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Full Length Research Paper

Cost of quality management: An empirical study from Turkish marble industry

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In this study, a quality cost model to measure and control costs of quality (COQ) occurring in marble plants was developed. In the marble industry, most properties associated with quality depend on uncontrolled and mostly immeasurable natural and geological conditions. And because of these nature-related problems, it is difficult to apply commonly used quality cost models to the marble industry and there has not been any application of cost models to the marble industry in literature. For the first time, quality costs occurring in marble production systems are determined, classified and calculated. A computer program containing this model and statistical quality control tools was developed. The software was tested using data from marble plants located in the Diyarbakir (Turkey) Region that has a significant share of the Turkish natural stone industry. It was found that quality costs vary depending on product types in range from 9 to 34% of total production costs for three different stone types.

Key words: Quality, cost of quality, quality cost model, PAF model, marble plant, computer program.

INTRODUCTION

The primary principles affecting product manufacturing and service sectors, along with free market competition have drastically changed over the last five decades. As a result of these changes, the world has become a single market and providing good quality products and/or services is the rule for maintaining a presence in these new market conditions. On the other hand, any serious attempt to improve quality must take into account costs associated with achieving it, since the objective of continuous improvement programs is not only to meet customer requirements, but also to do it at the lowest cost.

This can only happen by reducing the costs needed to achieve quality and the reduction of these costs is only possible if they are identified and measured. In order to both satisfy customers and control costs, a control of quality costs is needed. Therefore, measuring and reporting the COQ should be considered an important issue for managers (Schiffauerova and Thomson, 2006).

Although, empirical researches show that quality management practices improve organizational performance and profitability, unfortunately, the implementation of quality management has not occurred at the same pace in different regions of the world. Early implementation of total quality management (TQM) started in Japan and was later adopted by the US, Europe and the South East Asian countries. Despite the number of publications and quantity of research on TQM, little empirical work has been carried out in developing countries (Parast et al., 2007).

However, this is not an easy task, because there is neither a unique definition of quality nor a unique cost model to identify and control quality costs. The key problem when dealing with quality costs is to define which cost item could be classified as a quality cost, because differentiating it from other costs is a major problem. Usually, COQ is understood as the sum of conformance plus non-conformance costs, where cost of conformance is the price paid for prevention of poor quality and cost of non-conformance is the cost of poor quality caused by product and service failure. One way of approaching this problem is to use COQ or quality cost models (QC models) defined as an economical control method to

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uncover and classify costs occurring in the manufacturing system. By using these models, it can be possible to identify, classify and evaluate quality costs.

But, the marble industry is different compared to others regarding quality and its tools because in this industry most properties associated with quality depend on uncontrolled and mostly immeasurable natural and geological conditions. In the marble industry, inputs are non-renewable natural resources. Because of these nature-related problems, it is difficult to apply commonly used QC models to the marble industry. On the other hand, quality control and efficiency is very important in mining because they may decelerate depletion of natural resources.

Inputs to the marble system are quarried raw natural stone blocks that have been formed geologically in nature for millions of years. Almost all of their properties that directly affect standards and control of the quality is almost impossible in this sector. The only option available is to rigorously select the best blocks from the beginning of the process, and to control the process closely. And because of these difficulties, classification and calculation of quality costs in the natural stone industry is very difficult and uncommon.

This paper is about the studies to identify, classify and measure the COQ occurring in the marble processing system in plants. In order to identify and classify COQ, prevention-appraisal-failure model (PAF) was described and applied. In addition, a new computer program which can be used for these quality related issues for marble plants was introduced. The program consists of several modules to identify, classify, calculate and control costs occurring in plants. SQC (Statistical quality control) applications can be applied by using this program at every point in the marble processing system.

COST OF QUALITY AND QC MODELS

Although the primary definition of the term quality is customer satisfaction through a product or service, there are a number of different definitions for quality and quality costs available in the literature. Campanella and Corcoran (1983) and Paul (1990) defined quality costs from zero failure viewpoints as the difference between actual costs and the ideal one. Juran and Gryna (1993) defined quality as ‘fitness for purpose,’ whereas for Crosby (1979) quality was ‘conformance to requirements’. According to Deming (1986), quality is uniformity with respect to a correct target. Crosby (1983) defined quality costs as costs of non-conformance. Szymanski (1985) argued that quality cost is a tool that displays trends for management to act on.

The aspect of measuring and collecting quality cost is the core of the COQ technique and QC models. Various approaches for identifying quality cost elements were suggested by several researchers (Hollocker, 1986; Dahlgaard et al., 1992; Asher, 1987; Gibson et al., 1991; Morse, 1993). These approaches included the questionnaire, brainstorming, and brief interview sessions with key supervisory personnel, root cause analysis for identifying non-conformance quality activities and value chain concepts. Whitehall (1986) and Brennan et al. (1990) used structured interviews and flowcharts for identifying quality cost elements. Schniederjans and Karuppan (1995) developed a goal-programming model to aid in selecting the best set of quality control instruments leading to the design of a quality control system. Desai (2008) state that, although, many papers and books touch on quality cost collection, they give little help and guidance on setting out methodology of cost collection.

