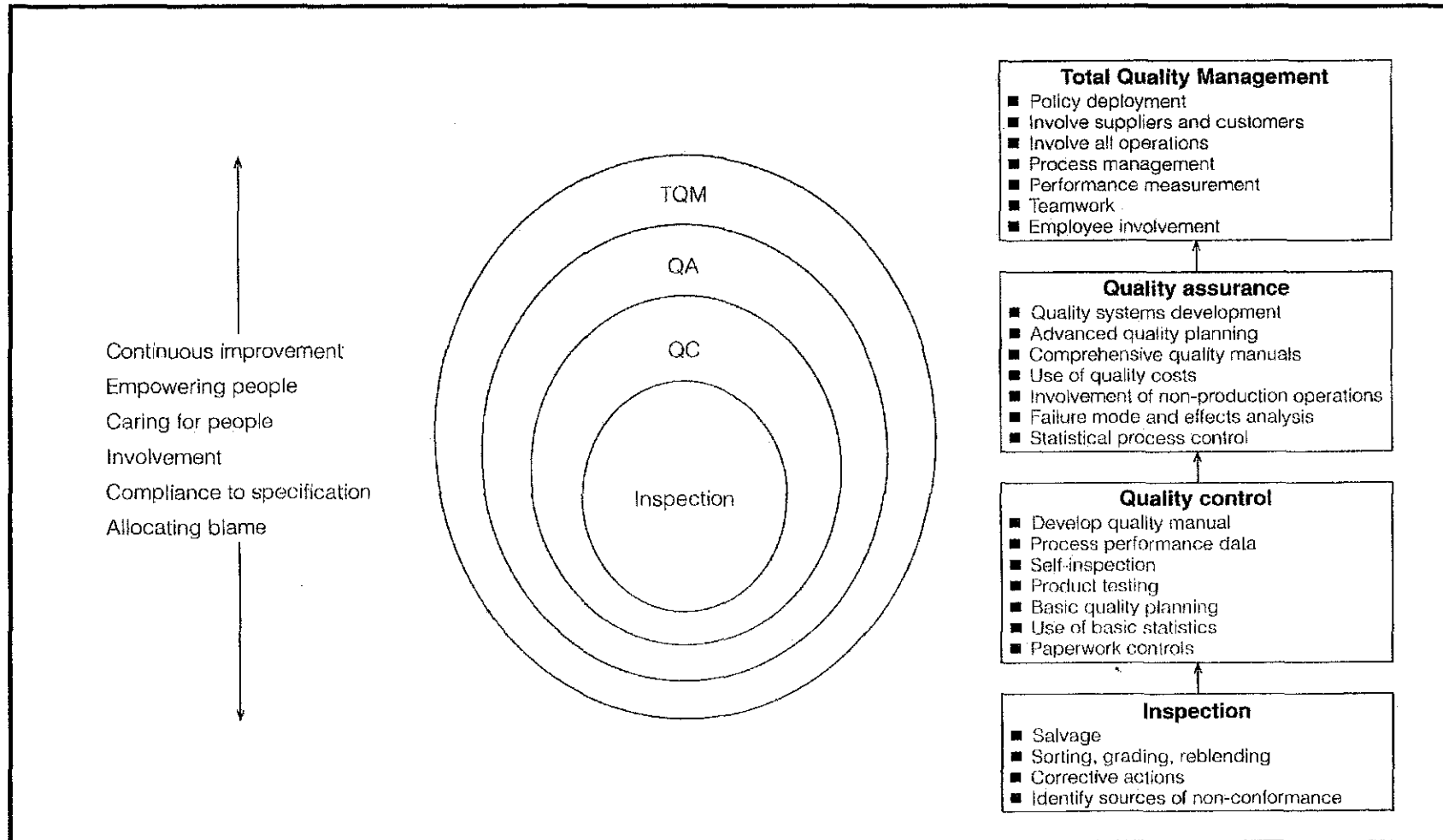


Figure 2.1: The four stages of quality management (Dale, Boaden and Lascelles, 1994)

Goals of total quality are lower costs, higher revenues, delighted customers, and empowered employees. Quality does not mean just conformance to specifications and requirements. Quality also means meeting and even exceeding the needs and expectations of customers and reducing all the costs of poor quality.

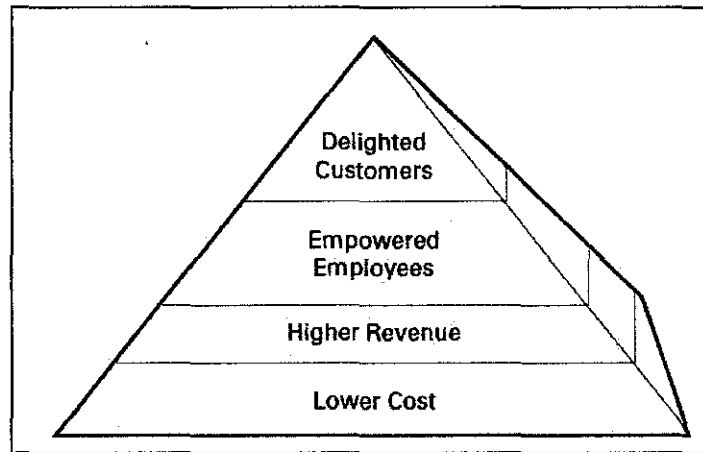


Figure 2.2: Results of TQM (Juran, Godfrey, 1999)

Lowering costs can lead to higher quality as we lower the costs by reducing errors, reducing rework and reducing non-value-added work. Sörqvist (1998) defines these costs in five basic categories: traditional poor-quality costs, hidden poor-quality costs, lost income, customers' costs, and socioeconomic costs. Higher revenues can be achieved as higher quality can mean better satisfied customers, increased market share, improved customer retention, more loyal customers, and even premium prices. By exceeding the levels of quality offered by competitors in the marketplace, organizations can add new customers, retain old customers, and move into new markets.

Delighted customers are customers who buy the company products over and over again, advertise the goods and services to other people and check the company first when they are going to buy anything else to see if the company also offer those goods or services. Empowered employees are a means for achieving lower costs, higher revenues, and delighted customers. Now most leading organizations realize that creating such employees is also a major goal of total quality management. These organizations not

only aim to solve the problems of today but to create an organization that can solve or avoid the problems of tomorrow (Juran, Godfrey, 1999).

2.3 PAF Modeling

The basic suppositions of the PAF model are that investment in prevention and appraisal activities will reduce failure costs, and that further investment in prevention activities will reduce appraisal costs (Dale, Plunket, 1995). The above-mentioned classical view of quality cost behavior in the PAF model holds that an optimum economic quality exists at the level at which the cost of securing higher quality would exceed the benefits of the improved quality (BS 4778, 1987). This concept is, however, often challenged, and it is argued that there is no economic level of quality, that the spending on prevention could be always justified and that optimum quality level in fact equals zero defects (Dale, Plunket, 1995; Fox, 1989; Schneiderman, 1986).

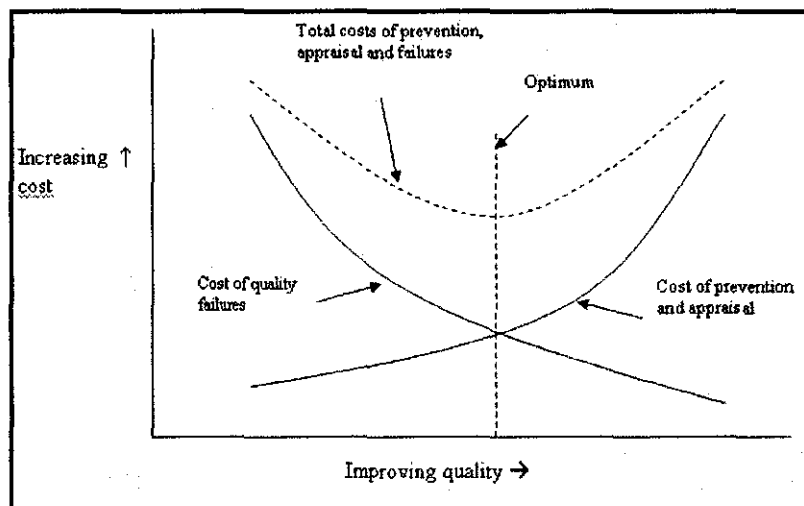


Figure 2.3: Optimization of Quality and Cost (Foster, 1996)

As shown in the figure above, the failure cost are very high corresponding to low quality and vice versa, because of higher defect rate and the system is in chaotic condition (Zhao, 2000). From the figure, we also know that when the cost of prevention and appraisal decrease, the cost of failure increase and vice versa.

Somehow there are many arguments about the disadvantage of using PAF modeling in quality costing (Liu, Cui, Meng, Pan, 2008; Oakland, 1993):

1. Difficult to decide which activities stand for prevention of quality failures since almost everything a well-managed company does has something to do with preventing quality problems.
2. There are a range of prevention activities in any company which are integral to ensuring quality but may never be included in the report of quality costs.
3. PAF model does not include intangible quality costs such as “loss of customer goodwill”.

2.4 Vandermonde Technique

In Vandermonde technique, the substitution of the points into the desired polynomial yields a system of linear equations in the coefficients of the polynomial which may then be solved using Gaussian elimination or PLU decomposition. This technique also generalizes for interpolating non-polynomial functions or points in more than two dimensions (ece.uwaterloo.ca). The best known algorithm for polynomial interpolation, unlike the barycentric formula, is exponentially unstable (Trefethen, 2010).

Suppose we want the interpolating polynomial p^n in the monomial basis (Farin, 2002):

$$p^n(t) = \sum_{j=0}^n a_j t^j \quad (2.2a)$$

The standard approach to finding the unknown coefficients from the known data is simply to write down everything one knows about the problem:

$$\begin{aligned} p^n(t_0) &= p_0 = a_0 + a_1 t_0 + \cdots + a_n t_0^n \\ p^n(t_1) &= p_1 = a_0 + a_1 t_1 + \cdots + a_n t_1^n \\ &\vdots \\ p^n(t_n) &= p_n = a_0 + a_1 t_n + \cdots + a_n t_n^n \end{aligned}$$

In matrix form

$$\begin{bmatrix} p_0 \\ p_1 \\ \vdots \\ p_n \end{bmatrix} = \begin{bmatrix} 1 & t_0 & t_0^2 & \cdots & t_0^n \\ 1 & t_1 & t_1^2 & \cdots & t_1^n \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & t_n & t_n^2 & \cdots & t_n^n \end{bmatrix} \begin{bmatrix} a_0 \\ a \\ \vdots \\ a_n \end{bmatrix} \quad (2.2b)$$

We can shorten this into

$$p = Ta \quad (2.2c)$$

We already know that a solution a to this linear system exists, but one can show independently that the determinant $\det T$ is nonzero (for distinct parameter values t_i). This determinant is known as the Vandermonde of the interpolation problem. The solution, that is, the vector a containing the coefficients a_i , can be found from

$$a = T^{-1}p \quad (2.2d)$$

This should be taken only as a shorthand notation for the solution – not as an algorithm. Note that the linear system (2.2c) really consists of three linear systems with the same coefficients matrix, one system for each coordinate. It is known from numerical analysis that in such cases the LU decomposition of T is a more economical way to obtain the solution a . The interpolation problem can also be solved if we use basis functions other than the monomials. Let $\{F_i^n\}_{i=0}^n$ be such a basis. We then seek an interpolating polynomial of the form

$$p^n(t) = \sum_{j=0}^n c_j F_j^n(t) \quad (2.2e)$$

This reasoning again leads to a linear system (three linear systems to be more precise) for the coefficients c_j , this time with the generalized Vandermonde F :

$$F = \begin{bmatrix} F_0^n(t_0) & F_1^n(t_0) & \dots & F_n^n(t_0) \\ F_0^n(t_1) & F_1^n(t_1) & \dots & F_n^n(t_1) \\ \vdots & \vdots & \dots & \vdots \\ F_0^n(t_n) & F_1^n(t_n) & \dots & F_n^n(t_n) \end{bmatrix} \quad (2.2f)$$

Since the F_i^n form a basis for all polynomials of degree n , it follows that the generalized Vandermonde det F is nonzero. Thus, for instance, we are able to find the Bézier curve that passes through a given set of data points: the F_i^n would then be the Bernstein polynomials B_i^n .

