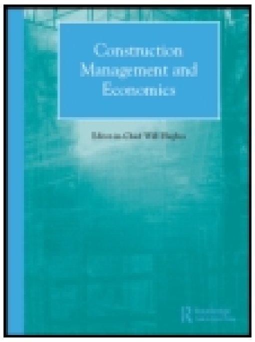

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A process approach in measuring quality costs of construction projects: model development

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One of the most effective tools for evaluating the success of a quality management programme is the measurement of quality costs (prevention, appraisal and failure costs). The application of the concept of quality costs originated in the manufacturing industry in the early 1950s. As increasing attention has been given to improving the overall quality in the construction process since the early 1980s, the application of total quality management (TQM) practices in the construction industry has gained much popularity. A systematic approach is needed for measuring quality costs, especially in the construction industry, due to the great number and complexity of activities involved in a typical project. This paper describes how a simple methodology can be used to capture quality costs in construction projects. Pre-existing models for capturing construction quality costs, by Davis, by Abdul-Rahman, by Low and Yeo and by others, recognize quality cost components but do not address the causes or sources of unwanted deviations. This paper proposes an alternative approach, based on the process cost model and in conformance with BS6143 (1992), which is thought to better facilitate the fundamental goal of TQM, i.e. continual process improvement. A number of professionals involved in construction quality management were interviewed and responded favourably to the practicality of the proposed framework in the construction context.

Keywords: TQM, construction, quality management, quality costs, process cost model

Introduction

In recent years, increasing attention has been given to improving the overall quality of construction works. Many organizations have undertaken initiatives to implement various quality management techniques. Due to the success of total quality management (TQM) practices in the manufacturing industry, its application in the construction industry has received much attention. TQM may be presented in various theoretical forms, but its fundamental goals are customer satisfaction and continual improvement. According to Dale and Plunkett (1991), TQM not only leads to improved productivity, higher standards, improved systems and procedures, improved motivation, and increased customer satisfaction, but also to lower costs and bottom line savings. Some construction industry companies have implemented TQM successfully, and reasons for these successful implementations were summarized by Kuprenas *et al.* (1996). In order to quantify the benefits of TQM, quality must be measurable. Although there are numerous tools for measuring quality, the 'cost of quality' (or quality costs) is considered by both Crosby (1984) and Juran (1988) to be the primary one. Oberlender (1993) summarized quality costs as follows. 'Quality costs consist of the cost of prevention, the cost of appraisal, and the cost of failure. Prevention costs are those resulting from quality activities used to avoid deviations or errors, while

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appraisal costs consist of costs incurred from quality activities used to determine whether a product, process or service conforms to established requirements. Failure costs are those resulting from not meeting the requirements, and can be divided into two aspects. Internal failure costs are the costs incurred on the project site due to scrap, rework, failure analysis, re-inspection, supplier error, or price reduction due to non-conformance. External failure costs are costs that are incurred once the project is in the hands of the client. These include costs for adjustments of complaints, repairs, handling and replacement of rejected material, workmanship, correction of errors, and litigation costs.'

Through the measurement of quality costs, management can be alerted to the potential impact of poor quality on the financial performance of the company. Moreover, management can also determine the types of activities that are more beneficial in reducing quality costs.

In construction, many organizations have implemented quality assurance programmes, such as ISO 9000 and TQM, just as a means of staying in business. In a recent survey (Ahmed and Aoieong, 1998), a questionnaire was sent to 150 project managers/quality managers of contractors in the construction industry in Hong Kong. Among the 30 respondents, approximately 90% wrote down 'fulfilling clients'/authorities' requirements' as their reasons for implementing ISO 9000 while only 46% said 'improve profitability'. In order to improve quality and profit, designers, consultants, contractors and also subcontractors must do more than merely provide a minimum level of assurance to their clients. They must aim at reducing cost without sacrificing quality.

In the USA, the Construction Industry Institute (CII, 1989) conducted research to identify and quantify the rework costs of correcting quality deviations in nine construction projects. It was found that the deviation costs averaged 12.4% of the total project cost. With this high percentage of deviation costs, a slight reduction may result in significant savings. In order to do this, quality costs must be identified and assessed. Clearly this points to the importance of knowing how and where quality costs have been incurred, so that remedial actions may be taken to prevent their recurrence, thereby reducing the costs of construction and benefiting contractors, clients and end-users. The result of the survey quoted above also showed that close to 60% of the respondents said that they had not attempted to measure defects-related costs. Those who did measure noted that the cost of correcting defects was approximately 5% of the total construction costs. Similar results (about 5–6%) were also reported by Abdul-Rahman (1995).

Dale and Plunkett (1991) reported that, despite the great quantity of literature discussing quality cost, there was no uniform view of what quality cost means and how it can be measured. Researchers have proposed various approaches for measuring and classifying quality costs, and reviews of the quality costs literature can be found in Plunkett and Dale (1987) and Porter and Rayner (1992). A brief summary of the most widely recognized approach, the prevention-appraisal-failure (PAF) model, is as follows.

- *Prevention costs*. The cost of any action taken to investigate, prevent or reduce the risk of nonconformity or defects.
- *Appraisal costs*. The cost of evaluating the achievement of quality requirements.
- *Failure costs*. The costs of nonconformity both internally (discovered before delivery to the customer, including scrap, rework, re-inspection and redesigning) and externally (discovered after delivery to the customer, including warranty costs and service calls).

Although the PAF model is universally accepted for quality costing, Porter and Rayner (1992) described some of the drawbacks of this approach as follows.

- It is difficult to decide which activities stand for prevention of quality failures since almost everything a well-managed company does has something to do with preventing quality problems.
- It is sometimes difficult to uniquely classify costs into prevention, appraisal, internal failure, or external failure costs (example will be given later).
- The PAF model does not include intangible quality costs, e.g. loss of reputation.
- The key focus of TQM is on process improvement, while the PAF categorization scheme does not consider process costs.

The objective of this paper is to investigate whether or not the PAF model is suitable for capturing quality costs in the construction industry and, if not, what kind of a model will be more suitable.