The PAF model, the oldest of the QC models, was developed by Feigenbaum (1956) and Masser (1957). Quality cost models have been used to identify and segregate costs and help accounting systems record costs associated with quality. Although, quality cost models are classified into four groups, (PAF model, opportunity cost model, process cost model and activity-based cost model) in general, most cost of quality models are based on the PAF classification (Plunket and Dale, 1987; Machowski and Dale, 1998; Sandoval-Chávez and Beruvides, 1998; Hwang and Aspinwal, 1996; Desai, 2008). The PAF model is one of the most well-known quality cost models among quality practitioners and has found applications in both manufacturing and service industries and it is based on classifying quality costs into three main categories: prevention, appraisal and failure costs. In addition to these three categories, Abed and Dale (1987), proposed that failure costs can be divided into two sub-classes as internal and external failure costs. They also found that quality cost elements could be categorized easily into prevention, appraisal and internal and external failure costs for all companies. Prevention costs are associated with actions taken to ensure that a process provides quality products and services. Appraisal costs are associated with measuring the level of quality attained by the process and failure costs are incurred to correct quality in products and services before (internal) or after (external) delivery to the customer (Schiffauerova and Thomson, 2006).

The PAF approach helps to examine company operating procedures, accounting systems and monthly departmental reports to identify various cost elements associated with four cost categories (Sharma et al., 2007). The objective of a COQ system is to find the level of quality that minimizes total cost of quality. Feigenbaum’s and Juran’s PAF scheme has been adopted by the American Society for Quality Control (ASQC, 1970) and the British Standard Institute (BS 6143, 1990) and is employed by most of the companies which use quality costing (Porter and Rayner, 1992). In this study, in order to identify and separate quality costs occurring in marble plants, the PAF model was used and a special module of the program was coded; associated

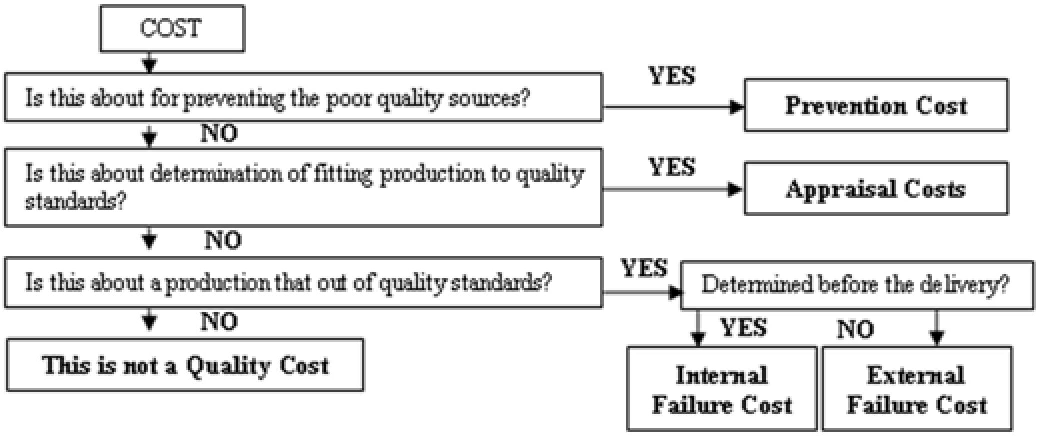


Figure 1. An algorithm for determination and classification the quality costs.

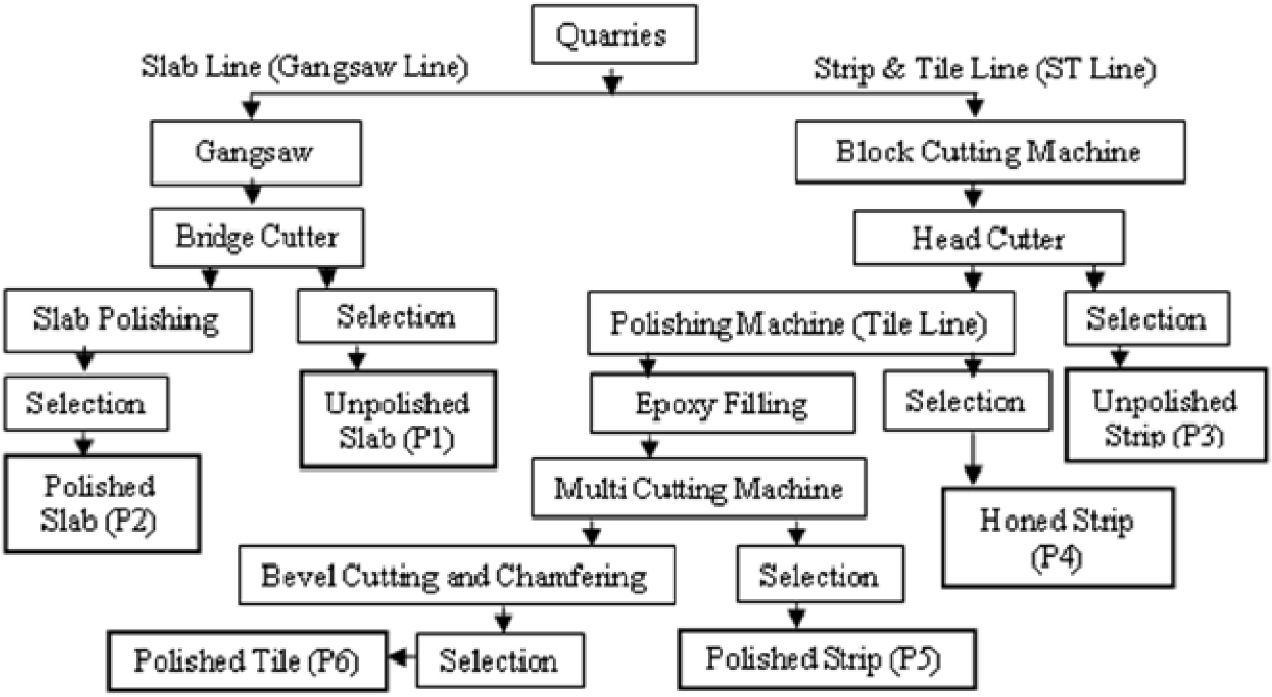


Figure 2. Production lines and products of an ordinary marble plant.

with the PAF algorithm stated by Campanella (1990) (Figure 1).

