THE COST OF QUALITY REDUCTION ON A CROSS COUNTRY PIPELINE CONSTRUCTION PROJECT

By

Mr. Chenggong FENG

A Thesis Submitted in Partial Fulfillment of the Requirements
for Master of Engineering (ENGINEERING MANAGEMENT)
Department of INDUSTRIAL ENGINEERING AND MANAGEMENT
Graduate School, Silpakorn University
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In today's increasingly fierce market competition, enterprises optimization to maximize profits through continuous innovation and minimization of costs to increase their competitiveness in the market. The Cost of Quality method has been widely used in the manufacturing industry to improve product quality and save the cost of quality since the 1990s, but seldomly used in construction projects. The author introduces the successful application of the Cost of Quality method to a cross country pipeline construction project. After evaluation of the cost of quality of an on-going oversea pipeline project, the attention and commitment of top management of the construction company have been drawn. The author started a campaign to reduce the cost of quality by conducting a root cause analysis to find the root causes of quality failures and applying a brainstorm method to construct preventive actions to utilized them in the construction project. With the use of preventive measures, internal & external failures such as rework and repair at work were significantly reduced. After reassessing the cost of quality at the end of the project, the figure shows the overall cost of quality has been reduced from 15.7% to 9.9% of the contract value. The finding of this study can be a very useful lesson to other pipeline construction projects and at the same time help other quality management peers to continuously improve the quality management programs and to increase the profit of their own projects.

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At last, I hope this thesis will also inspire and encourage my children to get excellent achievements in the future and to make more contributions to society.

Chenggong FENG

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Currently, Chinese construction enterprises have gained a certain market share in the international market. By the end of 2015, there were nearly 3,000 Chinese companies are working in over 180 countries and regions (Zehua, 2016). In the 2018 US engineering news records (ENR) Ranking of the world's 250 largest engineering contractors, 69 numbers come from China.

Since the "One Belt and One Road" initiative was proposed five years ago, China state-owned enterprises have taken an active part in the construction of "One Belt One Road" and delivered satisfactory results: 47 state-owned enterprises have participated in, or invested in, and jointly built 1,676 projects with countries along the belt and road. It promoted infrastructure development, established in-depth cooperative relations in energy and resources, promoted employment and development in countries along the belt and road, and made great contributions to the sustainable development of the global economy (Xiran, 2018).

From 2013 to 2018, China's total import and export volume with countries along the "One Belt and One Road" belt and road reached 6.47 Trillion us dollars, of which over 500 billion us dollars was newly signed on foreign contract projects("Say "One Belt And One Road" report card," 2019). In the field of international engineering construction, large state-owned enterprises are the leaders in implementing the "One Belt One Road" initiative. With the promotion of "One Belt and One Road" construction, some medium-sized private enterprises, also embrace new opportunities for development and accelerate the pace of "going out", have participated in well-known overseas projects. It is estimated that the annual investment in infrastructure in Asia will reach 800 billion US dollars in the next 10 years, which will create favorable conditions for Chinese construction enterprises to enter the international construction market on a large scale and bring new hope to the temporarily depressed Chinese construction industry. Faced with opportunities, Chinese construction enterprises should learn from international companies with international and global vision, to keep itself in an invincible position constantly. What is the gap between Chinese construction enterprises and international contractors? The core competitiveness of large international engineering enterprises is not formed in a day, and the cultivation of core competence is a long-term accumulation process. By comparing the development status of Chinese construction enterprises in overseas markets with that of large international engineering enterprises, it can be found that there is a crucial problem in the internationalization process of Chinese construction enterprises: scale enlarged, but poor profitability. Chinese construction companies over the years in overseas markets, especially in Asia, Africa, and the Middle East regional market development speed is very quick, the turnover has been increased tremendously, but only a few of them can achieve profits in overseas markets. The purpose of an enterprise is to make profits. If it cannot make profits for a long time, internationalization is bound to be unsustainable. On the other hand, a big mount of well-known international engineering enterprises derives their profits from the international market, and they will not do unprofitable projects unless they are particularly needed.

It is quite common to observe that huge re-works or repairs have been done on engineering projects. These unnecessary works increase the cost of quality tremendously, as a result, the cost of the project is over-spending. The cost of quality has been overlooked by many companies in the past due to the cost of quality is barely accounted in the time-starved engineering project.

Gupta and Campbell (1995) did two surveys and found that only 33-40% of companies tracked quality costs (Gupta, 1995). Viger and Anandarajan (1999) found that only about half of the companies they surveyed calculated quality costs, in their experimental study, they also found that managers who have access to quality cost data make different decisions than managers who do not have quality cost data available (Viger, 1999). This illustrates that if quality costs are not visible, managers are unable to use quality cost information to make wise decisions.

A.V. Feigenbaum (2001) said that Globalization makes measuring, managing quality costs even more critical to success. By tracking business failure costs, opportunities for improvement are more easily identified (Feigenbaum, 1956).

The total costs of quality have been estimated by Crosby (1984) at 20-35 percent of sales for manufacturing and service companies in the USA (Crosby, 1984), by Feigenbaum (2001) at 10 percent of revenues (Feigenbaum, 1956), by Boukamp, F. (2004) at 6-15% of construction cost is found to be wasted due to rework of defective components detected late during construction and 5% of construction cost is wasted due to rework of defective components detected during maintenance (Boukamp, 2004), and by Kent (2005) at 5-15 percent of turnover for companies in Great Britain (Kent, 2005). In fact, that most conservative of these estimates might exceed a company's net profit highlights the potential importance of COQ, generally the net profit objective is lower than 10% of revenues (Sower, 2007). In fact, the additional cost to an engineering project caused by nonconformance may be even higher because the schedule delays, indirect cost and other intangible costs of poor quality normally are not considered.

The percentage of useless-cost figures could be higher, if the engineering project has been done by a state-owned enterprise (short as SOE hereafter), due to the productivity, efficiency and profitability of SOE are relatively lower than the private-owned enterprise. Due to globalization, many SOE are looking for opportunity and working in foreign countries, the biggest challenge for them is cost control, business losses occur from time to time. Measures must be taken to improve the quality assurance and control, to reduce the cost of quality under the fierce competing marketing today, especially for the SOE which is in the reforming stage.

1.2 Rationale of the Research and Problem Statement

As per American Society for Quality (ASQ), Cost of quality (COQ) is defined as a methodology that allows an organization to determine the extent to which its resources are used for activities that prevent poor quality, that appraise the quality of the organization's products or services, and that result from internal and external failures. Having such information allows an organization to determine the potential savings to be gained by implementing process improvements. The cost of quality is comprised of prevention costs, appraisal costs, internal failure costs and external failure costs. The majority of COQ comes from the internal and external failure costs due to the imperfection of working processes. Many experiments have proved that reduce the internal and external failure can save the COQ tremendously. To control the cost of quality at the lowest level will benefit the overall cost of the project. Adopting this concept to a crossing country pipeline project, the cost of quality is summarized in Table 1 below.

Cost category	Detail contents
Prevention cost	Quality assurance team (recruit, wage and insurance, etc.) Training costs Traveling costs Certification costs Internal and external auditing costs Procure qualification costs Function test costs
Appraisal cost	Quality control team (recruit, wage and insurance, etc.) Traveling costs Inspection or test is done by 3rd party required by contract (witness at vendors shop, laboratory analyses, etc.) Planed test or inspection (procured material or equipment from vendors, each working process, all deliverables, etc.) Material sampling and test Procurement of instrument or equipment Calibration of instrument or equipment Depreciation cost of instrument or equipment
Internal failure cost	Repairs Reworks Downgrading of product Scraps Re-inspection or re-test for repair or rework Enlarged or added inspection or test due to defect found
External failure cost	Repairs Reworks Scraps Re-inspection or re-test for repair or rework

	Compensation for Owner's business loss Insurance cost increasing

Table 1 Summary of The Cost of Quality

To realize that, the first thing is to survey out the what is the current status of quality performance on a project, then find out the root causes of the poor quality, make preventive measures correspondingly, apply the precautions on each working process. Finally, re-measure the quality performance, to verify if the preventive actions work.

To find out the present quality management performance on construction projects, the author of this literature took a case study on a cross-country gas pipeline project carried out by an SOE of China. The project locates at oversea. The main scope of the project includes construction and commissioning as per the requirements of the Owner. A project is a temporary endeavor undertaken to create a unique product, service, or result (PMI, 2018). Due to the special characteristics of the project, the project management team is temporary, construction personnel is temporarily recruited from society. This study will address the common poor quality in each process of the project. Analysis and calculate the cost of quality after completion 33% of construction works, use monetary data to bring the attention of the project manager because money is the basic language of upper management. The cost of quality at that time was significantly higher than the budget planned. To make effective measures to improve quality performance, a root cause analysis has been carried out between workers. According to one of the quality "gurus", W. Edwards Deming, "Inspection to find the bad ones and throw them out is too late, ineffective, costly. Quality comes not from inspection but the improvement of the process." The workers from each working process make quality and nonconformance on a daily bases, it is necessary to find out the root causes from this level of the organization other than the project management level. After finding out the desire and main reasons for non-quality, a series of precautions will be applied to site working crews, then observation and record the influence of the experiment, make sure the precautions are functional. Through the empirical analysis, the author will prove that the investment of precaution and prevention can save the cost of non-quality. Finally, a new perspective on the classic project management triangle will be introduced.

1.3 The objective of the Study

The cost of poor-quality continues to affect the project cost performance throughout the construction industry. Many companies are improving the project performance by reducing the cost of poor quality. The main objective of this thesis is to evaluate the general cost of quality on a gas pipeline project carried out by an SOE of China, take action to reduce the COQ. Specific objectives are:

Objective 1: to calculate COQ of the cross-country gas pipeline project, use the monetary data to bring the attention of management, find the critical areas which need to be improved.

Objective 2: to use root cause analysis method in order to analyze the root causes of non-quality, make and apply preventive actions correspondingly to improve the quality performance.

Objective 3: to remeasure the total COQ at the end of the project, to verify the applied preventive actions.

1.4 Scope and Limitations

The experimented project (Hereinafter referred as Project A) was a crossing country gas pipeline construction project in oversea, consisted of construction and commissioning of a 120Km gas pipeline in 30” diameter, with a launcher station and a receiver station, under emergency, the pipeline can be isolated by 6 block valve station in the middle of the pipeline at each 20km interval. The pipeline is requested to transport sour gas from the launcher station to the receiver station under 9.6 Mpa pressure. The contract value for the development was around 30 million US dollars, with a contract period of 22 months. All the quality requirements come from the contract’s scope of work. A front-end engineering design (FEED, means Basic Engineering which is conducted after completion of Conceptual Design or Feasibility Study) is incorporated in the scope of work, includes that project specification, drawings, design base manual, mater and vendor list, environmental impact assessment (EIA) reports and so on. The experimented enterprise (Hereinafter referred to as Company B) was invited to bid base on the scope of work and FEED documents.

The project was requested to use a traditional lump sum contract, with an international project management consultant team to act as owners professional repetitive, they will cooperate with owner's own project management team to supervise the EPC contractor together.

Company B is a big and top SOE of China, it became an ISO9000 quality certification holder since 2003, the quality management system has been set up, continuous quality improvement was committed by top management. The cost of quality system was never applied in any projects carried out by Company B. Normally, the project manager does not use the cost of the quality system because the project team has too many administrative works that need to be done. Moreover, they consider their cost control system is adequate to indicate all the finical information needed. Same as Abdul-Rahman (1993) argues that time pressures and fixed preliminaries hindered the implementation of the quality cost system (Abdul-Rahman, 1993). It is the first time that the cost of quality system has been used in Project A.

Burati et al. (1992) claim that the indirect costs of rework can be significant and that the direct costs are only the 'tip of the iceberg'. Normally, the cost of quality only represents the direct, visible and tangible portion of the real total quality costs (Burati, 1992). Due to the indirect costs are intangible and vague, it is difficult to measure and evaluate, therefore, the indirect costs of poor-quality in the projects are not presented in this thesis.

The VDA treats pre-commissioning and commissioning as a validation process which's expenditures shall belong to prevention cost (Industry, 2015). In a pipeline construction project, the pre-commissioning and commissioning activities are normally treated as a working process, therefore, these costs are not calculated as the cost of quality in this thesis.

1.5 Definitions of Terms

ASQ	The American Society for Quality
One belt one road	The Belt and Road Initiative (BRI), also known as the One Belt One Road (OBOR) (or the Silk Road Economic Belt and the 21st-century Maritime Silk Road, is a development strategy adopted by the Chinese government involving infrastructure development and investments in 152 countries and international organizations in Europe, Asia, Middle East, Latin America and Africa ("Belt and Road Initiative," 2019).
VDA	Verband der Automobilindustrie
MC	Means mechanical completion, it is a milestone of the project schedule, the project is ready for commissioning after MC date.

1.6 Organization of the Thesis

This thesis is organized by six chapters, they are:

Chapter 1	gives a general introduction to this study.
Chapter 2	describes the previous researches.
Chapter 3	documents the methodology used in this study.
Chapter 4	describes the measuring of current quality performance level and calculation of COQ of the pipeline project. Use the monetary data

to bring the attention of management, find the critical areas which need to be improved.