Construction quality cost approaches by previous researchers

Quality costs in the construction industry as a whole are relatively high in terms of total project costs. However, due to the complexity of construction processes, measuring quality costs is often difficult. An extensive literature review shows that, so far, only a few papers (Davis, 1987; Abdul-Rahman, 1995; Low and Yeo, 1998; Barber *et al.*, 2000; Love and Li, 2000) have been written in the context of construction on how quality costs could be determined. The following is a brief discussion of their approaches.

Davis' approach

In 1987, the CII (1989) Quality Management Task Force developed a Quality Performance Management System (QPMS) to track quality costs. It is a management tool providing for the quantitative analysis of certain quality-related aspects of design and construction by systematically collecting and classifying the costs of quality. The cost of quality is defined as the cost of correcting deviations (rework) plus the cost of quality management activities. The QPMS is based on the assumption that quality costs can be adequately tracked using 11 rework causes and 15 quality management activities. The rework causes, when coupled with four phases of a project, give a total of 40 (instead of $11 \times 4 = 44$) deviation categories with some illogical combinations eliminated. Fifteen quality management activities covering the main activities involved in design and construction were used to track quality management costs. Nine industrial projects were tested, yielding an average cost of rework of 12.4% of the project cost.

Although the QPMS is simple and flexible, Abdul-Rahman (1995) stated that QPMS does not consider the effect of failure on time-related cost and knock-on cost, i.e. the cost to speed up work to make up for lost time. Moreover, the procedure does not show the specific source of problems, but rather five major causes of origin, i.e. the owner, designer, vendor, transporter, and constructor, were stressed (see Table 1).

Similar to the QPMS, Davis' (1987) quality performance tracking system (QPTS) is an updated version of QPMS. In the QPTS, extensive costs coding to classify the various items were used so that costs data captured will be compatible with the works breakdown structure (WBS) of a project. Attempts were made to trace the sources of deviations by the use of source codes. Source codes were assigned to the accepted disciplines (civil, structural, electrical, and mechanical) plus sources of deviations such as labour, equipment and contract. However, the specific source of deviations was not recorded by the QPTS.

Abdul-Rahman's approach

Abdul-Rahman (1993) developed a quality cost matrix to capture the cost of nonconformance during construction. The matrix lists such information as 'problem category', 'specific problem', 'when problem was discovered', 'causes of problem', 'extra duration needed to correct problem', 'additional cost of activity', 'amount of additional time-related cost', and 'any additional cost'. Two construction projects were used to test the model, and the total costs of nonconformance incurred were 5% (1995) and 6% (1996) of the tender value. In Abdul-Rahman's cost matrix, the focus was on capturing the cost of nonconformance, and no attempts were made to quantify other classifications of quality cost, including prevention and appraisal costs. In problem categorization, the items used were rather broad. In order to capture the cumulative effect of problems in a specific area, effective cost coding, similar to that used by Davis, should be employed. Moreover, Abdul-Rahman did not consider the origin of deviations as Davis did. In the present authors' view, in order to have a better understanding of quality costs data, the question 'who caused the deviation?' should be essential.

Low and Yeo's approach

In view of the shortcomings of Davis' and Abdul-Rahman's approaches, Low and Yeo (1998) proposed a construction quality cost quantifying system (CQCQS). The cost system is basically a documentation matrix that accounts for quality costs expressed as prevention, appraisal and failure costs. The headings of the matrix are 'cost code', 'work concerned', 'causes', 'problem areas', 'time expended', 'cost incurred' and 'site record reference'. The main feature of this model is the use of coding to classify the various items under the heading 'work concerned'. The items

Table 1 Summary of three models designed to capture quality costs

	Measurement of prevention and appraisal costs	Measurement of failure cost	Origin of deviation[a]	Specific source of deviation[b]	Use of coding system	Effect of failure	Field tests
Davis	✓	✓	✓	✗	✓	✗	✓
Abdul-Rahman	✗	✓	✗	✓	✗	✓	✓
Low & Yeo	✗	✓	✗	✓	✓	✗	✗

[a]Origin of deviation: owner, designer, vendor, transporter, constructor.
[b]Specific source of deviation: formwork, reinforcement, concrete, etc.

that constitute 'work concerned' can be obtained from the works breakdown structure (WBS) of a typical project. Under the heading 'cost code', various components of quality costs, such as prevention, appraisal and failure costs, can be classified. However, similar to Abdul-Rahman's approach, the matrix was designed to capture the cost of failure primarily, and little effort was made to quantify the prevention and appraisal costs. Moreover, Low and Yeo also did not consider the origins of deviations.

Other approaches

Barber *et al.* (2000) developed a method to measure costs of quality failures in two major road projects. The method was based largely upon work-shadowing. Personnel on-site were shadowed for a period of time and the quality problems encountered were recorded. Only direct costs of rework for the failures and the related costs of delay were included in their study. Of the weekly budgeted cost of the specific areas of work studied, failure costs amounted to about 16% and 23% of the weekly budget, respectively.

Love and Li (2000) quantified the causes, magnitude and costs of rework experienced in two construction projects. Data were collected from the date on which construction commenced on-site to the end of the defects liability period. A variety of sources such as interviews, observations, and site documents were used to collect the rework data, and only the direct costs of rework were included. The costs of extra work, including variations and defects, were found to be 3.15% and 2.40% for the two projects. It was also concluded that the primary causes of rework were changes initiated by the client and end-user, together with errors and omissions in contract documents.

