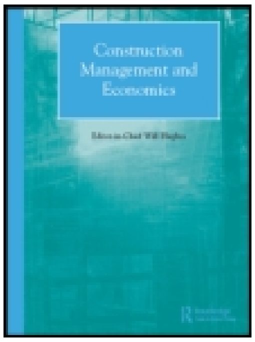

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The use of Process Cost Model (PCM) for measuring quality costs of construction projects: model testing

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A 'Process Cost Model (PCM)' approach has been proposed previously (Aoieong *et al.*, 2002) for measuring the quality costs of construction projects. The PCM is proposed because the traditional models on PAF (prevention, appraisal and failure) quality costs have been found to be unsuitable for the construction industry, although they may be successful in the manufacturing industry. The focus of PCM, unlike PAF model, is no longer on capturing the total quality costs of an entire project but the quality costs of a particular process. It is simple and more feasible to be applied in construction projects and is in line with the 'process approach' and 'continual improvement' concepts of the latest (year 2000) version of the ISO 9000 quality management system, which is a step closer to Total Quality Management (Aoieong and Tang, 2002). The current paper describes two case studies using the PCM to capture quality costs on two construction projects. The case studies reveal that the PCM is feasible, practicable and easy to use. It is also possible to use the model to achieve 'continual improvement' by referencing the quality costs of a particular construction process. The Process Cost Model (PCM) is therefore a better model than the traditional PAF model for application in the construction industry for measuring quality costs.

Keywords: Process cost model, PCM, PAF, quality, costs, construction, processes, TQM, Hong Kong

Introduction

Quality management systems (QMS) for construction projects based on ISO 9000 series have been implemented in many parts of the world in recent years and particularly in the past ten years in Singapore and Hong Kong (Kam and Tang, 1997; Kam and Tang, 1998; Ahmed and Aoieong, 1998; Tang and Kam, 1999). The implementation of these QMS, according to their reports, is in certain ways successful and in certain ways unsuccessful, yet an improving trend is observed in general. Capturing quality costs of construction, however, has been done to a less extent. Research works in construction quality costs such as Davis and Ledbetter's (1987), Abdul-Rahman's (1993, 1995, 1996), Low and Yeo's (1998), Barber *et al.*'s (2000), and Love and Li's (2000) were reported. The results of all these works have been summarized and their merits and demerits compared in the authors' previous paper (Aoieong *et al.*, 2002) and therefore will not be repeated in this paper. The most recent work, and the most comprehensive one too, is of Hall and Tomkins' (2001). In this work, the PAF (prevention, appraisal and failure) costs of an entire construction project in the UK were captured and reported. The origin of deviations and the effects of failure were also covered in the study. This is the only work based on the PAF model that can be considered by the authors as comprehensive and successful for capturing quality costs. Construction quality costs based on PAF are extremely difficult to capture, as explained

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in the authors' previous paper (Aoieong *et al.*, 2002). It is believed that the success of Hall and Tomkins is because the project under study was small, with a contract sum of only US$3 million approximately. Construction projects in most cases are much bigger than that. The PAF approach for capturing quality costs is in fact not suitable for construction projects, as they are usually big and complex. A new approach called Process Cost Model (PCM) for construction has been developed by the authors. It is suitable for use in construction projects, regardless of the sizes of the projects.

The focus of PCM, unlike PAF model, is no longer on capturing the 'total quality costs' of an entire project but on capturing the quality costs of a particular process. The detail development of the PCM has been reported in the authors' previous paper (Aoieong *et al.*, 2002). A typical process model for a construction process is shown in Figure 1, which is reproduced from the said paper. Industrial feedback on the concept of PCM, from nine experienced construction professionals in Hong Kong and six in the USA, is encouraging (Aoieong *et al.*, 2003). The majority of the interviewees have a positive view on its practicability for construction projects. In this current work, the authors attempt to apply the PCM to study two cases. They are two construction projects in Hong Kong, a building project and a civil engineering project. The objective of this paper therefore is to report the findings of these two case studies in which the PCM is used to capture quality costs.

The Process Cost Model (PCM) applied for concreting process

As mentioned before, the PCM is not used for capturing quality costs of an entire construction project but for capturing that of a particular process. This is in line with the 'process approach' and 'continual improvement' concepts of the latest (year 2000) version of the ISO 9000 quality management system, which is a step closer to the concept of Total Quality Management (Aoieong and Tang, 2002). The 'continual improvement' element of the PCM will be illustrated in the later case studies. In applying the PCM, a construction process must be identified. In theory, the PCM can be applied to any construction processes, but the authors have chosen the 'concreting process' for study in this paper because it is the most common and well known process in any construction projects. Figure 2 shows the PCM adopted for the 'concreting process'. The boundary defined for the process includes formwork placing, reinforcement placing and concrete placing.

