Sixth International Conference on Construction in the 21st Century (CITC-VI)
"Construction Challenges in the New Decade"
July 5-7 2011, Kuala Lumpur, Malaysia

PAF Model for Quality Cost Estimation in Mass-Housing Projects

Amirhosein Jafari
Graduate student, School of Civil Engineering, University of Tehran, Tehran, Iran
Amir_h_jafari@yahoo.com

Gholamreza Heravi
Assistant Professor, School of Civil Engineering, University of Tehran, Tehran, Iran
Heravi@ut.ac.ir

Abstract
Cost and quality are considered vital competitive factors for construction firms, and studying their relationship plays an important role in the construction industry. The objective of achieving a good-quality product is not only to meet the customers` requirements, but also to do it with the lowest cost. Therefore, a realistic estimation of CoQ and improvement benefits (which is the trade-off between the level of conformance and non-conformance costs) should be considered a critical quality activity for contractors. This paper studies and estimates quality costs in a mass-housing project in Iran. First, background information is presented on quality costing, and the prevention-appraisal-failure (PAF) model, which is the most widely used model for determining the quality cost and the optimum level of quality. Second, some previous studies are presented as benchmarks and their assumptions and conditions are discussed. Finally, a mass-housing project in Abeyek, Iran including 288 residential units is considered as a case study and its quality costs are estimated by using the selected benchmarks.

Keywords
Cost of Quality, Prevention-Appraisal-Failure approach, PAF model, Mass-housing projects

1. Introduction

In the new and competitive world, it is important to have a reasonable cost and enough quality for firms. Nevertheless, making a balance between these parameters is more important. Not only must a firm provide its product to meet the clients` requirements and at a quality that satisfies them, but it also must provide clients with the lowest cost possible. One effective way to achieve this purpose is using quality costs. Although there are numerous tools for measuring quality, the quality costs is considered by both Crosby (1984) and Juran (1988) to be the primary one. If firms and organizations can record and analyze the quality costs in their projects, they can use these data as a tool for identifying the roots of problems and having continuous improvements (CI) to reduce these costs in their projects. On the other hand, measurement of cost of quality (CoQ) is one of the most effective tools for evaluating the success of a quality management program.

There is a big problem in using this tool for firms and organizations. The first step to use quality costs is identifying and measuring them. Most quality costs are hidden and measuring them is difficult. On the other hand, contractors generally are not willing to exhibit their own costs and their quality problems such as reworks and omissions. So measuring and reporting the CoQ should be considered an important effort

for firms. Unfortunately in Iran, it`s not a proven matter that using the CoQ system is cost-effective, and very few construction companies and firms measure their project's CoQ.

This paper targets the mass-housing projects in Iran and has three main objectives: (1) to have a literature review on PAF model to evaluate the cost of quality in construction projects; (2) to state and select the best benchmark for mass-housing projects in Iran; and (3) to estimate the quality costs in a real mass-housing project in Iran.

2. CoQ and PAF classification

One of the earliest works related to the general concept of quality costs is Dr. J. M. Juran's first Quality Control Handbook. He suggested that the CoQ can be understood in terms of the economics of the end-product quality or in terms of the economics of the conformance quality (Juran and Gryna, 1988).

There are some different definitions with regard to CoQ terminology, such as: the control costs and the failure costs as Juran said (Juran and Gryna, 1988); the price of conformance and the price of nonconformance as Philip Crosby said (Shank and Govindarajan, 1994); and the controllable variables and resultant variables as H. James Harrington said (Corradi, 1994).

