

Cost-based analysis of quality in developing countries: a case study of building projects

Aynur Kazaz^{a,*}, M. Talat Birgonul^b, Serdar Ulubeyli^a

^aFaculty of Engineering, Department of Civil Engineering, Akdeniz University, 07200 Topcular, Antalya, Turkey

^bDepartment of Civil Engineering, Middle East Technical University, 06531 Ankara, Turkey

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Abstract

This paper examines construction quality costs in Turkey. First, background information is presented on quality costing, on the prevention, appraisal, and failure (PAF) approach, and on PAF components. Secondly, a model is presented for determining the optimum level of total quality cost. Finally, a case study in which the costs of quality in a mass-housing project were collected and evaluated is presented. For the case study, the data were obtained in two stages: (i) during the construction period and (ii) after the delivery of residences. During the construction period, data were collected in collaboration with quantity surveyors and site engineers. During the delivery of residences, a questionnaire was administered to 655 householders, using face-to-face interviews. The importance of construction quality in a developing country was clarified by means of a cost-based analysis, in which the percentages of quality costs in the total cost to client were calculated separately, as was the optimum cost value of total quality. © 2004 Elsevier Ltd. All rights reserved.

Keywords: Prevention; Appraisal; Failure (PAF) approach; Optimum cost of quality; Least-squares method; Mass-housing projects

1. Introduction

Completing a quality work on schedule is one of the most important factors in minimizing the cost of civil engineering projects. The detailed planning and prevention of non-conformance usually represent a secondary priority in developing countries, such as Turkey. The approach “solve the problem as the problem appears” is commonly preferred in the management of the most construction projects. On other hand, quality (including aesthetic value) is perceived as one of the most important features in developing countries. Achieving high quality is a fundamental way of meeting the needs of customers and reducing non-conformance. High quality is therefore always more cost effective than poor quality in the long term.

2. Quality costing

Juran and Gryna [1] defined quality as ‘fitness for purpose’, whereas Crosby [2] defined it as ‘conformance to requirements’. According to Deming [3], quality is uniformity with respect to a correct target. In the construction sector, quality is understood as the ability to meet the requirements contracted with clients. The concept of quality costs was first mentioned by Juran [4] and this concept was applied in the manufacturing industry in the early 1950s. In the construction industry, increasing attention has been given to improve the overall construction quality since the early 1980s. Quality costs are a measure of costs specifically associated with the achievement or non-achievement of product quality, as defined by all product requirements established by the company and its contracts with customers and society [5]. Juran [4] has suggested that the cost of quality can be understood in terms of the economics of the end-product quality or in terms of the

*Corresponding author. Tel.: +90 242 3237073;
fax: +90 242 3232362.

E-mail address: akazaz@akdeniz.edu.tr (A. Kazaz).

economics of the conformance quality. There is a direct correlation between quality and profitability: higher quality results in lower costs, and profitability therefore increases [6]. Producing quality products and services is cost effective, and auditing the cost of quality is one of the most important parameters of achieving quality. Cutting the expenditures for quality might lead to undesirable quality levels. In contrast, increasing expenditures unnecessarily decreases the profit margin. As a result, the optimum level of quality expenditure should be determined by having information concerning the quality costs, because the cost of quality cannot be manageable unless it is measurable. Oliver and Qu [7] underlined the importance of quality cost reporting. Furthermore, it should be noted that quality costs and their methods of collection vary across industries and between companies. The other advantages of measuring and classifying quality costs are as follows:

- It ensures that the project tasks are completed correctly from the beginning, and warrant the effort required.
- It helps to identify the problems that reduce the overall cost of quality.
- It allows cost quantification of failure events and thus helps to reveal the anomalies in cost allocation, which might otherwise remain undetected.

An action based on a plan is more cost effective than an unplanned one. In this regard, a manager can determine the effect of investing in a process, changing a standard operating procedure, or revising a product design.

Results from the quality cost analysis can be used in all types of input selection processes. However, Deming [3] has stated that cost analysis for quality is not effective and that measuring quality costs to seek optimum defect levels is evidence of a failure to understand the problem. Crosby [2] argued that quality costs need to be measured not for management control, but for the development of quality thinking within the organization. The more popular approach is that of Juran [4], who advocated the measurement of costs on a periodic basis as a management control tool.

3. The prevention, appraisal, and failure (PAF) approach

The most widely accepted method for measuring and classifying quality costs is the prevention, appraisal, and failure (PAF) model. Although PAF is universally accepted for quality costing, it also has some drawbacks described by Aoieong et al. [8] and Porter and Rayner [9].

3.1. Prevention costs

The key to improving quality and profitability is prevention of non-conformity. Prevention costs are those

resulting from quality activities used to avoid deviations and errors [10]. Examples of such costs are design reviews, education, training, supplier selection, capability reviews, and process improvement projects. Harrington [11] provided an extensive list of the overall content of each cost type. Several measures of quality cost are also listed in Johnson's [12] study of *engineering-type settings*. 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. 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. Prevention expenses can be recovered many times over through reduced appraisal and failure costs. This means that more feedback is procured using prevention methods. Roberts [13] found that by spending 1% more on prevention efforts, the failure costs of construction can be reduced from 10% to 2%.