METHODOLOGY AND MODEL DEVELOPMENT

In the marble industry, production systems start with quarrying raw natural stone blocks by separating the raw block from the excavation site, usually by using diamond wire cutting tools or/and chainsaw block cutters. The most important stage of the production system is the selection of quarried blocks. After the selection, blocks are transported to plants and they are sorted according to production schedule and transferred to the stone cutting lines. In marble plants there are two main cutting lines: strip (or tile line) and slab line. The presentation of cutting lines of marble plants, working stages and names of final products are depicted in Figure 2.

Different sets of costs can take place depending on the selection of cutting lines, types of products and types of production methods used in the marble processing system. Major costs that occur in the cutting lines are energy, consumables and labor costs. In addition to these, costs of abrasives used for calibrating and polishing the marble surfaces and of epoxy which is used as filling material to consolidate and embellish the marble can be considered important cost items.

In order to determine and calculate all these costs incurred in marble production systems and convert them into unit costs ($/m^2), a series of surveys and measurements were carried out and operating data obtained from marble plants located in Diyarbakir Region (Turkey).

After these surveys carried out at several marble plants located in Diyarbakir natural stone basin, it was concluded that calculation of the unit cost of marbles directly by monitoring their progress in the production lines was very difficult. Calculations became complicated due to recirculation and losses in lines and a variety of feed and product types associated with each line. Machines in each cutting lines have different consumption properties and cost types. Eventually, a new methodology was developed to calculate unit costs.

By this method (Akkoyun, 2006), unit cost of marbles are calculated indirectly by using two parameters; unit time cost ($/minute) and processing time (minute). It was found that measuring and calculating of these two parameters were relatively simple as compared to direct calculation. As the first step, production system was divided into working stages representing a machine in a line or an independent unit operation (for example gangsaw machine in slab line, or work of wax filling of tiles). Then, a large number of measurements were performed for each stage of block processing to determine costs per unit operation per unit time under normal factory operating conditions and by this way it would be possible to measure unit processing time needed for each stone type. By combining unit time cost with processing time needed for a given stone type, all costs incurring in each stage could be calculated as a unit of $/minute applicable to any marble and product type. Eventually, it was possible to calculate unit costs ($/m^2) for any product by measuring the processing time in working stages involved in production of this particular product.

In marble processing system, the high-cost sub-processes are cutting and polishing. Processing time for these depends on the properties of the stones directly. Consequently, the cost calculation method proposed in this study is accurate only for those with known cutting and polishing properties. Processing time or unit time values determined for one type of stone might not be used for other type of stones. Therefore, processing time values must be measured again whenever types and/or properties of stones change. The method is summarized in Equation 1.

$$UC = \frac{C * T}{A} \qquad (1)$$

Where:

UC = unit cost ($/m^2);
C = cost of unit time ($/minute);
T = process time (minute);
A = total area of marble to be processed (m^2).

This method is applied into all working stages needed to produce several types of marble products (Table 1).

Finally, a general cost model to calculate total production cost of the factory taking account of stone type, working stages and cost types was developed. Before the model can be used, data for process time and unit cost for each working stage should be collected. The model is expressed as;

$$TC = \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{p} (((C * T)_k)_j)_i \qquad (2)$$

Where:

TC = total cost ($);
C = cost of unit time ($/minute);
T = process time (minute) for every i (stone types), j (working stages) and k (cost types).

Total cost of any marble and/or product type can be measured with this model and it is possible to calculate unit costs by dividing this value to the area of the production (m^2).

This cost model would allow calculation of quality costs, if their occurrence could be identified within a given stage (as in Table 1). The next step of the study is identification of quality costs in these stages and several case studies and surveys were carried out at the plants. In the scope of this study, over 1300 cost related parameters are evaluated, and for the first time in literature, almost all costs were evaluated and main quality cost items were identified (Table 2). Finally, these costs are classified into quality cost types as PAF model by using the algorithm given in Figure 1.

Almost all costs that occur in the preliminary stage of building a plant (that is site selection, finding quarries, selection of machine types and staff, designing flow sheet and educating and training) are considered as major prevention costs. Training costs for machine operators, raw block selectors and costs of labor selection for final products can be considered as prevention costs. Finding new quarries for new products is very important for the marble industry and costs of sample testing from potential quarries can be classified as prevention costs. Furthermore, exhibition and advertising costs can also be classified as prevention costs. On the other hand, during the production stage, appraisal and failure costs would be

Table 1. General flow sheet for marble production.