Summary of the three major approaches

1. Measurement of failure cost was the focus of all the first three models. However, only Abdul-Rahman's and Low and Yeo's models pinpointed the causes of problems. While Abdul-Rahman used wording to describe the problem area, Low and Yeo found using codes to be more convenient.
2. Measurement of prevention and appraisal costs is important due to the fact that they could be a significant part of the total quality costs. Without quantification, the relationship between prevention cost, appraisal cost, and failure cost cannot be fully understood. However, the definition of what constitute quality management activities is somewhat arbitrary, and therefore exact definition of each activity is necessary.
3. Extensive coding was used in Davis' model to capture quality management costs and deviation costs. However, when compared with Low and Yeo's model, the latter is easier to implement and less costly.
4. Only Abdul-Rahman considered the effect of failure on time-related cost and knock-on cost. The heading 'any other additional cost' was used in his cost matrix to capture any other remedial costs incurred indirectly due to the failure of an activity. It is essential to include the above as part of the cost of failure because this cost could be substantial. Without measurement, the full impact of the failures on the project costs cannot be determined.
5. Due to the short time frame involved, Low and Yeo's model was not tested.
6. The specific sources of deviations were not considered in Davis' approach. It is essential to pinpoint the specific source of deviations so that preventive measures can be employed and improvements can be made.

The three models' similarities and differences are summarized in Table 1.

A proposed PAF quality cost model

In principle, applying the quality cost concept to the construction industry is straightforward. However, in practice, it is rather complex. A recent survey carried out in Hong Kong (Ahmed and Aoieong, 1998) indicates that close to 60% of the respondents do not measure costs related to defects. The main reason for that could be just a lack of interest in knowing the quality costs. Moreover, it is rather difficult to measure quality costs without the implementation of an effective quality cost tracking system. Last but not the least, all personnel, from top management to site staff, should be aware of the usefulness of quality cost data to the company. The top management should also do their best to remove any negative views on the system. Some of the main features of an 'ideal' quality tracking system are as follows.

1. The quality tracking system should be able to capture all components of quality costs. With one or more components missing, the effect of varying one component on the others cannot be visualized. Within each component of quality costs, standardization of category is necessary, so that meaningful data can be compared between projects. On the other hand, the categorization should be flexible enough to ensure that the system can be modified when necessary to suit different types of projects.

2. The use of a coding system in tracking quality costs is essential. As suggested by Low and Yeo (1998), the coding system should be compatible with the local quality assessment systems, if any.
3. The ease of use of the quality cost tracking system is essential. The system must be straightforward, because the people who would be collecting cost data are the personnel on site. Any extra workload created from the system must be kept to a minimum. Due to the highly competitive environment in the construction industry, it is impractical to implement any extra system that would result in much extra workload to site staff.
4. The practicality of the quality cost tracking system is essential. The main barrier to trying out the system is the long construction time involved. Recent interviews with some project managers also indicated other barriers as listed below.
   - Most companies considered quality cost data as confidential, and therefore were very reluctant to release any data. The top management must be convinced that collecting quality costs is beneficial to the company.
   - Lack of resources is another barrier. Depending on the complexity of the system, extra personnel would be involved in implementing the system, and that will result in extra cost to the company.

Improvement made based on the existing models

In PAF models, the three components of the quality costs in the building contractor's perspective are prevention cost, appraisal cost, and deviation (failure) cost. In order to obtain a general view from the industry on the categorization of quality costs, extensive in-depth interviews with contractors and local authorities should be conducted as a first step in developing the model. A list of quality management activities used in construction projects and a list of common deviations that occurred on these construction sites can then be established. Other than costs incurred from the quality-related activities and deviations, the origin of deviations is also a concern, as a deviation by any of the participants may cause quality costs for that particular participant or for others. Typical quality management activities, cause and source of deviations are shown below.

Prevention activities: activities used to avoid deviations or errors

- Quality system development
- Quality program development
- Personnel training
- Specifications/Design review

Appraisal activities: activities used to determine whether a product or process conforms to established requirements

- Materials inspections/tests
- Inspection
- Maintenance of testing/measuring equipment

Causes of deviations: the reasons for any deviations (a departure from established requirements to occur)

- Communications errors
- Defective materials
- Design errors or omissions
- Poor workmanship
- Faulty equipment

Origin of deviations:

- Davis' (1987) QPTS had identified five origins: owner, designer, vendor, transportation and constructor

Specific source of deviations:

- Specific area where problems occur, for example, formwork, reinforcement, concrete, etc.

Development of the coding system

In order to record and trace quality costs effectively, every item under each component of quality costs, the origin of deviations, and the source of deviations should be codified. The procedures can be summarized as follows.

- Conduct an investigation of the general practices in the construction industry with regard to the use of a coding system.
- Investigate the accounting procedures of contractors and attempt to integrate the coding system with the accounting cost coding system.
- Typical task codes can be generated from the work breakdown structure (WBS) of a typical project, using the standardized divisional breakdown (Masterformat) developed by the Construction Specification Institute (CSI). A master list of section titles and numbers can be found in the appendix of Oberlender's (1993) book. Major 'divisions' include sitework, concrete, metals, wood and plastics, doors and windows, conveying systems, mechanical and electrical, etc. An example of the master list is shown in Figure 1.
- The management activity code, task code and cause code can then be generated after the development of the categorization of quality costs as discussed above. The origins of deviations can also be traced by using a proper coding system.

DIVISION 3 --- CONCRETE	
Section Number	**Title**
03100	**CONCRETE FORMWORK**
-110	Structural Cast-in-Place Concrete Formwork
-120	Architectural Cast-in-Place Concrete Formwork
-130	Permanent Forms
03200	**CONCRETE REINFORCEMENT**
-210	Reinforcing Steel
•	
•	
•	
03700	**CONCRETE RESTORATION AND CLEANING**
-710	Concrete Cleaning
-720	Concrete Resurfacing
-730	Concrete Rehabilitation
03800	**MASS CONCRETE**

Figure 1 Typical master list developed by the Construction Specification Institute for division 3, concrete

Name *Chan Tai Man*
Project *XYZ*

1	2	3	4	5	6	7
Date	Task Code	Prevention Activity	Appraisal Activity	Time required	Cost incurred	Remark
Feb. 1	03110	P4		1 hr.	500.00	Formwork review
Feb. 2	03210		A3	2 hrs.	800.00	Reinforcement Inspection
Feb. 3	03310		A2	3 hrs.	1200.00	Concrete Testing
Feb. 5	03210		A3	1 hr.	400.00	Reinforcement Inspection
Feb. 6	03310		A2	3 hrs.	1200.00	Concrete Testing

