

Using System Dynamics Approach to Model Cost of Quality in the Procurement Process of the Construction Industry

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Abstract:

The aim of this research is to develop the Cost of Quality (COQ) model for the procurement process of the construction industry and establish a general course of action for minimizing quality costs. A case study in a large Canadian construction company was conducted and the use of the Prevention-Appraisal-Failure (PAF) approach for the COQ model of the procurement process was explored. In contrast to the conventional COQ analysis we take into account not only the internal quality costs within the company, but also the costs of its suppliers. Several different policies were designed and their effects on quality costs investigated through System Dynamics (SD) simulation. The findings suggest that prevention costs should be increased to minimize failures. It was also found that appraisal cost is quite high in the procurement process and should be reduced in order to minimize overall COQ. However, this strategy could increase failure occurrences thereby damaging a company's reputation. The possible reductions of appraisal cost in the construction companies should thus be carefully considered.

Keywords: Cost of Quality, Procurement, Construction, System Dynamics

1. INTRODUCTION

Industry practices nowadays have begun to introduce the notion that achieving desired quality and customer satisfaction is no longer sufficient. This must be done at the lowest possible cost as well. In order to facilitate this, companies and business owners must now consider cost of quality (COQ). This is not a straightforward task as there has been some debate about what these costs include (Machowski and Dale, 1998).

The widely accepted definition of the cost of quality, according to Dale and Plunkett (1995), is the costs that are incurred in the design, implementation, operation and maintenance of a quality management system, the cost of resources committed to continuous improvement, the cost of system, product and service failures, as well as any other necessary and non-value added activities required to achieve a quality product or service.

The purpose of COQ is to link the benefits of improving quality to customer satisfaction, and associate them with a corresponding cost. This is also known as the concept of coupling

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reduced costs and increased benefits. The cost of quality can thus be considered as a tradeoff between the cost of conformance and the cost of non-conformance (Schiffauerova and Thomson, 2006).

The traditional COQ model was suggested by Juran (1951) and later by Feigenbaum (1956.). This primary COQ model involved the prevention, appraisal and failure approach (PAF). In 1979, Crosby (1979) proposed a costing method similar to that of Juran's PAF method however Crosby saw quality as a measure of conformance to requirements and therefore defined COQ as the cost of conformance, which includes the price of doing things right the first time, and the cost of non-conformance which is the money wasted when a product or service fails to deliver its intent of conforming to customer requirements. Further development is attributed to Tsai (1998) proposed an integrated framework for measuring cost of quality under Activity Based Costing. Dale and Plunkett (1995) recently emphasized the importance of including intangible and opportunity costs when considering the cost of poor quality. Robison (1997) proposed another method of COQ analysis, which is the identification of the cost of everything that has gone wrong in a process. Regardless of the various costing methods, the concept of identifying the cost of quality encompasses one primary idea and that is to link all areas of improvement to a cost or customer expectation that is quantifiable, and thereby sufficiently actionable to reduce the overall cost of quality. All the COQ models developed so far have focused only on individual firms (*i.e.* on in-house quality costs) and have not estimated cost elements related to the customers or suppliers. This, however, does not reflect reality, since not all the COQ are generated internally. Suppliers, subcontractors, agents, dealers and customers each contribute (sometimes significantly) to an organization's indirect quality costs.

Since the dawn of quality improvement, it has become widely accepted, especially in the manufacturing industry that an increase in quality resulted in less expenses by improving productivity through the elimination of rework and unnecessary inspections (Gunasekaran et al., 1994). Implementing quality programs in the construction industry is however a relatively new concept. In fact, usually only the bigger construction firms implement a detailed quality program other than the common place ISO standards and even less practice measuring cost of quality.

Love and Li (1999) studied companies and consultant firms in Australia and their practices, or lack thereof, of quality costing. Seeing as it is not common to exercise quality costing methods in their day-to-day business culture, it is difficult to determine the benefits these businesses stand to gain by measuring their quality costs. The authors conclude that although direct quality costs such as salaries, documentation and audit costs can be measured with an acceptable degree of accuracy, their associated advantages are much more difficult to quantify. Otherwise the concept of COQ has not been examined for the construction industry.