The polynomial orders of Vandermonde fitting are varied and need to be tested as they pose lesser stability with simple calculation. This Vandermonde fitting would yield a smoother curve if the amount of data increase which would yield a more sensible outcome (Izzat, 2011). Thus when deciding to use this method to generate the curve, it is best to make sure that the data are sufficient so that it can plot a smooth curve and shows clear break-even of the costs.

2.5 Cubic Spline Approach

By using spline technique, a series of unique cubic polynomials are fitted between each of the data points, with the stipulation that the curve obtained be continuous and appear smooth. The fundamental idea behind cubic spline interpolation is based on the engineer's tool used to draw smooth curves through a number of points (McKinley, Levine, 1998). A spline is a piecewise polynomial satisfying continuity conditions between the pieces (Smith, 1983).

2.5.1 Cubic Spline Interpolant (Bradie, 2006)

A function S is a spline of degree k if it conforms to the following three conditions.

- i) The domain of S is $[a, b]$.
- ii) $S, S',$ and $S'', \dots,$ and $S^{(k-1)}$ are continuous.
- iii) There are points x_i (the knots of S) such that $a = x_0 < x_1 < \dots < x_n = b$ and such that S is a polynomial of degree k on each subinterval $[x_i, x_{i+1}]$.

Splines have a variety of uses and we will deal specifically with the subset of splines that interpolate data points. Assume we have a set of $n + 1$ data points (x_i, y_i) .

x	$x_0 \dots x_n$
y	$y_0 \dots y_n$

An interpolating spline has one additional requirement.

$$\text{iv) } S(x_i) = y_i \text{ for } i \in [0, n]$$

The most common choice of degree is three. The resulting splines are called cubic splines. We use cubic splines for several reasons.

- Because S , S' , and S'' are continuous, these splines appear to be smooth to the eye.
- They are not prohibitively smooth.
- They leave enough “left-over” conditions to be applicable in many cases.
- Odd polynomials have better properties.
- Cubic Splines are best available.
- It is widely used for real life application(Karim, 2008)

We will create a spline $S(x)$ by creating a cubic polynomial $S_i(x)$ for each $[x_i, x_{i+1}]$. We will then piece these n polynomials together in such a way as to conform to the three spline conditions and interpolate the $n + 1$ data points.

$$S(x) = \begin{cases} S_0(x) & x_0 \leq x \leq x_1 \\ S_1(x) & x_1 \leq x \leq x_2 \\ \dots & \dots \\ S_{n-1} & x_{n-1} \leq x \leq x_n \end{cases}$$

There are n cubic polynomials. Each polynomial has four coefficients. This results in $4n$ parameters. We use $4n - 2$ of these parameters to force the cubic spline to interpolate the data points and conform to the spline requirements of continuity in the function and

its first two derivatives. These conditions break down as follows. Note that the left column sums to $4n-2$.

Condition	Range	Number of Constraints
$S_i(x_i) = y_i$	$i = 0, \dots, n-1$	n
$S_i(x_{i+1}) = y_{i+1}$	$i = 0, \dots, n-1$	n
$S'_i(x_i) = S'_{i+1}(x_i)$	$i = 0, \dots, n-2$	$n-1$
$S''_i(x_i) = S''_{i+1}(x_i)$	$i = 0, \dots, n-2$	$n-1$

This leaves two free parameters. There are several common choices.

- Fixed slope at the end points

$$S'(x_0) = C_0$$

$$S'(x_n) = C_n$$

- Natural spline

$$S''(x_0) = S''_n = 0$$

- Not-a-knot condition

$$S''' \text{ is continuous at } x_1 \text{ and } x_{n-1}$$

2.5.2 Natural Spline (manually) (Bradie, 2006)

Below is the example of natural spline for further understanding which is manually done.

x	-1	0	1
y	1	2	-1

The first step is two write out the spline.

$$S(x) = \begin{cases} S_0(x) = ax^3 + bx^2 + cx + d & x \in [-1,0] \\ S_1(x) = ex^3 + fx^2 + gx + h & x \in [0,1] \end{cases}$$

Our next step is to use the spline conditions to find the coefficients a, b, c, d, e, f, g .

Requiring S_0 and S_1 to interpolate the data points we find that

$$S_0(0) = 2 \rightarrow d = 2$$

$$S_0(-1) = 1 \rightarrow -a + b - c = -1$$

$$S_1(0) = 2 \rightarrow h = 2$$

$$S_1(1) = -1 \rightarrow e + f + g = -3$$

Requiring continuity of the of the first derivatives we find

$$S'(x) = \begin{cases} S'_0(x) = 3ax^2 + 2bx + cx + d & x \in [-1,0] \\ S'_1(x) = 3ex^2 + 2fx + gx + h & x \in [0,1] \end{cases}$$

$$S'_0(0) = S'_1(0) \rightarrow c = g$$

Requiring continuity of the of the second derivatives we find

$$S''(x) = \begin{cases} S''_0(x) = 6ax + 2b & x \in [-1,0] \\ S''_1(x) = 6ex + 2f & x \in [0,1] \end{cases}$$

$$S_0''(0) = S_1''(0) \rightarrow b = f$$

Finally requiring the natural spine conditions to hold we find

$$S_0''(-1) = 0 \rightarrow 3a = b$$

$$S_1''(1) = 0 \rightarrow 3e = f$$

Solving all the linear equations we find that

$$a = -1$$

$$b = -3$$

$$c = -1$$

$$d = 2$$

$$e = 1$$

$$f = -3$$

$$g = -1$$

$$h = 2$$

We can plot this and see the results. Note that the first and second derivatives are both continuous and the second derivative is zero at the endpoints.

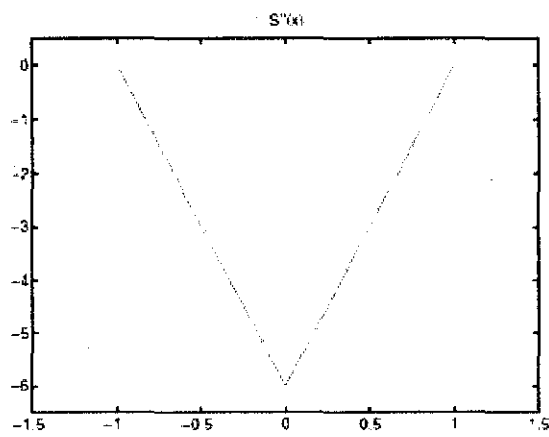
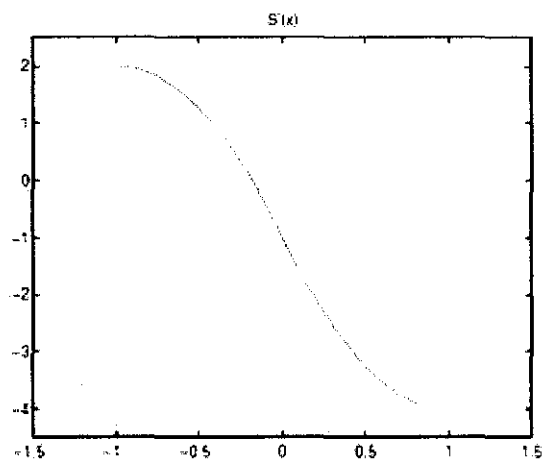
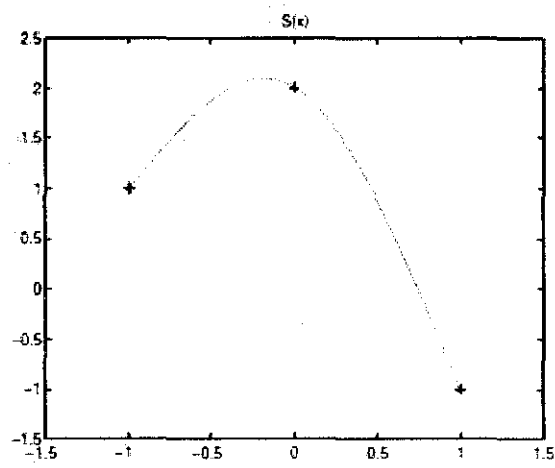


Figure 2.4: Natural cubic, quadratic and linear spline interpolation.

2.5.3 Automation (Bradie, 2006)

There are many ways to automate the construction of splines. Consider again the natural spline

$$S(x) = \begin{cases} S_0(x) & x_0 \leq x \leq x_1 \\ S_1(x) & x_1 \leq x \leq x_2 \\ \dots & \dots \\ S_{n-1} & x_{n-1} \leq x \leq x_n \end{cases}$$

$$S(x_i) = y_i$$

$S'(x)$ is continuous

$S''(x)$ is continuous

$$S''(x_0) = S''(x_n) = 0$$

Let $z_i = S''(x_i)$. Because we are using natural splines, this implies $z_0 = z_n = 0$. Suppose now we also know z_i for all $i \in [1, n - 1]$. Because S is a set of cubic polynomials with continuous second derivatives, $S''(x)$ is a linear interpolating spline over the points (x_i, z_i) . For example, in the previous section, S'' was a linear spline over the points $(-1, 0)$, $(0, -6)$, $(1, 0)$. We can simply write out one of S'' 's linear functions. Note that S''_i is z_i at the left end point and z_{i+1} at the right.

$$\begin{aligned} S''_i(x) &= \frac{z_{i+1}}{x_{i+1} - x_i}(x - x_i) + \frac{z_i}{x_{i+1} - x_i}(x_{i+1} - x) \\ &= \frac{z_{i+1}}{h_i}(x - x_i) + \frac{z_i}{h_i}(x_{i+1} - x) \end{aligned}$$

Integrating twice we find

$$S_i(x) = \frac{z_{i+1}}{6h_i}(x - x_i)^3 + \frac{z_i}{6h_i}(x_{i+1} - x)^3 + cx + d$$

$$S_i(x) = \frac{z_{i+1}}{6h_i}(x - x_i)^3 + \frac{z_i}{6h_i}(x_{i+1} - x)^3 + c_i(x - x_i) + d_i(x_{i+1} - x)$$

We have enforced that the second derivatives are continuous. We still must enforce that

$$S(x_i) = y_i \text{ for } i \in [0, n]$$

$S'(x)$ is continuous

Enforcing that $S(x_i) = y_i$ yields conditions on both the left and right endpoints of a S_i

$$\begin{aligned} S_i(x_i) = y_i &\quad \rightarrow 0 + \frac{z_i}{6h_i} h_i^3 + 0 + d_i h_i \\ &\quad \rightarrow d_i = \frac{y_i}{h_i} - \frac{z_i}{6} h_i \\ S_i(x_{i+1}) = y_{i+1} &\quad \rightarrow \frac{z_{i+1}}{6h_i} h_i^3 + 0 + c_i h_i + 0 \\ &\quad \rightarrow c_i = \frac{y_{i+1}}{h_i} - \frac{z_{i+1}}{6} h_i \end{aligned}$$

Enforcing continuity of the first derivatives yields equations relating S_i and S_{i-1} .

$$\begin{aligned} S_i(x) &= \frac{z_{i+1}}{2h_i} (x - x_i)^2 + \frac{z_i}{2h_i} (x_{i+1} - x)^2 + \frac{y_i}{h_i} - \frac{z_i}{6} h_i - \frac{y_{i+1}}{h_i} + \frac{z_{i+1}}{6} h_i \\ S'_i(x_i) &= \frac{-h_i}{6} z_{i+1} - \frac{h_i}{3} z_i + b_i \\ S'_{i-1}(x_i) &= \frac{h_{i-1}}{6} z_{i+1} + \frac{h_{i-1}}{3} z_i + b_{i-1} \end{aligned}$$