3.2. Appraisal costs

The second less expensive expenditure in quality management is to incur the appraisal means. Appraisal costs include all costs associated with measuring, evaluating, or auditing products to determine whether they conform to their requirements [2]. Examples of appraisal costs include inspections, material reviews, and calibration of measuring and testing equipment. 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. Prevention and appraisal costs, however, are unavoidable costs that must be borne by the construction companies and consultant firms if their products are to be delivered on schedule. Hays [14] and Ledbetter [15] reported that providing quality control in construction requires an expenditure ranging from 1% to 5% of total project costs. Gunneson [16] asserted that the appraisal costs gradually diminish as failure costs decrease because there is less need for inspection. In other words, appraisal costs can be reduced when the quality of the product reaches high levels. High appraisal costs combined with high internal failure costs signal that poor quality products are being produced.

3.3. 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 [17]. The costs can be divided into internal and external costs. Internal failure costs are those costs associated with

product failures found before the product is shipped to the customer—such as scrap and rework costs for the materials, labour, 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. External failures can include loss of future business through customer dissatisfaction, although this rarely occurs [18]. One result of failure costs is that clients must pay higher maintenance costs when construction ends: rework is a waste of expenditure. To improve the performance of projects it is necessary to identify and collect the costs of rework, and to measure the full impact of the failures on the project costs.

The literature indicates that the most construction firms have not measured all three cost categories, instead prefer to concentrate only on failure costs. Numerous studies have attempted to quantify the rework costs in civil engineering projects. These can be seen in Table 1. Reducing rectification costs is the most expensive portion of any quality cost in construction [33,34]. A slight reduction of this expenditure can result in significant savings or profits. Moreover, a decrease in failure costs will cause a decrease in prevention and appraisal costs. In contrast, it is expected that the cost of failures will be an insignificant percentage of total costs if the projects examined are relatively simple, such as mass-housing projects. Most failure costs can be eliminated with little investment in prevention and with timely inspection. Pinpointing the precise source of deviations assists in the prevention of the recurrence of that specific failure in future projects and in the remaining construction tasks of any current projects with the same potential failure. Nevertheless, the increase in expenditures for prevention and appraisal will not cause an immediate reduction in failure costs, primarily because of the time lag between the cause and the effect, as explained by Campanella and Corcoran [35].

Achieving a reduction in failure costs is not straightforward. For this purpose, the Pareto logic can be utilized. According to the Pareto logic, only about 20% of the failure incidents accounts for approximately 80% of the failure cost and thus less time should be allocated to investigate all possible non-conformances. The Pareto analysis (also known as the 80/20 rule) can be used to select the major non-conformances that are most beneficial in reducing 80% of the failure cost (according to Deming [3], this ratio is 85/15).

In the PAF method, several relationships exist between the quality costs, and these are fundamental to comprehending the model. As Banks [36] and Quinn [37] pointed out, more defects are caught internally and

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

Author	Country	%	Project type
Abdul-Rahman [19]	UK	2.5	Plant
Abdul-Rahman [20]	UK	5	Highway
Barber et al. [21]	UK	16–23	Road
Burati et al. [22]	USA	12.4	Industrial
BRE [23]	UK	15	Building
CIDB [24]	Singapore	5–10	General
Dale and Plunkett [25]	USA	12 <	General
Hall and Tomkins [26]	UK	5.84	Building
Hammarlund et al. [27]	Sweden	2–6	Building
Josephson and Hammarlund [28]	Sweden	2.3–9.4	Building
Love et al. [29]	Australia	3.15	Building
		2.4	Industrial
Love et al. [30]	Australia	10 >	Building
Nylen [31]	Sweden	10	Railway
Patterson and Ledbetter [32]	USA	25	Industrial

fewer are caught externally when appraisal costs increases. Internal failure costs increase when external failure costs decrease. Therefore, the total costs of quality remain nearly unchanged since the decrease in external failure costs is offset by the increase in appraisal and internal failure costs. Prevention costs also remain unaffected because both internal and external failure costs decrease in order to increase prevention costs. In contrast, prevention costs are expected to rise as more time is spent on prevention activities throughout the organization. As processes improve, appraisal costs reduce, because the need for inspection is no longer necessary. Savings in the total costs of quality can be derived from reducing both failure areas. Consequently, money spent on prevention produces a much more significant return than money spent on appraisal, although money spent on both prevention and appraisal helps to ensure that quality is delivered to the customer.