Many influential processes in the engineering, procurement, construction and management industry (EPCM) greatly impact the cost of quality failures. The procurement process has become notorious for leading to cost overruns on projects. Therefore it has become

apparent that in order to improve a projects performance, the causes and costs of rework must be determined. Despite the growing importance of this topic there is still a lack of research within this area. It is thus an objective of this paper to fill this research gap and to define the COQ model in the construction environment which would take into account the cost of its suppliers, while focusing specifically on the procurement function. Moreover, different policies will be designed and their effects investigated through System Dynamics (SD) simulation in order to find the best practices for minimizing COQ for the procurement function in the construction industry.

The contribution of this work is twofold. First, this study brings an important contribution to the advancement of knowledge in the area of the COQ in the construction industry. To our knowledge this is the first attempt to model the procurement function in this industry. Second, it is proposed here that by combining in-house quality costs and analyzing them together with the costs of the supply chain partners, COQ can be used as powerful measure of improvement in an organization. This work introduces the COQ model representing this framework.

The rest of the paper is organized as follows. First, in the methodology section the PAF model will be described and the case study will be defined. Second, the COQ model for the procurement function will be proposed. Furthermore, the SD model will be introduced to better define the problem followed by presenting the sub systems of the model. Finally, the possible policies and their effects on the system will be presented.

2. METHODOLOGY

The proposed COQ model for the procurement function in the construction industry is based on the most commonly used model, which is PAF model. The more detailed description of the PAF model follows in the next sub-section. Next, the taxonomy of quality costs relevant to the COQ in the construction industry was developed while taking inputs mainly from existing literature, expert insights and industry realities. A close collaboration with the construction industry was therefore required. In order to understand and accurately model the construction COQ a case study in a construction company was carried out. Three main sources of data were used: the company procedures, passive observation and interviews (conducted mainly with internal customers and with personnel at the contract manufacturing sites). Finally, the third sub-section presents a System Dynamics model that was built in order to study the effect of various policies. Several sets of simulations were run in order to fully understand the behavior of this model and to obtain conclusive results.

2.1 The Traditional PAF Model:

The traditional PAF model involves the costs coming from three sources of activities: prevention, appraisal and failure. Prevention costs are known as the costs incurred for preventing non-conformities by ensuring the process in place is capable of delivering high quality products or services. Love & Irani (2002) best described prevention costs as all amounts spent or invested to prevent or reduce errors or defects, that is, to finance activities aimed at eliminating the causes of defects.

Appraisal costs are in association with the measurement system used to appraise the quality of a product or service. In other words it is the detection of errors or defects by measuring conformity to the required level of quality: issued architectural and structural drawings, work in progress, incoming and completed material inspection (Love & Irani, 2002).

Failure costs are the efforts in place to correct a non-conformity that has taken place before or after delivery to the customer. Failure costs are thereby classified as internal failures and external failures. Internal failures would include costs due to scrapping or reworking defective product or compensation for delays in delivery whereas external failures would include costs that are incurred once the product or service has been delivered to customer such as cost of repairs, returns, dealing with complaints and compensations.

The most common COQ model used in industry is Juran's Model which states that in order for COQ to be at its lowest rate, failure costs must equal that of prevention and appraisal costs. This can be seen in the trend graph in figure 1.

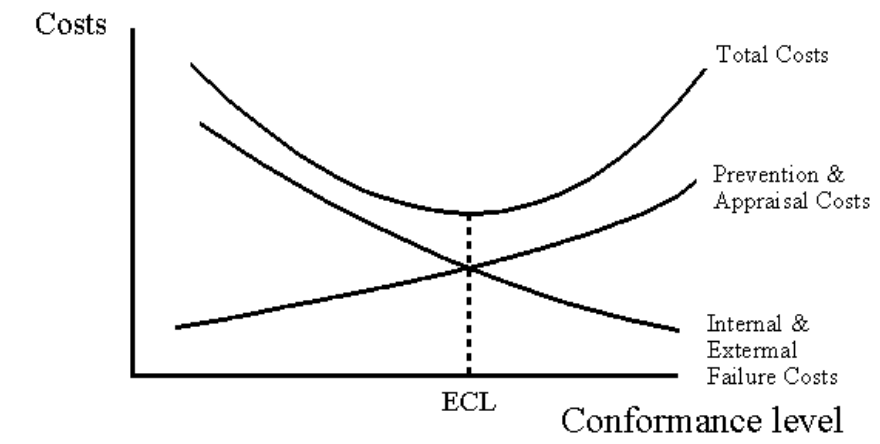


Figure 1. Juran's model for COQ

2.2 Case Study

The project is the construction of a \$4 billion aluminum smelter and the company has been hired by the client to oversee the engineering, procurement and construction management. The company is a well renowned global EPCM company and since its foundation, has frequently updated its procedures to include a thorough quality measurement system that

allows the approximate quantification of quality costs for prevention, appraisal and failure. The company deals with several suppliers to purchase and install several construction commodities required for the project.