Regardless of the above mentioned definitions, most CoQ definitions are based on the PAF classification, which is the most accepted method for classifying quality costs. Joseph Juran (1951) initiated the concept of quality costing, the economics of quality and the graphical form of the CoQ model. Later Armand Feigenbaum (1956) proposed the now widely accepted quality cost categorization of prevention, appraisal and failure (internal and external) costs (Schiffauerova and Thomsom, 2006). The model is easy to understand and easy applied, which are the most important advantages of PAF classification. The elements of PAF classification have been introduced as follows:

2.1. Prevention costs

The key to improving quality and profitability is preventing the non-conformity. Prevention costs are those resulting from quality activities used to avoid deviations and errors (Kazaz et al., 2005). Examples of such costs are design reviews, education, training, supplier selection, capability reviews, process improvement projects, quality system development, and quality program development. Preventing non-conformity before a product is manufactured or prepared to serve the customer is clearly the most appropriate action in reducing appraisal and failure costs because it is always the least costly, least time consuming, and least troublesome approach for providing a quality product (Abdelsalam and Ghad, 2009). Prevention efforts also try to determine the causes of problems and eliminate them at the source, because an organization can determine when and where it wants to implement such efforts.

2.2. Appraisal costs

Appraisal costs include all costs associated with measuring, evaluating, or auditing products to determine whether they conform to their requirements (Kazaz et al., 2005). Examples of appraisal costs include inspections, material reviews, calibration of measuring and testing equipment, and maintenance of testing. The most important characteristic of appraisal costs is that they are associated with managing the outcome, whereas prevention costs are associated with managing the intent. Both costs, however, are unavoidable and are to be borne by the construction companies and consultant firms if their products are to be delivered on schedule (Abdelsalam and Ghad, 2009).

2.3. Failure costs

Failure costs are incurred when it is necessary to correct the products that fail to satisfy the customer or do not meet company quality specifications. Failure costs are those losses associated with the production of a non-conforming product (Abdelsalam and Ghad, 2009). One result of failure costs is that clients must pay higher maintenance costs when construction ends; rework is a waste of expenditure. These costs can be divided into internal and external costs. Internal failure costs are those costs associated with product failures found before the product is delivered to the customer, such as scrap and rework costs for the materials and overhead associated with production. External failure costs are the costs that occur when a non-conforming product reaches the customer, such as those due to customer complaints and those associated with receipt, handling, repair, and replacement of non-conforming products. Warranty charges and product liability costs are also external failure costs (Kazaz et al., 2005).

Failures, especially external failures, are the most important elements in quality costs elements and can make too much detriment to a company. External failures might make customers dissatisfied and it could cause the loss of future business. Nevertheless, most failure costs can be eliminated with a little investment in prevention and with timely inspection. There is a relationship between failure costs and the time that failures are detected. To spend less money for failure costs, it would be better to discover them as soon as possible. That means discovering the failures closer to project delivery time, would inflict more expenses to the company. Figure 1 is an illustration of this concept. It shows that the most costly condition occurs when a customer finds defects. When the company or firm finds the defects, through much inspection, testing, and checking, a less costly condition would be the result. If the company or firm`s quality program prevents the defect with continuous improvement, resulting costs would be minimized; obviously it is the most desirable condition (Campanella, 1990).

Although the PAF method is universally accepted for classification of CoQ, it has some insufficiencies. One of them is that it does not include intangible costs, such as, loss of reputation (Aoienog et al., 2002). The effect of intangible quality costs, often called “hidden quality costs” is difficult to be measured clearly. As shown in Figure 2, if true failure costs are compared to an iceberg and the more commonly measured failure costs as just the “tip of the iceberg”, the bulk of failure costs are “hidden” below the surface and are usually responsible for “sinking the ship” (Campanella, 1990). So, it is important to find a way for eliminating and measuring hidden failure costs. Another disadvantage of PAF classification is that it does not attend to process improvement while the PAF categorization scheme does not consider process cost (Aoienog et al., 2002).