Chapter 5 states the finding of root causes of non-quality by root cause analysis method from the worker level of each process, then general preventive actions to each working process have been made to improve the quality performance. Remeasures of COQ at the end of the project, compares the investment on prevention cost and reduction from total COQ.

Chapter 6 makes a conclusion and recommendation.

1.7 Significance of the Study

Project quality cost data is an important indicator of quality defects and a weak point in quality management. The applied quality management strategy will benefit the company from both internal and external. It reduces the quality cost significantly, promotes the construction speed, enhances the costumer's satisfaction level, sets up a good company image and reputation. Eventually, the culture of quality will become more and more favorable.

The cost of quality is just a method that can measure the process failures and provide monetary information for project management to make decisions on activities that need to be prevented their occurrence. Furthermore, the cost of quality records about one project can be a very useful lesson learned to the next project. The findings of this study should be helpful to other quality management peers to continuously improve the quality management programs and to increase the profitability of other projects.

CHAPTER 2

LITERATURE REVIEW

2.1 Quality Definition in Construction Projects

Quality may have different meanings to different people. Many quality definitions were concluded by the quality organization and quality gurus.

The International Organization for Standardization (ISO 1994a) defines quality as "the totality of characteristics of an entity that bears on its ability to satisfy stated or implied needs" (ISO) .

The American Society for Quality (ASQ) defines quality as "a subjective term for which, each person has his or her definition. In technical usage, quality can have two meanings:

1. The characteristics of a product or service that bear on its ability to satisfy stated or implied needs.

2. A product or service free of deficiencies.

ASQ further concludes that quality is:

• Based on customers' perceptions of a product's design and how well the design matches the original specifications.

• The ability of a product and service to satisfy stated or implied needs.

• Achieved by conforming to established requirements within an organization (Quality, 2017).

The definition of quality has been vividly and pellucidly summarized by quality gurus who significantly contributed to the quality movement in philosophies, methods and tools, etc.

They defined quality as follows:

1. W. Edwards Deming—Quality should be designed into both products and the process.
2. Joseph M. Juran—Quality is fitness for use.
3. Armand V. Feigenbaum—Best for customer use and selling price.
4. Kaoru Ishikawa—Quality of the product as well as after-sales services, quality of management, the company itself, and the human being.
5. John S. Oakland—Quality is meeting customer's requirements.
6. Philip B. Crosby—Conformance to requirements not as "goodness" or "elegance."

Abdul Razzak (2011), concludes a method to make a common definition of quality according to the foregoing quality definitions, it is primarily related to the manufacturing, processes and service industries, i.e.: to meet the customer's need, fitness for use and conforming to requirements (Rumane, 2011).

However, the quality definition in construction projects is different from that of manufacturing or services industries due to the character of construction project which is not repeatable but a unique piece of work with specific requirements from clients. Abdul Razzak (2011) explained that the statistical process control (SPC) method is widely used in quality control of manufacturing industries, which could eliminate problem causes by reducing the variability and increasing the efficiency of the processes. The poor-quality products are identified as repaired, reworked, or scrapped, which could be reduced and ultimately eliminated. However, the quality management scenario in construction projects is different. The nonconforming work is not easy to be rectified if anything goes wrong, sometimes the nonconforming work has to be kept as it is.

Chung (1999) states that "Quality of construction is even more difficult to define. First of all, the product is usually not a repetitive unit but a unique piece of work with specific characteristics. Secondly, the needs to be satisfied include not only those of the client but also the expectations of the community into which the completed building will integrate. The construction cost and time of delivery are also important characteristics of quality" (Chung, 1999).

The American Society of Civil Engineers (ASCE) (2000) have defined quality as "the delivery of products and services in a manner that meets the reasonable requirements and expectations of the owner, design professional, and constructor, including conformance with contract requirements, prevailing industry standards, and applicable codes, laws, and licensing requirements. Responsibilities refer to the tasks that a participant is expected to perform to accomplish the project objectives as specified by contractual agreement and applicable laws, codes, standards, and regulatory guidelines. Requirements are what a team member expects or needs to receive during and after his or her participation in a project" (Engineers, 2000).

Abdul Razzak (2011), claims that quality in construction project related to the quality of products and equipment used in the project and total management approaches to complete the project, it depends primarily on management of construction processes, which is the contractor's main responsibility. He defined the quality of a construction project as to meet the needs of the project owner in accordance with the pre-defined scope of work within the cost and time. This concept can be called as " construction project trilogy," as shown in figure 1.

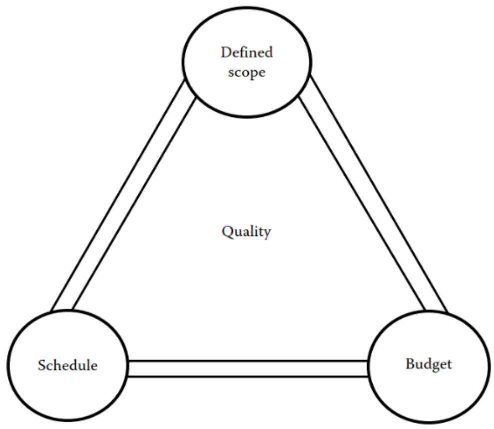

Figure 1 Construction project trilogy

Source: Abdul Razzak Rumane, 2011, Quality management in construction projects. p.9

2.2 Cost of Quality Method and Its Advantages

The concept of Cost of Quality emerged in the 1950s. The concept of quality cost is a way of quantifying the total cost of quality-related efforts and defects. It was first described by Armand V. Feigenbaum. Various concepts of Cost of Quality have emerged since. Juran has defined the Cost of Poor Quality (COPQ) as follows: "COPQ is the annual monetary loss of products and processes that are not achieving their quality objectives. The COPQ is not limited to quality but is essentially the cost of waste associated with the poor performance of processes". AjayKumar (2002) said that Cost-of-Quality measurement provides a yardstick for decision-making. The excessive waste and rework in processes can be identified by COQ (Mehta., 2012).

The function of a COQ program is not only to simply list all the COQ elements and the costs of each element but to use that monetary information to identify the best opportunities for improvement and, once an improvement endeavor is undertaken, to monitor its effect if the COQ has been reduced (Susanne, 2006).

Many enterprises use COQ as a key measure for improving business results, track the cost of quality and received remarkable benefits. Susanne Donovan (2006) states that after CRC industries applied COQ in 1997, the company has reduced failure dollars—the money they spend because of products and services that do not meet our customers' requirements-from 0.70 of sales to 0.21% of sales. The cost of quality can also be linked to other improvements at CRC Industries, including shipping error reductions, customer service order entry error reductions, productivity increases, hazardous waste reduction, and profitability (Susanne, 2006).

Frank Gryna (1999) states that the primary objectives of COQ as below (J. Juran, & Godfrey, A. B., 1999):

1. Quantify the size of the quality issues in language that will draw the attention of upper management. Use the monetary language to improve communication between middle managers and upper managers. Some managers may think it is not necessary to translate the quality defects into dollars, they knew that quality is important, also realized what are the major problems. Typically, when they saw the results of the study, these managers are surprised by two results. First, the quality costs turn out are much higher than what they thought. In many industries, COQ is more than 20 percent of sales. Second, while the distribution of the quality costs confirms some of the known problem areas, it also uncovers other problem areas that had not been recognized previously.

2. Finalize primary opportunities for reduction in the cost of poor-quality throughout all activities in an organization. Costs of poor quality do not exist in every activity. Instead, they are produced in specific processes, each traceable to some specific cause. These poor qualities are different in size, and a relatively vital few of the poor qualities account for the majority of the costs. A major function of evaluation of costs of poor quality is the identification of these vital few poor qualities. This results in setting priorities to assure the effective use of investments. We need to collect data

on the cost of poor quality, analyze these data, and make a plan for improvement strategy that targets on the vital few of the glacier rather than the whole ice ocean.

3. Identify opportunities for increasing customer satisfaction and reducing associated threats to sales revenues. Some costs of poor quality are due to the result of customer dissatisfaction with the goods or services provided by the company. This dissatisfaction results in a reduction of current customers (customer defections) and an inability to attract new customers. Identifying the areas where have the dissatisfaction promotes to improve retention of current customers and create attraction to new customers.

4. Provide a means of measuring the result of quality improvement activities instituted to achieve the opportunities in 2 and 3 above. Measuring progress helps to keep a focus on improvement and also spotlights conditions that require the removal of obstacles to improvements.

5. Align quality goals with organizational goals. Measuring the cost of poor quality is one of four key inputs for assessing the current status of quality (the others are market standing on quality relative to the competition, the organization quality culture, and the activities composing the quality system). Knowing the cost of poor quality (and the other elements) leads to the development of a strategic quality plan consistent with overall organizational goals.

Collectively, these objectives strive to increase the value of product and process output and enhance customer satisfaction. This section uses the framework shown in

Figure 2. Note that this framework extends the traditional concept of quality costs to reflect not only the costs of nonconformities but also process inefficiencies and the impact of quality on sales revenue. Sometimes, the term “economics of quality” is employed to describe the broader concept and differentiate it from the traditional concept of “quality cost.”

We must emphasize the main objective in collecting this data, i.e., to energize and support quality improvement activities.

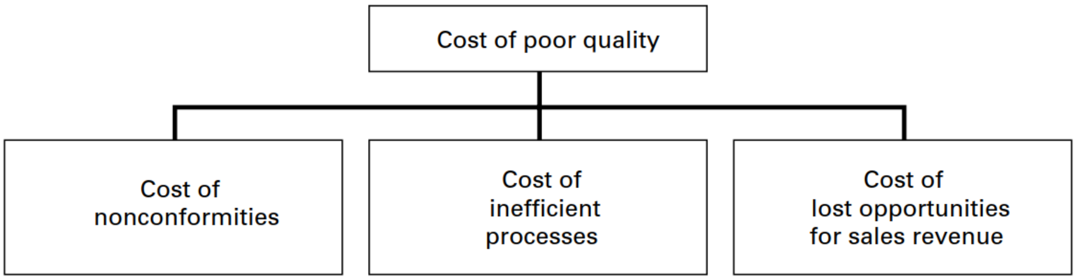

Figure 2 Components of the cost of poor quality

Source: Juran and Gryna, 1988, Quality handbook, p. 8.4

There is an old maxim about the quality that the sooner you catch the problem, the much less its impact. Trending the cost of corrective and preventive actions is a useful management indicator. It provides a powerful tool to help focus priorities and assess the return on quality. It is hoped that all quality professionals implement a quality cost tracking system as part of their corrective and preventive action system. AjayKumar(2002) claims that components of Cost of Quality as below:

A) Cost of Non-conformance: It represents the total costs to the organization of failure to ensure conformance to the requirements-which is "Bad Quality".The cost of Non-conformance is further classified into External failure costs and internal failure costs

B) Cost of conformance It is the total cost to ensure that a product conforms to the requirements-which it is of "Good Quality". It includes the costs of Quality Assurance and Quality Control activities. It represents an organization's investment in ensuring the quality of its products and services. The cost of conformance is further classified as Prevention costs and Appraisal costs

C) Lost opportunities for sales revenue: Customer lost: profits from potential customers who have shifted to competitors. Loss of new customers due to inefficient processes: profits lost from the potential customers because of inadequate processes to meet customer needs

Frank Gryna (1999) states that the cost of quality is normally divided into four parts, details as below:

1) Prevention costs.

These costs are incurred to keep failure and appraisal costs to a minimum. Prevention costs are costs of special planning, review and analysis activities for quality. Prevention Costs are any costs that are incurred to minimize appraisal and failure costs. This category is where most quality professionals want to live. They say an ounce of prevention is worth a pound of cure and it is what this category is all about. This includes the activities that contribute to the creation of the overall quality plan and the numerous specialized plans. Examples include:

Review of new products:	The quality planning and inspection planning for new products and design of new products. Process planning: Inspection planning, Process capability studies, various other work associated with the manufacturing and service processes.
Process control:	Evaluation of in-process inspection procedures and testing to determine the current status of a process
Quality audits:	Evaluating adherence and execution of the overall quality plan.
Supplier quality selection and evaluation:	Analyzing supplier quality activities before supplier selection, perform auditing of processes during the contract, education and training of suppliers.
Quality Training:	Preparation and implementation of quality training programs Similar to appraisal cost some of this work may be executed by personnel that is not in the quality assurance department. For accounting purposes, it's important to separate this by the type of work being performed and not the department of the employees performing the work. Activity-based costing accounting lends itself to this.
Main heads:	Process planning, Process control, Supplier evaluation Quality Planning/ audit, etc.

Table 2 Examples of Prevention Costs

2) Appraisal Costs

These are the costs incurred to determine the degree of conformance to the quality requirements. Appraisal costs constitute all costs that go testing and inspecting of products. The detection of defective parts and products should be caught as early as possible in the manufacturing process. Appraisal costs are sometimes called inspection costs and are incurred to identify defective products before the products are shipped to customers. The problem with appraisal costs is in the fact that they are not true "value-added'' activities since the general inspection and testing are not requirements of the customer. The customer just expects the product to function as advertised with no requirement for the product to be tested. The fact that the product is tested and advertised as such may make the customer feel better about the product but the expectation is for the product to, "just work" and if the product was never tested then the customer would not care anyway. There are exceptions to this rule when customers require product testing as part of their purchase order/ contract. Thus, why do we spend so many resources on testing and inspecting products? The answer is in the failure costs associated with allowing a defect to escape to the next process or customer. Another unfortunate aspect of performing appraisal activities is that it doesn't keep defects from happening again. Due to this reason, managers see that maintaining an army of inspectors can be a very costly and ineffective approach to quality control.