The quality costs in the PCM are called process costs, which can be divided into two parts: the costs of conformance (COC) and the costs of non-conformance (CONC) (Aoieong *et al.*, 2002). COC is the intrinsic costs involved for providing the finished concrete product as required in good order, and the CONC is the costs of wasted time, materials and resources and any costs associated with the rectification of the unsatisfactory concrete product. In applying the PCM to capture the quality costs (or the process costs) of the concreting process, data on COC and CONC have to be collected from construction sites.

There are two basic and important principles for PCM application: (1) the PCM must not be complicated and be easy to understand and use by site personnel of ordinary educational or technical level, and (2) the PCM must function as a tool for continual improvement of the process. These will be fully discussed in the two case studies presented in the following sections.

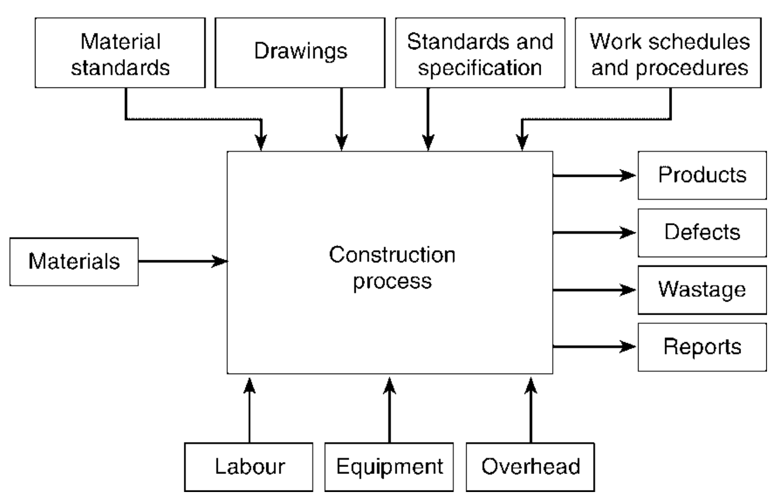

Figure 1 Typical process cost model for construction processes

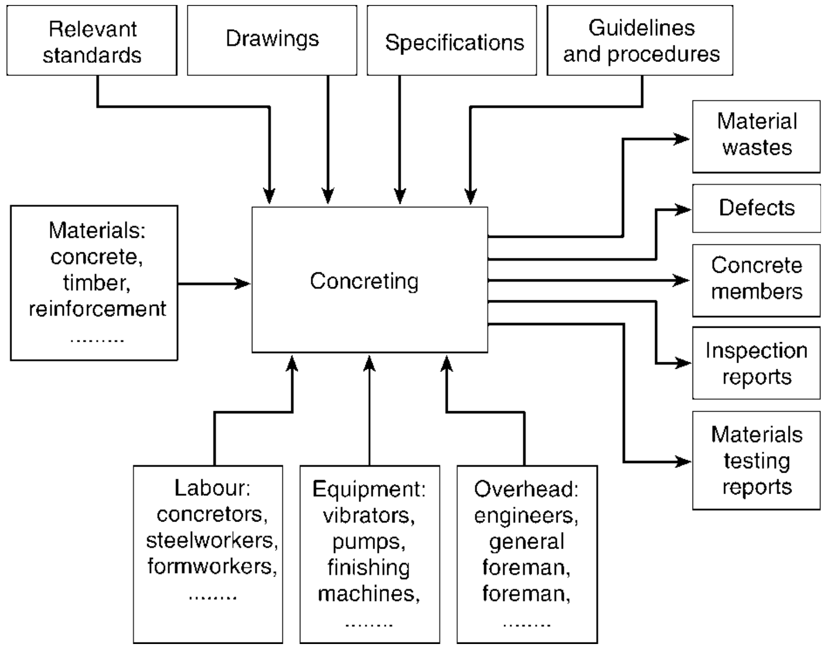

Figure 2 Process cost model for 'concreting process'

Case study1: a building project in Hong Kong

This project is a construction of 38-storey high twin residential blocks housing with 760 residential units. The gross area for each typical floor is 591 square metres. The contractor is a reputable construction firm founded about 40 years ago in Hong Kong having a yearly turnover of about US$1 billion, and the firm is ISO 9000: 2000 certified. The data collection started in the later part of 2001, which included COC and CONC for 18 typical floors (Floors 21 through 38). The quantity surveyor of this project was responsible for providing the COC data because he could retrieve them from the contract document, and the site engineer was responsible for providing the CONC data because he could conveniently record down the defects during his routine inspections. The COC provided by the quantity surveyor for each typical floor is shown in Table 1. He also indicated that it was difficult to separate the costs of labour and material from the information available in the contract document, because lump sum contracts were signed between the main contractor and subcontractors. The most significant cost item under equipment was the tower crane, which had been singled out in the cost items. Other equipment items (e.g. vibrators, compressors, etc.) were not known and were assumed to have been absorbed in the quoted prices. The ignorance of the costs of other equipment items is not harmful at all to the application of PCM. After all, any non-conformance costs related to defects caused by the inadequacy or misuse of equipment will be counted as CONC.