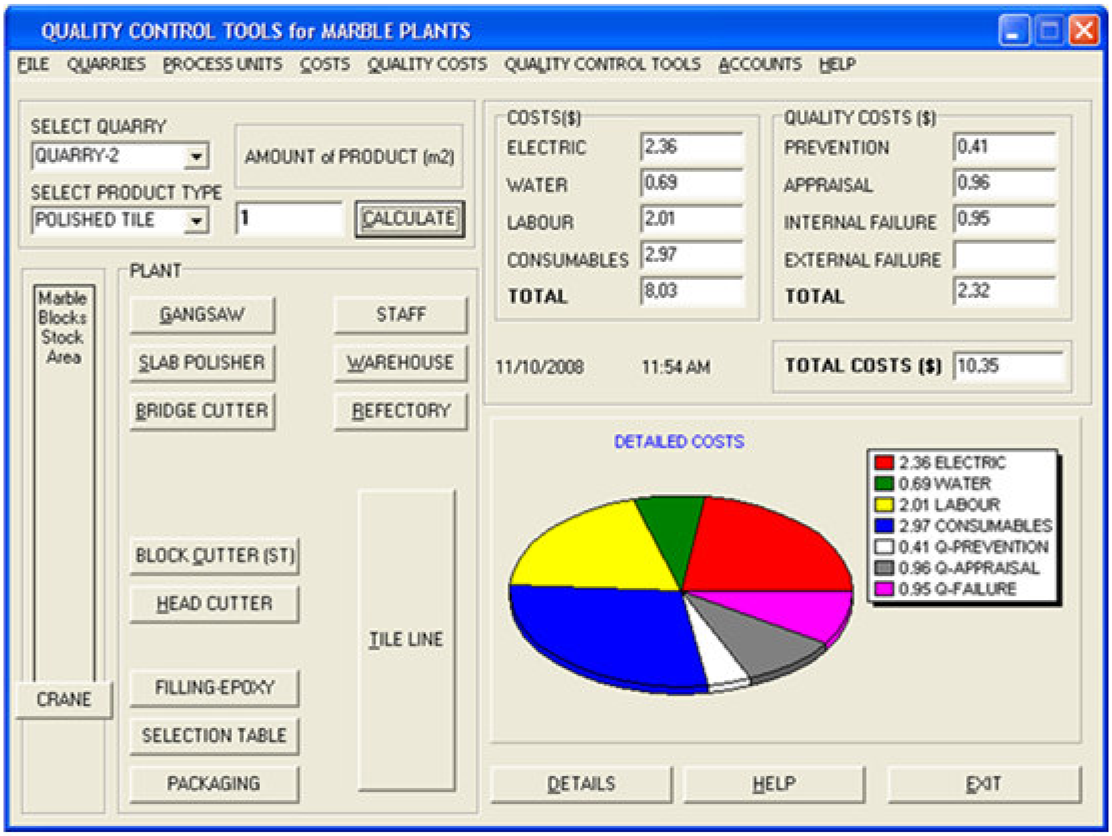
Working Stages (j)	Products					
	Unpolished slab	Polished slab	Unpolished strip	Semi polished strip	Polished strip	Polished tile
Shipping (Raw Blocks)	Y	Y	Y	Y	Y	Y
Stocking	Y	Y	Y	Y	Y	Y
Gangsaw	Y	Y	N	N	N	N
Bridge Cutter	Y	Y	N	N	N	N
Slab Polisher	N	Y	N	N	N	N
Block Cutter (ST)	N	N	Y	Y	Y	Y
Head Cutter	N	N	Y	Y	Y	Y
Polisher	N	N	N	O	Y	Y
Filling	O	O	O	O	Y	Y
Control & Selection	Y	Y	Y	Y	Y	Y
Packaging	Y	Y	Y	Y	Y	Y
Overheads	Y	Y	Y	Y	Y	Y
Other Costs	Y	Y	Y	Y	Y	Y

Y, Yes; N, No; O, Optional.
Detailed cost types for an ordinary stage are energy, water, abrasive consumptions and labor

Table 2. Quality cost types arranged as PAF model for marble production system.

Quality costs occurred in marble factories		
Categories	**Sub-categories**	**Detailed cost elements**
Prevention	Cost of preparation to production (in constructing step of factory)	Investigation and decision for factory location, flow sheet, machine types, energy, staff etc.
	Cost of determining customer demands	Advertising, market research, questionnaire, trips, fair, exhibition, web site cost etc.
	Cost of finding new quarries	Research trips, sampling and testing costs of possible new quarries
	Cost of Education or/and training	Costs of education and training (about block selection, cutting, filling, packaging, fair, software etc.) On-the-job training, Difficult test and inspection skill, Training for statistical tools, control tools, sampling
	Quality audit of suppliers	Selection & transport of raw blocks, stock verification
Appraisal	Cost of Inspection or test of parts, products and materials	Routine inspection, Clearing anomaly, system audit, machine test, product test, measurements, cost of samples, repairing and fixing, selection and test of consumption (socket, saw, abrasive, filling, packaging etc.)
	QC team costs	Salary, quality improvement activities, Technical search and reading, statistical tools, Labor, software, investigation quality problems and failures, corrective activities, plan tasks and procedures, meetings, reports, correction, establishing and planning education for workers etc.
Internal failure	Cost of internal defects	Cost of defect product, stocking defects, rejection, reworking, relative loss of 2nd quality level products
External failure	Cost of external defects	Cost of refused products by customer, assurance, shipping cost of refused products, rework after delivery

substantial. Appraisal costs are generally those incurred while controlling the system and labor costs of quality control workers. Measuring, sampling and test costs, costs of test tools and software together with sample preparation can be considered as appraisal costs. Research costs for developing optimum working condi-



SELECT QUARRY: QUARRY-2
SELECT PRODUCT TYPE: POLISHED TILE
AMOUNT of PRODUCT (m2): 1

COSTS($)	
ELECTRIC	2.36
WATER	0.69
LABOUR	2.01
CONSUMABLES	2.97
TOTAL	8.03

QUALITY COSTS ($)	
PREVENTION	0.41
APPRAISAL	0.96
INTERNAL FAILURE	0.95
EXTERNAL FAILURE	
TOTAL	2.32

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TOTAL COSTS ($) 10.35

Figure 3. Main window of the program.