Today's quality initiatives are increasingly asking employees and suppliers to be responsible for their quality control. Further innovations are being put into designing products to be manufactured in ways to eliminate the need for inspections or testing. Engineering reliability into a product is the most efficient process to reduce quality costs.

Main heads:	inspection and test of raw materials and other inputs Final process inspection and tests, Evaluation of stock in hand, etc.

Table 3 Examples of Appraisal Costs

3) Internal Failure Costs:

These are the costs of deficiencies discovered before delivery. Internal failure costs are costs that are incurred as a result of identifying defective products before they are shipped to customers. The labor, material, and (usually) overhead that created the defective product. The areas nomenclature is numerous and includes scrap, spoilage, defectives, etc.

The cost to correct the defective material or errors in service products that are found before sending it to the customer. Some examples of internal costs of quality are:

Lost or missing information:	The cost to retrieve this expected information The cost analyzing nonconforming goods or services to determine the root causes.

Supplier scrap and rework:	Scrap and rework costs due to nonconforming products received from suppliers. This includes the costs to the buyer of resolving the supplier quality problems
100% Sorting inspection:	The cost of completing 100% inspection to sort defective units from good units. Retest: The cost to retest products after rework or other revision
Changing processes:	The cost of modifying the manufacturing or service processes to correct the deficiencies. Redesign of hardware: The cost to change designs of hardware to correct the issues. Redesign of software: The internal cost of changing software designs.
The scrapping of obsolete product:	The cost of disposing scrap.
Scrap in support operations:	Costs from defective items in indirect operations
Rework in intimal support operations:	Costs from correcting defective items in indirect operations
Downgrading:	The cost difference between the normal selling price and the reduced price due to quality reasons.
Variability of product characteristics:	Rework losses that occur with the conforming product(e.g, overfill of packages due to variability of filling and measuring equipment
Unplanned downtime of equipment:	Loss of capacity of equipment due to failures.
inventory shrinkage:	Loss costs due to the difference between actual and recorded inventory quantity.

Non-value-added activities:	Cost due to redundant operations, sorting inspections and other non-value-added activities. A value-added activity increases the usefulness of a product to the customer; a non-value-added activity does not.
Main heads:	Rework, Increased/Re-inspection / re-testing, Scrap, Redesign/ Change in processes etc.

Table 4 Examples of Internal Failure Costs

4) External Failure Costs

External failure costs are associated with deficiencies that are found after the customer receives the product. External Failure costs represent a category in the total cost of quality where the quality costs are related to defects found after delivery of the product to the customer. External failure costs are generally the highest of the 4 cost of quality categories since the full value of work and processes had to be performed to get the product to the customer. These costs are incurred because the product shipped failed to conform to quality requirements and may include warranties, shipping charges, repairs, recalls, legal actions and lost sale.

External failure costs are notorious for being difficult to measure due to the hidden costs associated with defective products being received by the end-user. So how does one measure the cost of lost sales or loss of potential customers? One method is by using a customer survey that asks such questions regarding the behavior of returning products. For example, using a customer survey one might determine that 9 out of 10 customers who purchase a defective product are likely to discard it and only 1 of 10 return it to the manufacturer for refund or replacement a multiplier can be applied to estimate customer returns. In this case, multiplying actual customer returns can provide a reasonable estimate of this element of external failure cost. This number can help determine the typical customer's intention to on buying the product again after receiving a defective one and the number of dissatisfied customers that may provide a measure of lost sales.

Main heads:	Warranty charges, Complaints, Field returns, Penalties, Lost opportunities for sales revenue, etc.

Table 5 Examples of External Failure Costs

Comments on the Cost of Quality.

It is estimated that 60 to 70% of the total quality costs are the result of internal and external failures. These are controllable with concerted efforts by the management. When these figures are thrown up, the initial reaction of most of the management is to increase inspection activities. This will, in turn, increase the appraisal costs. This situation may not result in substantial changes either in improved quality or improved profitability. The following scenario has been observed in most of the companies before they had embarked on the formal Quality cost control program. The external failure costs found to be the highest followed by internal failure costs. The appraisal costs occupy the third position and the prevention costs are in the fourth position. It has been observed that an increase in prevention costs will result in generating larger reductions in the other cost categories

As per Frank Gryna (1999), the cost of poor quality may be underestimated due to some costs are difficult to calculate. He names these cost as "Hidden" costs occur in both service industries and manufacturing, includes:

1. Potential lost sales (see above under External Failure Costs).

2. Costs of a redesign of products due to poor quality.

3. Costs of changing processes due to the inability to meet quality requirements for products.

4. Costs of software change due to quality reasons.

5. Costs of downtime of equipment and systems including computer information systems.

6. Costs included in standards because history shows that a certain level of defects is inevitable and allowances should be included in standards:

a) Extra material purchased: The purchasing buyer orders 6 percent more than the production quantity needed.

b) Allowances for scrap and rework during production: History shows that 3 percent is "normal" and accountants have built this into the cost standards. One accountant said, "Our scrap cost is zero. The production departments can stay within the 3 percent that we have added in the standard cost and therefore the scrap cost is zero." It is like a make-believe "numbers game."

c) Allowances in time standards for scrap and rework: One manufacturer allows

9.6 percent in the time standard for certain operations to cover scrap and rework.

d) Extra process equipment capacity: One manufacturer plans for 5 percent unscheduled downtime of equipment and provides extra equipment to cover the downtime. In such cases, the alarm signals ring only when the standard value is exceeded. Even when operating within those standards, however, the costs should be a part of the cost of poor quality. They represent opportunities for improvement.

7. Extra indirect costs due to defects and errors. Examples are space charges and inventory charges.

8. Scrap and errors not reported. One example is scrap that is never reported because of fear of reprisals, or scrap that is charged to a general ledger account without identification as scrap.

9. The extra process costs due to excessive product variability (even though within specification limits): For example, a process for filling packages with a dry soap mix meets requirements for label weight on the contents. The process aims, however, is set above label weight to account for variability in the filling process. See Cost of Inefficient Processes above under Internal Failure Costs.

10. Cost of errors made in support operations, e.g., order filling, shipping, customer service, billing.

11. Cost of poor quality within a supplier’s company. Such costs are included in the purchase price.

These hidden costs can accumulate to a large amount—sometimes three or four times the reported failure cost. Where agreement can be reached to include some of these costs, and where credible data or estimates are available, then they should be included in the study. Otherwise, they should be left for future exploration. Progress has been made in quantifying certain hidden costs, and therefore some of them have been included in the four categories discussed above. Obvious costs of poor quality are the tip of the iceberg.

In one published study, Ittner (1992) summarizes data on the four categories for 72 manufacturing units of 23 companies in 5 industry sectors. Three conclusions on cost data do stand out: The total costs are higher for complex industries, failure costs are the largest percentage of the total, and prevention costs are a small percent of the total.

2.3 Why COQ was not used.

Baatz (1992) found that only 5 of 22 (23%) of the 1991 Malcolm Baldrige National Quality Award finalists measure COQ (Baatz, 1992). Gupta and Campbell (1995) cite two surveys that found only 33-40% of companies tracked quality costs (Gupta, 1995). Viger & Anandarajan (1999) found that only about half of the companies they studied calculated quality costs (Viger, 1999). Victor and Ross (2003) found that only about one-third of organizations track quality costs in a survey that approximately 3200 randomly selected members of the Quality Management Division (QMD) of ASQ (Victor E. Sower, 2003).

Pursglove and Dale (1996) suggest that the profitable nature of the business can make it hard to convince management of the need to track COQ. They also claim three key reasons for COQ failures:

(1) A lack of understanding of the concept and principles of QC among the management team;

(2) Lack of information and data;

(3) The profitable nature of the business making it hard to convince management of the need to track COQ (Pursglove, 1996).

Bottorff (1997) suggests that implementing COQ programs is one of the most difficult and critical undertakings in the quality journey. He found two primary reasons for not tracking COQ:

(1) Relying on an individual rather than a team;

(2) The culture of the organization does not support teamwork (Bottorff, 1997).

Wheldon and Ross (1998) argue that many firms tend to compartmentalize quality under the quality manager who tends to lack accounting knowledge (Wheldon, 1998). Shepherd (2001) claims that the cost of quality in some companies are not calculated clearly but are simply absorbed into other overhead costs. He agrees that lack of knowledge, inadequate tracking systems, and lack of management support are key reasons for the underutilization of COQ systems in these enterprises (Shepherd, 2001). Victor and Ross (2003) claim that four primary reasons for not tracking COQ:

(1) Lack of Management Interest/Support.

(2) Lack of Knowledge.

(3) the profitable nature of the business.

(4) Lack of Adequate Accounting and Computer Systems.

(5) Do Not See the Benefit of COQ (Victor E. Sower, 2003).

2.4 What are the general preventive actions to improve poor-quality?

Frank Gryna (1999) claims that the quality management in many companies use a recognizable process—when the defects increasing, they just increase the percentage of inspection, try to reduce the defect level in their company. However, this approach will not works due to it does not remove or eliminate the root causes of defects; i.e., it is detection but not prevention, in this case, the total quality cost increases because of the added appraisal costs. To achieve a significant and sustainable low level of defects and costs requires a structured process to attack the main reason of loss—the failure costs. Such an attack needs carrying out a project-by-project basis. These projects also require resources of various types. The resources or investments must be justified by the expected benefits (Gryna, 2001).

Jim Robison (2000) said Quality management systems are normally based on ISO 9000 which requires a documented system for implementing corrective and preventive action. Root cause analysis and corrective action is an important element of an effective proactive (rather than reactive) quality management system. A proactive system encourages reforming the processes to prevent costly nonconformities from occurrence and recurrence. He suggests A 10-step approach to improve the poor quality; they are:

1) Identify Opportunities for Improvement
2) Form Team and Scope Project
3) Analyze the Current Process
4) Define Desired Outcomes for Improved Process
5) Identify Root Causes and Proposed Solutions
6) Calculate the Cost of Quality (COQ)
7) Prioritize, Plan, and Test Proposed Solutions
8) Refine and Implement Solutions
9) Measure Progress and Hold Gains
10) Acknowledge Team and Communicate Results (Robison, 2000)

Heather McCune (2003) suggests turning toolbox talks into real-time quality improvement. Real-time quality improvement requires quick, simple training of the construction team and follow-up with an immediate inspection to ensure that workers were fully understood and applied on the job site. Ed Caldeira, the principal in Caldeira Quality, claims that a working-site rule - the toolbox talk - can be a perfect chance to communicate in a meaningful way. He suggests that for organizing an effective toolbox talk, 3 actions should be taken:

Illustrate the issue. Use 2 groups of dramatic photos to show the workers directly, which is right or wrong, one group of photos show the positives, good workmanship, the other groups show the negatives, bad workmanship, each photo shall be labeled— yes, no. All the unnecessary information shall be cropped out to avoid confusing the viewer. Distribute copies to everyone in the toolbox talk.

Keep it simple. With the pictures in hand, select on a point you want to talk, use the simple words which construction crews are easily understood, try to avoid the usage of professional definition or concept. Write a headline on the right photos. At the end of toolbox talk, ask a question to each attendee to make sure he or she is fully understood the content of toolbox talk.

Inspect. Follow-up is essential to verify that the toolbox talk is working. Routine inspections, document compliance and noncompliance, decide whether any corrections are further needed. This founding also tells you whether you need to identify unresponsive crews that require additional training or reinforcement (Vinod Bopalia, 2017).

Sergei Titov and his team made research in 2015 and found that implementation of learning practices on quality management is a potential tool for reducing the poor-quality costs in the construction projects. Learning practices can be divided as organizational learning and individual learning, organizational learning is a process of creating, retaining and transferring knowledge within an organization. An organization or individual improves over time due to the gained experience. Through this experience, knowledge can be created, benefits the organization or individual. The majority of Russian construction companies do not apply the learning practices as an integral part of their strategy, the learning capabilities are relatively low. The learning practices and rework cost reductions have a notable negative correlation. The firms with a low level of learning practices have higher risks of being less effective and or losing profit. In contrast, firms embrace learning practices to gain notable advantages. They suggest using learning practices as an effective tool to reduce the poor-quality cost in construction projects (Sergei Titov, 2015).

Abdul Razzak (2011) suggests using 10 quality control tools for quality control and quality improvement. These tools are widely used for creating ideas, engendering planning, analyzing the root causes, creating a wide variety of situations for continuous quality improvement. It can be used in each stage of a construction project. These tools are listed below:

1) Flowchart

2) Data collection

3) Control chart

4) Histogram

5) Pareto analysis

6) Pie chart

7) Run chart

8) Scatter diagram

9) Cause-and-effect diagram

10) Check sheet

These methods, tools or techniques are widely used at various stages of construction projects to collect data, analyze root causes of rejection and take necessary preventive or remedial action to continuously improve the project quality (Rumane, 2011).