The CONC is not as easy to acquire as the COC. The acquisition of CONC is to be described in three parts: (A) formwork placing, (B) reinforcement placing, and (C) concrete placing.

Table 1 Cost of conformance (COC) per typical floor

	Cost (HK$)	Remark
Formwork	321 505	Labour + Materials
Reinforcement	103 537	Labour + Materials
Concrete	162 290	Labour + Materials
Equipment	10 282	Tower crane
Material testing	225	Reinforcement
	1600	Concrete
Total Cost of conformance:	599 439	($1014/sq.m.)

(A) For formwork placing, the accuracy of the locations and dimensions of concrete members depends on the proper setting out and the proper support of the formwork. Major errors in setting out the location of formwork may result in a complete knock down and relocation of the concrete members. Fortunately, such problems usually are not expected to happen in typical floor construction because of its repetitive nature and of the close supervision by different parties. On the other hand, minor errors in setting out and slight formwork movement may happen quite often and it may lead to significant repair costs. For example, a concrete wall with a few millimetres off the centreline may result in extensive chiselling and cleaning to the finished concrete work. Proper written records of such defects are usually done by foremen and/or site engineers and kept in the site office for reference. As observed by the authors, typical defects were usually caused by insufficient supports of formwork that led to slight movement at the bottom during concrete placing. The related CONC can be calculated based on the estimated time and labour required for fixing each non-conformance occurrence. Data collected for CONC are shown in Table 2.

(B) For reinforcement placing in this case study, the cost of non-conformance for the reinforcement placing process included only those costs incurred due to defects found during the final inspection before concrete pouring. In order to compile a list of common defects found in reinforcement placing, the author had spent extensive time in observing the inspection process and discussing with the resident engineer. (It is a regulation in Hong Kong to have a resident engineer, a representative from the consulting firm, stationed on site to supervise a contractor's work.) It was concluded that non-conformances were mainly caused by poor workmanship of the subcontractor. A form containing a checklist of all the common defects was then designed to facilitate the site staff in the data collection process. A typical form used to collect the defect data for each floor is shown in Table 3. The number of occurrence of each type of defects was recorded and the time and cost required for the remedial work were then estimated based on current labour rate. These are also shown in Table 3. The CONC data for Floors 21 through 38 are shown in Table 4.

(C) For concrete placing, the site engineer indicated that honeycombing caused by insufficient compaction of freshly placed concrete was the most common non-conformance that required extensive repair work. After the formwork was struck, the resident engineer representing the consulting firm would inspect all concrete surfaces. Based on the judgement of the resident engineer, concrete honeycombs that required remedial works would be marked and photographed. The honeycombs would then be categorized into Type 1 and Type 2 according to the severity of the defects as shown in Table 5. The time and cost required to complete the remedial work of each type of honeycombs were then estimated based on the current labour and material rates as shown in Table 6.

Table 2 Cost of concrete repair works caused by formwork movement

Floor	No. of occurrences	Time to repair (hrs.)*	Cost to repair (HK$)**
21	10	20	1800
22	13	26	2340
23	8	16	1440
24	8	16	1440
25	11	22	1980
26	12	24	2160
27	10	20	1800
28	4	8	720
29	3	6	540
30	9	18	1620
31	7	14	1260
32	9	18	1620
33	10	20	1800
34	8	16	1440
35	11	22	1980
36	12	24	2160
37	9	18	1620
38	7	14	1260
Avg.			1609

*Based on an estimated time for each occurrence of 2 hours (information provided by the site engineer).
**Based on an hourly wage rate of HK$90 (prevailing wage of carpenters in Hong Kong).

The CONC of each typical floor for all the three processes is summarized in Table 7. A typical process cost report for the 31st floor is also shown in Table 8 (see Figure 12 of the paper by Aoieong *et al.*, 2002). The total process cost (COC +CONC) of each typical floor from 21/F to 38/F is tabulated and represented in Table 9. Due to certain missing data from the site, process cost for the 30th floor was not recorded.

Figure 3 shows the plotting of points for each process cost against each floor (or cycle). The slope of the linear regression line of these points is found to be negative. (The regression equation is: $y = -0.272x + 602\ 557$). This means that the process cost of each floor is decreasing when the level of the floor (or cycle) is going up. This is a good phenomenon because the concreting process is continually improving. The process cost therefore can serve as a tool for the indication of continual improvement.