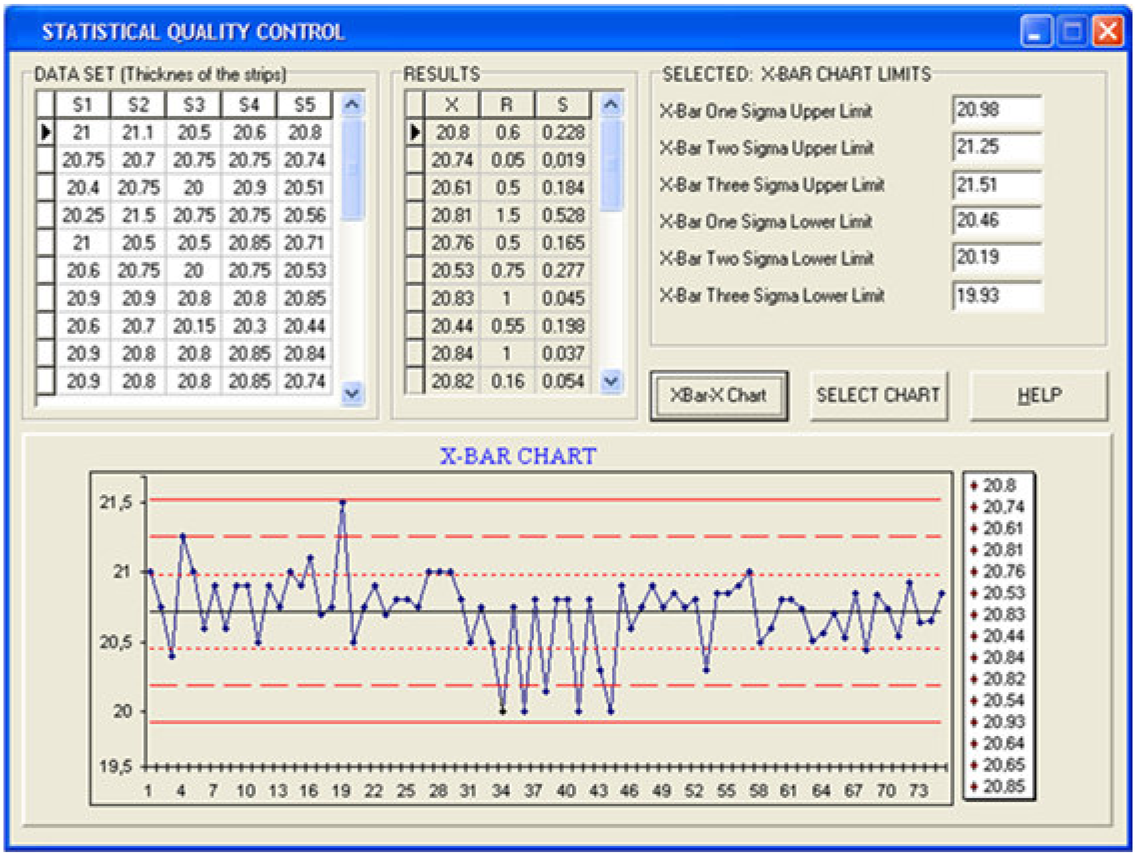
tions of machines and workers and equipment repair costs would also be included in this category.

THE DEVELOPMENT AND APPLICATION OF A NEW COMPUTER PROGRAM

Several case studies and surveys were conducted in plants and these studies showed that there are more than 1300 cost-related parameters in these systems. Following this determination, it was concluded that a computer program was needed to control all of the parameters. After several studies, a computer program which can be used to control quality costs in marble plants was developed to obtain and control data for a quality cost model. The program has several modules which help individual functions (Figure 3). The properties and working conditions of the machines, labor, products and raw blocks can be input to the program. By using these data, the program performs calculations to determine unit costs, total costs and cost details.

One of these modules works as a database for marble plants and nearly 1,300 cost-related parameters can be saved, sorted and changed with this module. This module can assist the accounting system of the plants. Another module is used for statistical quality control (SQC) application into any point of the marble processing plant system. By using this module and related program window, the program user can input data obtained from any point of the process (that is before or after any machine) and compute them. The program gives the average, normal distribution and SQC graphics known as Shewhart control charts in the same window (Figure 4).

After generating the PAF model for marble plants, the next step was to obtain detailed cost values and quality cost data associated with this model. Values of these cost titles were calculated by using several methods. Some of them were calculated by using accounting records of the companies (that is advertising, marketing and salary-related data). The other costs were calculated directly by taking measurements in the plants (that is sample costs, measurement costs, reworks and defects). First, a detailed flowchart of the plant production system was constructed to guide the remaining steps. After that, important points of this system were determined and these points were used to set control stations (that is after gangsaw, before ST, after ST, before tile line and in the tile line). The amount of sub-production, production and defects were measured and controlled at these points by using several methods. For example, in order to follow and calculate production and defect rates, a block tracing system was generalized. In this system, a new number



DATA SET (Thicknes of the strips)