Most authors group the prevention and appraisal costs together and divide quality costs into two components: prevention plus appraisal cost and failure cost, as shown in Table 2. The present authors adopt this practice, and the following equations and terms are therefore used in this study:

- (1) Quality cost = Prevention cost + Appraisal cost
- (2) Total quality cost = Quality cost + Failure cost
- (3) Total cost to client = Total quality cost + Initial investment cost

4. The model basis of optimum quality cost

In an attempt to represent the behavior of the total quality cost and to find the significance of its optimum level, many economic and mathematical models have

Table 2
The terms used to describe the two components of the total quality cost

Authors	Prevention cost plus appraisal cost	Failure cost
Besterfield [38]	Controllable costs	Uncontrollable costs
Blank and Solarzano [39]	Discretionary costs	Consequential costs
Crosby [2]	Conformance costs	Non-conformance costs
Davis et al. [40]	Cost of quality management activities	Cost of quality deviations
Feigenbaum [41]	Cost of quality control	Cost of failure control
Juran and Gryna [1]	Control costs	Failure costs

been developed. These models vary greatly in scope and complexity, but only few found practical utility [42]. Plunkett and Dale [43] pointed out that there are at least 20 such models. The traditional model detailed by Brown and Kane [44] is examined in this study because of its widespread acceptance. Nevertheless, the validity of the model has been questioned by many researchers. According to the classic model shown in Fig. 1, an increase in expenditures on prevention and appraisal ensures a decrease in the percentage of defects—that is, a higher quality level. In contrast, an increase in the percentage of defects is accompanied by increased failure costs. Accordingly, there is an inverse relationship between prevention and appraisal effort and failure cost [45]. The optimum conformance to quality or defect level is where the increasing costs of the prevention and appraisal curve converges with the curve of decreasing failure costs. Total quality costs are minimized to the point where the cost of prevention plus appraisal equals the cost of failure. The total quality cost curve represents the sum of the other two curves, and the location of the minimum point on the total quality cost curve, sometimes referred to as the optimum point, therefore depends on the shapes of the two lower curves. The optimum point will vary according to the nature of the project. Although it is the optimum from the standpoint of total quality costs, it might not be the optimum from the standpoint of profit. Brown and Kane [44] stated that it is rarely the optimum. The optimal point of total quality cost is located at a position that represents less than 100% quality conformance.

5. The case study

Every segment of the construction industry benefits from the quantitative analysis of quality-related efforts. The relationship between total quality costs cannot be completely understood without quantification. This matter has become important for mass-housing projects, which are aiming to provide house ownership to low-income and middle-income groups. This study collected and evaluated data regarding the costs of total quality in

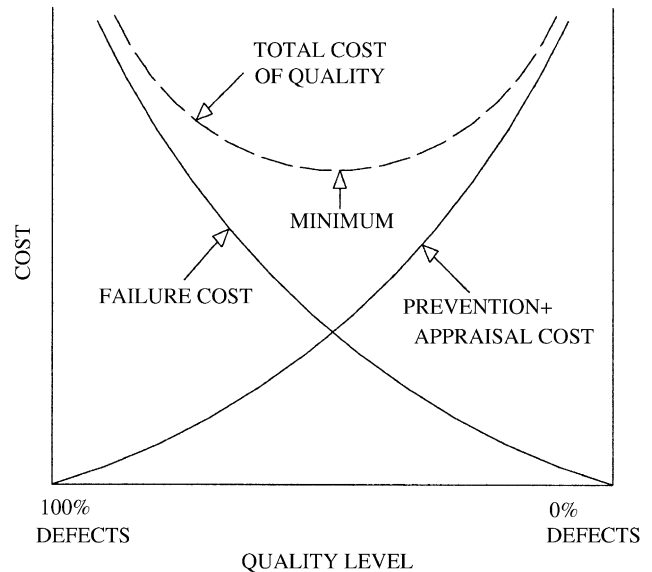


Fig. 1. Cost versus quality level—classic view adapted from Brown and Kane [44].

a mass-housing project in Turkey. To ensure a uniform comparison between the collected costs, the data were escalated to the base year 2003 by using the cost transformation coefficients as determined by the Ministry of Public Works and Settlement. All these values were converted to US dollars.

The data were obtained from one mass-housing project located in Elazığ [46,47]. There were 3100 housing units including 2200 high-rise residences (five or more storeys), 200 medium-rise residences (three to five storeys), and 700 two-storey 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 is a reputable construction firm (founded about 30 yr ago in Turkey), which has 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 collected data on prevention costs, appraisal costs, and internal failure costs include the information about all 3100 housing units. The data were collected throughout the construction period.

However, the data did not total 3100 residents because their numbers had decreased within the collection phase. Prevention and appraisal costs were provided by the project manager and quantity surveyors of the contractor and sub-contractors, whereas internal failure costs were determined by site engineers and the site manager. The visits to the site occurred monthly. The collection of prevention and appraisal data was mostly based on company records.