Table 3 CONC of reinforcement placing for a typical floor

Number of occurrences	30/F-31/F wall	31/F slab/beam	Time (mins.)	Cost* (HK$)
Date of inspection				
WALL Links				
Links missing				
Links not properly tied				
Links not properly spaced				
Cover not enough	5		5×10	100
WALL Main Bars				
Wrong size				
Bars missing				
Bars not properly spaced	5		5×15	150
Bar length not enough				
Lap length not enough				
BEAM Stirrups				
Stirrups missing		2	2×15	60
Stirrups not properly tied		17	17×5	170
Stirrups not properly spaced		10	10×10	200
Cover not enough		5	5×10	100
BEAM Main Bars				
Wrong size				
Bars missing				
Bars not properly spaced		5	5×15	150
Bar length not enough				
Lap length not enough				
SLAB				
Bars in AC hood not properly located		2	2×10	40
Bars in fins not properly located				
Bars in wrong layer				
Bars in wrong direction				
Bars not properly spaced		6	6×15	180
Cover not enough		4	4×10	80
Chairs not properly located		3	3×5	30
OTHERS				
Construction joints N.G.		1	1×15	30
Starter bars not cleaned		5	5×10	100
Clean up works required		5	5×10	100
Total cost of non-conformance:				$1490

*Based on an hourly wage rate of HK$120 (prevailing wage for steel workers).

By referencing the process costs, the contractor may know whether or not his own effort put in the work is sufficient and, hence, may develop appropriate strategies for achieving continual improvement.

Some other observations

(A) Completeness of non-conformance data

Due to the insufficiency of human resources for recording non-conformances in the 'reinforcement placing' process, only those discovered during the final inspection by the resident engineer on each floor were recorded. However, defects might be discovered by the contractor's foremen or subcontractors' foremen at any time during the process, and these were not recorded in this work. In order to obtain a full picture of all the defects occurring in the 'reinforcement placing' process, their involvement in the data collection process is essential. So, the CONC recorded in 'reinforcement placing' in the case study may be a little under-estimated. The non-conformances occurring in the concrete placing process were mainly honeycombing due to insufficient compaction of concrete. Since all related records for concreting were properly kept, the cost of non-conformance could be accurately estimated. Similarly, all records related to the remedial concrete works caused by improper alignment of formwork were also kept in the site office and, therefore, the related CONC can be easily retrieved and accurately estimated.

Table 4 CONC of reinforcement placing for floors 21 through 38

Floor	CONC(HK$)
21/F	1060
22/F	1320
23/F	1420
24/F	1120
25/F	1250
26/F	960
27/F	1250
28/F	1640
29/F	1750
31/F	1490
32/F	1260
33/F	1370
34/F	1480
35/F	930
36/F	1160
37/F	1180
38/F	1170
Avg.	$1283

(B) Involvement of the resident engineer

As mentioned earlier, it is a regulation in Hong Kong to have a resident engineer, a representative from the consultant firm, stationed on site to supervise the contractor's work. It is also a common practice in Hong Kong to have the resident engineer to inspect and ensure that all reinforcements are in conformance to the structural drawings prior to concrete placing. Since the resident engineer's inspection is fairly thorough and impartial, his (her) involvement in the data collection process will definitely enhance the quality of data recorded. However, though it is essential to get the involvement of all parties: the resident engineer (consulting firm), the site engineer (contractor) and the subcontractors to collect a complete set of data, the authors observed that these three parties were quite often in conflict with each other due to the inherent differences in their emphases, i.e. time, cost and quality. While the contractor's main concern is to get the work done as quickly as possible (time), the resident engineer, however, would like to see that every piece of work is done according to the standards and specifications (quality). On the other hand, the subcontractor's main concern is to make the highest profit (cost). Therefore, care must be taken to reduce conflicts among the three parties before they get involved in the data collection process. The recent concept of 'partnering' may be able to help reduce such conflicts.

(C) Short cycle time

The cycle time between the constructions of each typical floor may have a significant impact on the site staff's attitude towards quality. The targeted cycle time for this project was 4 days. This is something very peculiar and can only, as far as the authors know, happen in Hong Kong. Since the project was under such a tight schedule, the site staff, including the foremen and the engineers, had to work considerable overtime in order to meet the target date. During casual conversation with the site staff, the authors had observed that most workers indicated that quality was something to be considered only when they were not under a tight schedule. In other words, having reasonable time for workers to finish their works is a prerequisite for the success of any quality initiatives at the site level. The authors agree with this view of the workers.