S1	S2	S3	S4	S5
21	21.1	20.5	20.6	20.8
20.75	20.7	20.75	20.75	20.74
20.4	20.75	20	20.9	20.51
20.25	21.5	20.75	20.75	20.56
21	20.5	20.5	20.85	20.71
20.6	20.75	20	20.75	20.53
20.9	20.9	20.8	20.8	20.85
20.6	20.7	20.15	20.3	20.44
20.9	20.8	20.8	20.85	20.84
20.9	20.8	20.8	20.85	20.74

RESULTS

X	R	S
20.8	0.6	0.228
20.74	0.05	0,019
20.61	0.5	0.184
20.81	1.5	0.528
20.76	0.5	0.165
20.53	0.75	0.277
20.83	1	0.045
20.44	0.55	0.198
20.84	1	0.037
20.82	0.16	0.054

SELECTED: X-BAR CHART LIMITS

X-Bar One Sigma Upper Limit	20.98
X-Bar Two Sigma Upper Limit	21.25
X-Bar Three Sigma Upper Limit	21.51
X-Bar One Sigma Lower Limit	20.46
X-Bar Two Sigma Lower Limit	20.19
X-Bar Three Sigma Lower Limit	19.93

Figure 4. SQC module and related window of the program

was given to every raw marble block which came to the plant and all sub-products that came from the same block were noted with this number. A special pattern has been formulated in order to follow this number through the plant from the beginning to the end of the lines. Machine operators and workers use these patterns and record the data about processing and defects for every shift on their sheets. At every check point of the plant, total sub-products area and theoretical production area of the blocks were compared and defect and product rates could be calculated.

Although six different products (unpolished and polished slab, unpolished, honed and polished strip and polished tile) were processed from three different stone types in the plant, detailed quality cost data were obtained and calculated for only four (unpolished (P1) and polished slab (P2), polished strip (P3) and polished tile (P4)) different product types from three different limestone (LS-1, LS-2 and LS-3). The reason for this restriction was due to difficulties experienced in the case studies. Identification of quality cost values for some products was not possible and some expenditure values referred to not only one product, but two or more different product types in the accounting records. Also, it was not possible to identify quality costs for these items for every separate product type.

Experience gained during field trials showed that, in order to apply quality related applications to any industrial plant and obtain proper data and consequently control the process, detailed consideration and quality-based perspectives are needed at the very beginning of factory operation. It is very difficult to generate quality-related measurements and control systems in any industrial plant which is already planned, built and activated without quality control options in place. For example, a traditional accounting system does not lend itself to the identification and classification of quality costs. Instead of this, in order to bypass these problems, everything (that is types of machines, placement of them in the plant, quality of labor, measurement tools and methods, accounting systems, software, physical and chemical properties of the produced stones and market conditions) must be carefully considered at the planning stage of the plant to create a management system to control the quality of the products and services. On the other hand, quality control charts were applied to data obtained from selected points.

The use of quality control charts (QCC) is more common than that of quality cost models and there are many useful studies about quality control charts in literature (Rahim, 1989; Zhang and Trevor, 2000; Chen et al., 2001; Woodal et al., 2004; Surtihadi et al., 2004; Wu

Table 3. Unit and quality costs of marble production type.

Marble Type	Product Type	Unit Cost ($/m^2)	Quality Cost ($/m^2)	Percentage (%)
Marble A (LS-1)	Unpolished slab (P1)	7.12	0.98	13.8
	Polished slab (P2)	10.12	2.63	26.0
	Polished strip (P3)	8.08	1.89	23.4
	Polished tile (P4)	9.54	3.02	31.7
Average		8.72	2.13	23.73
Std. dev.		1.37	0.90	7.47
Marble B (LS-2)	Unpolished slab (P1)	6.48	0.61	9.4
	Polished slab (P2)	10.77	1.97	18.3
	Polished strip (P3)	8.75	1.32	15.1
	Polished tile (P4)	10.35	2.32	22.4
Average		9.09	1.56	16.30
Std. dev.		1.94	0.75	5.49
Marble C (LS-3)	Unpolished slab (P1)	8.24	1.24	15.0
	Polished slab (P2)	11.96	3.20	26.8
	Polished strip (P3)	9.82	2.65	27.0
	Polished tile (P4)	11.72	3.95	33.7
Average		10.44	2.76	25.63
Std. dev.		1.75	1.14	7.78

and Tian, 2005; Chen and Huang, 2006). When QCC were used in the system, several anomalies which caused defective products were found and corrected. One of these problems was an unbalanced saw on the block cutting machine and it directly and negatively affected the thickness of the strips which is crucial for marble production. Another problem discovered while using QCC was that the defect rate of the polished slab was very high in the polishing machine where QCC was applied. After some examination studies, it was found that the cause of this was the physical condition and origin of this type of marble. The slab polishing machine applies pressure and at that point the defect rate was very high, because this type of marble has very low strength resistance to direct pressure. But when the pressure level of the machine was lowered, the quality of the polishing decreased. After several studies, this problem was solved by applying epoxy filling to both sides and gluing a mesh to the back side of this type of marble slab. This method increased the strength of the slabs and decreased the defect rate.

After many surveys including measurements, calculations and statistical studies in marble plants, unit cost values of marble products and quality cost values of several products were obtained and calculated. Sample and measurement costs, SQC application costs, cost of stopping time, consolidation works (epoxy, UV, and filling), re-works and defect rates were found as the most important quality cost values for marble products. No external failure cost values were encountered. Obtained data and measured values of unit and quality cost values are given in Table 3 and 4 and Figure 5 and 6, respectively.