Data obtained from the procurement function was found to be more tangible and accessible than data recorded in other departments as well as behaving similarly to data found in the manufacturing industry. For this reason, it was easier to apply the PAF approach and categorize each form of quality cost. Although the entire projects life cycle is closer to 4 years, the procurement function has a life cycle of about 1.22 years (444 days). The following three sub-sections discuss how the costs were quantified for each of the PAF categories.

Due to the dynamic nature of construction projects, it is hard to compare costs and phases of several projects in order to draw meaningful conclusions about COQ costs in construction therefore it is simpler to look at particular functions in a construction project and conduct an in-depth analysis on the PAF costs.

For instance, procurement process can be studied and a comparison between the different POs can be considered in order to come up with conclusions about the different kinds of COQ costs incurred for different commodities in construction.

Given certain specific costs of every PO we may categorize these incurred costs into prevention, appraisal and failure in the following fashion.

Prevention Costs:

After conducting several interviews with a supplier quality engineer with over 20 years of experience and currently working on Project X, several assumptions were found to be useable yet not necessarily proven. These will be pointed out in the reasoning of every approximated cost incurred. It was necessary to use these assumptions due to the lack of an existing robust quality measurement system at company A (much like most other companies in the construction industry).

It is common knowledge amongst many quality engineers that an approximate 2% of all purchase order values are spent on preventing poor quality. This is a prevention cost incurred by the suppliers. Company A incurs a prevention cost of roughly the number of man-hours spent producing a Material Requisition report for every PO. A quick survey was taken of all the responsible engineers (RE's) that take care of engineering packages and they were asked on average how long it takes them to prepare the Quality section of their MR reports. This was averaged at 10 hours and considering that an RE's pay grade is usually between 24 and 25, the hourly rate is taken at \$36/hr. These two factors together make the cost categories associated with prevention costs incurred for every PO.

Appraisal Costs:

Appraisal costs incurred for every PO is calculated by supplier quality budgeted hours allocated for every PO. There are 4 different surveillance levels that a PO can be assigned. Important POs that require frequent surveillances will be assigned a level 3 or 4 as well as POs where the commodity tends to have high failure rates. Less important POs or commodities that have a higher tolerance for variance are usually assigned surveillance levels 1 or 2. Depending on these surveillance levels and the type of commodity in question, supplier quality inspection hours are budgeted and distributed to all the different purchase orders. A supplier quality engineer, usually with a grade level of 27-28 tends to these surveillances therefore the appraisal cost of purchase orders are calculated by a \$56/hr multiplied by the number of assigned supplier quality hours. This is an appraisal costs incurred by Company A. Another appraisal cost category, this time incurred by the suppliers for POs, is the number of inspection test plans that are required to be completed for every PO. These are reports that are required to be filled out on average every week by all suppliers and contractors on a project and take nearly an hour to fill out. They are usually taken care of by a field engineer therefore costing approximately \$25/hr. These two components comprise of the appraisal costs calculated for each purchase order.

Failure Costs:

There are two main forms of failures that can occur during the procurement process for Company A, and its suppliers working on Project X; internal to supplier failures that consist of supplier quality issues and external to supplier failures that comprise of errors found after the delivery of the commodity to Company A. Supplier Quality issues can take the form of minor issues such as administrative errors that can usually be corrected immediately or within 24 hours or more serious errors such as dimensional or performance errors whereby correction may often mean that the manufacturing process must be restarted. For the purpose of this study, only the more serious issues recorded are taken into consideration as the smaller issues may have almost negligible correction costs.