(D) Process cost for the construction of typical floors

Based on the data collected, the average process cost of the concreting of a typical floor was $602 549. When it was expressed in terms of unit floor area, the process cost was $1020/sq.m. The cost of nonconformance ranged from 0.39% to 0.65% of the total process cost. It can be seen that the cost of non-conformance for this particular process is quite insignificant for the following reasons:

- Both the concreters and steel fixers of this project were highly skilled workes.
- For reinforcement placing, only non-conformances

Table 5 Concrete honeycomb categorization

Defect type	Estimated time to complete (1 labour per occurrence)		Total time
	Chiselling/cleaning	Repair	
Type 1: Without formwork involved e.g. typical honeycombs at faces/bottom of wall	10 mins	5 mins	0.25 hour
Type 2: With formwork involved e.g. typical honeycombs at top of wall/ column with reinforcement totally exposed	30 mins	120 mins	2.50 hours

Table 6 Cost estimation of concrete honeycombs for typical floors

Floor	Type 1			Type 2			Total cost to repair (HK$)
	No.*	Total time to repair (hrs.)	Total cost to repair** (HK$)	No.*	Total time to repair (hrs.)	Total cost to repair** (HK$)	
21	1	0.25	23	0	0	0	23
22	2	0.50	45	1	2.50	225	270
23	3	0.75	68	0	0	0	68
24	3	0.75	68	0	0	0	68
25	2	0.50	45	1	2.50	225	270
26	1	0.25	23	0	0	0	23
27	4	1.00	90	1	2.50	225	315
28	4	1.00	90	1	2.50	225	315
29	2	0.50	45	0	0	0	45
30	6	1.50	135	0	0	0	135
31	4	1.00	90	1	2.50	225	315
32	2	0.50	45	0	0	0	45
33	5	1.25	113	2	5.00	450	563
34	6	1.50	135	1	2.50	225	360
35	4	1.00	90	0	0	0	90
36	8	2.00	180	1	2.50	225	405
37	7	1.75	158	1	2.50	225	383
38	6	1.50	135	0	0	0	135
Avg.							$217

*Number of occurrences observed after the inspection.
**Based on an hourly wage rate of HK$90.

Table 7 Cost of nonconformance of each process

Floor	Cost of Nonconformance (HK$)						Total (HK$)
	Reinforcement placing		Formwork placing		Concrete placing		
21/F	1800	62%	1060	37%	23	0.8%	2883
22/F	2340	60%	1320	34%	270	6.9%	3930
23/F	1440	49%	1420	48%	68	2.3%	2928
24/F	1440	55%	1120	43%	68	2.6%	2628
25/F	1980	57%	1250	36%	270	7.7%	3500
26/F	2160	69%	960	31%	23	0.7%	3143
27/F	1800	53%	1250	37%	315	9.4%	3365
28/F	720	27%	1640	61%	315	11.8%	2675
29/F	540	23%	1750	75%	45	1.9%	2335
31/F	1260	41%	1490	49%	315	10.3%	3065
32/F	1620	55%	1260	43%	45	1.5%	2925
33/F	1800	48%	1370	37%	563	15.1%	3733
34/F	1440	44%	1480	45%	360	11.0%	3280
35/F	1980	66%	930	31%	90	3.0%	3000
36/F	2160	58%	1160	31%	405	10.9%	3725
37/F	1620	51%	1180	37%	383	12.0%	3183
38/F	1260	49%	1170	46%	135	5.3%	2565
Avg.	$1609	51%	$1283	42%	$217	7%	$3110

observed in the final inspection were recorded. The CONC therefore were underestimated.

- The use of aluminium formwork greatly reduced defects caused by traditional timber formwork. An average of 51% of the cost of non-conformance was related to improper placing and supporting of formwork. As a result, the labor cost in chiseling finished concrete was extensive.

Table 8 Process cost report for the concreting process of the 31st floor

Process cost report

Process name: Concreting
Boundary: "Formwork construction" to "Formwork striking"
31st floor of Building XXX
Process owner: various

Process Conformance	Cost (HK$) Act.	Cost (HK$) Est.	Process Owner	Process Non-conformance	Cost (HK$) Act.	Cost (HK$) Est.	Process Owner
Activity: Formwork erection			Formwork subcontractor	Activity: Formwork erection			Formwork subcontractor
• Labour & materials	321 505			• concrete rework due to formwork movement		1260	
Activity: Reinforcement			Steel subcontractor	Activity: Reinforcement			Steel subcontractor
• Labour & materials	103 537			• rework due to non-conformance		1490	
Activity: Concrete placing			Concrete subcontractor	Activity: Concrete placing			Concrete subcontractor
• Labour & materials • testing	162 290			• rework due to honeycombs in concrete		315	
Others:			General contractor				
• Material testing	1825						
• Equipment	10 282						
Total process conformance cost		$599 439		Total process non-conformance cost		$3065	