Imposing continuity yields

$$S'_{i-1}(x_i) = S'_i(x_i) \quad \rightarrow h_{i-1} z_{i-1} + 2(h_{i-1} + h_i) z_i + h_i z_{i+1} = 6(b_i - b_{i-1})$$

Note that above equation already encodes interpolating the data points (because we substituted for c_i and d_i) and continuity of the second derivatives. Now we are ready to write out this in matrix form. Letting

$$u_i = 2(h_{i-1} + h_i)$$

$$v_i = 6(b_i - b_{i-1})$$

we find the following

$$z_0 = 0$$

$$h_{i-1}z_{i-1} + u_i z_i + h_i z_{i+1} = v_i \quad i \in [1, n-1]$$

$$z_n = 0$$

This can be organized in to a matrix.

$$\begin{bmatrix} 1 & 0 & & & & & \\ h_0 & u_1 & h_1 & & & & \\ & h_1 & u_2 & & & & \\ & & \ddots & \ddots & & & \\ & & & h_{n-2} & u_{n-2} & h_{n-1} & \\ & & & & 0 & 1 & \end{bmatrix} \begin{bmatrix} z_0 \\ z_1 \\ z_2 \\ \vdots \\ z_{n-1} \\ z_n \end{bmatrix} = \begin{bmatrix} 0 \\ v_1 \\ v_2 \\ \vdots \\ v_{n-1} \\ 0 \end{bmatrix}$$

The first and last equation can be eliminated to get a tridiagonal system of order $n - 1$.

$$\begin{bmatrix} u_1 & h_1 & & & & \\ h_1 & u_2 & h_2 & & & \\ & \ddots & \ddots & \ddots & & \\ & & h_{n-3} & u_{n-2} & h_{n-2} & \\ & & & h_{n-2} & u_{n-1} & \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \\ \vdots \\ z_{n-1} \end{bmatrix} = \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_{n-1} \end{bmatrix}$$

One way to solve the system is to use Gaussian Elimination without pivoting.

1. Forward substitution. For $i = 2, 3, \dots, n - 1$

$$u_i \leftarrow u_i - \frac{h_{i-1}^2}{u_{i-1}}$$

$$v_i \leftarrow v_i - \frac{h_{i-1} v_{i-1}}{u_{i-1}}$$

2. Backward substitution. First assign z_{n-1}

$$z_{n-1} \leftarrow \frac{v_{n-1}}{u_{n-1}}$$

Next assign the rest. For $i = n - 2, n - 3, \dots, 1$

$$z_i \leftarrow \frac{v_i - h_i z_{i+1}}{u_i}$$

2.5.4 Algorithm (Bradie, 2006)

Input: $n + 1$ interpolation points $(x_0, y_0), \dots, (x_n, y_n)$

Output: Cubic interpolating spline $S(x)$

i) For $i = 0, 1, \dots, n - 1$ compute

$$h_i = x_{i+1} - x_i$$

$$b_i = \frac{y_{i+1} - y_i}{h_i}$$

ii) Set

$$u_1 = 2(h_0 + h_1)$$

$$v_1 = 6(b_1 - b_0)$$

and then compute for $i = 2, 3, \dots, n - 1$

$$u_i = 2(h_i + h_{i+1}) - \frac{h_{i-1}^2}{u_{i-1}}$$

$$v_i = 6(b_i - b_{i-1}) - \frac{h_{i-1} v_{i-1}}{u_{i-1}}$$

iii) Set

$$z_0 = 0$$

$$z_n = 0$$

and then compute for $i = n - 1, n - 2, \dots, 1$

$$z_i \leftarrow \frac{v_i - h_i z_{i+1}}{u_i}$$

iv) Substitutes all the coefficients into the S_i 's

$$S_i(x) = \frac{z_{i+1}}{6h_i}(x - x_i)^3 + \frac{z_i}{6h_i}(x_{i+1} - x)^3 + \left(\frac{y_{i+1}}{h_i} - \frac{z_{i+1}}{6}h_i\right)(x - x_i) + \left(\frac{y_i}{h_i} - \frac{z_i}{6}h_i\right)(x_{i+1} - x)$$

It can be shown that for all i , u_i is never zero. The algorithm cannot fail.

In general, the key characteristics of cubic spline interpolation are:

1. The curves pass through all specified data points.
2. 1st derivative (slope) continuity at interior points.
3. 2nd derivative continuity at interior points.
4. Boundary conditions specified at the free ends.

Different situation with spline interpolation technique, data size does not affecting the fitting of the interpolation as it is using third degree polynomial. This interpolation possesses better stability although they just using simple calculation compared to Vandermonde interpolation. Spline interpolation do provide better analysis of a company's prevention-appraisal-failure cost (PAFC) as they effectively show the break-even points in the total cost than Vandermonde.

2.6 Similar Case Study

This study is continuity from previous case study conducted by Izzat (2011), where the size of the project used to obtain the data is rather small which is about 18 months hence, the data are limited. Findings obtained from the study are:

	Vandermonde Interpolation	Spline Interpolation
Curve Fitting	For small sets of data, fitting is not being well done as it requires large sets of data for appropriate fitting.	Data size does not affect the fitting of the interpolation as the interpolation interval is divided into small subintervals.
Polynomial orders	Polynomial orders are varied and need to be tested in order to suit the data sets.	Each of the subintervals is interpolated by using the third-degree polynomial.
Stability	Posses lesser stability with simple calculation as interpolation between each point is randomly distributed.	Posses stability and calculation simplicity as interpolation between each points are adequately distributed.
Error incurred	Incurs relatively higher error than spline interpolation and the interpolant is less smooth.	Incurs a smaller error than Vandermonde interpolation and the interpolant is smoother.
Evaluation	Harder to evaluate compare to spline as spline uses piecewise polynomial interpolation.	The interpolant is easier to evaluate than the high-degree polynomials used in polynomial interpolation.

Table 2.1: Comparison between Vandermonde and Spline Interpolation

PAF Modeling limitation

- Could not retain the fine details in the data.
- Cannot reveal the correlation between costs of prevention, appraisal and failure.
- Hard to determine the break-even point.

Conclusion

- PAF modeling is not suitable to analyzed and identify the company's performance and efficiency.
- Spline interpolation technique do provide better analysis of a company's PAFC as they effectively show the break-even points in the total cost than Vandermonde.
- The prevention and appraisal cost is relatively higher than the failure cost which implies that the company may have already implement quality improvement activities.

Recommendation:

- Company should record fine details of prevention, appraisal and failure cost. E.g., labor cost, consulting cost, inspection cost, auditing cost and etc.
- Vandermonde fitting would yield a smoother curve if the amount of data increase which would yield a more sensible outcome.
- Implementation of interpolating techniques should be done accordingly with the progress of the project

By looking at the findings and recommendation for improvement above, larger case study will be used this time in order to overcome the problems faced previously when using Vandermonde interpolation especially in term of curve fitting based on the data provided. We expect the results obtain from this analysis will be more accurate and show clearer and better results. Moreover, both methods can be compared fairly this time without any limitation.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

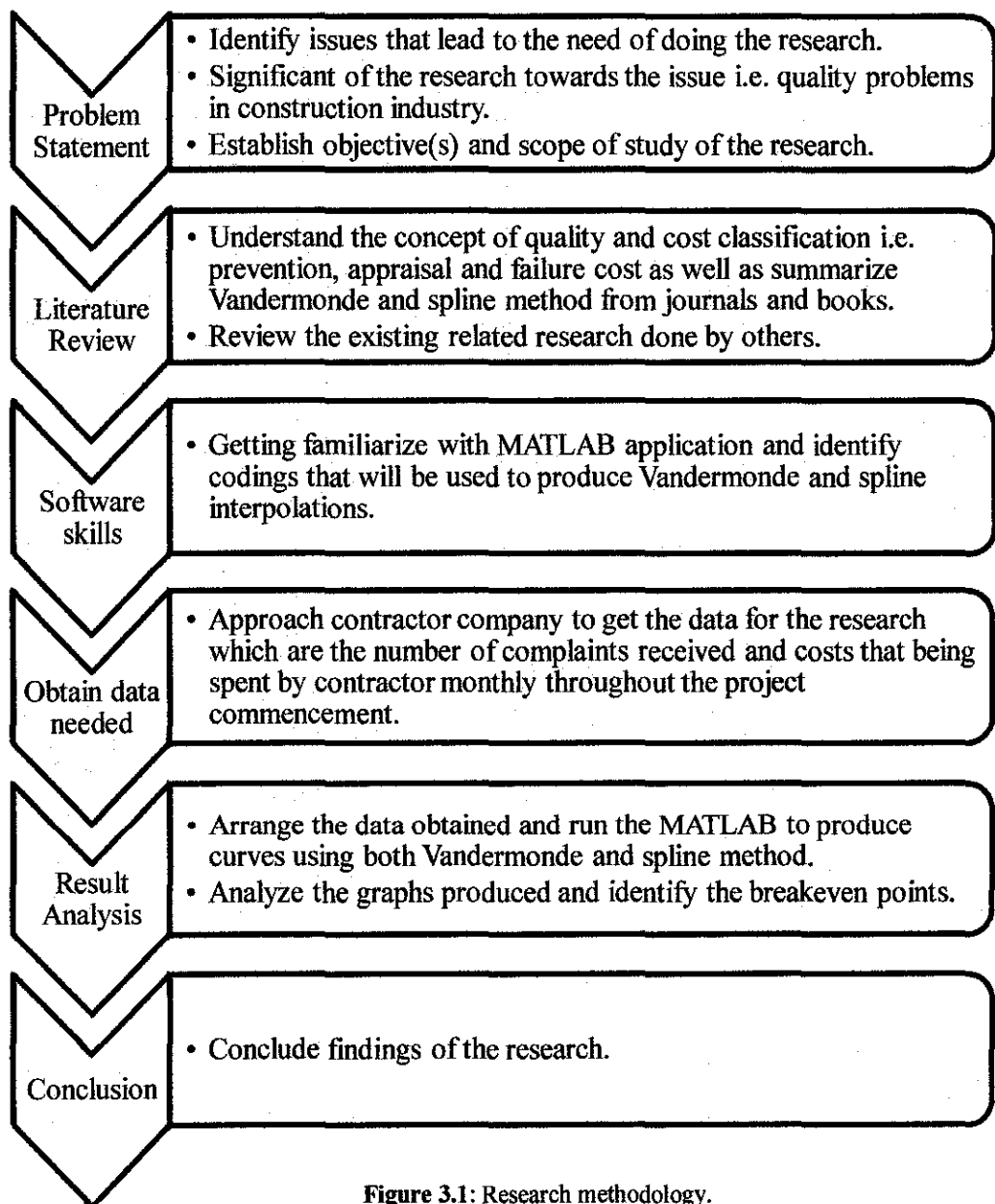


Figure 3.1: Research methodology.

3.2 Gantt Chart

Overall, the activities for FYP 2 are summarized in the Gantt chart below:

NO	ACTIVITIES	WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Approach companies to obtain data needed	■	■	■	■										
2.	Arrange data before starting to plot the curves					■									
3.	Produce curves using MATLAB for both Vandermonde and spline						■	■	■						
4.	Submission of progress report								*						
5.	Do detail explanation on the curves and finalize the findings									■	■	■	■		
6.	Pre-EDX											*			
7.	Submission of Draft Final Report												*		
8.	Submission of Final Report and Technical Paper													*	
9.	Oral presentation (viva)														*

Table 3.1: Research's Gantt Chart

3.3 Data Required

Firstly, we are targeting a completed project to be adapted in our study. And from the project, there are two types of data needed to start the research. The first one would be costs that already being spent by the contractor monthly from the start until the completion of the project. Somehow the costs need to be classified into two classes i.e. prevention and appraisal costs as well as failure cost depending on what purpose are the money being spent on. The cost can be classified accordingly by referring to examples for each cost in companies operation as being listed by Juran and Godfrey, 1999 (Section 2.1 of this report).