After conducting interviews with the Supplier Quality engineers working on Project X, it was decided that the most effective way to properly estimate the impact of SQ issues on COQ is to assume that for every severe SQ issue, 1% of the corresponding PO value is used to correct it. This is a rough assumption but after applying it to a few case studies where the correctional costs of the issues were recorded, it was found to render a value that is within 4% of the real value. Depending on the source of the failure, it is corrected by Company A or the corresponding supplier. When a commodity has been delivered and is found to be unacceptable by any means, a UOSD report is written up. This report states whether the product is unsatisfactory, there is a miscalculation of the quantity or the product is damaged or defective. This is considered a supplier's external failure and, is therefore, a cost incurred by the supplier. The cost for this type of failure can differ tremendously, for example if there is a shortage in quantity, the supplier would have to cover the cost of shipping more and any inconvenience fees that company A may have stipulated in the agreement. This cost when compared to the cost of a product being

defective or damaged is insignificant as in this scenario, a supplier will have to ship back the defective product, and re-ship the correct product as well incur any inconvenience fee. This potentially renders the initial batch of products wasted and may even imply that the suppliers manufacturing process has to be reassessed. An exception is in the event the product was damaged during shipment (which happens often) in which case there is usually insurance to cover any associated fees. Unfortunately, very few records are kept that list the costs associated with UOSD for a couple of reasons, this information can be very sensitive suppliers, who often protect their reputation by keeping this information confidential, and also there lies many difficulties in collecting all this information in one place as the costs can often come from a combination of different sources. For this reason, a rough estimate of 2% of the cost of the PO is assumed for UOSD related failures.

Thus we find that there are two main visible failure costs in procurement process of construction; supplier quality related failures, and failures appearing after the delivery of a commodity from a supplier.

2.3 The Proposed Model

Looking at all these different parameters, the general model for COQ costs in the procurement process in construction is as follows:

$$\begin{aligned} \mathbf{COQ} &= \mathbf{f}(\mathbf{P}, \mathbf{A}, \mathbf{F}) \\ \mathbf{P} &= \mathbf{P}_{\text{supplier}} + \mathbf{P}_{\text{company}} = \\ &\text{Percent spent by supplier on Prevention} + \text{Hours spent by company on QA+QC} = \\ &(0.02 * \text{PO Value} + \text{Hours spent by company on QA+QC}) \end{aligned}$$

$$\begin{aligned} \mathbf{A} &= \mathbf{A}_{\text{company}} + \mathbf{A}_{\text{supplier}} = \\ &\text{Company inspection hours} + \text{Supplier inspection hours} = (\text{Cost per hour for SQRs} \times \\ &\text{Numbers of SQ hours for each PO}) + (\text{Numbers of SQ hours for each PO} \times 0.1 \times \text{Cost} \\ &\text{per hour for field engineers}) \end{aligned}$$

$$\begin{aligned} \mathbf{F} &= \mathbf{F}_{\text{internal}} + \mathbf{F}_{\text{external}} \\ \mathbf{F}_{\text{internal}} &= \mathbf{f}(\mathbf{P}, \mathbf{A}) \\ \mathbf{F}_{\text{external}} &= \mathbf{f}(\mathbf{P}, \mathbf{A}, \mathbf{F}_{\text{internal}}) \end{aligned}$$

It is important to mention that for every purchase order on the critical path, a failure can cause up to a full weeks delay in first hot metal (start of production of the plant under construction, therefore resulting in a cost of a full week of production). This is not considered in the analysis as this type of failure is not tolerated. The client would soon rather employ extra employees overtime in order to meet critical path deadlines therefore this type of failure has not been recorded on this project.

3. SIMULATION

3.1 Simulation Model

System dynamics approach has been used to describe the structure of this complex system. As there are complicated relationships between variables of this system, using this approach can help to study the feedback behavior of each variable and its effect on other variables and the system as a whole. (Sterman, 2000)

Since there is a great difference between using the SD approach in COQ for manufacturing and COQ for construction project, the following model has been defined specifically for the cost of quality for the function of procurement. The most important difference to mention is that construction projects are extremely dynamic and are executed in phases, therefore there cannot be an accurate comparison between one phase and another as they differ in value, activities and final result. Another important difference to note is defining the time horizon in this type of project. Project performance is constantly changing and therefore the model should reflect this. The duration of this function within the project is 444 days, which has been considered as the time horizon of this study in the model. There 12 purchase orders during this project, that's why there are 12 different days in our simulation.

The main purpose of this simulation is to verify the predicted behavior of COQ models in construction environment and study the feedback behavior of each variable and its effect on other variables and the system as a whole.