The collection of internal failure costs was mostly based on research conducted at each residence. The data collection of external failure costs was carried out after the product delivery in collaboration with householders. To achieve this, a questionnaire comprised of 118 detailed questions was administered to 655 residents by face-to-face interviewing in each residence between late 2001 and early 2003. The 655 housing units examined in the study consisted of 450 high-rise (20.45%), 55 medium-rise (27.5%) and 150 two-storey (21.43%) residences. Thus, the consistency of the study was improved by the relatively large sample number (655), which was an adequate representation of the entire 3100 residences (21.13%). Four criteria had to be satisfied in the selection of samples:

- that the house was not empty,
- that the resident was not a tenant,
- that the house had been occupied continuously for 5 yr (according to Turkish Tender Law, the contractor is responsible to the client for the failures that would have appeared in the first 5 yr) and
- that the resident was willing to co-operate with interviewer.

In the determination stage of external failure incidents, particular attention was given not to confuse external failures with reworks created by household mistakes. Moreover, costs associated with internal and external failures were assumed to be equivalent to the costs of rework. Initial investment costs were obtained from monthly dues paid by the residents from early 1991 to late 1995. Although these payments were collected from the bank records kept by householders, householders had also recorded separately their payments, so it was not difficult to collect these data.

In the manufacturing industry, a product's failure costs can be obtained by spending different quality costs for a product. The optimum cost of total quality can therefore be ascertained by means of the curves described above. In other words, the relationship between the quality and failure costs can be observed easily in the manufacturing industry, whereas it is more difficult to do so for the construction industry. This is because, in the construction industry, products are

created over much longer durations, and steady production does not normally occur. Therefore, some assumptions were made to adopt the model. One assumption was to search for the optimum point of total quality cost using the data existing in the sample. To achieve this, all the collected prevention, appraisal, and failure costs were used. Initially, quality costs were arranged in order from lowest to highest, and failure costs were arranged in decreasing order. The lowest quality cost and the highest failure cost were then matched with 0% conformance to quality, whereas the highest quality cost and the lowest failure cost were matched with 100% conformance. Conformance percentages of 0% and 100% were not interpreted as absolute values, but merely as points on a scale.

6. Curve fitting with polynomials

With the aim of adapting the curves of Fig. 1 to practice, thin curves in Figs. 4–6 have been drawn by the real-cost values, and thick lines were plotted to fit the data. In this phase, the method of least squares was utilized for fitting the curves. In approximating functions, the most commonly used equation form was the polynomial [48]. Various means were used to select the appropriate degree of a polynomial that would yield the best fit for a certain set of data points. A statistical method called the standard error of the estimate was used to obtain the optimum degree of polynomial that best fits the data because the standard error of the estimate is more easily associated with a tangible meaning. The standard error (or residual variance) of the equation for each polynomial degree was found, and then the smallest was chosen as the optimum degree polynomial. However, a quadratic polynomial was accepted in this study before analysing the standard error because the curves should be in harmony with those of the traditional theory. In other words, the data were fitted with a discrete least-squares polynomial of degree two and the functional relationship was assumed to be

$$y = c_0 + c_1x + c_2x^2 \quad (1)$$

with errors defined by

$$e_i = y(x_i) - y_i, \quad (2)$$

where $y_i = y$ are data values correspond to x_i and $y(x_i) = y$ are values of fitting curve at $x = x_i$.

The sum of squares was minimized as follows:

$$S = \sum_{i=1}^n e_i^2. \quad (3)$$

At the minimum, all the partial derivatives vanish. Writing the equations for these gives three equations,

we have

$$\frac{\partial S}{\partial c_0} = 0, \tag{4}$$

$$\frac{\partial S}{\partial c_1} = 0, \tag{5}$$

$$\frac{\partial S}{\partial c_2} = 0. \tag{6}$$

The three constants were thus evaluated by means of the three equations. The standard errors σ_e were calculated to see whether they were statistically significant and, indirectly, whether choosing a polynomial degree was a correct supposition. The errors were calculated by taking the square root of the quotient formed by dividing the sum of the squares of the deviations of the data points from their corresponding points on the curve by the degrees of freedom of the fit [49]. The latter is equal to the number of the data points n minus the number of quantities derived from the data. Since all of the constants (c values) of the fitting polynomial are derived from the data, the degrees of freedom equals $n - m$ and the residual variance can be expressed as

$$\sigma_e = \sqrt{\frac{S}{n - m}}, \tag{7}$$

where n = number of data points and m = number of c values in polynomial (degree of polynomial plus 1).

7. Findings and analysis

Love and Li [50] stated that quality failures have become an inevitable feature of the procurement process in construction. In contrast, Low and Yeo [51] reported that rework costs can be regarded as almost zero in construction when a quality management system is implemented, although it is difficult to avoid defects entirely. In this study, the minimum cost value of failure in all housing units was zero, as seen in Table 3. This

means that, in some housing units, there was an absence of non-conformance events. Hence, the zero defect level (i.e., 100% conformance to contracted requirements) can be obtained in these construction projects, in accordance with Low and Yeo’s [51] thesis. This also confirms Crosby’s [2] zero defect concept.