Apart from that, we also need to identify the number of complaints received from Resident Engineer (RE) and customers monthly. The complaints can be in the form of non-compliance record (NCR) or oral complaints that can be detected. The complaints will be used to quantitatively stimulate quality by using the formula (Tam and Le, 2007):

$$Q = 1 - \frac{\chi_1 + \chi_2}{M}$$

where Q is the quality value of complaints, χ_1 is the number of oral complaints received, χ_2 is the number of formal complaints received and M is the maximum number of received complaints.

Then, we can start generate the curves out of the data using MATLAB application and try to get the best-fit curves for both Vandermonde and spline interpolation.

3.4 Software Involved

To analyze the data and conduct plot-fitting curves, we are using MATLAB application, where MATLAB that is a short form of matrix laboratory is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation (<http://cimss.ssec.wisc.edu>).

Typical uses of MATLAB include:

- Math and computation
- Algorithm development
- Modeling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics
- Application development, including Graphical User Interface building

During the development of software, MATLAB has been very convenient and practical software for engineering researchers. It's very easy to be operated due to its wide coverage, assembly-based language, and the very simple algorithms. It's possible for the users to develop their own calculation functions and integrate them into the toolbox; this can enhance the MATLAB functions to a great deal. It's also very convenient to process graphics with MATLAB. The graphics can be displayed as soon as the data are loaded into the MATLAB system. In addition, there are many other toolboxes in MATLAB for convenient operation with specific calculations for users of different application domains (MATLAB User Guide: version 5.3)

In addition to above advantages listed MATLAB also host of built-in routines where if you compare MATLAB with C++, we can use libraries in C++, but MATLAB routines are standardized; which means the code will run on any MATLAB installation. Besides that, MATLAB has vectorized code means a lot less looping and code that is much easier to read compared to C++.

3.5 Vandermonde Interpolation

We are using "polyfit" command in MATLAB that stand for polynomial curve fitting to do Vandermonde interpolation. Syntax that being used in the coding are (www.mathworks.com):

1. `p = polyfit(x,y,n)`
2. `[p,S] = polyfit(x,y,n)`
3. `[p,S,mu] = polyfit(x,y,n)`

`p = polyfit(x,y,n)` finds the coefficients of a polynomial $p(x)$ of degree n that fits the data, $p(x(i))$ to $y(i)$, in a least squares sense. The result p is a row vector of length $n+1$ containing the polynomial coefficients in descending powers:

$$p(x) = p_1x^n + p_2x^{n-1} + \dots + p_nx + p_{n+1}.$$

[p,S] = polyfit(x,y,n) returns the polynomial coefficients p and a structure S for use with polyval to obtain error estimates or predictions. Structure S contains fields R, df, and normr, for the triangular factor from a QR decomposition of the Vandermonde matrix of x, the degrees of freedom, and the norm of the residuals, respectively. If the data y are random, an estimate of the covariance matrix of p is (Rinv*Rinv')*normr^2/df, where Rinv is the inverse of R. If the errors in the data y are independent normal with constant variance, polyval produces error bounds that contain at least 50% of the predictions.

[p,S,mu] = polyfit(x,y,n) finds the coefficients of a polynomial in:

$$\hat{x} = \frac{x - \mu_1}{\mu_2}$$

where $\mu_1 = \text{mean}(x)$ and $\mu_2 = \text{std}(x)$. mu is the two-element vector $[\mu_1, \mu_2]$. This centering and scaling transformation improves the numerical properties of both the polynomial and the fitting algorithm.

3.6 Spline Interpolation

For interpolating spline in MATLAB, we can use the command “*spline*” that represents cubic spline data interpolation to generate all of the piecewise function of each curve which connects each node appropriately. Syntax that being used in the coding are (www.mathworks.com):

1. yy = spline(x,Y,xx)
2. pp = spline(x,Y)

yy = spline(x,Y,xx) uses a cubic spline interpolation to find yy, the values of the underlying function Y at the values of the interpolant xx. For the interpolation, the independent variable is assumed to be the final dimension of Y with the breakpoints defined by x.

The sizes of xx and yy are related as follows:

- i. If Y is a scalar or vector, yy has the same size as xx .
- ii. If Y is an array that is not a vector,
- iii. If xx is a scalar or vector, $\text{size}(yy)$ equals $[d1, d2, \dots, dk, \text{length}(xx)]$.
- iv. If xx is an array of size $[m1, m2, \dots, mj]$, $\text{size}(yy)$ equals $[d1, d2, \dots, dk, m1, m2, \dots, mj]$.

$pp = \text{spline}(x, Y)$ returns the piecewise polynomial form of the cubic spline interpolant for later use with $ppval$ and the spline utility unmkpp . x must be a vector. Y can be a scalar, a vector, or an array of any dimension, subject to the following conditions:

- i. If x and Y are vectors of the same size, the not-a-knot end conditions are used.
- ii. If x or Y is a scalar, it is expanded to have the same length as the other and the not-a-knot end conditions are used.
- iii. If Y is a vector that contains two more values than x has entries, the first and last value in Y are used as the endslopes for the cubic spline.

Somehow there are some exceptions when using spline function in MATLAB:

- i. If Y is a vector that contains two more values than x has entries, the first and last value in Y are used as the end slopes for the cubic spline. If Y is a vector, this means:
 - $f(x) = Y(2:\text{end}-1)$
 - $df(\min(x)) = Y(1)$
 - $df(\max(x)) = Y(\text{end})$
- ii. If Y is a matrix or an N -dimensional array with $\text{size}(Y, N)$ equal to $\text{length}(x)+2$, the following hold:
 - $f(x(j))$ matches the value $Y(:, \dots, :, j+1)$ for $j=1:\text{length}(x)$
 - $Df(\min(x))$ matches $Y(:, \dots, :, 1)$
 - $Df(\max(x))$ matches $Y(:, \dots, :, \text{end})$

3.7 Details of Case Study

The case study that will be analyzed is one of mix development projects known as KP Perdana Fasa 1 project, situated at mukim Kubang Parit, Kuala Terengganu, Terengganu Darul Iman. The development is a large-scale project with many phases of construction whereby the duration taken is about 30 months. The project consists of:

- i) 52 units of 2-storey terrace houses
- ii) 38 units of 2-storey semi-D houses
- iii) 39 units of 2-storey bungalow houses

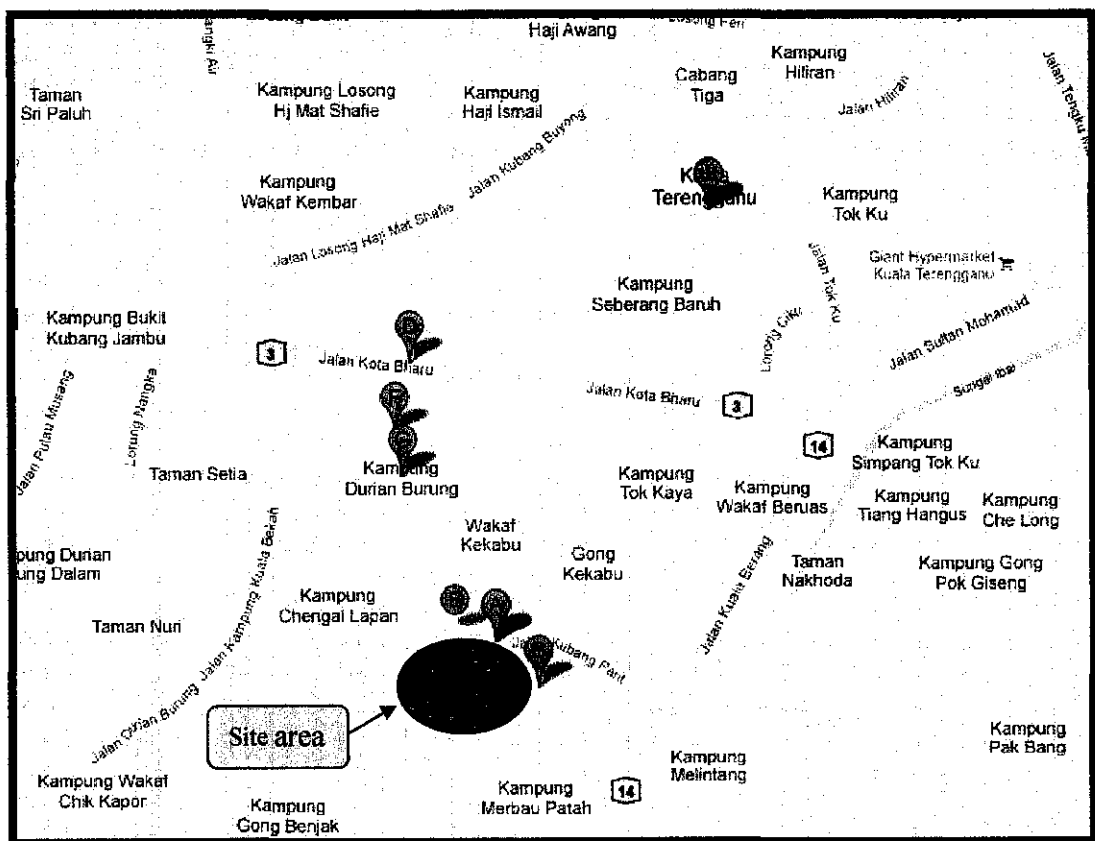


Figure 3.2: Case study's area

CHAPTER 4

RESULT AND DISCUSSION

4.1 Data Gathering and Analysis

The data is taken with the help and assistant from consultant of the project and for the use of academic purposes only. As being mentioned earlier, from the data obtained, we are expecting to find a way on how to maintain or better to improve the quality of services with minimum costs possible. Based on the findings that had been done during previous research, what we can improve for this time around is by using bigger data size as last time the data size was around 18 months and as a result the fitting of Vandermonde curves were not smoothly done. To improve the findings, the project that being adopted this time is having total construction time of 30 months, that is more than two years time.

The first step taken after received the data from the company was sorting the costs into their classes which is prevention and appraisal costs as well as failure costs depending what are the money being spent on. The after works are shown in Table 4.1. Meanwhile, to get the value of quality as being shown in Table 4.2, we need to use the formula by Tam and Le, 2007. The formula was already being mentioned in Section 3.3 of this report.