Table 9 Total process cost for typical floors

Floor	Cost of conformance (HK$)*		Cost of non-conformance (HK$)**		Total process cost (HK$)
21/F	599 439	99.52%	2883	0.48%	602 322
22/F	599 439	99.35%	3930	0.65%	603 369
23/F	599 439	99.51%	2928	0.49%	602 367
24/F	599 439	99.56%	2628	0.44%	602 067
25/F	599 439	99.42%	3500	0.58%	602 939
26/F	599 439	99.48%	3143	0.52%	602 582
27/F	599 439	99.44%	3365	0.56%	602 804
28/F	599 439	99.56%	2675	0.44%	602 114
29/F	599 439	99.61%	2335	0.39%	601 774
31/F	599 439	99.49%	3065	0.51%	602 504
32/F	599 439	99.51%	2925	0.49%	602 364
33/F	599 439	99.38%	3733	0.62%	603 172
34/F	599 439	99.46%	3280	0.54%	602 719
35/F	599 439	99.50%	3000	0.50%	602 439
36/F	599 439	99.38%	3725	0.62%	603 164
37/F	599 439	99.47%	3183	0.53%	602 622
38/F	599 439	99.57%	2565	0.43%	602 004
Avg.	$599 439	99.48%	$3110	0.52%	$602 549

*Obtained from Table 1.
**Obtained from Table 7.

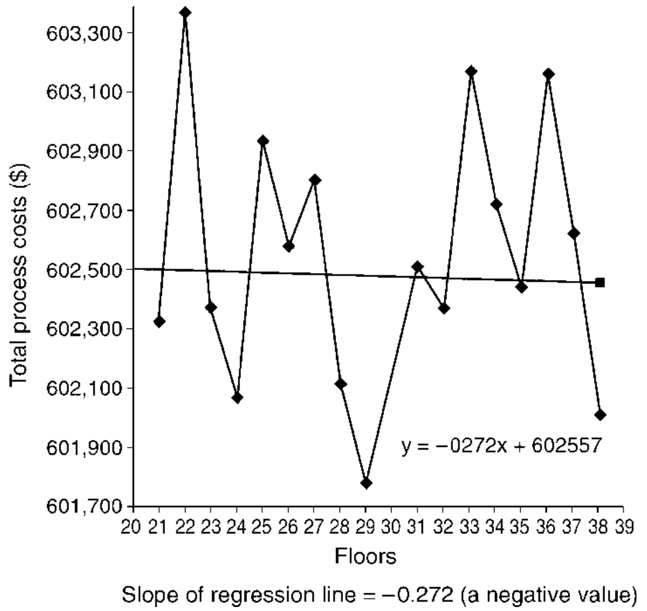

Figure 3 Linear regression of total process costs vs floors

(E) Continual improvement

The continual improvement observed in the case study could possibly be a result of the fact that the contractor and the subcontractors knew at the beginning that this project was to be used for PCM testing. Therefore, it is possible that for a project when the contractor knows that his work is going to be monitored by PCM, he will probably be more careful and pay more attention to the quality of his work.

Case study 2: a civil engineering project in Hong kong

The project is a government-initiated project involving the construction of about 800 m of single two-lane carriageway, drains, sewers, waterworks, landscaping works and about 570 m of noise barriers. The main contractor of this project is a corporation headquartered in Beijing with major construction activities throughout Asia, Middle East and Africa. Its major lines of business include international construction contracting, design and consulting services. The Hong Kong Branch was established in 1988 and, since then, the corporation has been an active participant in the Hong Kong construction industry. The company has also obtained the ISO 9000:1994 certifications in year 1994. For this project, the only construction activity that involved formwork, reinforcement and concrete placing was the construction of 50 pile caps. The data collection started in the later part of 2001, which included COC and CONC for the first 30 pile caps. Similar to the collection of COC and CONC in Case Study 1, it was reckoned by the authors that the COC and CONC data could be more conveniently captured by the Quantity Surveyor, and the Site Engineer and the Resident Engineer, respectively. The COC provided by the quantity surveyor for each typical pile cap is shown in Table 10. Typical cost items related to the construction processes of pile caps are labour, materials and material testing. Additional materials were required for the provision of construction joints between individual pile caps.