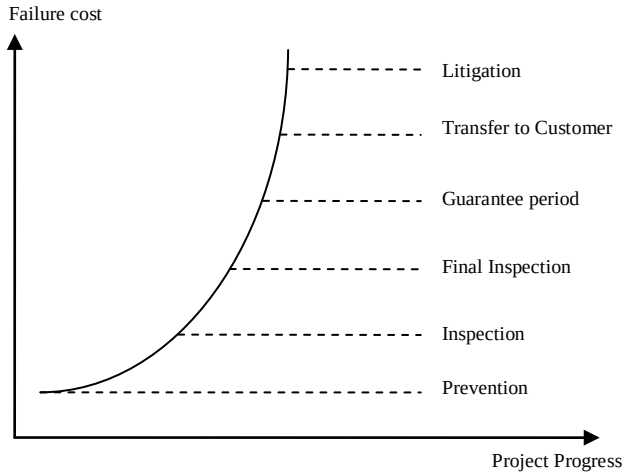

Figure 1: Failure cost as a function of detection point

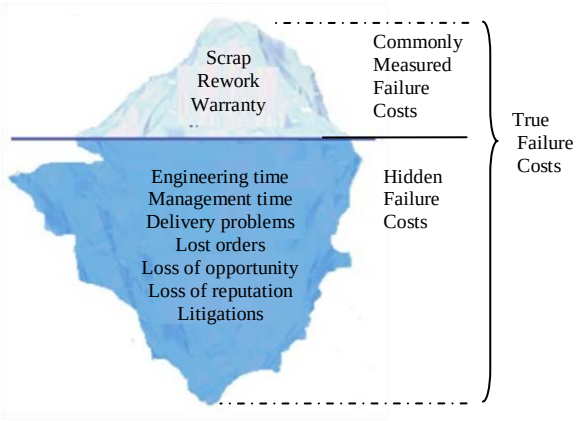

Figure 2: Hidden failure costs effect

3. Root Causes of Failure Events

In order to have continuous improvement, the quality failures should be analyzed to determine causes of deviations and divide them into the categories. The causal analysis will reveal a number of common issues ('root' causes) that indicate directions for possible improvement in the future and indicates to firms that it could lead to reduced quality failure costs on future projects. Casual analysis helps management determine the types of activity that are most beneficial in reducing quality costs and alerts management of the potential impact of poor quality. On the other hand casual analysis indirectly urges people in the industry to pay attention to continual improvement, which is a basic requirement in the implementation of TQM (Abdul-Rahman, 1993).

Numerous studies have attempted to quantify the rework costs (failure costs) in civil engineering projects. Yet, attention to the failure costs is merely not enough and all components of CoQ must be considered when analyzing the costs` related quality.

Burati et al. collected data on quality deviations from nine industrial engineering projects. According to them (1992), the cost of quality deviations can be as high as 12.4% of the project cost (Burati et al., 1992). Abdul-Rahman et al. (1996) studied plant construction and found that the failure costs were found to be 6% (Abdul-rahman et al., 1996). Love and Li (2000) had a study on a project consisting of two 6-story residential apartment blocks and they found that direct costs of failure were found to be 3.15%. Hammarlund and Josephson (1991) estimated quality failures that occur after a project has been completed to be as high as 4% of actual project production cost (Love and Li, 2000). The above mentioned results are summarized in Table 1. It shows that the failure costs have a variable value in different projects, but its value can be considerable in some projects.

Table 1: The percentage of failure cost in the total project cost

Author	Country	Project type	Failure
Abdul-Rahman et al.	UK	Plant	2.5%
Love et al.	Australia	Building	6%
Hammarlund et al.	Sweden	Building	4%
Burati et al.	USA	Industrial	12.4%

4. Benchmarks

Literature review shows that only a few researches have been made to study all components of CoQ in a real project as a case study. In this section, two researches of mass-housing projects as case studies are introduced. In these researches, CoQ components have been measured and analysed.

The first research was done by Kazaz et al. (2005). They studied a mass-housing project in Elazing, Turkey. This project contained 3100 housing units including 2200 high-rise residences (five or more stories), 200 medium-rise residences (three to five stories), and 700 two-story residences. All were constructed under the same project by one firm between the first half of 1992 and the second half of 1996. The main contractor had a yearly turnover of about US$100 million, although it does not have any international quality certification. This project was realised in collaboration with seven sub-contractors and many suppliers. The data were collected throughout the construction period. The findings of this study revealed that the prevention and appraisal costs are 64.18% of total quality cost whereas failure cost was 35.82%. The findings also revealed that the total quality cost constituted a substantial proportion of the total cost to residents, amounting to 32.36%. They stated that the percentage of 32.36 is a very high value, and therefore, total quality efforts should be performed more effectively in the future projects. The details of these percentages for the three kinds of residences are shown in Table 2. They also calculated

the optimum (minimum) cost of total quality for this project. It was 16.75% of the total cost to the client in high-rise housing residences, 24.96% in medium-rise residences, and 24.75 in two-story residences (Kazaz et al., 2005).