MONTH	PREVENTION & APPRAISAL COST (RM)					FAILURE COST (RM)	TOTAL COST (RM)
	TEST/INSPECTION-	NEW MACHINE	SUPERVISOR	ENGINEER	TOTAL	Rectification & Rework	
Sep-07	7,000.00	0.00	2,700.00	4,000.00	13,700.00	0.00	13,700.00
Oct-07	5,000.00	25,000.00	2,700.00	4,000.00	36,700.00	0.00	36,700.00
Nov-07	0.00	0.00	2,700.00	4,000.00	6,700.00	10,000.00	16,700.00
Dec-07	0.00	0.00	2,700.00	4,000.00	6,700.00	0.00	6,700.00
Jan-08	0.00	0.00	2,700.00	4,000.00	6,700.00	0.00	6,700.00
Feb-08	10,000.00	0.00	2,700.00	4,000.00	16,700.00	2,280.00	18,980.00
Mar-08	0.00	0.00	2,700.00	4,000.00	6,700.00	0.00	6,700.00
Apr-08	3,000.00	0.00	2,700.00	4,000.00	9,700.00	700.00	10,400.00
May-08	0.00	0.00	2,700.00	4,000.00	6,700.00	0.00	6,700.00
Jun-08	0.00	10,000.00	2,700.00	4,000.00	16,700.00	0.00	16,700.00
Jul-08	6,000.00	0.00	2,700.00	4,000.00	12,700.00	0.00	12,700.00
Aug-08	0.00	0.00	2,700.00	4,000.00	6,700.00	1,600.00	8,300.00
Sep-08	0.00	0.00	2,700.00	4,000.00	6,700.00	0.00	6,700.00
Oct-08	0.00	0.00	2,700.00	4,000.00	6,700.00	22,000.00	28,700.00
Nov-08	0.00	16,000.00	2,700.00	4,000.00	22,700.00	0.00	22,700.00
Dec-08	0.00	0.00	2,700.00	4,000.00	6,700.00	0.00	6,700.00
Jan-09	13,000.00	0.00	2,700.00	4,000.00	19,700.00	5,000.00	24,700.00
Feb-09	0.00	0.00	2,700.00	4,000.00	6,700.00	0.00	6,700.00
Mar-09	5,000.00	0.00	2,700.00	4,000.00	11,700.00	0.00	11,700.00
Apr-09	0.00	0.00	2,700.00	4,000.00	6,700.00	0.00	6,700.00
May-09	0.00	0.00	2,700.00	4,000.00	6,700.00	0.00	6,700.00
Jun-09	0.00	0.00	2,700.00	4,000.00	6,700.00	0.00	6,700.00
Jul-09	0.00	10,000.00	2,700.00	4,000.00	16,700.00	14,000.00	30,700.00
Aug-09	3,000.00	0.00	2,700.00	4,000.00	9,700.00	0.00	9,700.00
Sep-09	5,000.00	0.00	2,700.00	4,000.00	11,700.00	0.00	11,700.00
Oct-09	0.00	0.00	2,700.00	4,000.00	6,700.00	0.00	6,700.00
Nov-09	2,000.00	0.00	2,700.00	4,000.00	8,700.00	9,000.00	17,700.00
Dec-09	6,000.00	0.00	2,700.00	4,000.00	12,700.00	0.00	12,700.00
Jan-10	0.00	0.00	2,700.00	4,000.00	6,700.00	3,000.00	9,700.00
Feb-10	0.00	0.00	2,700.00	4,000.00	6,700.00	0.00	6,700.00
OVERALL TOTAL					327,000.00	67,580.00	394,580.00

Table 4.1: Total prevention, appraisal and failure cost

MONTH	NO. OF COMPLAINTS	CUMULATIVE NO. OF COMPLAINTS	QUALITY
Sep-07	0	0	1.000
Oct-07	0	0	1.000
Nov-07	2	2	0.000
Dec-07	0	2	1.000
Jan-08	1	3	0.667
Feb-08	1	4	0.750
Mar-08	0	4	1.000
Apr-08	0	4	1.000
May-08	4	8	0.500
Jun-08	1	9	0.889
Jul-08	2	11	0.818
Aug-08	0	11	1.000
Sep-08	0	11	1.000
Oct-08	1	12	0.917
Nov-08	0	12	1.000
Dec-08	0	12	1.000
Jan-09	0	12	1.000
Feb-09	3	15	0.800
Mar-09	0	15	1.000
Apr-09	0	15	1.000
May-09	2	17	0.882
Jun-09	1	18	0.944
Jul-09	0	18	1.000
Aug-09	0	18	1.000
Sep-09	4	22	0.818
Oct-09	0	22	1.000
Nov-09	1	23	0.957
Dec-09	0	23	1.000
Jan-10	1	24	0.958
Feb-10	0	24	1.000

Table 4.2: Quality values

Based on the value of quality shown in Table 4.2, the value of '1' means that for that particular month, there is no complaint at all hence the quality is at its best. Meanwhile there is only one month where the performance was under bar which is on November 2007 where the value is '0'.

4.2 PAF Modeling

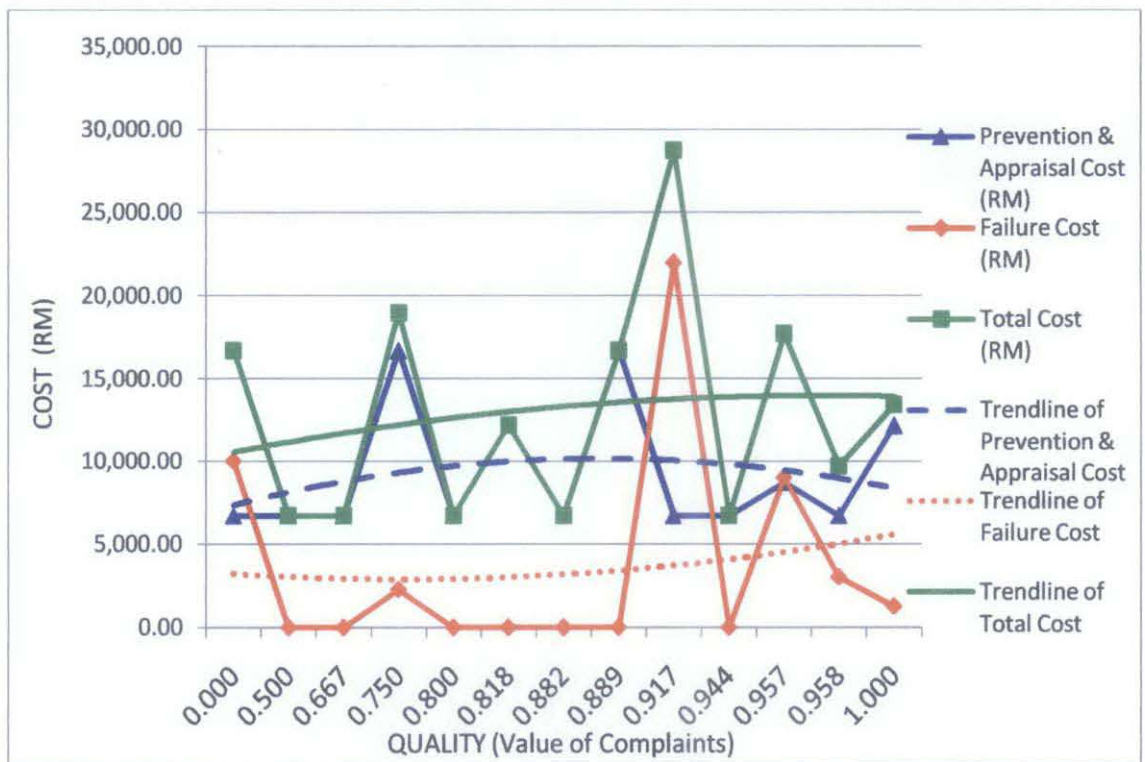


Figure 4.1: PAF model of KP Perdana Fasa 1 (cost against quality)

As the concept stated by Foster (1996) on cost and quality optimization in Section 2.3 of this report, when the cost of prevention and appraisal decrease, the cost of failure will increase and vice versa. Referring to Figure 4.1, we can see from the trendline that cost of failure is relatively lower than the costs of prevention and appraisal. This situation indicates that this construction company may already use adequate investments in order to avoid any possible failures that might occurred in the future and at the same time to improve quality of the services.

However it is difficult for us to identify any break-even point from the trendlines. As shown, we should be clear by now that PAF modeling method unable to reveal the correlation between the costs of prevention, appraisal and failure, hence it is necessary to find another way in order to individually study each of these costs by using other effective methods which in this paper, we proposed to use Vandermonde and spline approaches.

The main motivation of using this method is because the Vandemonde interpolation technique is been successfully used in the field of signal and image processing to best-fit a given data set (Izzat, 2011). Meanwhile for spline interpolation, its stability of computing process and calculation simplicity are strong points to be implemented in this study. Sets of linear equations which should be solved to construct splines are very well-conditioned; therefore, the polynomial coefficients are calculated precisely and the calculation scheme stays stable even for bigger data set (www.simumath.com).

4.3 Vandermonde Interpolation

For Vandermonde interpolation, the plot is done until 8th order as for 9th order and above, the MATLAB software displayed a warning stating that the polynomial is in bad conditioned. The plot results are shown below:

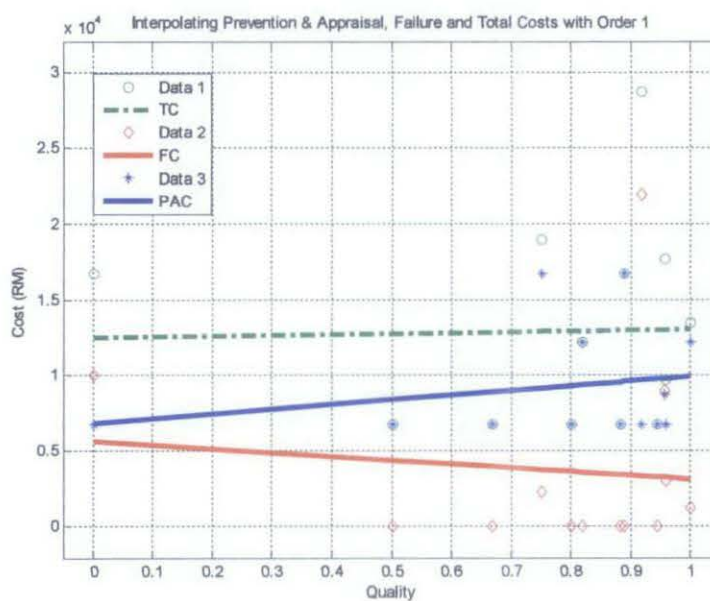


Figure 4.2: Interpolation of prevention and appraisal, failure and total costs using 1st order polynomial

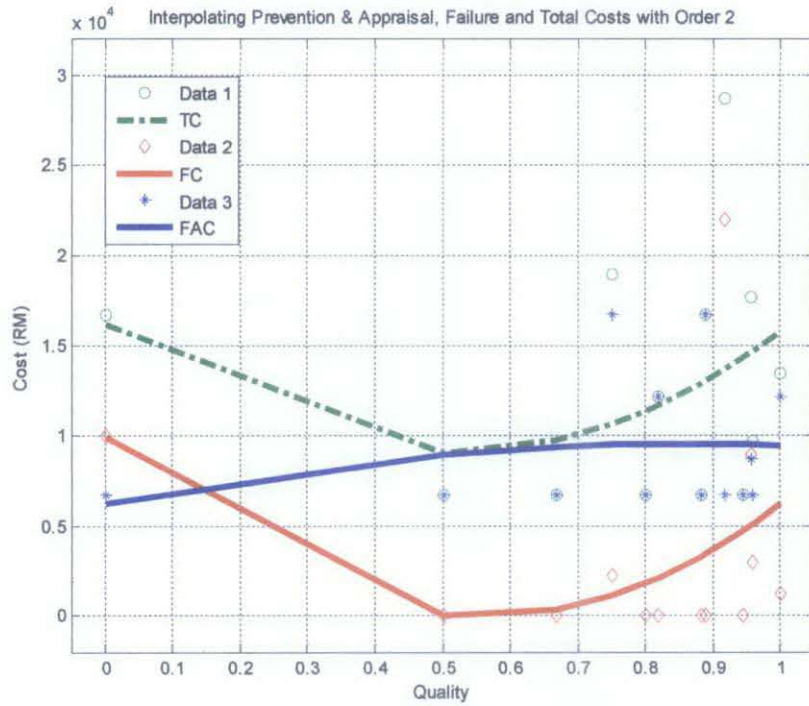


Figure 4.3: Interpolation of prevention and appraisal, failure and total costs using 2nd order polynomial