During the meeting with the resident engineer, he indicated that concrete related defects in pile cap construction might be ignored in the study due to the ease of construction of such work. In terms of concrete honeycombing, it usually occurs in areas where the reinforcements are congested and the space is tight. Such conditions usually do not exist in pile cap construction. In terms of remedial work due to misalignment of formwork, the resident engineer also indicated that it usually doesn't happen because of the close supervision of land surveyors who are responsible for the setting out. Therefore, the authors then decided to include only those defect costs incurred from reinforcement placing in the CONC calculation. A typical form, similar to the one as shown in Table 3 for Case Study 1, was used by the resident engineer to record the occurrence of nonconformance related to reinforcement placing. The CONC data for a typical pile cap (pile cap 2) is shown in Table 11. A typical process cost report for this pile cap is also shown in Table 12. The total process costs (COC + CONC) of pile caps 1 through 30 are tabulated and

Table 10 Cost of conformance (COC) per pile cap

	Cost (HK$)	Remark
Formwork	11 536	Labour + Materials
Reinforcement	49 432	Labour + Materials
Concrete (including blinding)	75 720	Labour + Materials
Water-stop	117	
Movement joint	1807	Joint filler, sealant + dowel bars
Material testing	75	Reinforcement
	300	Concrete
Total Cost of conformance:	$138 987	

Table 11 CONC of reinforcement placing for Pile Cap 1

Pile Cap 1	# of occurrences	estimated time for re-work (mins.)	estimated labour for re-work	estimated cost for rework*
REINFORCEMENT (1st pour)	Date of inspection Sept. 27, 01			
Wrong size				
Bars missing	1	10	2	42
Bars not properly spaced				
Bars not properly tied				
Bar length not enough	1	30	2	125
Lap length not enough				
Cover not enough	5	10	2	42
OTHERS				
Construction joints N.G.				
Starter bars not cleaned				
Clean up works required				
Remedial work of welded bars				
REINFORCEMENT (2nd pour)	Date of inspection Oct. 9, 01			
Wrong size				
Bars missing				
Bars not properly spaced				
Bars not properly tied	1	30	1	63
Bar length not enough				
Lap length not enough				
Cover not enough	~100	600	2	2500
OTHERS				
Construction joints N.G.				
Starter bars not cleaned				
Clean up works required				
Total cost of non-conformance:				$2771

*Based on an hourly wage rate of HK$125.

presented in Table 13. Similar to the previous case study, Figure 4 shows the plotting of points for each process costs against each pile cap (or cycle) and the linear regression line of these points. The slope of the regression line is found to be negative. Once again, this is a good phenomenon because the concreting process is continually improving.

Some other observations

Observations (A), (B) and (E) discussed in the first case study also apply to the second case study. Other observations are as follows.

(C) Cycle time

Unlike the previous case study, the cycle time of the construction of pile caps was relatively long. The average cycle time was four days. All site workers, including those at the supervisory level, had reasonably sufficient time to finish their works with good quality.

(D) Process cost for the construction of pile caps

Based on the data collected, the average process cost of the concreting of a pile cap was $139 344. The cost of non-conformance ranged from 0.03% to 3.55% with an average of 0.25%. With the exception of the first two pile caps, the cost of non-conformance for this particular process is relatively low. This observation can be explained by the following reasons:

- The concreting process of pile caps is relatively simple and the cycle time is relatively long.
- In building projects (e.g. Case Study 1), it is a general practice that the resident engineer is the only person responsible for the inspection of structural works on behalf of the consulting company.

Table 12 Process cost report for the concreting process of pile cap 2

Process cost report

Process name: Concreting

Boundary: "Formwork construction" to "Formwork striking"
Pile Cap 2

Process owner: various

Process Conformance	Cost (HK$) Act.	Cost (HK$) Est.	Process Owner	Process Non-conformance	Cost (HK$) Act.	Cost (HK$) Est.	Process Owner
Activity: Formwork erection			Formwork subcontractor	Activity: Formwork erection			Formwork subcontractor
• Labour & materials	11 536			• concrete rework due to formwork movement			
Activity: Reinforcement			Steel subcontractor	Activity: Reinforcement			Steel subcontractor
• Labour & materials	49 432			• rework due to non-conformance		2771	
Activity: Concrete placing			Concrete subcontractor	Activity: Concrete placing			Concrete subcontractor
• Labour & materials	75 720			• rework due to honeycombs in concrete			
Others:			General contractor				
• Material testing	375						
• Water-stop	117						
• Movement joint	1807						
Total process conformance cost		$138 987		Total process non-conformance cost		$2771	

In civil engineering projects, however, particularly for government projects, a relatively large team of technical staff is responsible for the supervision of construction works. The team usually includes resident engineers, inspectors-of-works, work supervisors, quantity surveyors, and land surveyors. The placing of reinforcement cannot commence before the approval of the land surveyors, who are responsible for checking the alignment of formwork. The reinforcement steel bars must be checked carefully by the resident engineer before any concreting can commence. The placing of concrete is also under continuous supervision of the inspectors-of-works and work supervisors. The supervision is very tight in this pile cap construction process. These good preventive measures can effectively reduce the occurrence of non-conformances.