Table 2: Kazaz et al. Findings in mass-housing project

kind of residence	Total CoQ	Prevention plus appraisal costs	Failure costs
high-rise residences	27.97%	17.70%	10.27%
medium-rise residence	35.89%	24.79%	11.10%
two-story residences	33.23%	20.00%	13.23%

The second research was done by Abdelsalam and Ghad (2009). They believed that Dubai city in United Arab Emirates (UAE) is one of the biggest and fastest growing construction markets in the world. So, they studied residential construction projects that were located in Dubai, UAE. The project consisted of constructing 291 multi-storied residences with a total budget of around $870 million ($595 million for civil work). The project was divided into 11 sub-projects with the number of buildings in each project ranging from 16 to 36. The project was constructed by 9 main contractors and was supervised by one multidisciplinary consultant and was managed by an international project management company specializing in managing complex large-scale projects. All sub-projects had the same technical specification; thus, the same level of quality was expected. All sub-projects were inspected daily by the consultant and the project management team`s (PMT) quality control staff. Each contractor had his own quality control procedures and quality test plans. As all the sub-projects shared the same consultant and the same PMT, it was reasonable to assume that all of the work in all of the sub-projects was inspected with the same quality control to achieve the same level of quality. The findings of this study revealed that the total cost of quality for the project was 1.3% (without external failure costs) of the total project civil work value. The average failure cost (internal) in the construction industry in Dubai was 0.7% of the project total cost. They stated that this value is low and this can be reasoned to uniqueness of the construction industry in Dubai, project owners (clients) have to interfere, using the PMT and the consultant, to improve the quality of the performed works in the project, with no additional cost to the contractors. In this research, the cost of external failures was not studied because the project was not yet handed over to the client or to the end user (Abdelsalam and Ghad, 2009).

According to what was mentioned, these projects had some differences. The first one that was studied by Kazaz et al. was located in Turkey and another one that was studied by Abdelsalam and Ghad was located in Dubai, UAE. As Abdelsalam and Ghad have said, Dubai is one of the biggest and fastest growing construction markets in the world, but according to the Kezaz et al. Turkey is a developing country. Also, according to the Abdelsalam and Ghad study, the client used the PMT and the consultant to improve the quality of the performed works in the project, but, according to Kazaz et al. study, not only did the client not use an additional inspection firm, but also the contractor did not have any international quality certification. In the Kazaz et al. study, the external failure costs are measured after transferring the buildings to the customers, but in Abdelsalam and Ghad study, no external failure costs are collected. Iran is a developing country and construction condition in this country, is more similar to Turkey than Dubai. But there is an important difference between Iran and Turkey tender law. According to Turkish tender law, the contractor is responsible to the client for the failures that would appear in the first 5 years, but in Iran, usually this duration is about 1 year. So, if a failure event occurs after this time, instead of the contractor, the client will be responsible for it.

5. Case Study

5.1. Project scope

The project is located in Abeyek, Qazvin, Iran. This mass-housing project consists of constructing 12 seven-story buildings with 4 units in each story and one story for pilot; 288 residential units in total. The area of each unit is 94.8 m2; 27302.4 m2 in total. The project is constructed by 3 main contractors: one contractor for constructing all foundations, and two contractors for constructing the project. The foundation contractor had a unit price contract, but two main contractors have a lump sum contract, as $300 (#3,000,000 Rials) per square meter; $8,190,720 in total. The guarantee periods of the contracts are 8 months.