Prevention Activity Code	Activity
P1	Quality system development
P2	Quality program development
P3	Personnel training
P4	Specifications/Design review
•	•
•	•
•	•

Appraisal Activity Code	Activity
A1	Maintenance of equipment
A2	Materials inspections/tests
A3	Site inspection
•	•
•	•
•	•

Figure 2 Sample of prevention and appraisal costs record sheet

Development of the quality cost model:

With the categorization of quality costs developed and the coding system in place, the next phase is the development of a quality cost system to capture all the quality-related costs. In the development of the system, the users who would be operating the system must first be identified. Most likely, the person who would be analysing quality costs data will be the quality manager of the project. A user-friendly computer program developed to track quality costs will definitely make the system easier to implement. In the development of the computer program, flexibility is essential to ensure that the system can be modified when necessary to suit different types of project. On the other hand, the people who would be recording quality costs data will be the site staff. Considering their heavy workload, attention must be given to the design of the site quality cost record sheets so that staff resistance can be reduced to a minimum. Typical site record sheets for recording prevention and appraisal costs and failure costs are shown in Figures 2–4.

In recording the failure cost, record sheets can be grouped together according to divisions (or subdivisions) as shown in Figures 3 and 4. At the end of a project, with quality costs data collected from all sources, reports relating task, prevention, appraisal and failure costs can be generated readily from the program, as shown in Figure 5. Depending on the information required by the end-user, quality cost reports can be presented in different formats. By grouping entries according to task code (division) as shown in Figure 6, the prevention, appraisal and failure costs of each division can be identified. Similarly, by grouping entries

Name *Lee Tai Man*
Project *XYZ*
Division 3 - CONCRETE

1	2	3	4	5	6	7	8
Date	Task Code	Cause Code	Origin Code	Extra Time*	Cost incurred	Additional Cost**	Remark
Feb. 10	03110	D4	C	5 hrs.	2500.00	7000.00	Poor workmanship in formwork
Feb. 13	03250	D3	D	4 hrs.	2000.00		Missing anchors in beams
Feb. 15	03350	D2	V	10 hrs.	5000.00	2000.00	Wrong type of floor finishes

Figure 3 Sample of failure cost record sheet for division 3

Name *Ho Tai Man*
Project *XYZ*
Division 5 - METALS

1	2	3	4	5	6	7	8
Date	Task Code	Cause Code	Origin Code	Extra Time*	Cost incurred	Additional Cost**	Remark
Feb. 14	05310	D1	T	8 hrs.		2000.00	Wrong sizes of steel delivered
Feb. 25	05310	D3	D	3 hrs.	1800.00		Wrong openings in steel deck

Cause Code	Deviation	Origin Code	Origin
D1	Communication errors	O	Owner
D2	Defective materials	V	Vendor
D3	Design error	C	Constructor
D4	Poor workmanship	D	Designer
•	•	T	Transportation
•	•		
•	•		

* Extra time required for remedial work
** Additional cost incurred as a result of the failure

Figure 4 Sample of failure cost record sheet for division 5

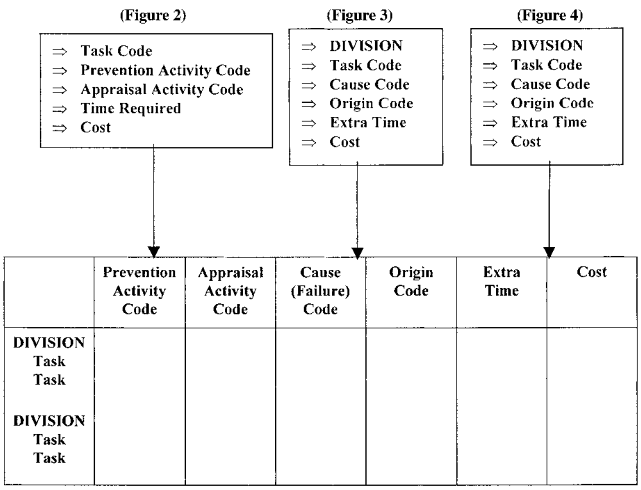

Figure 5 Flow of information

Name *Ho Tai Man*
Project *XYZ*

	Prevention Cost	Appraisal Cost	Activity Code	Failure Cost	Cause Code	Origin Code	Extra Time	Total
DIVISION 3								
Task 03110	500.00		P4					
Task 03110				9500.00	D4	C	5 hrs.	
Task 03210		800.00	A3					
Task 03210		400.00	A3					
Task 03250				2000.00	D3	D	4 hrs.	
Task 03310		1200.00	A2					
Task 03310		1200.00	A2					
Task 03350				7000.00	D2	V	10 hrs.	
Sub-Total	500.00	3600.00	→	18500.00	→	→		22100.00
							↓	↓
DIVISION 5							↓	↓
Task 05310				2000.00	D1	T	↓	↓
Task 05310				1800.00	D3	D	↓	↓
Sub-Total				3800.00	→	→		3800.00
							↓	↓
TOTAL								25900.00

Figure 6 Sample of quality cost report sheet (sorted by tasks)

according to activity code or cause code, as shown in Figure 7, the prevention/appraisal cost of any particular quality management activity and the failure cost of a particular cause can be determined. Similarly, by grouping entries according to origin code, as shown in Figure 8, the distribution of failure costs among the parties involved in the project can be determined.

Implementation of the model on a pilot project

After the development of the model, pilot projects should be conducted. A particular operation, concrete for example, of a building project should be selected first as a pilot study. Once the initial trial of the costs system is completed and if the result is satisfactory, projects involving full implementation of the model can then be conducted. Before the implementation of the model, training of the personnel involved is required.