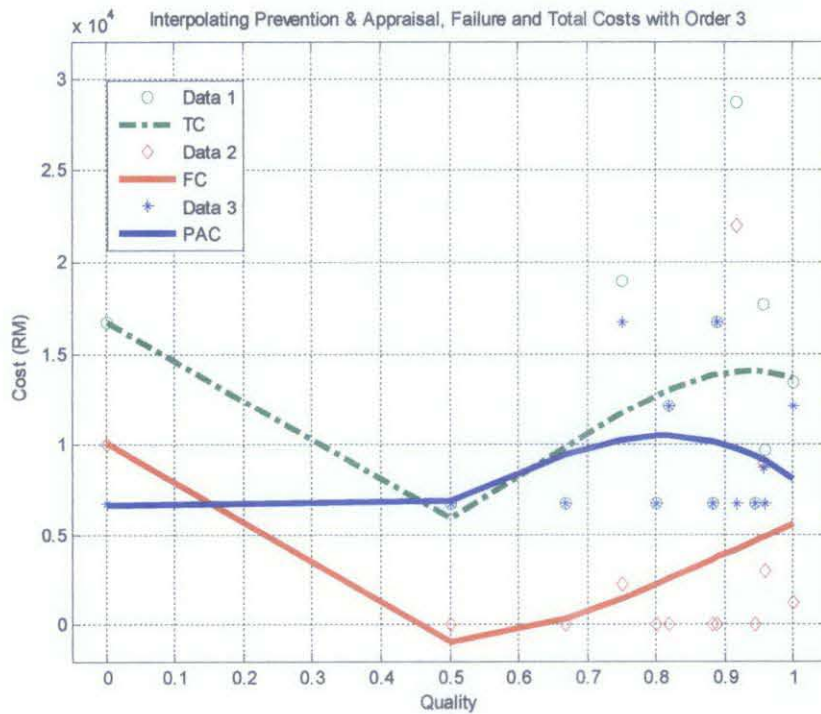


Figure 4.4: Interpolation of prevention and appraisal, failure and total costs using 3rd order polynomial

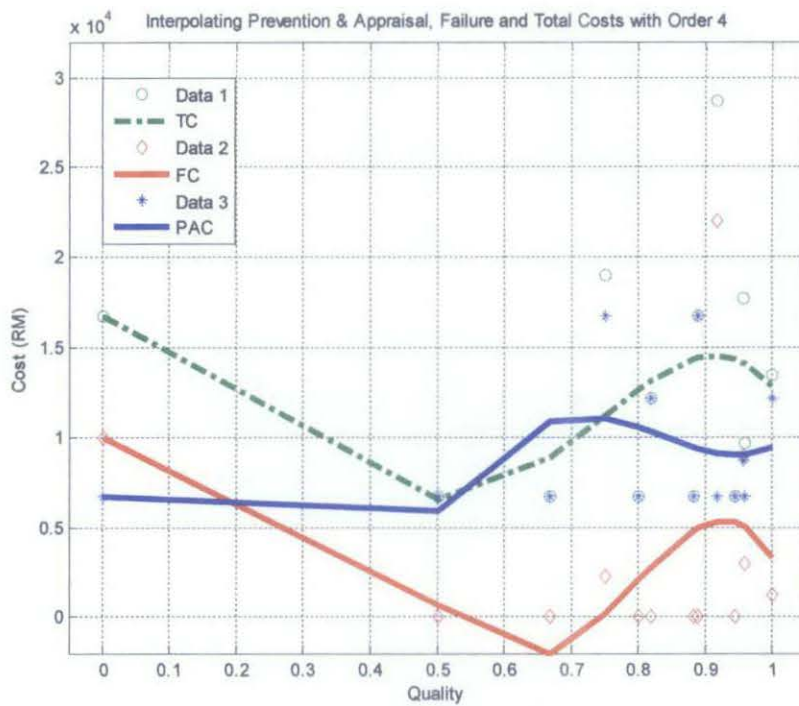


Figure 4.5: Interpolation of prevention and appraisal, failure and total costs using 4th order polynomial

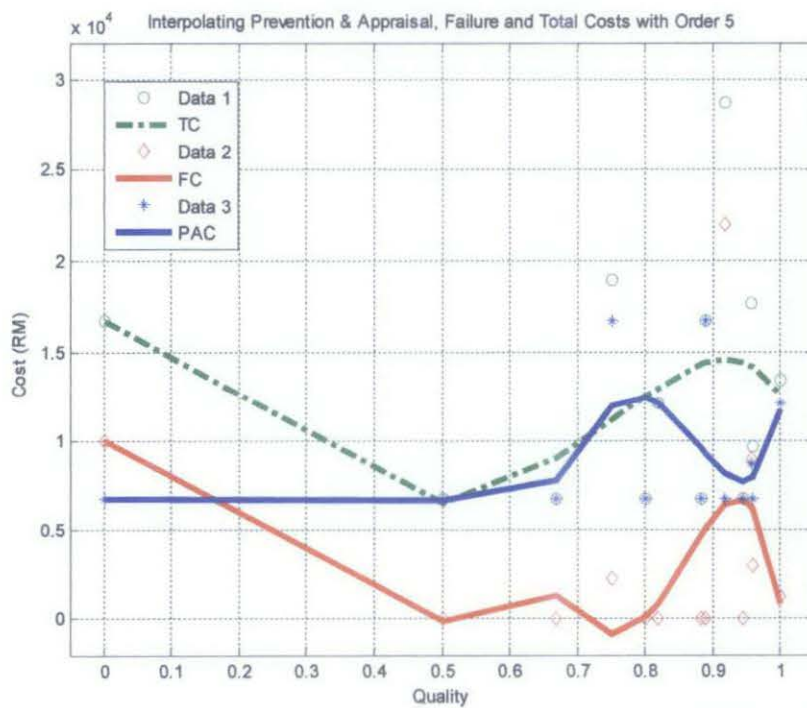


Figure 4.6: Interpolation of prevention and appraisal, failure and total costs using 5th order polynomial

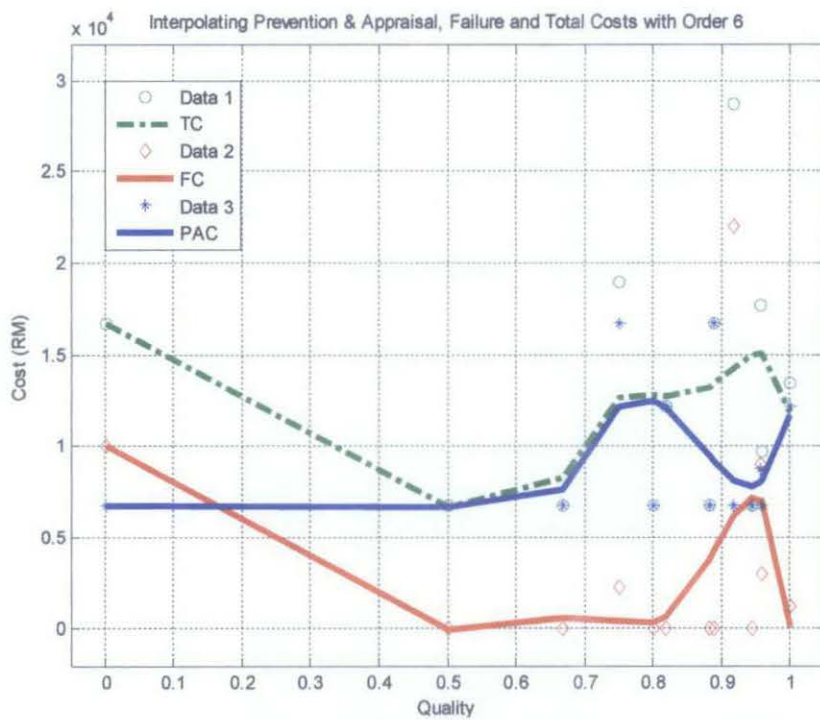


Figure 4.7: Interpolation of prevention and appraisal, failure and total costs using 6th order polynomial

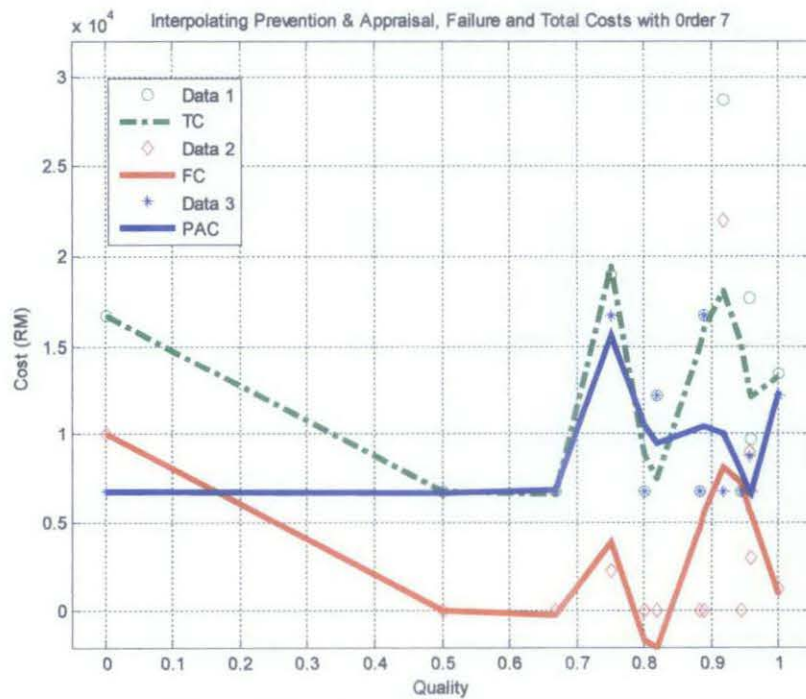


Figure 4.8: Interpolation of prevention and appraisal, failure and total costs using 7th order polynomial

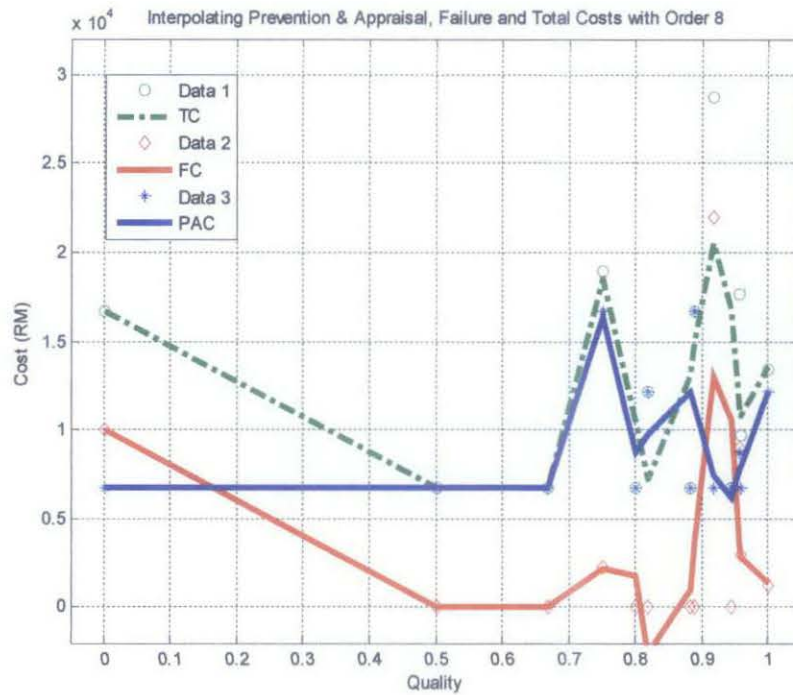


Figure 4.9: Interpolation of prevention and appraisal, failure and total costs using 8th order polynomial

Generally, it should be noted that changing the polynomial order does not affect the analysis and outcome of the data as the company's performance is still correctly being assessed. Referring to the results of the curves fitted using Vandermonde method, we can see the pattern where when the prevention and appraisal cost (blue line) increase, the failure cost (red line) decrease as being directly portrayed using 1st order in Figure 4.2. As the order increase, we can see that curves are slowly forming into something sensible and the best curves would be during the 7th order where we can see all the curves (TC, FC and FAC) are beautifully being fitted but when we reach the 8th order, the curves starting to be unstable.