Sub systems of the model include the following:

Prevention costs consist of percentage spent by supplier on prevention as an auxiliary variable, which is 2% of the related purchase order (PO). PO value is imported to the model for each day and hours spent by company on quality assurance and quality control (QA+QC) is 10 hours.

Appraisal Costs are made up of company and supplier inspection hours. Each of these are determined by observing the number of hours used for inspection multiplied by the number of records obtained documenting each inspection. The company has budgeted supplier quality (SQ) hours for inspection and suppliers are mandated to produce inspection test plans (ITP).

Failure costs are categorized as an external failure costs and internal failures. These costs have been calculated based on number of internal and external issues. There is a relation between internal failure, prevention costs and appraisal costs with external failure costs and prevention costs and appraisal costs with internal failure costs which are generated based on the raw data of the project.

Rate of COQ change is the rate variable of the model and cost of quality is the level variable in this model.

The constant data has been imported to this model from excel sheet and they are updated daily due to the nature of data obtained in construction.

The model is presented in Figure 2:

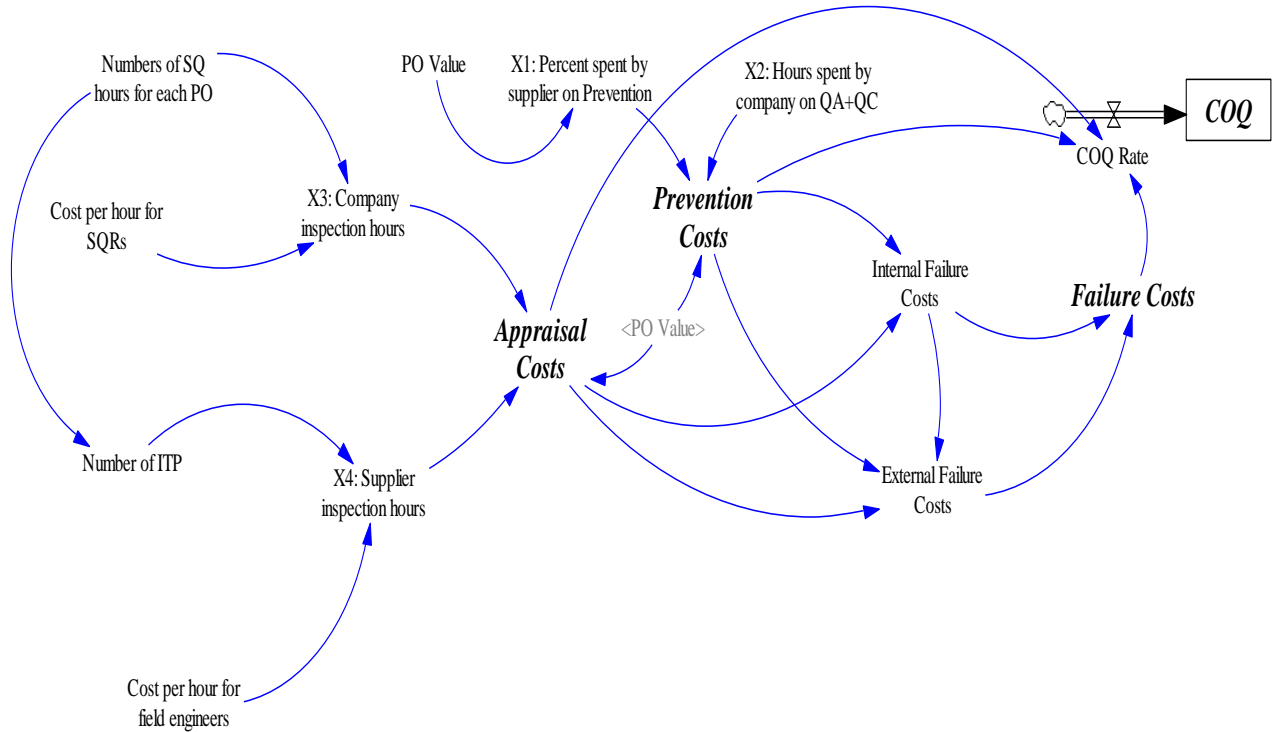


Figure 2 – Proposed Model

3.1.1 Validation of the Model

To check the validity of our model, the structure of the model against the structure of the real system and patterns has been compared. (Barlas, 1994) Juran's model is the base for this study and the research is trying to compare its behavior with that model. (Juran, 1951) The agreement for the model was acceptable (>90%) for system studies.