Name *Ho Tai Man*
Project *XYZ*

Activity Code	Task Code	Prevention Cost	Appraisal Cost
A2	03310		1200.00
	03310		1200.00
Sub-Total			2400.00
A3	03210		800.00
	03210		400.00
Sub-Total			1200.00
P4	03110	500.00	
Sub-Total		500.00	
TOTAL		500.00	3600.00

Cause Code	Task Code	Failure Cost
D1	05310	2000.00
Sub-Total		2000.00
D2	03350	7000.00
Sub-Total		7000.00
D3	03250	2000.00
	05310	1800.00
Sub-Total		3800.00
D4	03110	9500.00
Sub-Total		9500.00
		22300.00

Figure 7 Sample of quality cost report sheet (sorted by prevention/appraisal/failure)

Name *Ho Tai Man*
Project *XYZ*

	Task Code	Failure Cost
Origin of Deviation		
O (Owner)	-----	------
D (Designer)	03250 05310	2000.00 1800.00
V (Vendor)	03350	7000.00
C (Contractor)	03310	9500.00
T (Transportation)	05310	2000.00
TOTAL		22300.00

Figure 8 Sample of quality cost report sheet (sorted by origins)

The objectives of the training would be to educate the staff on the importance of quality costs and to prepare those who would be collecting the quality cost data.

Data analysis

Typical analysis of the data can include the following.

- The average quality costs of building projects expressed as a percentage of the total project cost.
- The distribution of quality costs according to the PAF categories.
- The distribution of quality costs according to the origins (parties involved) in the project.
- The analysis of the interrelationship among prevention, appraisal and deviation costs.

Summary

A PAF cost model to capture the cost of quality for construction projects has been presented. In order to solicit the general view of the construction industry regarding the practicality of the model, extensive interviews with personnel in the industry were conducted.

Feedback from the industry about the proposed PAF model

In-depth interviews with leading construction contractors in Hong Kong were conducted. The details of the PAF approach described above were presented to the interviewees. Comments regarding the implementation of such a quality cost tracking system based on the PAF approach were obtained and are summarized in the following paragraphs.

Interviews

The purpose of the interviews was to obtain views from personnel involved in quality assurance on issues relating to quality cost in the construction industry. Twelve contractors were selected from the Hong Kong Housing Authority list of building contractors. They represented 38% of all the contractors who were eligible to tender for contracts valued at above HK$300M (HK$7.80 = US$1.00). Nine interviewees were quality managers while the remaining three held senior managerial positions.

Discussion on results of interviews

Awareness of quality cost in the construction industry

All contractors interviewed have obtained ISO 9000 certification. Although all expressed that they were aware of the concept of quality cost, there was no uniform view about what quality costs are or about what should be included under the quality costs umbrella. When the interviewees were asked if they knew what is meant by quality costing, the majority thought that it was just a process to measure the cost of nonconformance. The reason for this incomplete view of quality costing could be traced to the nature of their jobs. Most of the interviewees are quality managers, so probably their main concerns are costs related to nonconformance.

As far as the classification of quality cost is concerned, the majority were aware of the quality cost terms of prevention, appraisal, and failure. However, after understanding the correct definition of those terms, most of the interviewees expressed that, in order to avoid confusion, standardized classification of quality cost for the construction industry was essential.

Quality cost measurement

All interviewees said that they did not measure quality costs according to the PAF classification. Their reasons for not measuring could be summarized as follows.

a) No system set up for the measurement
In order to capture the quality costs of a project effectively, a quantitative system is essential. No such system has been established in any one of the companies interviewed. The reason for not establishing such a system is the lack of resources. One interviewee commented: 'The design of such a system is not too difficult. However, it is nearly impossible to implement such a system on a construction project site.'

b) No resources available for the measurement
Whether or not a company has extra resources to implement a quality cost measurement system depends very much on its profit margin. All interviewees shared the view that measurement of quality costs is beneficial. However, due to the highly competitive nature of the construction industry, most contractors have to cut their profit margin to a minimum in order to tender a bid successfully. It is for this reason that most contractors are reluctant to spend more to improve their quality system. One quality manager commented: 'If we commit more on quality, more than the minimum required level, our construction cost will be higher than our competitors and therefore the project will most likely be awarded to others.'

c) Multi-level contracting hinders the measurement of the total quality costs
Subletting works by the main contractor to subcontractors is a very common practice in Hong Kong. Over 90% of the labourers on a building site belong to subcontractors (Tang *et al.*, 1998). It is also very common to have a few levels of contracting between the general contractor and the labourers. In order to measure the quality costs of a particular trade, it would require the full co-operation of all levels of subcontractors. Bearing in mind that the subcontractors are under no obligation to do additional work to collect quality cost data, it would be rather difficult to get their co-operation, even though there is a strong commitment from the general contractor. In order to capture the total quality costs of a project, all subcontractors from different trades have to be involved.

From the general contractor's point of view, most contractors interviewed indicated that they were not enthusiastic about obtaining facts on quality costs. This is simply because most of the projects are contracted out, and only the final 'product' and not the 'process' is their concern. From the subcontractors' point of view, instead of committing extra resources to collect data (which hinders the effectiveness in processing the works), they would much rather allocate their resources to rectifying problems.

Moreover, there is a negative side to the system because contractors/subcontractors will have to admit and report their mistakes during the implementation of the system, which they would rather not do.

Benefits of measuring quality cost

In spite of the negative feedback, all interviewees shared the view that there were merits in measuring quality costs. Some benefits are listed as follows.

- Measuring quality costs helps in identifying problem areas.
- Measuring quality costs helps in reducing the cost of nonconformance.
- Results from quality cost analysis can be used in the contractor/subcontractor selection process.
- Quality cost measurement is an effective tool for the implementation of TQM.

Personnel responsible for measuring quality cost

Most interviewees said that quantity surveyors and site engineers would be in the best position to record quality costs on site. They are the persons on site who are responsible for the assessment and inspection of work done.

Interview results

In addition to the above comments, all interviewees indicated that such a proposed model would be too complicated to use in practice and straight implementation of the PAF model might not be possible. It was probably due to the complexity of the structure of the construction industry. The interviewees also suggested that, if feasible, a more practical model for measuring quality costs should be developed for the benefits of the construction industry.