Bopalia and Aramco (2017) suggest documenting all strengths and weaknesses as lessons learned throughout a project's life cycle, through the lessons learned to discover opportunities for improvement (Vinod Bopalia, 2017). The documented lessons provide a chance for all team members to share successes and failures during the project and give recommendations for others working on similar future projects. It also allows project members to talk about alternative solutions for things might be done differently, discuss the root causes of failure and preventive measures to avoid those problems in later project phases. All the experience gained during the past or ongoing projects can be documented as a lesson learned. These lessons come from working with or solving real-world problems throughout the project life cycle. Collecting and sharing these lessons learned promotes to eliminate the occurrence of the same problems or provide options for difficulties in future projects The main purposes of Lessons Learned are to avoid repeating the same mistakes, to improve the probability of balancing the constraints such as schedule, quality and cost issues on future projects. Before it can be considered as "lesson learned", below steps should be done:

1. Reflect on Experience. Discuss on past and think as a team about "what happened?

2. Identify the learning points. Was there a difference between what was planned and what happened? Either a positive or a negative difference need to address.

3. Analyze. The reasons for a difference? Root causes for the deviations occurred?

4. Generalize. What is the learning point? What are the preventive measures that should be done in future activity to avoid the failure or repeat the success part?

Lesson Learned process can be defined in Figure 3, is to record the learning throughout the project and captured detail to all applicable team members. A recorded lesson learned can be captured in an audio, video or document upon the subjects. Audio is probably the best media method of recording lessons-learned meeting minutes due to the low cost and flexibility. The project team could utilize conference call recording facility to record meeting minutes. This also involves storing e-mails, presentations, etc. in a central folder. The method used to share a lesson learned does not require high tech. It can be knowledge sharing' Lessons Learned session with a wide group or sent notification to all employees.

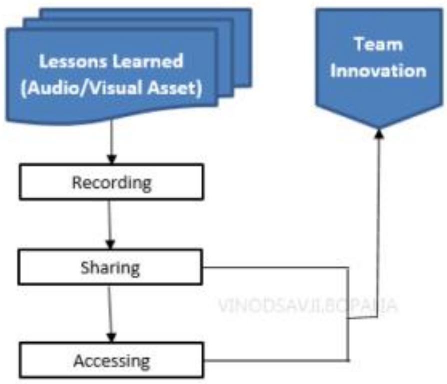

Figure 3 Lesson Learned Process

Source: Bopalia and Aramco, 2017, p.8

Accessibility is also important. It is preferred to easy searching for a relevant lesson learned for future use from the stored asset location (either physical or online content). Using lessons learned as a valuable tool to avoid repetition of similar mistakes in other projects to improve the quality and saving quality costs, it should be a principal content of an organizational culture committed to continuous improvement (McCune, 2003).

2.5 What is the existing cost of quality model?

Under the grievous competitive pressure of the market, the management of firms has to focus on the cost of quality and methods to reduce it. General actions are carried out as per the cost of quality theory (J. M. a. G. Juran, F.M. , 1988), is to increase the investment in prevention and appraisal. These actions should result in reducing the overall COQ by lowering in cost of poor quality. The below section introduces the basic COQ concepts.

Traditionally the total cost of quality (TQC) is claimed as the sum of the prevention costs, appraisal costs, internal and external failure costs incurred. Figure 4 (J. M. a. G. Juran, F.M. , 1988) illustrates the manner of their relationship. As can be found, the lowest COQ will occur at the intersection point of the failure and prevention plus appraisal cost curves.

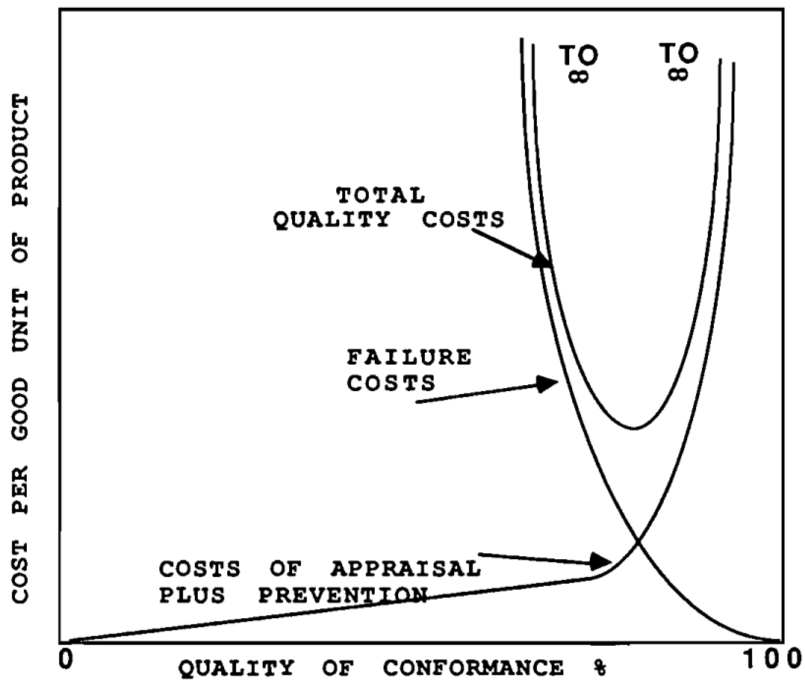

Figure 4 Classic model of optimum quality costs

Source: Juran and Gryna, Quality planning and analysis, 3rd ed., 1993

Juran and Gryna (1988) revised the classic COQ model graphic as showing in Figure 5. His study based on the major categories of COQ, further explored the correlation of prevention costs, appraisal costs, internal and external failure costs incurred.

1) The failure costs: When the product is defect-free, the failure costs are zero, then increase to infinity when the product is 100 percent defective.
2) The costs of prevention and appraisal: These costs are zero when 100 percent defective, and rise when the perfection of the product is approached.
3) Total quality costs: These costs are the sum of curves 1 and 2, indicated as the third curve represents the total cost of quality per good unit of product.

From this revised quality cost model, it can be seen that the lowest level of total quality costs occurs when the quality of conformance is 100 percent, i.e., perfection. This may not always happen in the real world. Due to the fallible nature of human beings, to attain perfection at finite costs in the Twentieth century is impossible. Furthermore, the inability to quantify the impact of poor quality on revenue resulted in underestimating the failure costs.

Juran and Gryna (1988) also state that gain perfection should be an ultimate goal for each company, however, there do have some pressure to push the industry to reach for perfection. Examples include:

1) Requirements of human safety and well-belling. The produced goods and services have a critical impact on human safety and well-being: Such as the

pharmaceuticals and generation of mutual fund statements are perfect illustrations.

2) Highly advanced and automated industries. Under the support of highly advanced and automated machinery, it is economically feasible to achieve a very low level of defect and 100 percent inspections to find them out before hand it over to internal or external customers.

3) Requirements from wealthy Clients. These customers are often willing to pay a premium price for a defect-free product or service, even a small risk of a defect.

4) Companies striving to optimize the user's cost. The optimize COQ model graphic indicates the idea of an optimum at the producer's point of view. If the user's costs curve due to the poor quality of the product is added to this model, those costs add further weight to the conclusion that the optimum point is perfection.

To gain the 100 percent conformance is a trend that will extend to more products and services of greater complexity. However, it is crucial to evaluate whether quality improvement activities have reached the economic limit, we have to compare the benefits gain from lower defect against the investment made to achieve these benefits, think it cost-effectively. If the investment put in prevention and appraisal costs have no longer got any feedback, the optimum point has been reached.

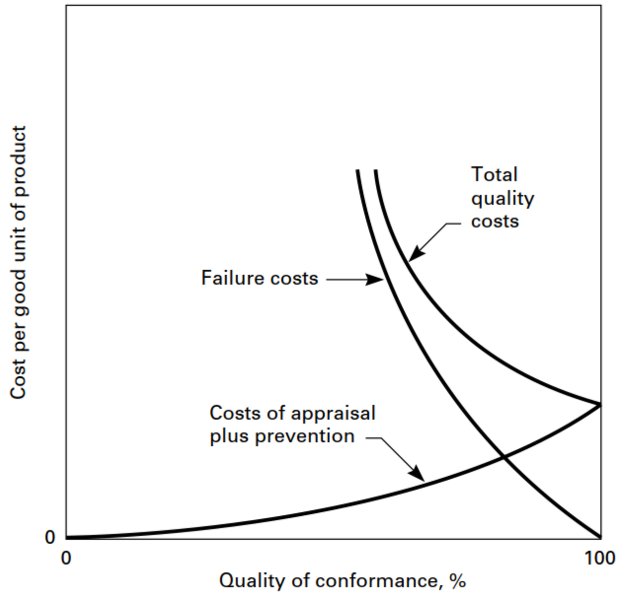

Figure 5 Model for optimum quality cost

Source: Juran and Gryna, 1988, Quality handbook, p. 8.22

Carl Wolf and Jorn Bechert (1994) made a research to justifying prevention and appraisal quality cost expenditures, based on the report wrote by Bechen and Jorn (1991), they set up a ‘’Operative quality cost model” for manufacturing firms, Figure 6 shows the graphs of cost of quality (Wolf, 2007).

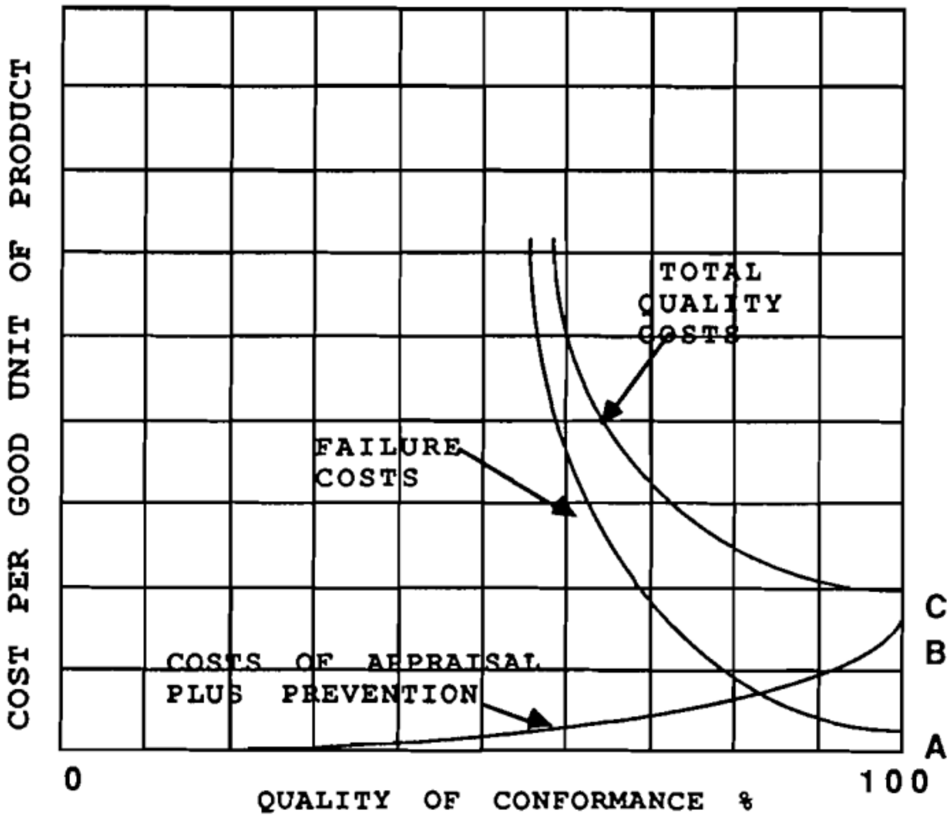

Figure 6 Operative quality cost model for manufacturing firms

Source: Wolf and Bechert, 2007, A benefit/cost decision model

The difference in this cost model is that when 100% quality of conformance is reached, there are still some failure costs (point A). Hence, the total cost of quality (point C), does not equal prevention and appraisal (point B), is the sum of both these costs (point A + B). Under is the situation, it is recognized that, as a practical matter, some failure costs will occur despite the concerted efforts to prevent them. This minimum is likely to be different in each company. The number is dependent on the nature of the business it is engaged in and the operating conditions in place. The figure can be assumed to be the average number for the industry of which the firm is a part. For the purpose of the discussion, this was done to develop Figure 7.