5.2. Benchmark selection

As mentioned, the construction industry in Iran is more similar to Turkey than the UAE. Consequently, the Kazaz et al. study was selected as a main benchmark for estimating the CoQ in the understudying project. In the Kazaz et al. study, the project included high-rise residences (five or more stories), medium-rise residences (three to five stories), and two-story residences. The high-rise residences in their study are more similar to residences in the understudying project. The results that have been used in this case study are shown in Table 3. As depicted in this Table, based on the Kazaz et al. study, the failure costs in both average and optimum level are approximately the same. It means that optimum level of CoQ occurs when the same failure cost is achieved with the lowest prevention plus appraisal costs.

Table 3: basis Data of benchmarks

Author	Location	P+A costs	F costs	CoQ	Optimum P+A costs	Optimum F costs	Optimum CoQ
Kazaz et al.	Turkey	17.70%	10.27%	27.97%	6.14%	10.61%	16.75%
Abdelsalam & Ghad	UAE	0.6%	0.7%*	1.3%**	-	-	-

P: Prevention, A: Appraisal, F: Failure
* Only internal failure cost
** Without external failure costs

5.3. Contract issues

Obviously, similar to any lump sum contract, in this project, contractors have accepted the project cost risks consisting of CoQ risks. According to General Provisions of Contracts in Iran, the client holds 10% of each payment to the contractor as a "Good Performance Guarantee." Half of the total Good Performance Guarantee will be released after the Provisional Acceptance and assessment of the Final Statement and the rest will be paid after Final Acceptance, which is the end of the Guarantee Period (in this project 8 months). So, if any failure appears during the Guarantee Period, the contractor is responsible to remedy it. Experiences have indicated that 8 months for the Guarantee Period is not enough time for probable failures in such a project to appear. Consequently, the client will be responsible for all failure costs that occur after the guarantee period.

Since in the Kazaz et al. study it was not stated what percent of failure costs is related to internal failure events and what percent is related to externals, it was decided to assume these values. Experiences have shown that more than half of failure costs will occur as external failure costs and also some amount of them might occur after short Guarantee Periods. Consequently, it is reasonable to assume that 50 percent of failure costs will occur as internal and the other 50 percent will occur as external.

According to the Kazaz et al. research results, the average failure costs are estimated at about 10% of the total client payment. Accordingly, it seems 10% of total payment as a Good Performance Guarantee is reasonable for this project too. But some failures might occur or appear after a very short Guarantee Period, and as a consequence the client is responsible to resolve them. Increasing the Guarantee Period is the best way to involve contractors in these costs and resolve this issue.

5.4. Estimating CoQ

For estimating the quality costs in the project, first the Kazaz et al. results are used because of the similar construction conditions between Turkey and Iran. Table 4 shows the average estimation of quality costs in the Abeyek project. As it shows, the amount of CoQ will be $2,290,944. That is a considerable amount for any contractor because decreasing this amount can increase the contractor`s profit. But, as stated, means of identifying the root causes of failures is an area that needs more inspection, the continual improvement can be done and the optimum level of CoQ can be achieved. The reduction in CoQ can be considered a part of contractors` profits. In this project, if the optimum level of CoQ is achieved, $918,998 will be added to the contractors` benefit. This benefit will be achieved by contractors rarely if they focus on the optimization of quality costs in the project. This value proves that unlike the belief of some contractors, focusing on the Quality costs and trying to achieve optimum level of CoQ is not wasting time and money.

Table 4: Estimating the quality costs of the Abeyek project

CoQ Component	Average		Optimum	
	Percent	Amount	Percent	Amount
Prevention + Appraisal	17.70%	$1,449,757	6.14%	$502,910
Failure (Internal + External)	10.27%	$841,187	10.61%	$869,035
Total CoQ	27.97%	$2,290,944	16.75%	$1,371,946

Finally, if the project had nearly ideal condition like Dubai, the amounts of quality costs would change too considerably. If a client hired adequate inspection and expert management team, all components of CoQ would decrease for contractors. Table 3 shows Abdelsalam and Ghad`s results, however the external failure costs were not measured in their study, so it is reasonable to assume that external failure costs are 0.7% just like internal failure costs, So, the failure costs will be about 1.4% of the total project cost and total CoQ will be about 2%. Table 5 shows that if this project was in the same conditions as the Abdelsalam and Ghad project, the estimation of CoQ would be less.