Both quality costs and failure costs varied considerably, even though the housing units belonged to mass-housing projects. This can be seen by comparing the means and the standard deviations of these costs. In some cases, it was observed that the standard deviation was greater than the corresponding mean. However, it is to be expected that the quality levels of housing units will be almost identical in this type of project, because the residences have identical features. Moreover, the quality level of the house in the construction phase should increase because of improved efficiencies over the building period. The fluctuation has various causes, and is very high for the finishings. These will be considered in detail in subsequent studies. For this study, the level of quality fluctuates not only between the apartment blocks but also between the apartments of the same building. That is, in the project there is no quality standardization, although the zero defect level was obtained in some cases. Consequently, the quality standardization of a project is as important as the defect level concept.

The non-conformances that appear after the delivery of non-residential constructions can be repaired by contractors whereas, in residential buildings, repairs are usually effected by householders, especially in developing countries. Therefore, the total cost to contractors is an erroneous method by which to estimate the cost of a project (even though the most studies shown in Table 1 used this method). As a result, the total project costs are not completely taken into consideration, and the total cost of the house to each client has to be obtained individually. In each residence type, the initial investment costs can show large differences. When the residents paid their dues on time, the initial investment costs are at the minimum. However, some residents had not paid their dues on time at the different construction

Table 3
Data used in the research

Type of housing unit	Type of cost	Min. (\$)	Max. (\$)	Mean (\$)	St. Dev. (\$)
<i>High-rise housing units</i>	Quality cost	210	16,355	4,994.26	5,023.75
	Failure cost	0	10,176	2,897.13	2,885.55
	Initial investment cost	11,151	30,659	20,327.18	5,330.70
<i>Medium-rise housing units</i>	Quality cost	629	18,758	7,458.90	5,885.23
	Failure cost	0	8,310	3,341.19	2,507.64
	Initial investment cost	14,124	26,761	19,286.82	3,496.18
<i>Two-storey housing units</i>	Quality cost	200	21,339	7,605.88	6,521.92
	Failure cost	0	11,505	5,031.94	3,212.06
	Initial investment cost	20,071	34,938	25,395.61	4,347.97

stages, and their payments increased because of the high inflation rates in Turkey. Another group of residents sold their houses with a profit margin before the construction was completed. Therefore, the initial investment costs for the three housing unit types fluctuated. The most expensive residences were two-storey units costing US\$20,071. Medium-rise and high-rise housing units cost US\$14,124 and US\$11,151, respectively. Nonetheless, the mean of the initial investment cost of high-rise housing units (US\$20,327.18) was higher than that of medium-rise housing units (US\$19,286.82) because of this fluctuation.

Quality costs accounted for a greater share of total quality costs compared with the costs of failure for three types of housing units, as shown in Fig. 2. The percentages of both quality costs and failure costs were almost the same for all residence types. This means that prevention and appraisal efforts did not improve, and that rework costs were not reduced, particularly in the two-storey housing units (because the residences became more expensive). It can be concluded that the quality cost was approximately 64.18% of total quality cost whereas failure cost was around 35.82%.

All of the studies regarding the percentage of failure cost within the total project cost for developed countries are presented in Table 1. The reported costs of rework in the case studies vary from 2% to 25% for the different project types. The present work can be considered as a similar study for a developing country, and it unexpectedly found that the failure cost averaged 11.53% of the total payments of residents, as shown in Fig. 3. In addition, the results demonstrate that the quality cost was 20.83% of the total cost to client. In Hall and Tomkins' [26] research the quality cost was 12.68%; this is the only work based on the PAF model that can be considered as comprehensive enough to measure the quality costs in construction. The findings in this study also revealed that the total quality cost constituted a substantial proportion of the total cost to residents, amounting to 32.36%. As shown in Table 4, this was

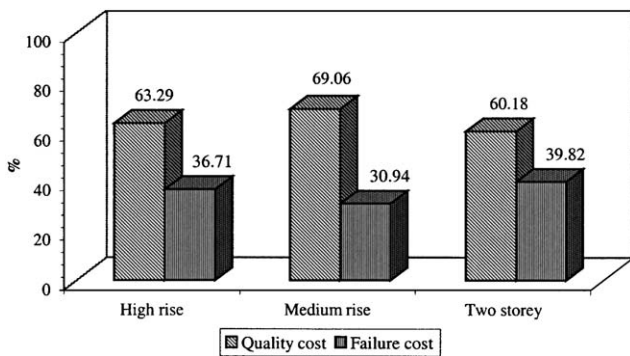


Fig. 2. Percentages of quality cost and failure cost within the total quality cost.

between 8% and 19% for the different construction projects (based on the previous papers focusing on the construction in developed countries). Namely, the percentage of 32.36 is a very high value, and therefore, total quality efforts should be performed more effectively in the future projects.