RESULTS AND DISCUSSIONS

The following can be said when these tables and graphs are evaluated: Unpolished slab has the lowest unit cost value in every product type in three stone types (6.48, 7.12 and 8.24 $/m^2). Unpolished slab also has the lowest quality cost values in three stone types (0.98, 0.61 and 1.24 $/m^2). However, polished slab has the highest unit cost values for every stone type (9.54, 10.35 and 11.72 $/m^2). The product type that has the highest quality cost value is tile for three stone types (3.02, 2.32 and 3.95 $/m^2).

On the other hand, Marble-A has the lowest average unit cost value (8.72 $/m^2). Marble-B has the lowest average quality cost value (1.56 $/m^2) and Marble-C has both the highest average unit cost and quality cost values respectively (10.44 and 2.76 $/m^2). The average prevention cost values are similar in every stone type (0.44, 0.38 and 0.46 $/m^2). However, appraisal cost value is high for Marble-C as cost values (0.81 $/m^2) and for Marble-B as a percentage (37.25%). Marble-C has the highest failure cost values both as cost values and a percentage (1.45 $/m^2 and 51.33%).

In this study, the quality cost model (PAF) for marble processing plants was developed. Data were collected from quarries and factories located in Diyarbakir Region (Turkey). All costs occurring in marble processing systems were examined, identified, classified and calculated. Several cost formulas were generated to define and control the system with models. A new computer program incorporating these models and other algorithms was developed to control total and quality costs in marble plants.

Table 4. Distribution of quality costs for each product and stone type.

Marble type	Product Type	Quality Costs						
		Prevention		Appraisal		Failure		Total
		($/m^2)	(%)	($/m^2)	(%)	($/m^2)	(%)	($/m^2)
Marble A (LS-1)	Unpolished slab (P1)	0.38	38.8	0.18	18.4	0.42	42.9	0.98
	Polished slab (P2)	0.57	21.7	0.80	30.4	1.26	47.9	2.63
	Polished strip (P3)	0.42	22.2	0.58	30.7	0.89	47.1	1.89
	Polished tile (P4)	0.39	12.9	0.94	31.1	1.69	56.0	3.02
Average		0.44	23.90	0.63	27.65	1.07	48.45	2.13
Std. dev.		0.09	10.81	0.33	6.17	0.54	5.48	
Marble B (LS-2)	Unpolished slab (P1)	0.27	44.3	0.13	21.3	0.21	34.4	0.61
	Polished slab (P2)	0.53	26.9	0.79	40.1	0.65	33.0	1.97
	Polished strip (P3)	0.32	24.2	0.61	46.2	0.39	29.5	1.32
	Polished tile (P4)	0.41	17.7	0.96	41.4	0.95	40.9	2.32
Average		0.38	28.27	0.62	37.25	0.55	34.48	1.56
Std. dev.		0.11	11.36	0.36	10.95	0.32	4.77	0.75
Marble C (LS-3)	Unpolished slab (P1)	0.42	33.87	0.26	20.97	0.56	45.16	1.24
	Polished slab (P2)	0.63	20.86	0.95	31.46	1.44	47.68	3.02
	Polished strip (P3)	0.47	17.74	0.87	32.83	1.31	49.43	2.65
	Polished tile (P4)	0.31	7.85	1.15	29.11	2.49	63.04	3.95
Average		0.46	20.08	0.81	28.59	1.45	51.33	2.72
Std. dev.		0.13	10.74	0.38	5.31	0.79	8.00	1.13

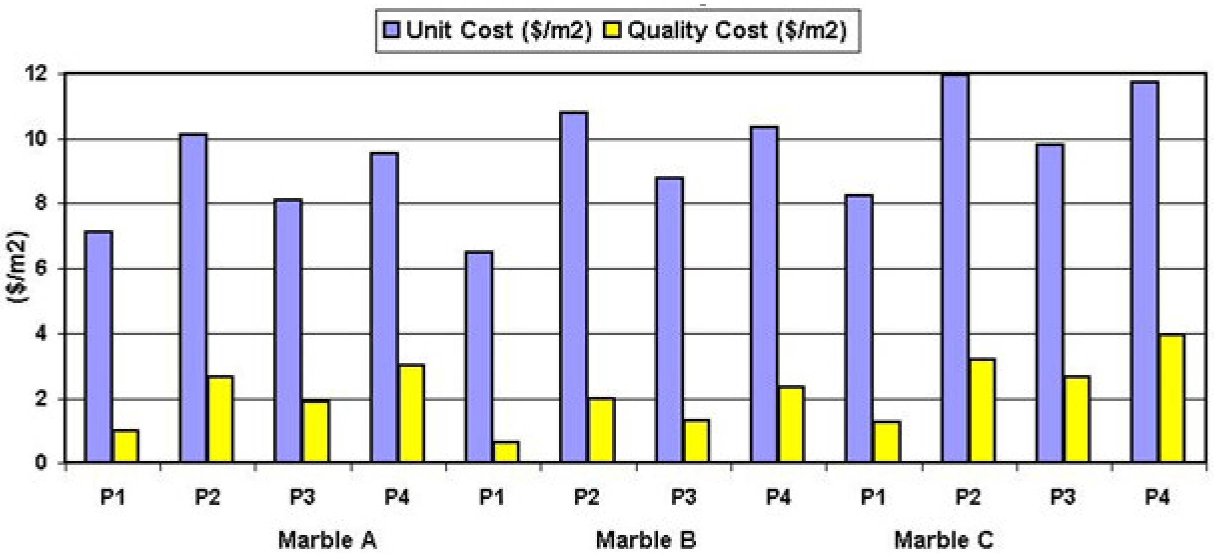


Figure 5. The unit and quality cost values for three different marble types.