From Figure 4.8 we can see that there are two break-even points being produced on the total cost's curve meanwhile on other graphs, they partially showed the break-even point. The first point being identified at quality value of 0.818 with total cost of RM 7,468 and the second point is at quality value of 0.958 with total cost of RM 12,090. Furthermore, total cost produces two vertexes at the quality of 0.75 and 0.92.

4.4 Spline Interpolation

For some cases, polynomials such as Vandermonde can lead to erroneous results because of round off error and overshoot. Hence alternative approach is to apply lower-order polynomials to subsets of data points. Such connecting polynomials are spline functions. In using spline method in this study, we can counter check with the results obtained by Vandermonde and try to choose the most suitable quality model produced between both methods.

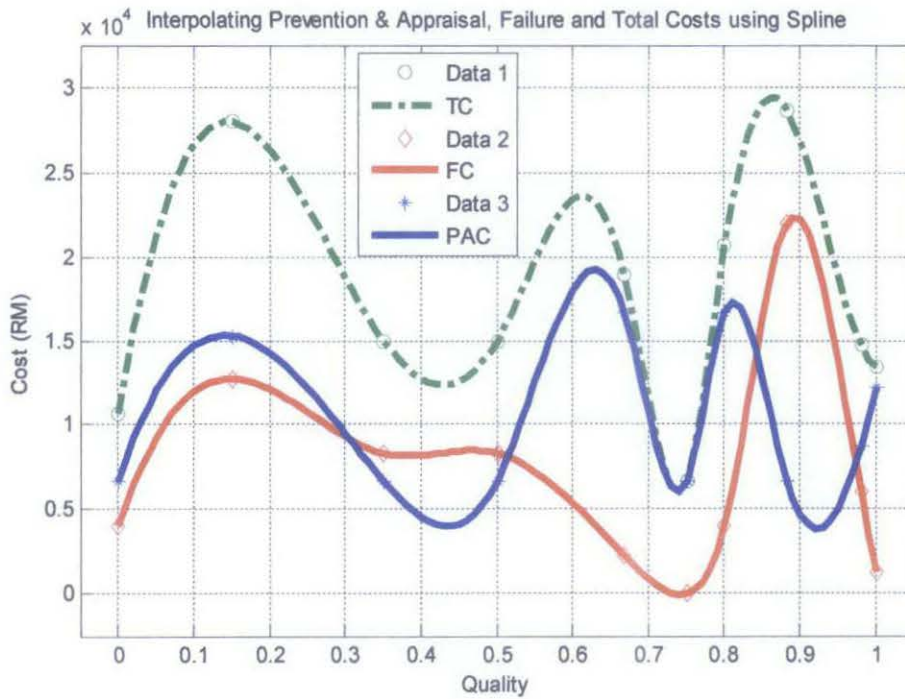


Figure 4.10: Interpolation of prevention and appraisal, failure and total costs using spline method

From the Figure 4.10, we can see that the curves produced using spline interpolation method is plotted smoothly. From close look, the total cost's curve (green line) possesses two break-even points which lie at quality 0.43 with the total cost of RM 12,340 and the other one is at quality 0.74 with total cost of RM 6,086. In addition, the total cost produces three vertexes points at the quality of 0.14, 0.61 and 0.87.

4.5 Discussion

Based on the observation from the findings of both methods, there are unclear pattern of curves for the prevention and appraisal, failure as well as total cost. In this case, we can try to overcome the problem by instantaneously monitor the failure cost, which appears to be random in nature, and prevent from checking it periodically in order to make sure managers can act accordingly whenever failure strikes and start to increase. This will lead to saving the company's resources because common practice by the industry, even the failure cost remains constant the company still blindly supplies resources until the end of the project.

As obvious as it might seems this situation is a trade-off between blindly supplying resources to prevent failures, and to instantaneously monitor when the actual failures occur before the company supply the resources. What is better the trade-off is obtained through mathematical studies hence there is higher reliability. Furthermore it is not always applicable that if we spend a lot of resources at a particular area, the area will be improved. Thus we need more clear view on the nature of the project itself in order to predict the project's behavior hence the company should implement quality model in their construction project.

By implementing quality model, the company can monitor the curve's pattern of the project they are conducting and take immediate action whenever they notice the increasing pattern of failure cost. We focus more on failure cost because the cost is something that we can avoid from happening and although the failure might seldom occurred but once it happened, it can cause the contractor to lose unnecessary a huge amount of money.

Simple analogy in break-even analysis is that if a business sells fewer than 200 tables each month, it will make a loss, if it sells more, it will be a profit. How the business managers get this information is through break-even analysis. So basically for our case study, what we want at the end of the day is to produce the products (in this case, building) with the best quality and the same time with lowest cost possible.

From the findings, the break-even values yield by the spline method are at quality 0.43 with the total cost of RM 12,340 and the other one is at quality 0.74 with total cost of RM 6,086. Comparing both points, clearly what we will think is why bother spend twice the cost to get lower quality when we can cut the cost and get the best quality out of it.

Somehow the question of how the company can know when and where they can implement the quality model is another different story. This is because to thoroughly know the overall cost cycle of the company, a substantial amount of data is required. Hence to decide the location to invest the cost mentioned above whether at the commencement of the project, middle or approaching to the end, it is all depending on the cost cycle of the company itself.

The **purposes of finding the vertexes and break-even points** are to assist the company in order to implement appropriate periodic strategies for future project. Furthermore they are able to respond immediately on the random nature of the failure cost. Whenever they detect any sudden increase in the failure cost, they can attend to the problem as quick as possible to avoid any serious problems to occur later. Lastly, the company wouldn't have to constantly supplying resources on prevention and appraisal activities as they can watch the pattern of the curves and can stop supplying the resources whenever they see the failure cost reduces.

4.6 Comparing with Previous Study

Vandermonde Interpolation

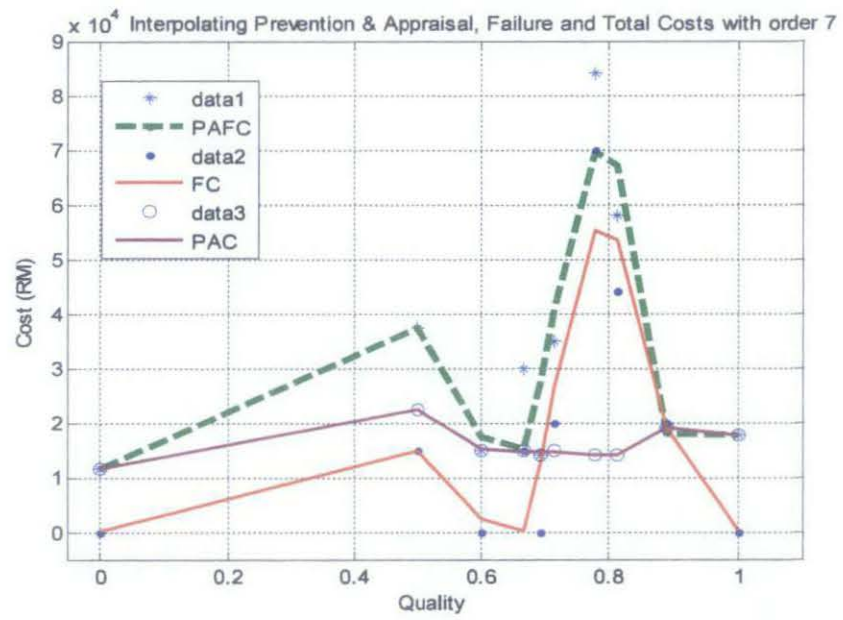
As can be seen on Figure 4.11, from Izzat (2011) and current study, the best-fitted curves for Vandermonde would be at 7th order compared to others. Somehow this condition may not be applicable in other situation because we still need to consider the pattern of the data itself. In addition, the total cost curves from both studies possess two break-even points and two vertexes:

Points	Izzat, 2011	Current case study
Break-even points	0.60, RM 17,310	0.818, RM 7,468
	0.67, RM 15,000	0.958, RM 12,090
Vertexes	0.50	0.75
	0.78	0.92

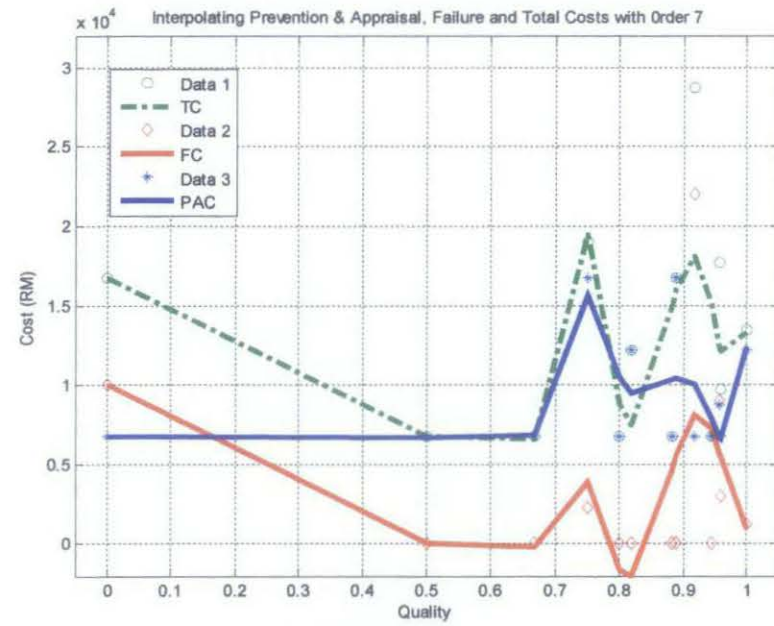
Table 4.3: Breakeven points and vertexes for Vandermonde curves

Comparing the two points from Izzat (2011), it is clear that the second break-even point is much better than the first one due to its higher quality and lower total costs. Meanwhile for current study, the first point is better compared to the second point. This is because when we equate the value to 1, the first point needs RM 9,129 to reach quality value of 1 meanwhile the second point needs RM 12,606 to reach quality value of 1. Hence in term of cost wise, the first point is better.

For both cases, the increasing of the failure costs started in the middle period of the project and oscillates further until a sudden increment towards at the end of the project .The prevention and appraisal cost curve seems to be constant with relatively small oscillation ripples while the failure curve appears to be random. Hence, the total cost curve is merely dependent on the failure cost. Thus, it can be concluded that both companies implement the strategies of constantly feeding its prevention and appraisal cost activities to prevent failures which is a common practice in the industry where they learnt to always play on the safe side in order to avoid failure cost outbreak.



(Izzat, 2011)



(Current case study)

Figure 4.11: Comparing Vandermonde's curves

As being recommended by Izzat (2011), Vandermonde fitting would yield a smoother curve if the amount of data increase which would yield a more sensible outcome. Somehow after using a larger set of data for this study i.e. 30 months compared to previous study (18 months), in the end of the day the number of data is reduced. This is because when we converted the number of complaints into quality's value, there are many of them having similar quality's value which is 1. So in order to plot the curves, we cannot just simply take the data as it is but rather take the average where it leaves us with lesser data size that lead to the failure of Vandermonde to yield smoother curves. Due to this, other than increasing the data size to be used in the research, we also need to ensure that the data after being converted to quality's value are having different value from each other so that we do not need to take the average in order to preserve the data size.