3.2 Policy Design

3.2.1 Prevention Cost Analysis

In this analysis, the effect of different prevention costs was observed to determine the relationship between prevention, COQ and Failure costs.

First, the existing conditions were simulated in Vensim using the model to ensure the proper functionality of the model. Then four different prevention scenarios were simulated and compared to the existing conditions to observe the relationship between changing prevention and other factors.

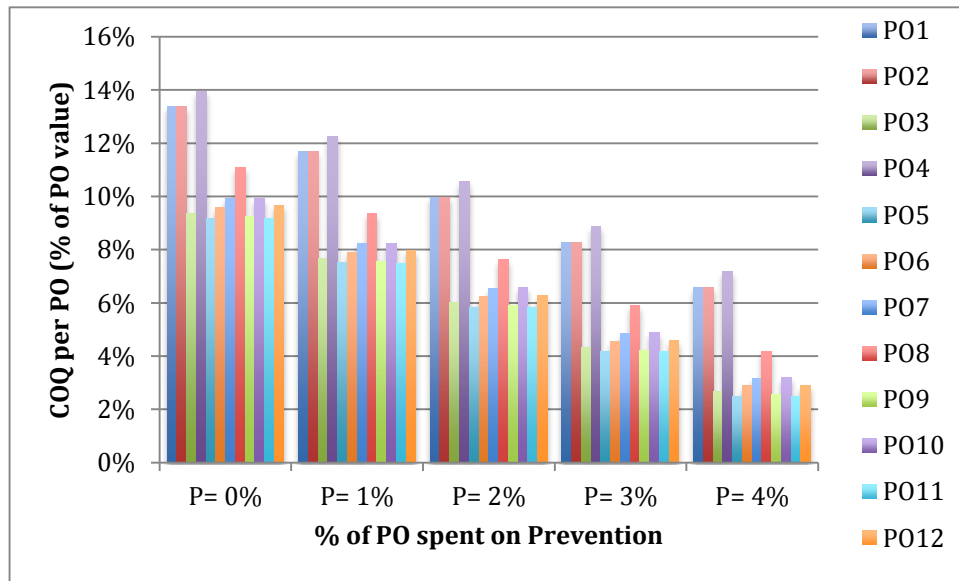


Figure 3- % of PO spent on Prevention vs. COQ per PO

Figure 3 shows the relationship between prevention and COQ. From this figure it can be observed that although increasing prevention is likely to add to COQ costs, it actually decreases total COQ. The more that is spent on prevention, the lower COQ gets. This is a similar result to what you would expect in manufacturing and complies with Juran's model for cost of quality. This is likely explained by the decrease in total failure being larger than the increase in prevention causing the overall COQ to decrease. Figure 4 further confirms this expected result. In this Figure it can be seen that as prevention is increased, failure is decreased with the lowest failure rate seen at 4% of PO spent on prevention.