Unpolished slab was found to have the lowest unit and quality cost values for all product types. These are expected results because unpolished slab needs less production treatment, which results in low cost values. In order to produce unpolished slab, only cutting and dimensioning of the marble blocks are required. Because of the same reason, polished slab has the highest unit cost values. Polished slabs have big dimensions and in order to improve their strength and consolidate them for some natural stone types which have weak physical properties, they need several extra chemical treatments (that is filling, epoxy). These processes eventually increase their cost values.

Tiles have the highest quality cost values because of the fact that tiles are produced by means of more treatments and applications in comparison with the other

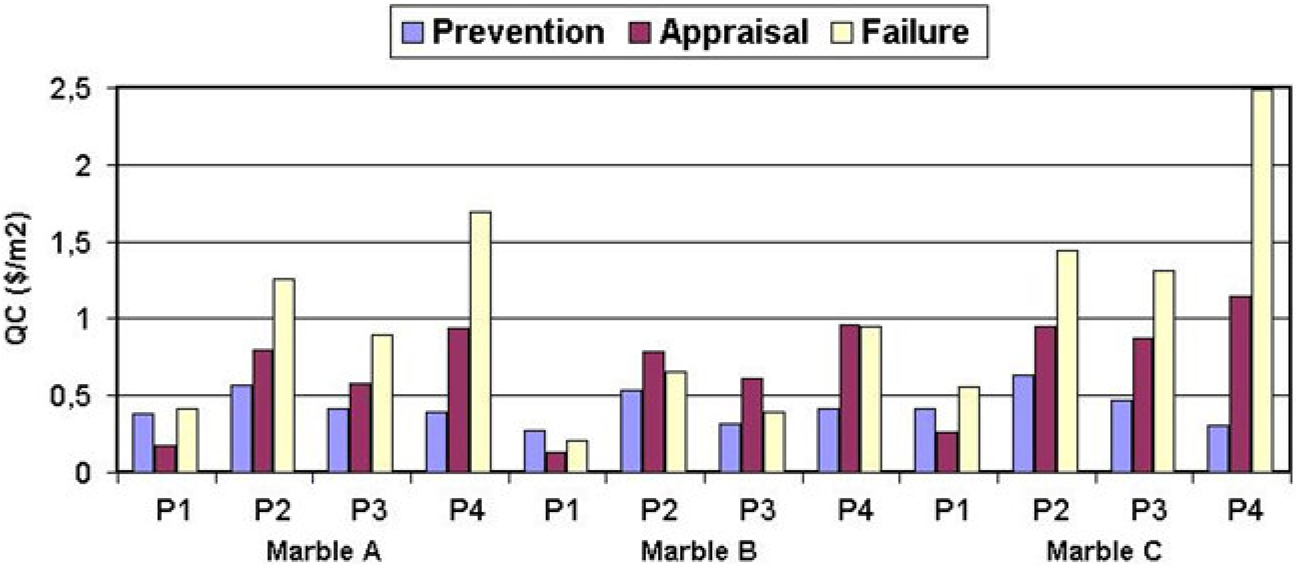


Figure 6. Distribution of the PAF costs for three different marble types.

products. There are several cutting, re-dimensioning, filling, heating, cooling, and polishing processes at several points in the tile line applied by different machines in the plants and all these processes increase both their unit costs and quality cost values. All these sub-processes mean more feeding to the machines, more transportation in the plant, and more workers to handle them. Furthermore, unlike other marble products, tile has only 10 mm thickness and this makes it weaker. Eventually during all of these treatments both the failure rate and quality cost values of the tiles increase. The highest failure rates measured in the study were at the tile line.

As the tiles have smaller surface area, effect of color and texture variation is superior for their categorization of in the form of various quality products in comparison to slab and strips. Therefore, failure rate of tiles is consequently higher than that of the strip and slabs (tile has smaller size than slab and strip).

Prevention and appraisal costs were found to be nearly the same in every stone type. This can be attributed to the fact that 'prevention and appraisal' activities are general activities and deal with whole plant conditions (see Table 2). This type of cost does not depend on stone or product types. Therefore, prevention and appraisal costs are almost the same for every stone and product type (Table 4).

In general, failure costs are considered to be directly depending on stone and product properties and plant conditions as results obtained this study support this prediction. The biggest standard deviation values are measured in failure cost values. This is because failure rates depend on color, texture, fossil content, strength and other physical properties of the stone. All of the properties mentioned above may change from stone to stone and product to product.

Precautions to reduce the failure rate and failure costs should be taken at initially starting at quarrying. Selection of high quality blocks obtained from quarries after proper cutting operation is a prerequisite for high quality marble products controlling the machines and the products in lines are also very important for quality. All of these activities increase prevention and appraisal costs whereas the failure and defect rates are decreased. The main aim of quality cost models is to optimize these costs in order to achieve minimum total quality and total cost values. This can be accomplished by the application of methodology presented in this paper. The results are obtained at this study is very promising. However, it is strongly recommended that quality models depending on longer surveys should be used in the future.

For the first time in literature, quality costs in marble plants were identified and classified and quality models were applied to the mining industry. This study shows that quality cost models can be applied in marble plants and it is possible to identify and calculate almost all costs incurred in the marble processing system. It is also shown that it is useful to use a computer program to help the quality-based studies in plants. The results indicated that total quality costs are in the range of 10 to 34% of total production costs for three different stone types and are dependent on product types.

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