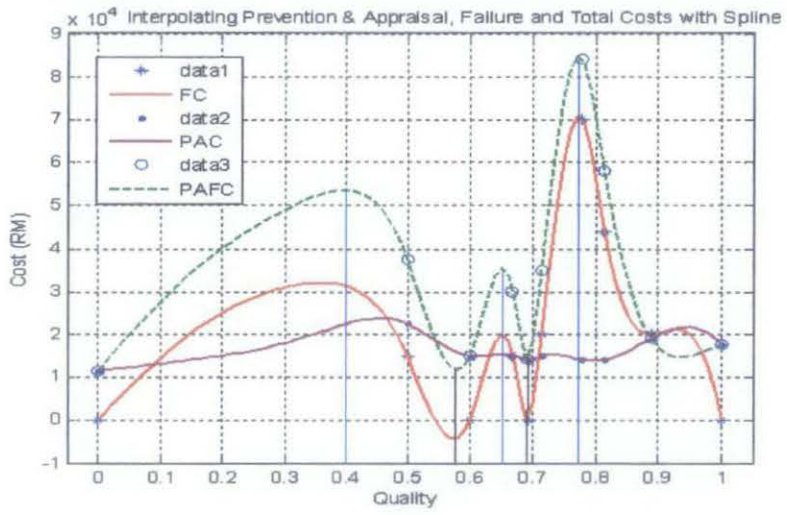
Somehow, looking at every aspect of the results, for both studies, the spline is doing much better than Vandermonde in term of curve fitting thus giving better break-even points.

Spline Interpolation

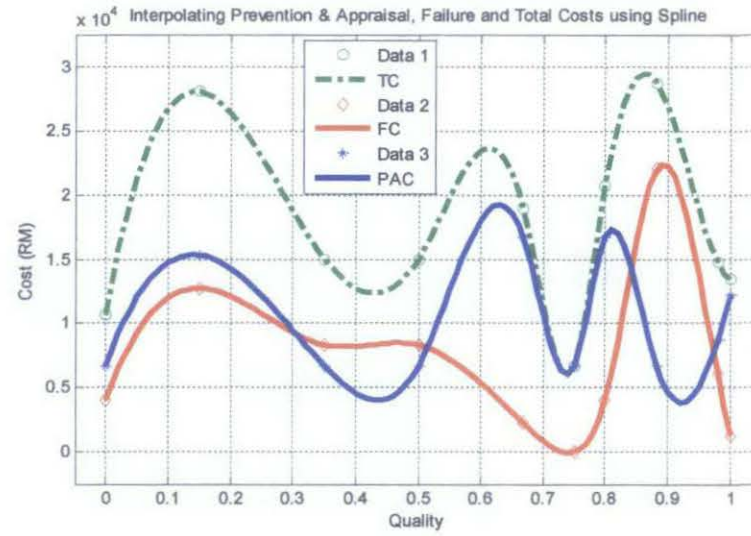
Comparing the two points from Izzat (2011) from Table 4.4, it is clear that the second break-even point is much better than the first one due to its higher quality and quite considerable amount of cost. Meanwhile for current study, the second point is obviously better compared to the first point as it possesses high quality value with lesser amount of cost needed.

Points	Izzat, 2011	Current case study
Break-even points	0.58, RM 11,650	0.43, RM 12,340
	0.69, RM 13,990	0.74, RM 6,086
Vertexes	0.40	0.14
	0.65	0.61
	0.77	0.87

Table 4.4: Breakeven points and vertexes for spline curves



(Izzat, 2011)



(Current case study)

Figure 4.12: Comparing Spline's curves

For both studies, the increasing of the failure costs started in the first quartile and the middle period of the project and oscillates further until a sudden increment towards at the end of the project .The prevention and appraisal cost curve seems to be constant with relatively small oscillation ripples while the failure curve appears to be random. Hence, the total cost curve is merely dependent on the failure cost.

The total cost curves differ with regard Vandermonde and spline graphs where Vandermonde interpolation produces two vertexes while spline interpolation produces three vertexes for both studies. Hence, it is clear that **spline interpolation gives the best fitting of the data comparing to Vandermonde interpolation** where Vandermonde produces a quite similar curve pattern to linear regression curve while the spline method produces a cubic interpolating curve pattern. The reason why spline interpolation is better is because the relationship between cost and quality is not linearly related to each other. Hence, choosing a linear regression curve pattern would not be appropriate and would not yield sensible results.

In brief, from the findings in this study, it is proven that spline interpolation produces more desirable and better-fitted curves compared to Vandermonde. Somehow initially we aimed to improve the Vandermonde curve fitting by using larger case study compared to Izzat (2011) with 30 months duration. Somehow when converting the number of complaints to quality values, there are several months with the same value hence we need to take the average of it when plotting the curves. That is why the size is reduced from 30 to 14 and affects the ability of Vandermonde to come out with smooth curves. Hence this study is unable to portray the best curves for Vandermonde although the data used is large. To overcome this problem in future study, we need to ensure that apart from using larger set of data, the data need to be in the same size even after converting the value of number of complaints to quality. This is because we want to avoid taking average when plotting the curves that will lead to decrease in data size and at the end of the day affecting the Vandermonde curves.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The quality of products or services surely does not focus only on the delivery or end product but on the quality of whole business process. Although various methods of quality management have been implemented, the quality performance still cannot achieve the requirements. Hopefully with this study, we can develop effective quality management tools so that contractors can utilize the tools in order to further improve quality by minimizing the number of defects and maximizing the yield percentage in a population. As a result, the project cost will be significantly reduced without compromising the quality of the end products.

As mentioned earlier in the literature review section, similar case study had been conducted, somehow using smaller data size which is about 18 months. And from the results we found out that Vandermonde interpolation does not produce good and smooth curves due to limited data size. Hence, in order to improve the curve plotting, we are using larger data size than before for this time around which is around 30 months. Meanwhile for spline interpolation technique, due to 3rd degree polynomial nature, it is able to produce smooth curves even for smaller data size.

Overall, the main objective of this study is to use the Vandermonde and spline interpolation techniques to best-fit the data used. PAF modeling cannot show the correlation between costs of prevention, appraisal and failure as we cannot determine the break-even point out of it. Meanwhile for Vandermonde and spline techniques, they are able to show the break-even point(s) out of the total cost. Somehow after comparing both methods, it is clear that spline does produce better and smoother curves and better value of break-even points compared to Vandermonde.

In comparison with previous study conducted by Izzat (2011), the Vandermonde and spline interpolation showed similar properties as being shown in Section 4.6. Somehow detailed comparison between the curves obtained this time around and previous is not possible because both projects are different in the sense of location, period of construction and type of development.

In addition, there are several recommendations had been made to assist future research on this topic so that there will be improvement in the findings and able to produce more reliable quality model which are:

- i) In order to produce sensible outcome from Vandermonde interpolation, other than increasing the data size to be used in the research, we also need to ensure that the data after being converted to quality's value are having different value from each other so that we do not have to take the average in order to preserve the data size.
- ii) To make it easier for analysis and to produce more reliable results, companies should keep better records of fine details related to prevention, appraisal and failure costs as not all the costs are being mentioned and recorded in their documents.
- iii) The contractors also need to keep on track the number of complaints that they received every month either in the form of non-compliance report (NCR)/written or orally reported.
- iv) When implementing the quality model in the company, the data need to be plotted in the same pace with project's progress so that if the curves show significant increase in failure cost spent, they can take immediate action to solve the problems.

REFERENCES

Ahire, S. L. 1997. Management Science- Total Quality Management interfaces: An integrative framework.

Alvy Ray Smith, 1983, Spline Tutorial Notes, Computer Graphics Project, *Lucasfilm Ltd.*

Berengard Y., 2010-2011, Applied and Engineering Mathematics
<<http://www.simumath.com>>

B.Bradie. (2006), *A friendly introduction to numerical analysis*. Pearson Prentice Hall, New Jersey.

Arditi, D., & Gunaydin, H. M., 1997, Total quality management in the construction process. *International Journal of Project Management*.

BS 4778, 1987, "*Quality Vocabulary*", British Standards Institute, London.

Chapter 3; Interpolation, 1994-2011 <<http://www.mathworks.com>>

Dale, B.G. and Plunkett, J.J. 1995, *Quality Costing*, 2nd edition, Chapman and Hall, London.

Department of Community and Family Medicine, Duke University Medical Center, 2005, "Patient Safety – Quality Improvement"
<<http://patientsafetyed.duhs.duke.edu/>>

- Elghamrawy, T., & Shibayama, T., 2008. Total quality management implementation in the Egyptian construction industry. *Journal of management in Engineering (ASCE)*, 24(3), 156-161.
- Farin, G, *Curves and Surfaces for Computer-Aided Geometric Design*. Fifth edition. Academic Press, 2002.
- Foster, JST, 1996, "An Examination of the Relationship Between Conformance and Quality-Related Costs", *International Journal of Quality & Reliability Management*.
- Fox, M.J., 1989, "The great economic quality hoax", *Quality Assurance*
- Griffin J., 2003, *Customer Loyalty*, Jossey-Bass, Inc., a John Wiley and Sons, Inc. Company
- Gutierrez P.H. & Dalsted N.L., 2010, *Break-Even Method of Investment Analysis*, Colorado State University <<http://www.ext.colostate.edu>>
- Hellard, R. B.,1994, *Quality management in construction; Quality Management in Building and Construction*, 41-48.
- Introduction to MATLAB, Cooperative Institute for Meteorological Satellite Studies <<http://cimss.ssec.wisc.edu/>>
- Jr, J. L. B., Matthews, M. F., & Kalidindi, S. N., 1991. Quality management in construction industry; *Journal of Construction Engineering and Management*, ASCE, 117(2), 341-359.

- J.S. Oakland, 1993, *Total Quality Management*, 2nd ed., Butter worth Heinemann Ltd, Oxford.
- Juran, J. M., 1989, *Universal Approach to Managing for Quality, Executive Excellence, ABI/Inform Global*.
- Juran, J.M.; Godfrey, A.B., 1999, *Juran's Quality Handbook (5th Edition)*, McGraw-Hill
- Liu X.B., Cui F.J., Meng Q.N., Pan R.L., 2008, *Research on the Model of Quality Cost in CIMS Environment, Dalian University of Technology (DUT)*
- M. Izzat M. I., 2011, "Quality Improvement in Construction Project in Malaysia: Evaluation using Vandermonde and Spline Techniques", Thesis, *Universiti Teknologi PETRONAS*.
- Matlab Company, 2002, "Matlab User Guide: version 5.3," Matlab Company, USA.
- McCabe S., 1998, *Quality Improvement Techniques in Construction, Addison Wesley Longman Limited*.
- McKinley S. and Levine M., 1998, *Cubic Spline Interpolation*.
- Numerical Analysis for Engineering, *University of Waterloo* <<https://ece.uwaterloo.ca>>
- Roberts, R. (1991), "Quality does not cost - it pays", *Australian Construction Law Report, Vol. 10*.
- Schiffauerova, A. and Thomson, V., 2006, "A Review of Research on Cost of Quality Models and Best Practices", *International Journal of Quality and Reliability Management*.

Schneiderman, A.M., 1986, "Optimum quality costs and zero defects", *Quality Progress*

Sörqvist L.,(1998). "Poor Quality Costing." Doctoral Thesis No. 23, Royal Institute of Technology, Stockholm.

Tcherpokov M., 2006, A Training Tool on the Trilogy Quality Model slides, *Brigham Young University, Provo, Utah.*

The Original Quality Gurus, *Department of Trade & Industry, UK* <www.dti.gov.uk>

Trefethen N., February 2010, "Approximation Theory and Approximation Practice", TU Berlin

Vivian, W.Y.T., Khoa, N.L. and Hoang, N.L., 2008, "Using Gaussian and Hyperbolic Distributions for Quality Improvement in Construction; Case Study Approach", *Journal of Construction Engineering and Management @ ASCE.*

V.W.Y. Tam, K.N. Le., 2007, *International Journal of Project Management* 25

Wan Yusof, W.M., A. Hakim Mohammed, M. Saidin Misnan, Zakaria, M.Y. and A. Bakri, 2006, "Development of Quality Culture in the Construction Industry", *Universiti Teknologi Malaysia (UTM) Skudai.*

Wong, A., & Fung, P., 1999, Total quality management in the construction industry in Hong Kong: A supply chain management perspective. *Total Quality Management*, 10(2), 199-208.

Zhao, J., 2000, An Optimal Quality Cost Model, *Applied Economic Letters.*