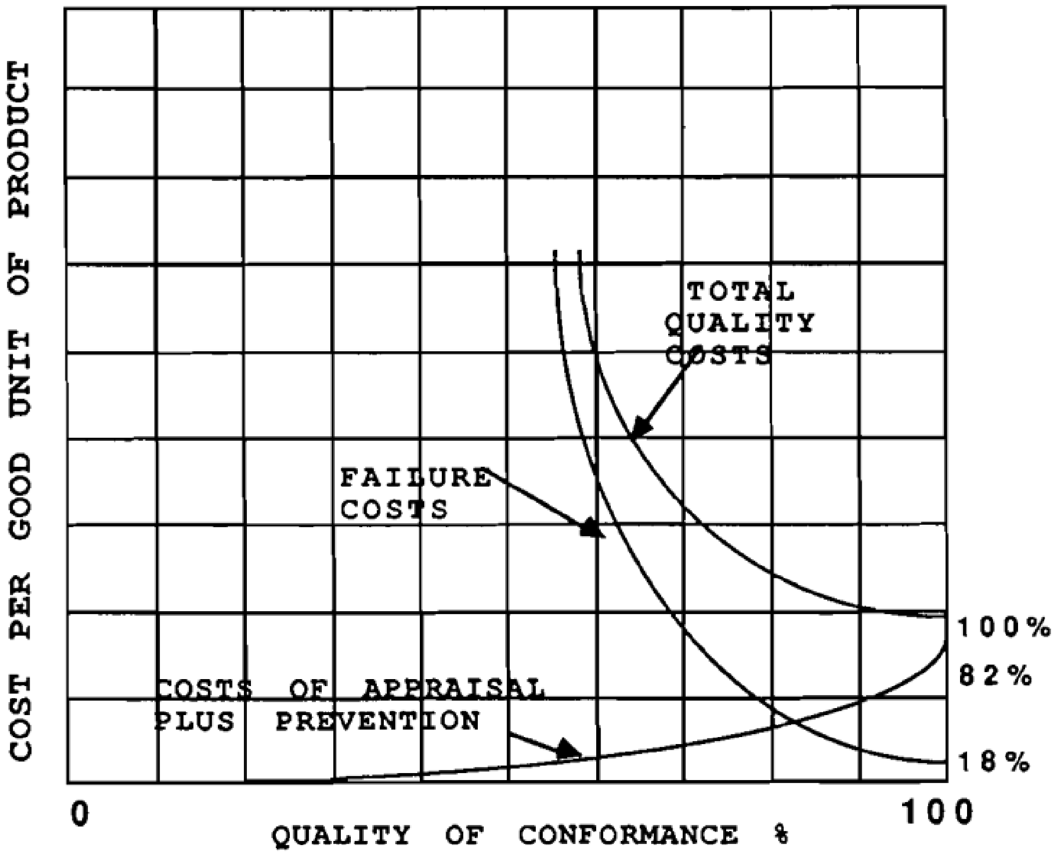

Figure 7 Operative quality cost model for manufacturing firms

Source: Wolf and Bechert, 2007, A benefit/cost decision model

It can be seen from this graph that at 100 percent quality of conformance, there still has 18 percent of failure costs exist. Therefore the total cost of quality is the sum of 18% failure costs and 82% of appraisal plus prevention costs. In this case, the total cost of quality is not only appraisal and prevention costs anymore when 100 percent of quality of conformance is reached. Here, 18% of the total cost of quality (measured as a percentage of sales) is specified as being equal to the realization of zero failure cost. This number is the percentage expressed to us by quality practitioners in manufacturing firms who thought it to be the lowest realistic failure cost percentage that could be achieved. Therefore, 100% quality of conformance is shown to intersect at 18% of total quality cost. Correspondingly, the prevention and appraisal costs have to be 82%; the sum of these costs represents the total quality cost which can be anticipated at the defined optimum achievable quality level.

They also take Figure 7 to be an operative total cost of quality model applicable for manufacturing firms. This concept serves as the basis of the cost-benefit graph (Figure 8) because it allows the specification of point G. This point, G [N, M], indicates the potential maximum percentage savings in total quality costs possible under the present procedure and how much in additional investments have to be expended for these to be realized. The starting point (0, 0) represents the company's current TQC status. There are three curves which promote the TQC savings that can be anticipated when a specific prevention and appraisal cost expenditure is made. Each curve is based on a different cost-benefit relationship assumption. The Pareto curve speculates that 80% of the possible TQC savings can be reached with the first extra 20% prevention and appraisal (P&A) cost expenditure increase. The remaining 80% expenditure is required for the 20% TQC reduction, the reduction from point T to G is very likely to gain with most difficulties. The linear curve assumes that an equal return for each dollar expended. The curve of the operative TQC model is assumed to follow behavior analogous to that shown in Figure 7. Because it is based on TQC theory, using situation-specific data represents the company's current TQC environment argues that this curve is utilized in the benefit-cost evaluation. The operative TQC model and linear approach can also be considered if under an appropriate situation.

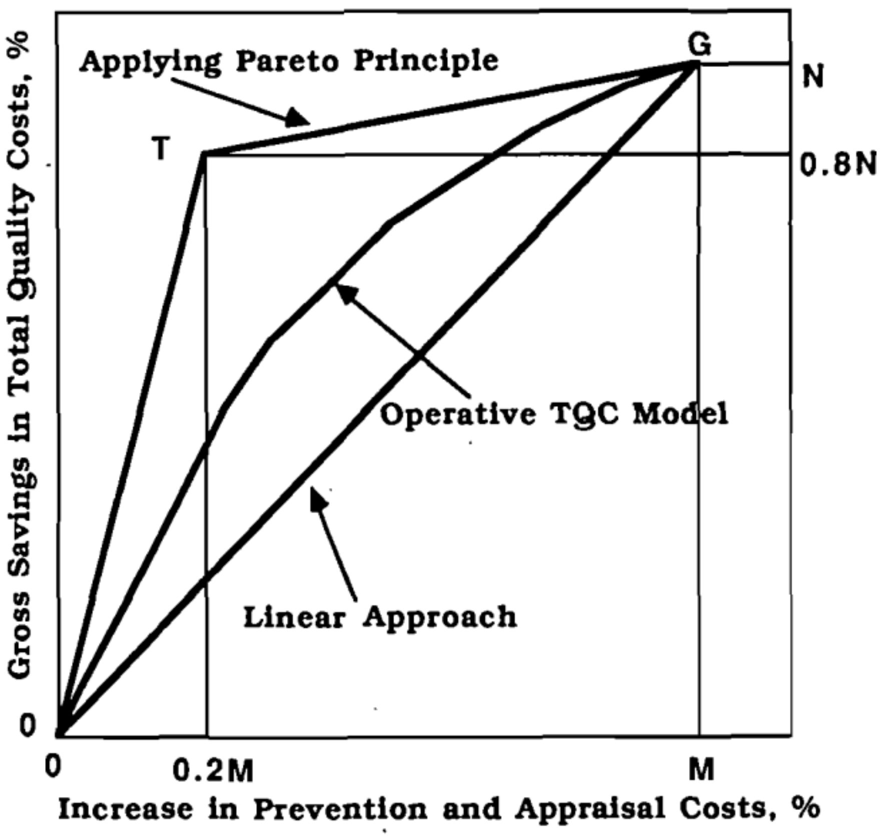

Figure 8 Cost/benefit graph

Source: Wolf and Bechert, 2007, A benefit/cost decision model

CHAPTER 3

OVERALL RESEARCH METHODOLOGY

3.1 Summary of poor quality and cost by COQ method

Obstacles for application of COQ is listed in previous section 2.3 of this thesis, the quality cost program will not happen automatically. The quality manager is acting as an advocate and champion within company B to start this “quality revolution”. He needs to have a clear view and belief in their application of COQ and value to company B. The first step is to present to top management with facts that the COQ can be beneficial to company B. A summary of the existing quality level with major quality cost shall be estimated and determined, then the opportunity for improvement or cost-saving should be obvious. It is necessary to draw management interest and attention, to get the support and commitment of top management. Once the top management is agreed to apply the COQ system, training shall be held to introduce the COQ for the project management team.

To collect quality costs an organization needs to adopt a framework to classify costs; however, there is no general agreement on a single broad definition of quality costs. COQ is usually understood as the sum of conformance plus non-conformance costs, where the cost of conformance is the price paid for prevention of poor quality (for example, inspection and quality appraisal) and cost of non-conformance is the cost of poor quality caused by product and service failure (for example, rework and returns). After Feigenbaum (Feigenbaum, 1956) categorized quality costs into prevention-appraisal-failure (PAF), the PAF scheme has been almost universally accepted for quality costing. The failure costs in this scheme can be further classified into two subcategories: internal failure and external failure costs. In general, these costs are described as follows:

The basic suppositions of the P-A-F model are that investment in prevention and appraisal activities will reduce failure costs and that further investment in prevention activities will reduce appraisal costs (J.J. Plunkett, 1988). The objective of a COQ system is to find the level of quality that minimizes total COQ. Feigenbaum's and Juran's P-A-F scheme has been adopted by the American Society for Quality Control in 1970 (Quality, 2013) and the British Standard Institute (BS 6143 pt.2) (Institution, 1990), and it is employed by most of the companies which use quality costing (L.J. Porter, 1992).

Based on the P-A-F model, the COQ of Project A will be calculated. All the quality issues have been registered in the quality issue log since day 1 of the project. Use the P-A-F model, to categories all the issues into 4 categories, they are prevention costs, appraisal costs, internal failure costs and external costs. In a crossing county pipeline project, all the quality costs occurred can be grouped and divided as below as per author's experience:

Cost category	Detail contents
Prevention cost	Quality assurance team (recruit, wage and insurance, etc.) Training costs Traveling costs, communication costs, internet costs, etc. Certification costs Internal and external auditing costs Procure qualification costs Function test costs
Appraisal cost	Quality control team (recruit, wage and insurance, etc.) Traveling costs, communication costs, internet costs, etc Inspection or test is done by 3rd party required by contract (witness at vendors shop, laboratory analyses, etc.) Planed test or inspection (procured material or equipment from vendors, each working process, all deliverables, etc.) Material sampling and test Procurement of instrument or equipment Calibration of instrument or equipment Depreciation cost of instrument or equipment
Internal failure cost	Repairs Reworks The downgrading of the product Scraps Re-inspection or re-test for repair or rework Enlarged or added inspection or test due to defect found
External failure cost	Repairs Reworks Scraps Re-inspection or re-test for repair or rework

	Compensation for Owner's business loss Insurance cost increasing

Table 6 Details of Cost Category

Once the project contract has been signed, the appraisal costs are almost fixed due to the contract requirements that have clearly stated the scope, frequency, percentage of appraisals. Due to the safety concern, 100% of the weld, coating, hydro testing, etc. will be carried out to ensure the integrity of the pipeline before commissioning. This concept may be difficult with other industries where the sampling method may be used for quality inspection. Therefore, Prevention costs, Appraisal costs and Failure costs are needed to record and calculate, two forms will be used, one is the prevention & appraisal cost form, the other one is the quality issue log. In the quality issue log, the below information should be recorded for future evaluation usage:

Item Name	Detail description
Construction date:	the date when the works have been done
Rectification date:	the date when the works have been rectified.
Discipline:	detail discipline of the works, such as pipe transportation, welding, coating, trenching, backfilling, NDT, etc. each working process' name.
Construction crew No.:	the team who did the construction works
Start location:	the starting point of works
End location	The ending point of works
Quality issue description	What happened on site, reasons caused the quality issue.

Rectification actions description	The rectification actions description, what should be done for the quality issue.
Status of quality issue	Ongoing, closed, or outstanding.
Manpower required	The manpower required for rectification works
Equipment required	The equipment required for rectification works
Material required	The construction materials required for rectification works
Schedule impact	Time impact to the project, such as 2 days in the critical path of schedule
Cost Impact	Cost impact due to the quality issue
Cost categories	Internal or external cost

Table 7 Information to be Recorded in Quality Issue Log

The cost can be evaluated by the project accounting team, use unity price or sum of manpower, material and equipment cost. The quality team is required to record all the information needed for cost evaluation.

After all the costs are calculated for each quality issue, further data analysis should be carried out to find out the weak points or areas where more attention or precaution needs to be taken, to reduce the poor-quality reoccurrence.

3.2 Using root cause analysis to find out the root cause of the poor quality

A cause and effect diagram (or Ishikawa diagram) is widely used when looking for the root cause of a quality problem. A cause and effect diagram is an illustration that is used to explore potential or real root causes of quality problems. Causes are arranged in four or five major inputs in the past, such as material, machine, man, method and environment(4M&1E). From their relationships and hierarchy of sub-causes, the cause and effect diagram can help search for root causes and identify areas where the problem may be related. At present, more inputs are considered, such as material, machine, man, method, measure, environment and information, etc. (5M&1E&1I). The root causes due to the human always cause the majority of the quality problem, and it is also difficult to solve when compared with other aspects of root causes. The author of this thesis will focus on the human causes, through interview, fishbone Diagram and 5 Whys method, find out the opinions, suggestions and demands of workers, then take effective measures to improve the quality.

The collection of data through root cause analysis method is quite popular, especially dealing with construction teams. It is being adopted by all kinds of research, such as private individuals, private and public organizations and even by governments. During the root cause analysis, methods such as Pareto Chart, brainstorm, interview, fishbone Diagram or 5 Whys method will be used. There are 4 construction crew working in Thailand which are belong to Company B, due to the same environment and culture within the same country, the root cause analysis will be carried out to all the construction teams on site. Before root cause analysis commencement, the brief introduction will be given to explain the purposes of the analysis, to make sure the respondents understanding and cooperating with the analysis.

After the interview or brainstorm has been done, the analysis will be carried out to find out the root cause of the poor-quality and suggestions and demands of workers.