Conclusion

The use of PCM to capture quality costs in concreting process for two projects, the 38-storey building and the civil engineering pile cap construction, was successfully tested in this study demonstrating that the PCM is feasible, practical and easy to implement. The model permitted the identification of key activities of the concreting process such as formwork placing, reinforcement placing and concrete placing, and for estimating the costs of conformance (COC) and costs of non-conformance (CONC).

As a part of the PCM model, continuous analysis of the process cost control report for each activity can reveal some of the shortcomings of the process and allow immediate corrective actions to be taken to reduce the CONC and improve the overall process quality. The requirement of continual improvement as stipulated in the ISO 9000 Quality Standards (year 2000 version) can therefore be realized. In the case of the 38-storey building, the costs of non-conformance were down from 0.48% of the total process costs in the 21st floor (the 1st cycle) to 0.43% at the end of the project in the 38th floor (the 18th cycle or the last cycle). In the civil engineering project, the PCM model showed that the CONC fell dramatically from 3.55% of the total process costs (the 1st cycle) to an insignificant 0.03% (the 30th cycle or the last cycle). The continual improvement illustrated in this paper is the improvement of a process within a project. Continual

Table 13 Total Process Cost for pile caps

Pile cap	Cost of conformance (HK$)		Cost of non-conformance (HK$)		Total process cost (HK$)
1	138 987	96.45%	5115	3.55%	144 102
2	138 987	98.05%	2771	1.95%	141 758
3	138 987	99.78%	302	0.22%	139 289
4	138 987	99.83%	240	0.17%	139 227
5	138 987	99.86%	188	0.14%	139 175
6	138 987	99.93%	94	0.07%	139 081
7	138 987	99.95%	73	0.05%	139 060
8	138 987	99.84%	229	0.16%	139 216
9	138 987	99.96%	52	0.04%	139 039
10	138 987	99.95%	73	0.05%	139 060
11	138 987	99.95%	73	0.05%	139 060
12	138 987	99.93%	94	0.07%	139 081
13	138 987	99.96%	52	0.04%	139 039
14	138 987	99.96%	52	0.04%	139 039
15	138 987	99.98%	21	0.02%	139 008
16	138 987	99.93%	104	0.07%	139 091
17	138 987	99.96%	52	0.04%	139 039
18	138 987	99.93%	94	0.07%	139 081
19	138 987	99.95%	73	0.05%	139 060
20	138 987	99.95%	63	0.05%	139 050
21	138 987	99.96%	52	0.04%	139 039
22	138 987	99.89%	156	0.11%	139 143
23	138 987	99.89%	156	0.11%	139 143
24	138 987	99.88%	167	0.12%	139 154
25	138 987	99.97%	42	0.03%	139 029
26	138 987	99.90%	135	0.10%	139 122
27	138 987	99.95%	63	0.05%	139 050
28	138 987	99.96%	52	0.04%	139 039
29	138 987	99.97%	42	0.03%	139 029
30	138 987	99.97%	42	0.03%	139 029
Avg.	$138 987	99.75%	$357	0.25%	$139 344

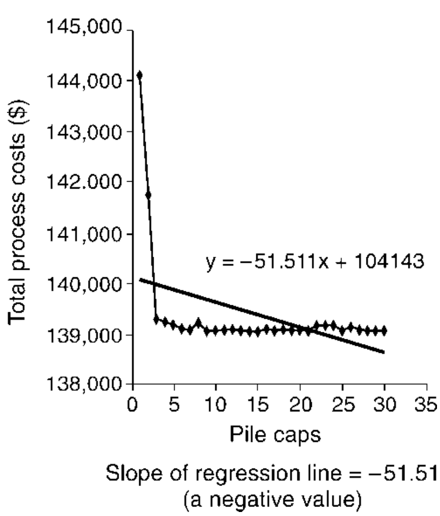

Figure 4 Linear regression of total process costs vs pile caps

improvement required in the ISO 9000: 2000 can also be interpreted as improved processes to be carried through from one project to the next. This paper only illustrates the former case, which is actually being practised by certain construction companies in Hong Kong (who have already gained ISO 9000: 2000 certification) for satisfying the 'continual improvement' requirement of the Year 2000 version. The authors believe that the PCM is also suitable to be applied for the latter case, although case studies on which have not yet been conducted.

The authors believe that the PCM approach is suitable and beneficial for application in the construction industry for measuring quality costs. Although the examples in this paper are related to the concreting process only, the model can in fact be applied to any construction processes in a similar manner. The suggested further work would be the application of PCM for management processes, such as the design process in an engineering consulting firm. In conclusion, the model is simple and flexible, and can be used in a wide range of activities or situations. The use of PCM (Process Cost Model) therefore should be promoted in the construction industry.

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