Table 5: Estimating the quality costs of the Abeyek project in a near ideal condition

CoQ Component	Percent	Amount
Prevention + Appraisal	0.6%	$49,144
Failure (Internal + External)	1.4%	$114,670
Total CoQ	2%	$163,814

6. Conclusions

Even though construction firms consider quality an important issue, they do not pay enough attention to CoQ and only a few of them use a formal quality costing system. CoQ programs must be a portion of any quality management program. An appropriate CoQ approach helps to identify and measure the quality costs, and thus continual improvement actions for reducing CoQ could be prepared.

In developing countries, the costs of quality include a high percentage of the total project cost; because there are not general quality standards and companies do not implement TQM and quality costing approaches. Nevertheless, if a client employs an eligible consultant and project management firms to manage and inspect the project activities, costs of quality are decreased sensibly and consequently the total cost of project is decreased.

According to this research, for the mass-housing project in Abeyek, which costs about $8,190,720 for civil works, there will be about $2,290,944 that contractors will have to pay for CoQ. This value is too considerable and proves that focusing on the Quality costs and achieving an optimum level of CoQ are important efforts in increasing the contractor`s benefit.

Also, it seems that 10% of total payment as a Good Performance Guarantee is reasonable for this project. But some failures might occur or appear after a very short Guarantee Period. Increasing the Guarantee Period is the best way to involve contractors in these costs and resolve this issue.

7. References

Abdelsalam, H., and Gad, M. (2009). "Cost of Quality in Dubai: An analytical case study of residential construction projects". *International Journal of Project Management*, 27, pp. 501-511.

Abdul-Rahman, H. (1993). "Capturing the cost of quality failures in civil engineering". *International Journal of Quality & Reliability Management*, 10(3), pp. 20-32.

Abdul-Rahaman, H., and Thompson, P., and Whyte, I. (1996). "Capturing the cost of non-conformance on construction sites: An application of the quality cost matrix". *International Journal of Quality & Reliability Management*, 13(1), pp. 48-60.

Aoienog, R., and Tang, S., and Ahmed, S. (2002). "A process approach in measuring quality cost of construction projects: model development". *Construction Management and Economics*, 20, pp. 179-192.

Burati Jr., J., and Farrington, J., and Ledbetter, W. (1992). "Causes of quality deviations in design and construction". *Journal of Construction Engineering and Management*, 118(1), pp. 34-49.

Campanella, J. (1990). *Principles of Quality Costs: Principles, Implementation, and Use*, 3rd edition, ASQC Quality Press, Milwaukee.

Corradi, P.R. (1994). "Is a cost of quality system for you?". *National Productivity Review*, 13, pp. 257–269.

Hall, M., and Tomkins, S. (2001). "A cost of quality analysis of a building project: toward a complete methodology for design and build". *Construction Management and Economics*, 19, pp. 727-740.

Juran, J.M, and Gryna, F.M. (1988). *Juran's Quality Control Handbook*, 4th edition, McGraw-Hill, New York.

Kazaz, A., and Birgonul, M., and Uniberyli, S. (2005). "Cost-based analysis of quality in developing countries: a case study of building projects". *Building and Environmental*, 40, pp. 1356-65.

Love, P., and Li, H. (2000). "Quantifying the causes and costs of rework in construction". *Construction Management and Economics*, 18, pp. 479-490.

Schiffauerova, A., and Thomson, V. (2006). "A review of research on cost of quality models and best practices". *International Journal of Quality & Reliability Management*, 23(4).

Shank, J.K., and Govindarajan, V. (1994). "Measuring the 'cost of quality': a strategic cost management perspective". *Journal of Cost Management* , 8(2), pp. 5–17.

Yasin, M., and Czuchry, A., and Dorsch, J., and Small, M. (1999). "In search of an optimal cost of quality: an integrated framework of operational efficiency and strategic effectiveness", *Journal of Engineering and Technology Management*, 16, pp. 171–89.