3.3 Brainstorming the preventive actions

Based on the root cause analysis data collected, the quality management team will use the brainstorming method to discuss and take necessary preventive actions. A group of quality-related persons or experts of subject matter are invited for brainstorming to gather creatively data. The method is used to create a list of ideas in a short period. A facilitator will lead the group environmental meeting. Brainstorming comprises two prime parts: idea generation and analysis. Brainstorming can be used to gather data and solutions or ideas from stakeholders, subject matter experts, workers, operators and other team members when developing the project charter. As a quality policy in Company B, the project manager is the first responsible person for quality management, therefor during the brainstorming meeting, the project manager shall be involved, the commitment and support from a project manager are crucial. The brainstorming activity should be attended by the project manager, quality manager, quality inspector, construction manager, foreman, workers' representatives, accountant, etc. Cost and time shall be considered when making decisions on the preventive measures which should be feasible, applicable, affordable, repeatable and measurable, and so on, also these preventive measures shall be in line with company regulations and policies, otherwise, it will be stopped by head office. Make a quality improvement plan that will be preferable, list the timeline for each action, responsible person and detail actions that need be taken.

3.4 Remeasuring the COQ

The QM team plan to measure the COQ level at end of 2018, based on the project progress and COQ spent, the total COQ at the end of the project can be evaluated assume that the quality performance of construction teams is stable.

In reality, from early Jan. 2019, the preventive actions for improving the construction quality have been applied and reinforced. From the daily quality issue log, it can be found that the construction failures reduce tremendously. At the end of 2019, the QM team remeasures the COQ level again.

As per C. R. Kothari's (2004) "Before-and-after with control design" theory, the treatment effect can be found by equation shows in Figure 9.

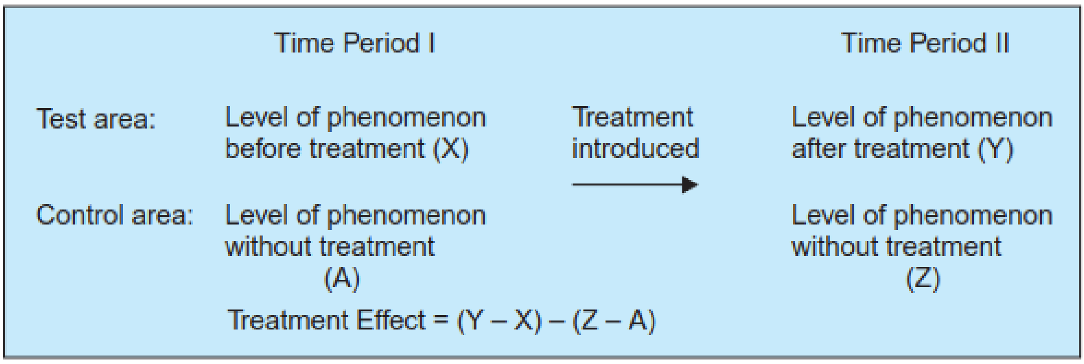

Figure 9 Before-and-after with control design

Source: C. R. Kothari. (2004). Research Methodology, 2nd ed. P.42 (Kothari, 2004)

The effect of applied quality improvement actions can be concluded by subtracting the change in the evaluated COQ at the end of the project from the change in the real COQ after quality improvement actions have been applied and reinforced.

CHAPTER 4

CALCULATION AND ANALYSIS OF CURRENT COQ

4.1 Summarize of the current quality cost

The construction works of Project A was started on 1st March 2018, planned to gain mechanical completion on 31st December 2019. In the scheduled project meeting, the construction department complains about the increasing quantity of rework; the financial team grumbles about the budget overspending. The project manager feels construction quality is not good enough, assigns the quality management team to improve the construction quality. In Dec 2018, the quality management team plan to start the reduction of quality cost campaign.

The 1st step was to evaluate the overall all quality performance of Company B. In Project A, the quality management department only uses few quality performance indicators to monitor the quality level, such as welding repair rate, coating repair rate, customer satisfaction level, the quantity of NCRs and auditing results, etc. However, none of these quality performance indicators could bring the attention of the project management team whose only language is money. Therefore, the current COQ must be calculated and analyzed, and to be presented to the project management team.

In the beginning, quality management team tried to find out the quality-related costs from the current accounting system of Company B, but the system does not capture the real overall cost of quality, only overt quality costs have been recorded in the system, the covert quality costs have not been labeled out. The overt quality costs are the cost relevant with quality management activities, easy to distinguish from others, such as salary and insurance cost of quality inspectors, water analysis cost, third party audit cost, calibration of the quality instrument, retest fees, etc. which has been spent because of quality assurance or quality control activities. On the contrary, the covert quality costs are difficult to distinguish from other costs, such as consumable material increasing, time extension of equipment and manpower usage due to reworks or repairs, etc., the accounting team treats these costs as normal construction cost or overhead cost. The overt and covert quality costs have been summarized in table 8 (further classified from table 1).

Cost category	Overt quality cost	Covert quality cost
Prevention cost	Quality assurance team (recruit, wage and insurance, etc.) Training costs Certification costs Internal and external auditing costs	Qualification costs Function test costs Traveling costs
Appraisal cost	Quality control team (recruit, wage and insurance, etc.) Planed test or inspection Inspection or test is done by 3rd parties, such as witness at	QC team traveling costs Depreciation cost of instrument or equipment

	vendors shop, laboratory analyses, etc. Material sampling and test Procurement of instrument or equipment Calibration of instrument or equipment	
Internal failure cost	Re-inspection or re-test fee for repair or rework Enlarged or added inspection or test fee due to a defect found	Material, man-hours and machine-hours increasing due to repairing and reworks Downgrading of product Scraps
External failure cost	Compensation for the 3rd party or project Owner Re-inspection or re-test fee for repairing or rework	Material, man-hours and machine-hours increasing due to repairing and reworks Scraps Insurance cost increasing

Table 8 Summary of The COQ in Overt and Covert Wise

Due to the covert quality costs that have not been distinguished and labeled by the accounting team, thus the quality costs recorded in the accounting system can not fully represent the real quality costs. However, the quality management team and construction team know the covert costs related to quality. All the quality issues have been registered in the quality issue log since day 1 of the project, refer to the Table 7-Information to be Recorded in Quality Issue Log. By using the quality issue log, with support from the quality and construction team, the covert quality costs have been calculated.

From the summary report of COQ, it can be seen that only 56% of total COQ is overt quality cost, the remaining 44% is covert quality cost. The nature of COQ shows in Figure 10.

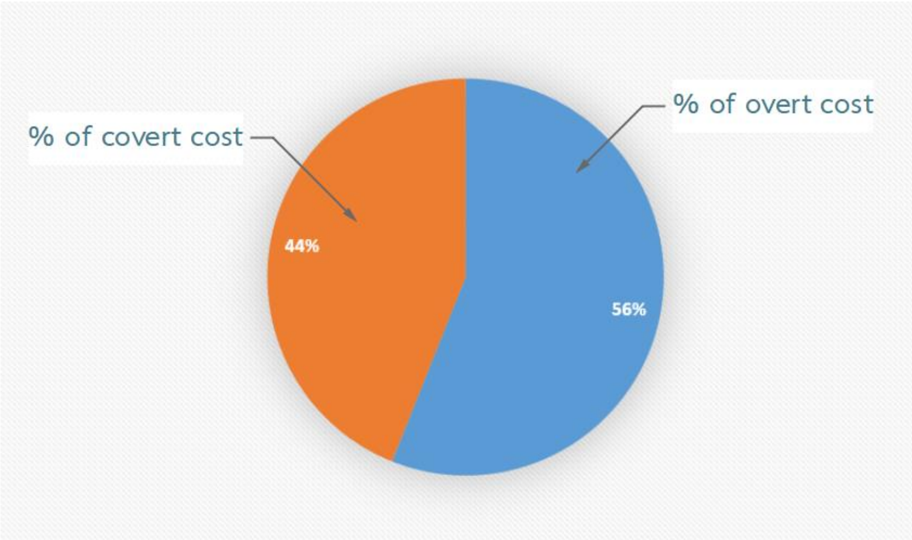

Figure 10 The nature of COQ

The total COQ up to 31^{st} Dec 2018 is round 52,487,175 THB, equal to 5.82% of the project contract value. Base on this trend, the total COQ at the end of the project will reach 15.74% of the project contract value. The current and estimated future COQ ratio shows in Figure 11.

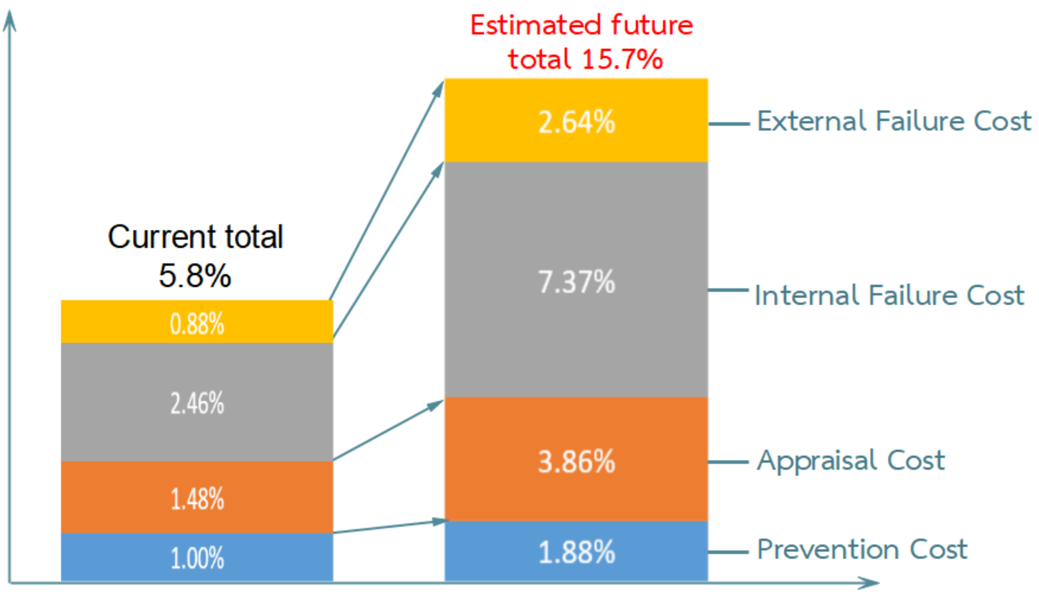

Figure 11 The current and estimated future COQ ratio

4.2 Analysis of the COQ data

Based on the PAF model, the COQ consists of prevention cost, appraisal cost, internal failure cost and external failure cost. The COQ distribution status shows in Figure 12.

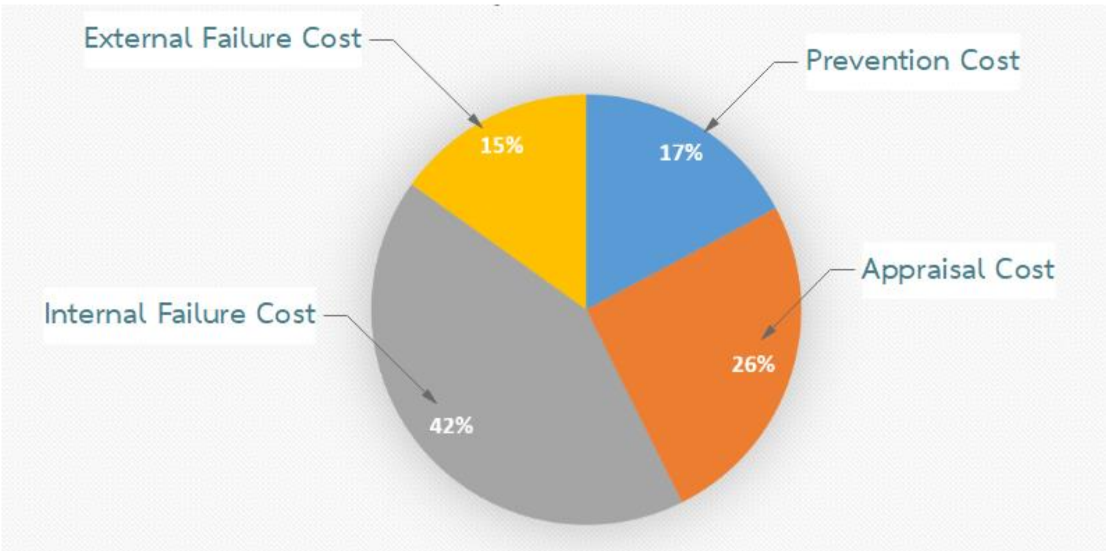

Figure 12 The COQ distribution

The above chart illustrates that in Project A, company B has spent 17% of COQ on the prevention activities, 26% on the quality appraisal, 42% of COQ was consumed on internal quality failure, and 15% was costed by external quality failure. As per the project contract, company B has to establish a quality assurance system that complies with the principles of ISO 9001 and other project requirements. Thus, a project QA/QC organization shall be established by sufficient qualified staff to constantly monitor and control all the quality aspects of the work. To fulfill the contract requirements, company B spent 43% of COQ as prevention and appraisal cost as per the project execution plan, these costs have been considered. On the other hand, 57% of COQ is internal and external failure costs which have not been considered or pre-planned. These costs cause a negative impact on to project budget. The distribution of internal and external quality failures shows in Figure 13.