Table 5 shows the cost-conformance equations for each cost type according to the type of housing unit, as well as their standard errors. The standard errors of all cost-conformance curves are not statistically significant. This confirms that choosing the quadratic polynomials was an acceptable assumption, and that all cost-conformance points are adequately represented by the equations. Furthermore, the convergent point of quality cost curve (qcc), the failure cost curve (fcc), and the minimum point of the total quality cost curve (tqcc)

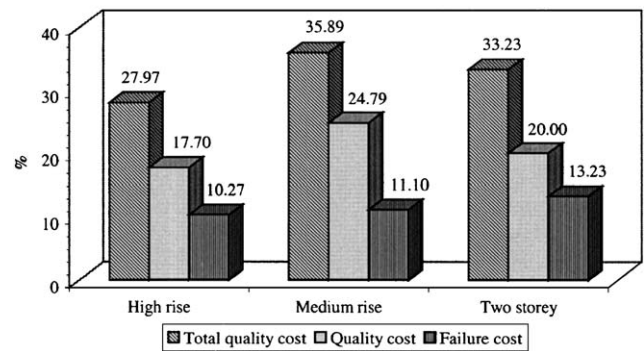


Fig. 3. Percentages of total quality cost, quality cost, and failure cost within the total cost to client.

Table 4
The percentage of total quality cost within the total project cost

Author	Country	%	Project type
Davis et al. [40]	USA	15	Industrial
Hall and Tomkins [26]	UK	18.52	Building
Lam [52]	Singapore	8–15	General
Willis and Willis [53]	USA	12	Industrial

Table 5
Standard errors of the cost-conformance curves (as per as Figs. 4–6)

Type of housing unit	Equation	σ_e
High-rise housing unit	y (qcc)	300,272
	y (fcc)	286,270
	y (tqcc)	481,471
Medium-rise housing unit	y (qcc)	601,610
	y (fcc)	346,562
	y (tqcc)	735,606
Two-storey housing unit	y (qcc)	566,263
	y (fcc)	350,666
	y (tqcc)	664,475

should be determined. The point at which the quality cost curve and the failure cost curve intersect was found for each housing unit type. It is the point where the quality cost curve equals the failure cost curve. It can therefore be calculated by means of the following equation:

$$y_{qcc} = y_{fcc} \tag{8}$$

The minimum point on the total quality cost curve has been calculated for each residence type by means of the following partial derivative:

$$\frac{\partial y_{tqcc}}{\partial x} = 0 \tag{9}$$

Results of the calculations can be seen in Figs. 4–6. In high-rise housing units the optimum (minimum) cost of total quality was 16.75% of the total cost to client. It was 24.96% in medium-rise residences and 24.75% in two-storey residences. In the traditional theory, the convergent point and the minimum point are on the same imaginary vertical line. However, in practice, the convergent point and the minimum point do not usually have the same conformance level and variations are always possible because the curves are produced by real-world data. Thus, a question is raised: “What is the meaning of the difference between the two points on the *x* axis, and is it important?”. When the defect levels of the two points are not equal, two alternatives exist. The first is that the convergent point is at the right side of the minimum point and the second is that minimum point is at the right side of the convergent point. In the first case,

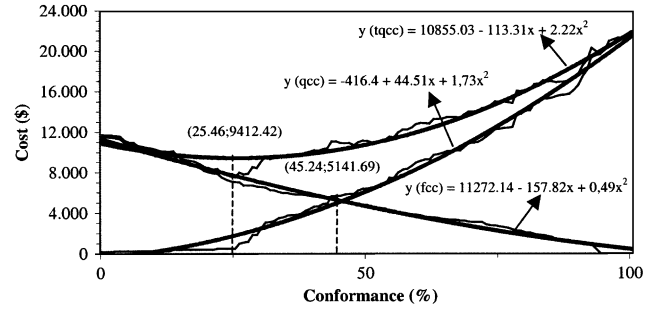


Fig. 6. Cost-conformance curves in two-storey housing units.

Table 6
The components of the optimum of total quality costs

Residence type	Components of the minimum point		Difference between the two costs
	Quality cost	Failure cost	
High-rise housing unit	1,732.96\$	2,993.63\$	1,260.67\$
Medium-rise housing unit	1,821.33\$	5,689.30\$	3,867.97\$
Two-storey housing unit	1,839.55\$	7,572.87\$	5,733.32\$

as in this study, failure cost is greater than quality cost at the minimum point. This means that more money has been spent in correcting products. In the second case, failure cost is less than quality cost at the minimum point. That is, more money was spent in controlling products—which is the preferred situation. As shown in Table 6, in this study it unexpectedly appears that the more expensive the residence was, the larger was the difference between these two points in the failure costs.

8. Concluding remarks

The importance of this study is that this is the first research aiming to quantify the magnitude of total quality costs in construction projects in a developing country. Previous studies in the construction industry have been undertaken in developed countries and have had a particular emphasis on estimating failure or non-conformance cost. It was demonstrated that there is a good agreement between the findings of this study and previous research. However, more studies should be undertaken to compare the quality costs in developing and developed countries.