An alternative approach to the traditional PAF model for the construction industry

Unlike a production line in the manufacturing industry, the construction process is far more complicated. Due to the vast number of parties involved and the uniqueness of each activity in a construction project, straight application of the concept of quality cost based on a manufacturing setting is rather difficult. However, if the measurement of quality cost is beneficial to the construction industry, attempts should be made to design a measuring system applicable to and acceptable by the industry.

Among the prevention, appraisal and failure costs, failure cost is the most difficult to identify and collect. As one quality manager expressed in an interview: ‘One will never get the whole picture of quality costs for a building project because there are so many parties involved’. Although this comment may be right, one can always focus on some areas of construction and determine the quality costs of the work done by a particular subcontractor. As another quality manager pointed out in an interview: ‘In order to easily attempt a trial on this quality cost exercise, we suggest simplifying the experimental model of building construction project in the areas where often quality nonconformance is found’. In other words, if there are not enough resources to implement the system on a full scale, a smaller scale implementation of the system can still be achieved. In fact, this is totally in line with the process cost model approach described in British Standard 6143 Part 1 (BSI, 1992).

In the past, the concept of quality costing has implied that certain identifiable costs are in some way related to the ‘quality’ of the end product. By contrast, within today’s TQM culture all activities are related to processes, and therefore a cost model should reflect the total cost of each process.

The definitions in BS 6143 Part 1 (1992) are as follows.

Process cost
: The total costs of cost of conformance (COC) and cost of nonconformance (CONC) for a particular process

Cost of conformance (COC)
: The intrinsic cost of providing products or services to declared standards by a given, specified process in a fully effective manner

Cost of nonconformance (CONC)
: The cost of wasted time, materials and resources associated with a process in the receipt, production, dispatch and correction of unsatisfactory goods and services

In the traditional prevention, appraisal and failure approach, many costs can be attributed to either prevention or appraisal. Design reviews, for example, may be considered to be a prevention cost; however, essentially they are a checking stage and, as such, could be considered an appraisal cost. Moreover, it is always difficult to decide which activities should be categorized as prevention cost because it can be argued that everything a well managed organization does is directed at preventing quality problems. This is one of the drawbacks of the PAF approach. A new approach, the process cost approach, presents a much simpler categorization than the PAF scheme. In the context of building construction, process cost models can be developed for any selected construction processes. The COC and/or CONC can then be measured and key areas for process improvement identified. Since usually both COC and CONC can be improved, the whole process is in tune with the fundamental goal of TQM, i.e. continual improvement. Since the TQM philosophy focuses on process improvement, the PAF approach has its limitations, because process costs are not considered in the cost categorization scheme.

The process cost model for building construction processes

Identification of process

TQM requires the management of processes, not just of outputs. In order to improve the quality and productivity of a process, top management must first identify specific processes with discrete activities that require improvement. Continual improvement of processes should be established as an organization's objective. Through systematic management review, top management can evaluate the effectiveness of processes, and actions can be taken accordingly. For example, in building construction, the process of concreting can be isolated and selected for process improvement.

Defining the process and its boundaries

Once a particular process is isolated, its boundaries must be properly defined so that all key activities will be included for investigation. An organization's resource availability must be considered when determining the process boundaries, so that no excessive resources will be demanded. For example, the process of concreting is bounded by the activities 'formwork construction' and 'formwork striking.

Flowcharting the process

The flowchart will facilitate the identification of all the key activities and process owners within the process boundaries. Based on the activities identified, appropriate inputs, outputs, controls and resources for each activity can be identified in the next step. A typical flowchart for the process of concreting is shown in Figure 9.

Identification of inputs, outputs, controls and resources

In the context of building construction processes, the elements of the process (see Figure 10) could be expressed as follows.

Inputs

Construction materials, such as concrete, admixtures, reinforcement, steel, waterstops, etc., that are transformed by the construction process to create building elements/system (shown at the left hand side of Figure 10)

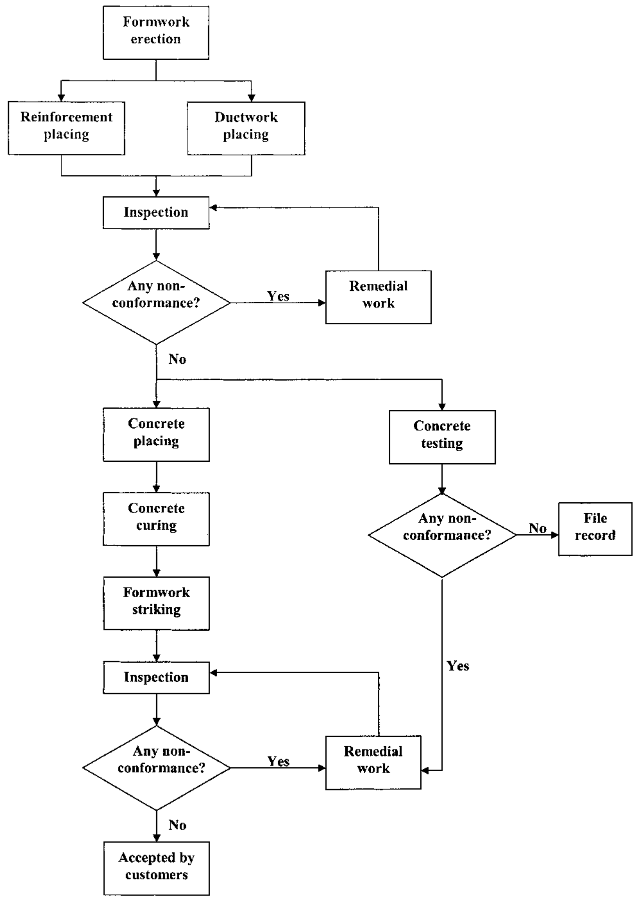

Figure 9 Flowchart for the process of concreting

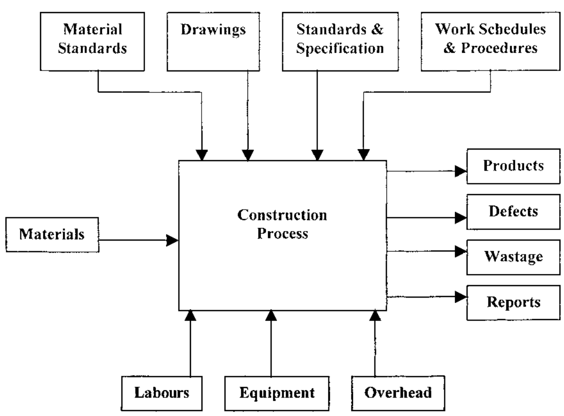

Figure 10 Typical process model of construction processes

Outputs

The end products of the construction process (right hand side of Figure 10), which include