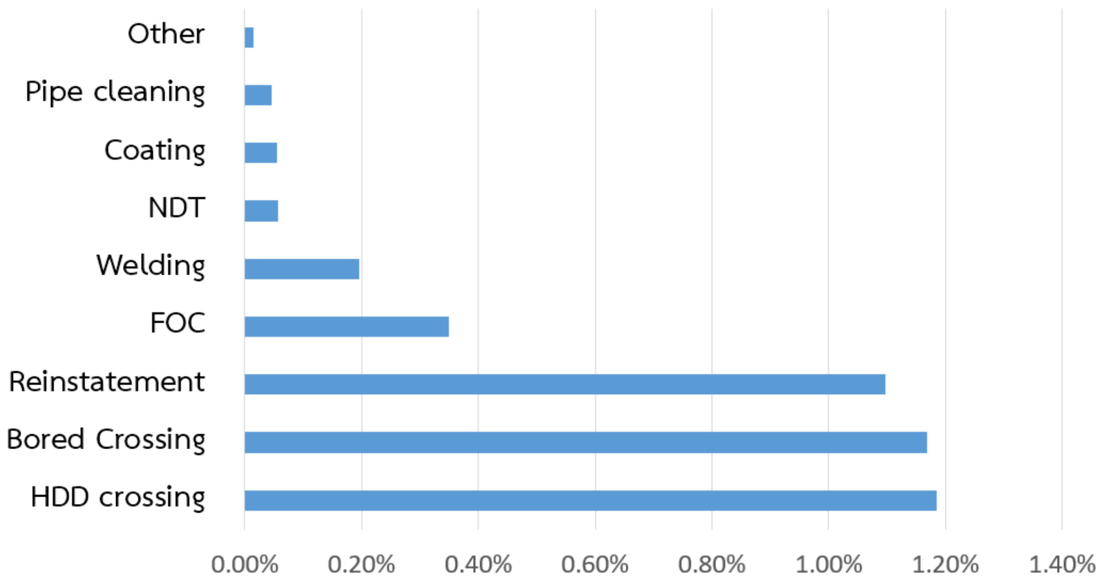

Figure 13 The distribution of internal and external quality failures

From the internal and external failure cost data analysis, we also learned that the majority of the quality failures comes from different discipline of works, shown in the above Figure. The majority of quality failures come from HDD crossing, bored crossing and reinstatement works, almost equal to 83% of the total quality failures. Therefore, a clear improving target has been set up to reducing or eliminate the reworks or repairs from these disciplines.

4.3 Present the COQ data to project management team

After the COQ has been calculated and analyzed, the project quality management team presented the findings to the project manager, **not surprisingly,** the PM was shocked. The total COQ at present and estimated value on project mechanical completion date are much bigger than his observation and estimation, which will cause the over budgeting and time extension of the project, the project will be failed. From the weekly or monthly financial report provided by the accounting department, he monitors the COQ numbers, but that number is not the real overall COQ number, which is only the overt part of it, equals 56% of COQ. Another surprising finding is that 57% of COQ is caused by internal and external quality failures, these non-value-added costs cause serious negative impact to project budget and schedule. How does the high rate of quality failures impact the project budget and schedule?

4.3.1 The high rate of quality failures causes project overdue

Let's look at the project schedule first. The project schedule is stated in the contract, it is a date that the owner expected the project to be completed. Normally, the contractor gets a penalty if the scope of work has not been completed within the required date. Thus, the contractor must organize enough resources, such as manpower, equipment, materials, etc., to complete the work on time. Normally the contractor will make a construction plan as per below equation:

$$\mathrm{PT} + \mathrm{BT} = \text{Project Schedule} \tag{4.1}$$

Where

-PT is planned working time, which means time is estimated from the past work experience, the planner estimates the time base on a similar workforce, natural conditions, contract conditions, etc.

-BT is Buffer time which means the time reserved for unexpected or unforeseeable issues which cause a negative impact on the project schedule, such as bad weather, equipment breaks down, etc.

Normally, the time consumed by quality failures is not considered by the planner. To rectify the quality failures, the contractor must use the buffer time. Therefore, there is a very high risk that projects overdue because of the high rate of quality failures.

4.3.2 The high rate of quality failures causes project overbudget

Normally, there are three industry standards for pricing options: lump sum pricing, cost-plus pricing (with or without a guaranteed maximum price) and unit price. In lump-sum pricing, the owner's risk is reduced due to the price of the contract being fixed and variations are not as much like other contracts. Thus, lump-sum contracts are preferred by project owners. In the lump sum contract, the contractor must estimate and submit the overall project budget at one time. During the project bidding phase, every bidder wants to win the bidding at the lowest price. The contractor estimates the project budget as per the scope of work, project schedule, expected profit value, marketing strategy, etc., In the past, contractors used to make a commercial proposal as per below equation:

$$\mathrm{EC} + \mathrm{CC} + \mathrm{P} = \text{Overall Cost Submitted} \tag{4.2}$$

Where

-EC is estimated cost, which is the money will be spent to complete the contract scope of work within the project schedule, based on the resource input, marketing trend information, and experience, etc., risks or abnormal issues are not considered in this part.

-CC is contingency cost, which is the cost reserved for unexpected or unforeseeable issues which may cause a negative impact on project cost, such as bad weather, exchange rate fluctuations, etc.

-P is profit, which is the money that the construction company expects to earn after accounting for all costs and expenses, 5%~10% of the Estimated cost, it depends on the marketing strategy of a construction company.

However, under the fierce business competition, bidders from domestic and oversea try to win and survive. Take the SOE as an example, SOE keeps the employee with them permanently, if there is no project to do, SOE still pays for the employee for standby, few finical supports from the government could not save SOE forever. Another reason is cash flow, every enterprise needs it, especially the construction company. Therefore, the bidding strategy has been changed a lot, the contingency cost and profit have been far reduced or directly cut off from the overall cost submitted. Thus, equation 4.2 has been changed as below:

$$\text{Estimated cost} = \text{Overall Cost Submitted} \tag{4.3}$$

Many risks may happen during the execution of the project if there is no contingency cost and profit have been considered in the bidding phase, how to allocate or handle these risks? Some construction companies' strategy is to use equation 4.3 to win the bidding first, then use process optimization, innovation and claim from changes by the project owner, to save cost. The saved cost can be used as a contingency cost and profit of the project. Therefore, we got a new equation below:

$$\text{Optimization saving} + \text{Innovation saving} + \text{Claim}$$
$$= \text{Contingency cost} + \text{Profit} \tag{4.4}$$

We can see that from equation 4.4, the profit depends on how the project has been managed and executed. There is not much COQ has been considered during the bidding. The bidder may only consider the prevention cost and appraisal cost. Internal failure cost and external failure cost may not be considered at all. If the quality performance is low, the project is overbudgeted.

4.3.3 The decision from the PM

The decision from the PM is very clear that to reduce the COQ with 10% of the contract value at the completion date of Project A. As per the quality model introduced in section 2.5 of this thesis, for reducing the overall COQ, we have to increase the prevention and appraisal investment, then the internal and external quality failure costs will be reduced consequently. As per the quality model described in section 2.5 of the thesis, the Pareto curve in Figure 8 Cost/benefit graph showing that 80% of the possible COQ savings can be reached with the first extra 20%

prevention and appraisal (P&A) cost expenditure increase. It is a preferred cost-effective way to reduce the COQ for company B.

CHAPTER 5

IMPROVING THE CONSTRUCTION QUALITY AND REMEASURING OF COQ

5.1 Use root cause analysis method to find out root causes of poor quality

As we know the quality is made by workers, not by inspectors. The construction teams have the true answer to why the poor quality produced. Therefore, the quality management team made a root cause analysis for the site workers to look for the root causes of poor quality.

5.1.1 Preparation for root cause analysis

The construction quality failures are not produced on purpose, nobody wants to see his/her work been rejected. Do things right at the first time is what everybody wants. To prepare a root cause analysis, we have to know what motivates the worker to produce quality, then we can dig the answers out from the construction team. The quality management team used a brainstorming method to list all the motivation that may affect the construction quality as below:

a. Welfare.

Welfare is related to income, food, transportation, working uniforms, vacation arrangement, the living condition of workers.

b. Fairness.

People want to be treated equally. The regulations of the company B, the management from crew leader make the fairness. If the workers have been treated unequally, internal failures may be produced.

c. Workload.

This means the number of works assigned to workers within limited working time. If the workload is not reasonable, the worker may use a shortcut to execute some works.

d. Competence.

Training should be given to construction teams; the relevant knowledge or requirements should be noticed. Only competent workers can produce sound quality.

e. Recognition

Recognition should be given to workers about their good performance. It could be as simple as letting them know how much you appreciate the efforts they have done, such as a good welder who shall be rewarded or promoted for his good welding performance.

f. Vision and goal

Many workers are motivated by the team reaching new heights together. The vision or target of quality should be set up, thus, the construction team can work towards it, such as a welding repair rate target as lower than 2%, 0 rework of bored crossing works, etc..

The above aspects shall be addressed during the root cause analysis. The questions in the interview and quality circle meeting have been listed below:

1) Can you complete the workload within the working hours?
2) How many hours overtime have you done in a week?
3) Are you satisfied with your overtime payment?
4) Are you satisfied with your salary compared with the works you have done?
5) Have you been treated equally by the leader in the construction team?
6) Are you satisfied with company B's regulations?
7) Have you got training for all the works you assigned to do?
8) Do you clear about all the quality requirements for the work assigned to you?
9) Is there a reward and penalty system relevant to the quality performance that exists in your team?
10) Have you been rewarded due to good quality performance?
11) Have you been punished due to poor quality performance?
12) Does the traceability available for the works have been done?
13) Do you clear about the quality goal of your team?
14) What is the reason that quality failures happened in your team?
15) What is your suggestion to improve quality performance?

5.1.2 Carry out Root Cause Analysis

Before conducting the quality circle meeting and interview with construction team, a brief introduction should be given to workers. This introduction should remove the resistance and negative feeling of workers, and let them be willing to accept the root cause analysis and give the answer from their heart. Below issue was stated in the introduction.:

A. **Present situation.** Briefs the construction progress, appreciates the endeavor from all team members. Briefs the COQ numbers, especially how much quality failure cost is there, what it would be at the end of the project if no improvement is applied. The surveyor should point out that failures didn't come from the construction team but the direction or management from the project management team. The voices and desires from the construction team shall be heard and responded to.

B. **Purpose of the root cause analysis.** Quality management (QM) team is looking for the true answer that high quality failures were produced.

C. **Method.** Set up a quality circle meeting with each construction team, discuss the reasons of high rate of quality failure, record the finding of meeting. After meeting interview all the attendees, ask the questions has been prepared. The interview will be conducted anonymously, no personnel name or crew number will be mentioned to others.

D. **Benefits of this analysis.** After finding the root cause of poor quality, preventive actions will be taken, construction quality will be improved, then both employee and enterprise will be benefited from the cost which will be saved from the good quality performance.

5.2 Finding from the root cause analysis.

There are total 114 employees of company B joined the quality circle meeting and interview, they come from 4 construction team, and covered all the construction processes. The minutes of meeting, interview results have been recorded and discussed. The main findings of the root cause analysis are summarized in the below table.

Table 1. Summary of root cause analysis.

Item	Description	Agree
1	Shortage of support from Engineering team for HDD design	95%
2	Change suitable bored crossing equipment	79%
3	Need more quality training	89%
4	Over workload assignment	74%
5	Need policy of recognition of good quality performance.	77%
6	Increasing wages	95%
7	Improve the document control system, receives the latest drawing timely	84%

From the internal and external failure cost data analysis, we also learned that the majority of the quality failures comes from different discipline of works, shown in Figure 14

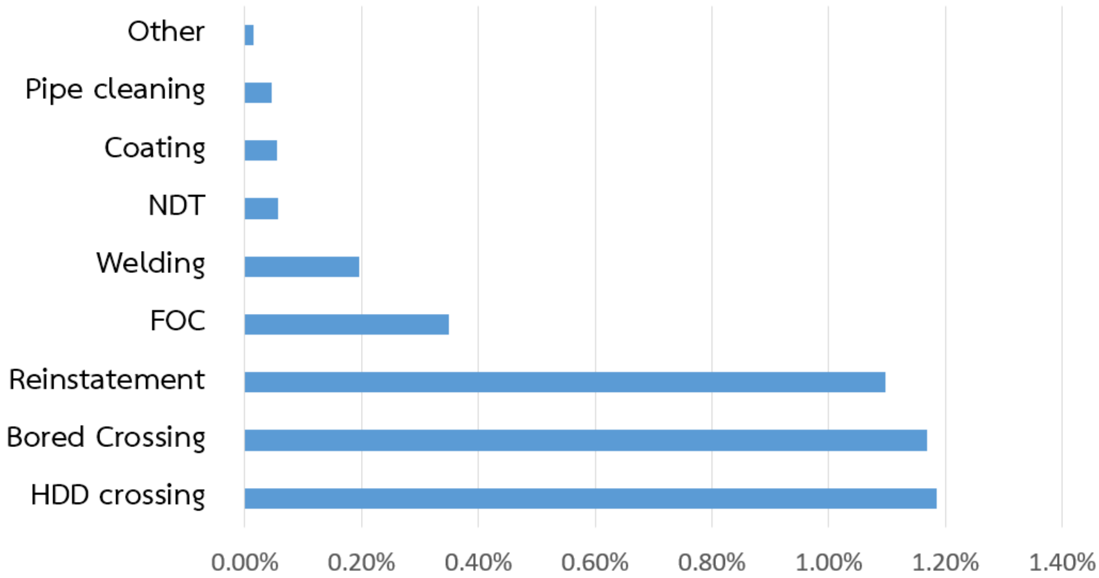

Figure 1. Quality failure distribution by the discipline of work

The majority of quality failures come from HDD crossing, bored crossing and reinstatement works, almost equal to 83% of the total quality failures. Therefore, a clear improving target has been set up to reducing or eliminate the rework or repair from these disciplines.