To estimate the real project cost, the most studies have considered the total cost to contractor, whereas this study was focused on the total cost to client. In addition, the PAF approach was used in determining the total quality costs. The PAF method is prevalent in the manufacturing industry and there is a widespread

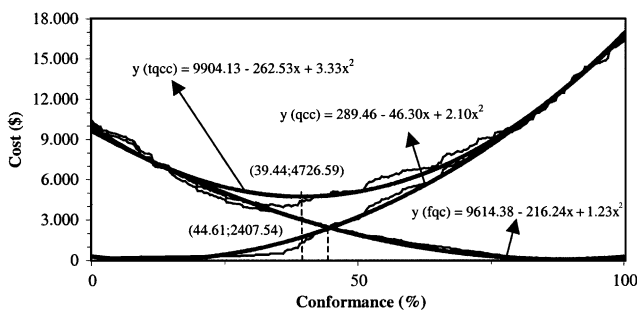


Fig. 4. Cost-conformance curves in high-rise housing units.

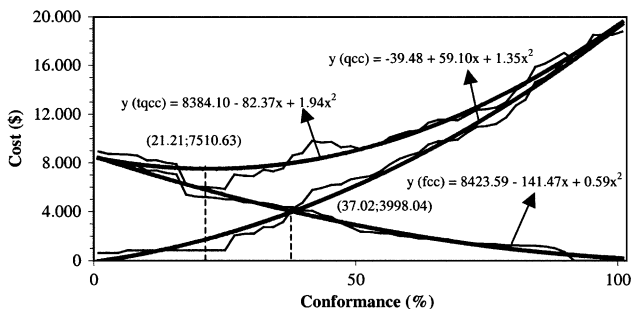


Fig. 5. Cost-conformance curves in medium-rise housing units.

opinion regarding its applicability for the construction industry. However, this study has shown that it can be applied to construction projects. To calculate the optimum cost of total quality, the traditional model was utilized. It was demonstrated that the cost-conformance curves derived from the manufacturing industry are also valid for mass-housing projects. Both researchers and practitioners can use this research to improve their estimations for not only total quality costs and to prevent the rework efforts, but also to set these parameters to their optimum levels.

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References

- [1] Juran JM, Gryna FM. Quality planning and analysis, 3rd ed. New York: McGraw-Hill; 1993.
- [2] Crosby PB. Quality is free. New York: McGraw-Hill; 1979.
- [3] Deming WE. Out of crisis: quality, productivity and competitive position. Cambridge: Cambridge University Press; 1986.
- [4] Juran JM. Quality control handbook. New York: McGraw-Hill; 1951.
- [5] ASQC Quality Costs Committee. Quality costs—what and how. Milwaukee, WI: ASQC Press; 1974.
- [6] Evans JE, Lindsay WM. The management and control of quality, 2nd ed. St. Paul: West Publishing; 1992.
- [7] Oliver J, Qu W. Cost of quality reporting: some Australian evidence. International Journal of Applied Quality Management 1999;2(2):233–50.
- [8] Aoieong RT, Tang SL, Ahmed SM. A process approach in measuring quality costs of construction projects: model development. Construction Management and Economics 2002;20:179–92.
- [9] Porter LJ, Rayner P. Quality costing for total quality management. International Journal of Production Economics 1992;27:69–81.
- [10] Oberlender GD. Project management for engineering and construction. New York: McGraw-Hill; 1993.
- [11] Harrington JH. Poor quality cost, 1st ed. Milwaukee, WI: ASQC Press; 1987.
- [12] Johnson MA. The development of measures of the cost of quality for an engineering unit. International Journal of Quality and Reliability Management 1995;12(2):86–100.
- [13] Roberts R. Quality does not cost—it pays. Australian Construction Law Report 1991;10(4):137–44.
- [14] Hays R. Conference summary. Proceedings of the national conference: quality assurance in the building community. Texas; 1983. p. 209–10.
- [15] Ledbetter WB. A construction industry cost effectiveness project report. Proceedings of the national conference: quality assurance in the building community. Texas; 1983. p. 7–45.
- [16] Gunneson AO. How to effectively implement a quality cost system. In: Campanella J, editor. Quality costs: ideas and applications. Milwaukee, WI: Quality Press; 1989. p. 375–85.
- [17] Feigenbaum AV. Total quality control. Harvard Business Review 1956;34(6):93–101.
- [18] Tsai WH. Quality cost measurement under activity based costing. International Journal of Quality and Reliability Management 1998;15(7):719–52.
- [19] Abdul-Rahman H. Capturing the cost of quality failures in civil engineering. International Journal of Quality and Reliability Management 1993;10(3):20–32.
- [20] Abdul-Rahman H. The cost of non-conformance during a highway project: a case study. Construction Management and Economics 1995;13(1):23–32.
- [21] Barber P, Graves A, Hall M, Sheath D, Tomkins C. Quality failure costs in civil engineering projects. International Journal of Quality and Reliability Management 2000;17(4/5):479–92.
- [22] Burati JL, Farrington JJ, Ledbetter WB. Causes of quality deviations in design and construction. Journal of Construction Engineering and Management 1992;118(1):34–49.
- [23] Building Research Establishment. Quality in traditional housing: an investigation into faults and their avoidance. Garston: BRE; 1982.
- [24] Construction Industry Development Board. Managing construction quality. A CIDB manual on quality management systems for construction operations. Singapore: CIDB; 1989.
- [25] Dale BG, Plunkett J. Quality costing. London: Chapman & Hall; 1991.
- [26] Hall M, Tomkins C. A cost of quality analysis of a building project: towards a complete methodology for design and build. Construction Management and Economics 2001;19(5):727–40.
- [27] Hammarlund Y, Jacobsson S, Josephson PE. Quality failure costs in building construction. CIB International Symposium at The University of Technology, Sydney 1990:14–21.
- [28] Josephson PE, Hammarlund Y. The causes and costs of defects in construction: a study of seven building projects. Automation in Construction 1999;8:681–7.
- [29] Love PED, Smith J, Li H. The propagation of rework benchmark metrics for construction. International Journal of Quality and Reliability Management 1999;16(7):638–58.
- [30] Love PED, Li H, Mandal P. Rework: a symptom of a dysfunctional supply chain. European Journal of Purchasing and Supply Management 1999;5:1–11.
- [31] Nylen KO. Cost of failure in a major civil engineering project. Licentiate thesis, Stockholm: Department of Real Estate and Construction Management, Royal Institute of Technology; 1996.
- [32] Patterson L, Ledbetter WB. The cost of quality: a management tool. In: Bard RJ, editor. Excellence in the construction project. American Society of Civil Engineers; 1989. p. 100–5.
- [33] Israel A, Fisher B. Cutting quality costs. Quality Progress 1991;24(1):46–8.
- [34] Mansour P, Usmen MA. Study of construction quality by the analysis of rework costs. Proceedings of 22nd IAHS World Housing Congress. Salzburg, Austria; 1994. p. 163–79.
- [35] Campanella J, Corcoran F. Principles of quality costs. In: Campanella J, editor. Quality costs: ideas and applications. Milwaukee, WI: ASQC Press; 1983. p. 502–15.
- [36] Banks J. The essence of total quality management. New Jersey: Prentice-Hall; 1992.
- [37] Quinn MP. Cost of quality and productivity improvement. In: Campanella J, editor. Quality costs: ideas and applications. Milwaukee, WI: Quality Press; 1989. p. 176–89.
- [38] Besterfield D. Quality control, 1st ed. New Jersey: Prentice-Hall; 1979.
- [39] Blank L, Solarzano J. Using quality cost analysis for management improvement. Industrial Engineering 1978;10(2).