1. that which conforms to the requirement; e.g. structural members, HVAC system
2. that which does not conform to the requirement; e.g. defects
3. waste; e.g. material waste

4. construction process information; e.g. inspection reports;

Controls

Inputs that define, regulate and/or influence the construction process. Examples of controls embrace construction procedures, method statements, work plan, drawings, standards and specification (shown at the top of Figure 10)

Resources:

Contributing factors that are not transformed to become an output. Examples of resources include labour, equipment and overheads (shown at the bottom of Figure 10)

A typical process model developed based on the above concept for the process of concreting is shown in Figure 11.

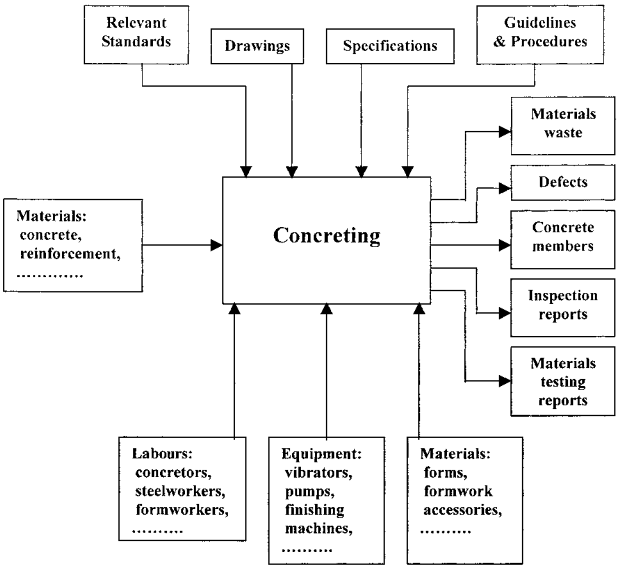

Figure 11 Process model for concreting

Identification of the process cost elements and calculation of the quality costs

Each process contains a number of key activities. Once the process model is prepared, all the cost elements associated with the key activities of the process in the flowchart can be identified and established as a cost of conformance (COC) and/or a cost of nonconformance (CONC). In particular, the nonconformance activities can be readily identifiable as rework loops in the flow of activities. Both types of cost offer opportunities for improvement. The quality costs of the process is the sum of COC and CONC. The process owners from whom data are obtained should also be identified. In listing the activities, the contractor's coding system can also be employed, so that data can be retrieved directly from the accounting system. Table 2 is a typical presentation containing the key activities, code numbers, COC and CONC of the process of concreting, and will be used as a reference in preparing the 'process cost report'.

Constructing a 'process cost report'

A typical process cost report is shown in Figure 12. The report should contain a complete list of the costs of conformance and nonconformance elements. Items in Table 2 can be extracted directly for use in Figure 12 when they are applicable. The report should also specify whether actual or estimated costs are used. In addition, the process owner who is responsible for a particular key activity can also be included in the report.

Table 2 Identification of costs for key activities: concreting

Key activities	Code	Cost of conformance	Cost of nonconformance
Formwork	3110	Cost of materials and labour Cost of temporary shoring	Cost of waste materials Cost of rework due to wrong dimensions
Reinforcement	3210	Cost of materials and labour	Cost of rework due to incorrect size of reinforcement Cost of extra labour and materials due to changes
Concrete accessories	3250	Cost of materials and labour	Not applicable
Cast-in-place concrete	3300	Cost of materials (concrete, admixtures, etc.) and labour Cost of equipment for concrete placing	Cost of waste materials Cost of extra labour and materials due to changes
Materials testing	3301	Cost of testing of materials for conformance to standards	Not applicable
Concrete curing	3370	Cost of materials and labour	Not applicable
Rework	3201	Not applicable	Cost of extra labour and materials due to defects

Process cost report
Process name: Concreting
Boundary: "Formwork construction" to "Formwork striking"
5th floor to 10th floor of Building XXX
Process owner: various

Process Conformance	Cost Act.	Cost Est.	Process Owner	Process Nonconformance	Cost Act.	Cost Est.	Process Owner
Activity: 3110 (Formwork erection) • labour • materials			Formwork subcontractor	Activity: 3110			
Activity: 3210 (Reinforcement) • labour • materials			Steel subcontractor	Activity: 3210 (Reinforcement) • waste • rework due to wrong length			Steel subcontractor
Activity: 3300 (Concrete placing) • labour • materials • equipment			Concrete subcontractor	Activity: 3300 (Concrete placing) • rework due to honeycombs in concrete • rework due to wrong opening location			Concrete subcontractor
Total process Conformance cost				Total process nonconformance cost			

Figure 12 Typical process cost report for the process of concrete

Improvement process

Once set up, the model is used for regular reporting on performance. Since construction processes are dynamic in nature, it is essential that the data collection process commences only after the construction processes become stable. Comparison with previous periods can then be made and areas for improvement identified. Failure costs, in particular, should be prioritized for improvement through reduction in cost of nonconformance. An excessive cost of conformance may suggest the need for process redesign. It is also essential that the process owners be involved in the improvement team. A flowchart that depicts the steps in implementing the process cost model is shown in Figure 13.

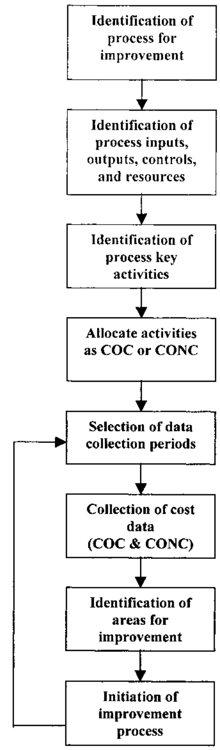

Figure 13 Flow chart of implementing the process cost model

The differences between the PAF models used by previous researchers and the proposed process cost model are shown in Table 3.