5.3 Preventive action initiatives

Based on the finding of the root cause analysis and the summarized COQ data, the quality management team used the brainstorming method to discuss and take necessary preventive actions. As a quality policy in Company B, the project manager is the first responsible person for quality management, the project manager shall be involved, the commitment and financial support from the project manager are crucial. The brainstorming activity should be attended by the project manager, quality manager, quality inspector, construction manager, foreman, workers' representatives, accountant, etc. Cost and time shall be considered when making decisions on the preventive measures which should be feasible, applicable, affordable, repeatable and measurable, and so on, also these preventive measures shall be in line with company regulations and policies, otherwise, it will be stopped by head office. Make a quality improvement plan is preferable, list the timeline for each action, responsible person and detail actions that need be taken. The main preventive action took as below:

5.3.1 The contract requirements should be studied.

The construction management team may so familiar with the pipeline construction works, due to the limited working time, they overlooked some special requirements from the contract. Different projects always have different requirements, the management team must study the contract documents to make the requirement clear and share the special requirement during the training time. The contract requirements can be found in the below document:

- Contract documents, such as the scope of work;
- The project survey report, specification, drawing, calculation report, etc.;
- Design base manual;
- Equipment or material vendors' instruction or manual;

- Equipment or material data sheet;
- International code or standard;

Base on requirements from the above documents, the construction management team has to prepare construction procedures and quality inspection and test plan before commencement of construction. These requirements should be fulfilled and applied on site. Otherwise, the non-conformity report may be issued by quality inspectors.

5.3.2 A quality training plan shall be made and applied.

Make a quality training plan to make sure 100% of the workers have been trained with the works assigned. All the requirements from contract and detail design documents shall be incorporated in the training. Training should not be treated as a 'one-off exercise, but an ongoing feature of routine business activity. The training can be formal or informal, it can in-room or on-site. Employers should take into account their capabilities to carry out the construction work with sound quality before allocating tasks to his employees.

5.3.2.1 When training is needed?

Employers should ensure that employees are provided with adequate technical and quality training:

- on recruitment - commonly known as 'Induction Training'.

- when workers are assigned to new tasks.
- transfer of work or having been given new responsibilities;
- new equipment or major changes to existing equipment;
- introduction of new technology or new construction method;
- the introduction of a new system of work or a change of a system of work already in use.
- Incorporated in the daily toolbox talk.
- when defects have been found by quality inspectors.
- take place during working hours.

The ability of workers not only to do their jobs but to do them to the required standards of safety, quality, efficiency, etc., means that the need for training should be under constant review. Therefore, the training plan should review and revised periodically.

5.3.2.2 Matters need attention to hold a training

There are several aspects need attention to hold training, they are listed as below:

A. Literacy of trainee

The trainer shall take into account the literacy and skills of the workers, make sure the training content has been fully understood by trainees. Especially, the construction team of company B is working oversea, workers speak different languages and with a different culture, thus, languages barrier and miscommunication should be taken care of by interpreters.

B. Sharing the common failure of past

It is important to share some common failures of the previous project, such as which area had the most failure happened, what kinds for failure happened, what is the root cause of the failure, what is the consequence of that failure, etc. Through the vivid poor-quality story, the trainee can be engaged in training and easy to memorize the training content.

C. Commitment from the trainee

The content of official training is always important; thus, the training shall be recorded by minutes, each trainee should sign the attendance sheet to commit that he or she has fully understood the training content. In this way, the trainee has given his/her commitment to the training content.

5.3.3 An HDD specialist has been recruited.

As per the site conditions and past construction experience, some open cut sections have to be changed as HDDs. Through these kinds of site optimization, the construction team can reduce the impact on the environment or community, or save the construction cost, or expedite the construction progress.

Optimizations or changes are quite often needed on site. However, the project engineering team who does the detail design is not responsible for site optimization.

Construction teams have to do it on their own. From the finding of section 5.2, it can be seen that the construction engineer is not competent to do the design and calculation. The construction engineer of company B makes the changes or optimizations base on experience or copy other design drawings. His or her design drawing is difficult to be approved, many comments from the owner and consultant take time to revise and resubmit. Many mistakes may be found later on. On the other hand, an HDD specialist is more competent to make a design and support by relevant calculation, submit to project owner and consultant for approval. This can expedite the engineering progress, based on the optimized drawing, construction engineer can prepare the relevant construction procedure before the commencement of construction works. The construction team need the engineering support all the time, this is the key reason that a construction team does not only need the construction engineer but also the design engineer on site.

5.3.4 Replacing the unsuitable boring machine

Due to the tight project budget, company B hired the lowest-priced bored crossing subcontractor, the machine is very old and malfunction frequently. During the boring processing, if the cutting head is broken, the crossed pipes have to be pulled out, and cut to pieces, after the boring machine has been repaired, the work has to be started over. Find a new bored crossing subcontractor or buy a new bored crossing machine to replace the existing machine which's malfunction caused all the reworks. Company

B decided to hire a new boring subcontractor with the new boring machine to do the remaining boring works.

5.3.5 Reinforce the quality reward and punishment system

Revise the quality reward and punishment system, make sure all the good quality performance has been recognized, such as a high welding acceptance rate; all the poor-quality behaviors have been punished, such as non-conformance of a working procedure or testing plan. 5% of saved COQ shall be rewarded to the construction team for quality improvement.

5.3.6 Reinforce to use the AFC document on site.

The AFC documents mean documents that have been approved for construction. A document control system should be set up and work efficiently. To avoid the below issues happen on site:

- The construction documents are distributed to the wrong people.
- The construction documents distributed to the right person but after construction has been done.
- The construction team doesn't use the latest revision of documents.
- The construction team doesn't use the AFC document, the comments inside the document have not been incorporated during the construction.
- The previous documents have not been collected back.

- The document receivers didn't sign for the reception.

All the above issues could cause the repairs or reworks on site. Therefore, the AFC documents shall be kept on-site and applied during the construction. The engineering work shall be done ahead of construction. The document system shall be audited periodically and randomly. Periodic audit means the audit held by the quality assurance team, looking for the deficiency of the document control system, the auditing should be carried out as per the quality audit plan. Aperiodic audit means the document inspection held by the quality control team during the site surveillance activity. If the wrong version of documents has been used on-site, the finding should be noticed to the quality assurance team and document control person.

5.4 Remeasuring of COQ

It is crucial to evaluate whether quality improvement activities have reached the economic limit, we have to compare the benefits gain from lower quality failures defect against the investment made to achieve these benefits, think it cost-effectively. If the investment put in prevention and appraisal costs have no longer got any feedback, the optimum point has been reached. However, in the real world, the optimum point is not easy to be located. The prevention and appraisal investments have been required by the contract; company B has to fulfill it.

5.4.1 Remeasuring of COQ on Project B.

After the preventive actions have been applied and reinforced, the construction quality failures have been reduced significantly. In Dec 2019, the COQ of project A has been remeasured, it reduced to 9.9% of the contract value which was estimated at 15.7%. The COQ reduction trend shows in Figure 15.

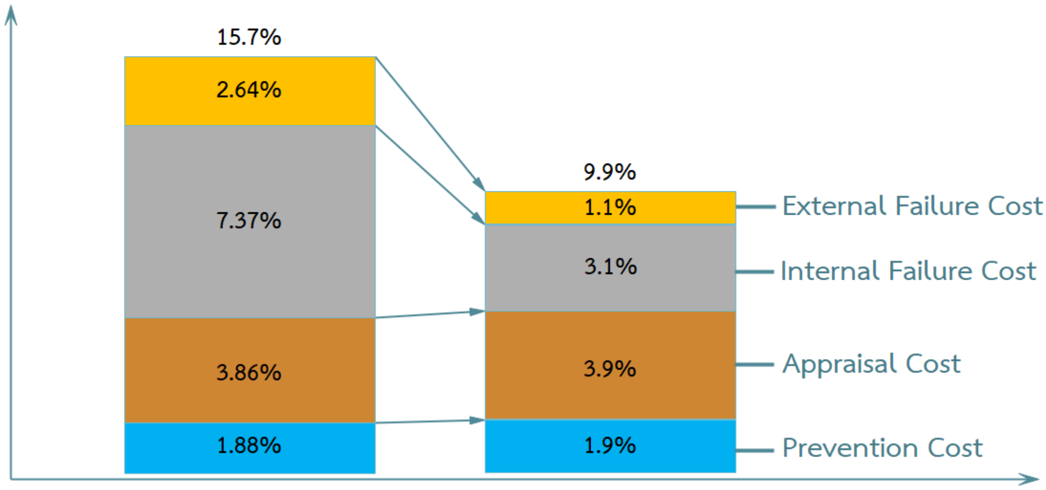

Figure 2. COQ Reduction Ratio

The investment in prevention and appraisal activities has increased by 0.06% of the contract value, but the total COQ has reduced 5.8% of the contract value. The overall COQ has been controlled to an acceptable level, the negative impact on the project has been reduced.

5.4.2 New Perspective on Classic Project Management Triangle

The quality of work is constrained by the project's budget, deadlines and scope, it is called as the Classic Project Management Triangle (Figure 16), it has become firmly linked with measuring the success of project management since the 1950s [44].

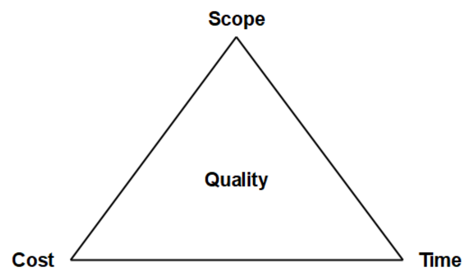

Figure 3. Classic Project Management Triangle

Changing of one constraint, the others automatically change to compensate, otherwise quality will suffer. The realization of COQ reduction in Project A proved that reducing internal and external quality failures can save cost and time tremendously than its estimation. People overlooked that the word “Quality” in the middle of the Triangle is not only quality requirements, but also means the quality performance of the construction team. If the quality requirements have been fulfilled by the highly efficient quality performance which higher than it was planned, the budget and duration of the project can be saved. This phenomenon can be illustrated in Figure. 17 below.

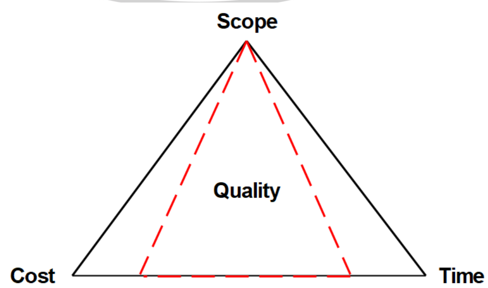

Figure 4. Optimal Project Management Triangle

CHAPTER 6

CONCLUSIONS

The QM team of company B has applied the COQ method to successfully draw the attention and commitment of project manager by monetary data, and easily identified the quality improving target. After located the root causes of internal and external quality failures, preventive measures have been produced and put in force. They found that the poor qualities are different in size, and a relatively vital few of the poor qualities account for the majority of the costs. A major function of the evaluation of COQ is to identify these vital few quality failures. This results in setting priorities to assure the effective use of investments.

The majority of quality issues are produced due to a shortage of engineering support and training for the construction crews. Normally, a detailed engineering contractor is not responsible for optimization or deviation on-site; therefore, construction teams should hire their professional engineer to fulfill the optimization purpose, otherwise either the works will be delayed or reworked. Due to the fast track of project management, lots of construction works have been started without the design have been officially approved, make sure all the lasted revision of designs on-site, and all the comments on the drawing or procedure have been incorporated during construction works.

The main findings of this thesis are summarized below:

1) In project A, 44% of the covert COQ has been overlooked by the accounting team and the project manager.

2) High construction quality failures can cause serious negative impacts to project cost and schedule, it is the key to project management, it determines the success or failure of the project because quality failures are rarely considered or planned during the bidding phases.

3) COQ system should be used on quality management of pipeline construction project, it can draw the attention and commitment of project managers by summarized

monetary data. Put investment in prevention activities, to tremendously reduce the internal and external quality failure costs.

4) The comprehensive training plan should be prepared and applied, 100% of the employee should be trained and competent for the works they are assigned.

5) Engineering supports are essential for site construction teams, especially dealing with site optimization and changes.

6) Not always subcontract the works to lowest-price bidders, their proposed construction resources should be considered, such as equipment and key personnel.

7) Set up a quality reward and punishment system, encourage and recognize the good quality performance by capital which have been saved from the reduction of COQ.

8) An efficient document control system should be on-site, and audited periodically and randomly. It is preferred that the engineering work can be done ahead of construction, to reduce the potential changes during or after the construction.

9) The classic project management iron triangle can be broken, if the majority of poor-quality issues have been reduced or eliminated, the good quality performance of the construction team can save the budget and time of the project tremendously than it was planned.

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