- [40] Davis K, Ledbetter WB, Burati JL. Measuring design and construction quality costs. *Journal of Construction Engineering and Management* 1989;115(3):389–400.
- [41] Feigenbaum AV. *Total quality control*. New York: McGraw-Hill; 1991.
- [42] Yasin MM, Czuchry AJ, Dorsch JJ, Small M. In search of an optimal cost of quality: an integrated framework of operational efficiency and strategic effectiveness. *Journal of Engineering and Technology Management* 1999;16:171–89.
- [43] Plunkett JJ, Dale BG. Quality costs: a critique of some economic cost of quality models. *International Journal of Production Research* 1988;26(11):1713–26.
- [44] Brown FB, Kane RW. Quality cost and profit performance. In: Campanella J, editor. *Quality costs: ideas and applications*. Milwaukee, WI: ASQC Press; 1984. p. 203–9.
- [45] Shank JK, Govindarajan V. Measuring the cost of quality: a strategic cost management perspective. *Journal of Cost Management* 1994;summer:5–17.
- [46] Kazaz A. *Poor quality costs in mass housing projects*. PhD thesis. Elazığ: The Graduate School of Natural and Applied Science, Firat University; 1997, unpublished (in Turkish).
- [47] Birgonul MT, Kazaz A, Ozdogan ID. Investigation of quality related problems in mass housing projects. *Proceedings of the 27th IAHS World Congress on Housing. Housing issues and challenges for the new millennium*. California; 1999. p. 575–83.
- [48] James ML, Smith GM, Wolford JC. *Applied numerical methods for digital computation*, 4th ed. New York: HarperCollins College Publishers; 1993.
- [49] Gerald CF. *Applied numerical analysis*, 2nd ed. Reading, MA: Addison-Wesley Publishing Company; 1980.
- [50] Love PED, Li H. Quantifying the causes and costs of rework in construction. *Construction Management and Economics* 2000;18:479–90.
- [51] Low SP, Yeo HKC. A construction quality costs quantifying system for the building industry. *International Journal of Quality and Reliability Management* 1998;15(3):329–49.
- [52] Lam SW. *ISO 9000 in construction*. Singapore: McGraw-Hill; 1994.
- [53] Willis TH, Willis WD. A quality performance management system for industrial construction engineering projects. *International Journal of Quality and Reliability Management* 1996;13(9):38–48.