Advantages of adopting the process cost approach in the construction industry

1. The focus is no longer on capturing the 'total cost' of the quality of an entire project, which is rather difficult to do. Instead, specific processes in a project can be identified for monitoring and improvement.

Table 3 Differences between the models used by previous researchers and the authors

	Previous researchers			The authors
	Davis	Rahman	Low & Yeo	
Approach	Prevention/ Appraisal/Failure	Prevention/ Appraisal/Failure	Prevention/ Appraisal/Failure	Process cost
Cost measured	Prevention/ Appraisal/Failure	Failure	Failure	Costs of conformance and nonconformance
Scope	Whole project	Whole project	Whole project	Selected processes
Types of project used in testing	Industrial projects	Civil engineering projects	Not yet tested	Being tested in building and civil engineering projects
Emphasis	Reduction of failure costs	Reduction of failure costs	Reduction of failure costs	Continual process improvement

Winchell and Bolton (1987) did suggest that a small-scale PAF model could be used to measure quality costs in departments or sections of production. In the traditional PAF approach, total quality cost is essentially a build-up of many cost elements in many departments. The micro approach proposed by Winchell and Bolton, on the other hand, broke down the whole system and evaluated the effectiveness of an individual department. Although Gibson *et al.* (1991) had tested the micro approach in a manufacturing company, there is no literature on testing such an approach in the construction industry. It is the authors' view that the implementation of the micro approach in the construction industry is far less feasible than in the manufacturing arena, because production in a manufacturing company relies on contributions from different departments within a company, whereas the 'final product' of a construction company depends on the work contributed by individual subcontractors (many different companies). Also, for a PAF model, it is rather difficult to distribute accurately the prevention costs to individual construction processes, for example, the cost of maintaining a quality assurance system can be estimated readily for a construction project; however, the allocation of this cost to particular processes is not easy. Moreover, the micro PAF model does not include process costs, and therefore it is not fully compatible with the TQM concept of continual improvement.

2. Focus is no longer on the categorization of costs (P, A and F), which may be quite difficult and unsatisfactory. As pointed out in BS 6143: 'Many of the costs can be justified as fitting into any one of the three categories, i.e. prevention, appraisal, and failure. Process cost model offers a simpler categorization' (BSI, 1992).

3. Since the focus is no longer on capturing the 'total cost' of quality of an entire project, the demand of resources is considerably less, and much of it can be allocated to a particular process identified for monitoring and improvement.

Industrial feedback on process cost model

Eight construction professionals (two quality managers, two quantity surveyors, two ISO 9000 quality management system certification officers, a site agent and a civil engineer) were approached, and the details of the proposed process cost model (PCM) were presented to them. Their comments are summarized as follows.

Discussion on results of interviews

Flexibility and practicality

All interviewees shared the view that applying the model (PCM) in the construction industry is much more feasible than applying the traditional PAF model. When applying the PCM model, the resource level required in quality cost measurement will be more flexible, because the number of processes selected for monitoring can be varied according to the resources available. Moreover, when applying the PCM model, the timing in quality cost measurement is less rigid, because performance is only measured at selected periods.

Subcontractors' co-operation

In the PAF model, in order to capture the total quality cost of a project, it would require the full co-operation of all subcontractors. All interviewees agreed that, unlike the PAF model, the number of subcontractors involved in the PCM could be kept to a minimum, depending on the processes selected. For example, the number of subcontractors involved in the concreting processes could be as low as four. However, some interviewees still believed that it would be difficult to obtain the subcontractors' co-operation, because of the reasons given earlier.

Other benefits

In addition to the above, the two interviewees from certification bodies (certification officers) believe that the process cost model could be used as a simple tool to measure process improvement, a requirement in the latest edition of the ISO 9000 which, in addition to client satisfaction and continual improvement, emphasizes the process approach. Yet, they shared the view that it might be too early to comment on the new approach, since so far it has not been used as a tool to satisfy ISO requirements by any contractors in the industry.

Conclusions and suggestions for future research

Quality works in the construction industry have assumed increasing importance in recent years. Since the Hong Kong Government announced the requirement that all main contractors must attain the ISO 9000 certification for their projects from 1993 onwards, about 400 ISO9000 certificates have been awarded to Hong Kong-based construction companies. Following the implementation of ISO 9000 in the construction industry, it is imperative to know whether improvement in quality has been achieved or not. There are many ways for determining this. One of the ways to measure quality improvement is through the measurement of quality costs. In order to quantify the benefit after the implementation of the ISO 9000 quality system, a quality cost model is proposed in this paper. Some of the benefits of knowing how and where quality costs are incurred are listed as follows.

- Quality cost data alert management of the potential impact of poor quality.
- Quality cost data help management determine the types of activity that are most beneficial in reducing quality costs.
- Quality cost data makes all personnel aware of the importance of quality works.
- Quality cost data indirectly urge people in the industry to pay attention to continual improvement, which is a basic requirement in the implementation of TQM, and is consistent with the spirit of the latest version of ISO 9000.

Valuable feedback regarding the practicality of the proposed model was obtained by interviewing some leading main contractors in Hong Kong. Comments from the interviewees indicated that straight implementation of the PAF model might not be possible due to the complexity of the structure of construction industry.

An alternative approach, based on the BS 6143 process cost model (PCM), is proposed. To the authors' best knowledge, such a BS 6143 conceptual model is now proposed the first time for use in the construction industry. This approach is much more feasible than the previously proposed PAF model as one can select any processes within a project for study. Moreover, the 2000 version of the ISO 9000 standard places much attention on a requirement for measurement and monitoring of customer satisfaction through reviews and 'continual improvement'. The process approach proposed could serve as a simple tool for compliance with the Standard. Due to limited time, the authors were unable to test the proposed model. Further work on testing the model is recommended and is planned for the near future.

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