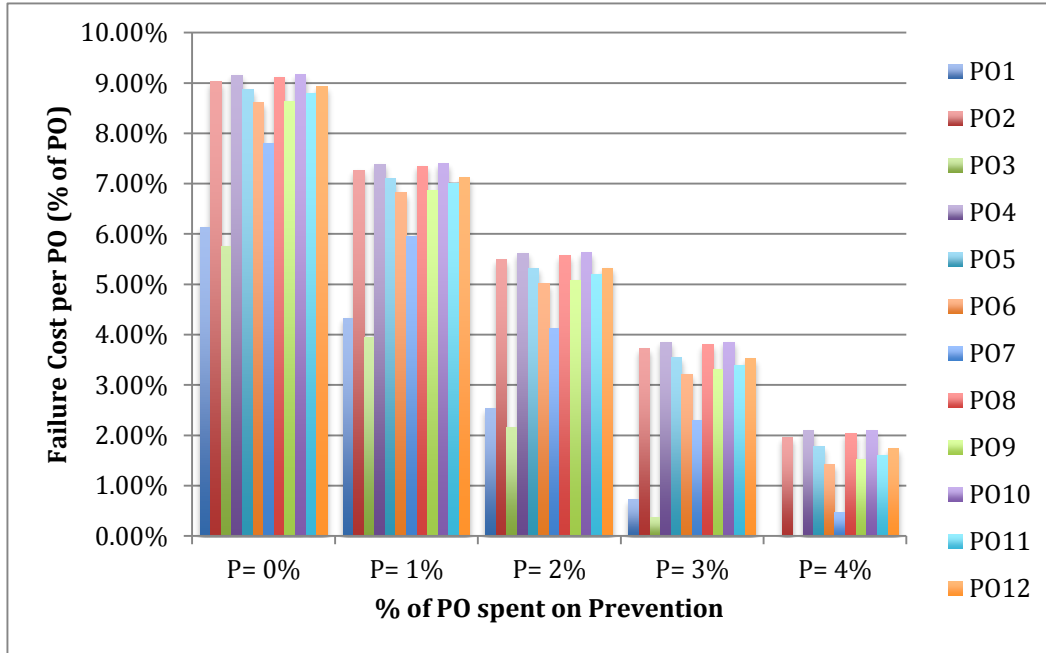


Figure 4- % of PO spent on Prevention vs. Failure Cost per PO

It is clear from these results that an increase in prevention can lead to a significant decrease in failure costs. This suggests that in the construction industry, the process of purchasing material can be streamlined by determining cost of quality using Juran’s model prevention. However, the effect of appraisal cost in construction still needs to be examined.

3.2.2 Appraisal Cost Analysis

A similar analysis was done on Appraisal costs. This time simulations were performed for 0% analysis, 50% less appraisal than the existing condition, 25% less appraisal than the existing condition and 100% more than the existing condition. The results can be seen in Figure 5.

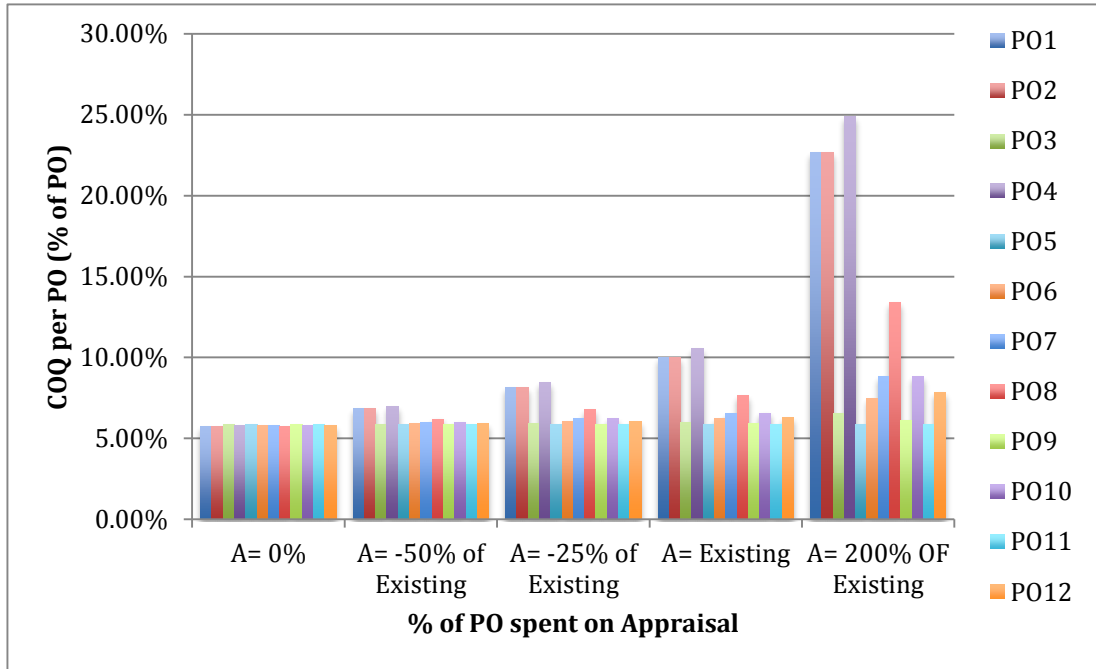


Figure 5- % of PO spent on Appraisal vs. COQ per PO

From this graph it can be observed that COQ is a lot less sensitive to changes in appraisal. In fact in the case of some POs, COQ increases with increasing appraisal costs. This is an unexpected result and the relationship between failure and appraisal needs to be established before any conclusions can be made.

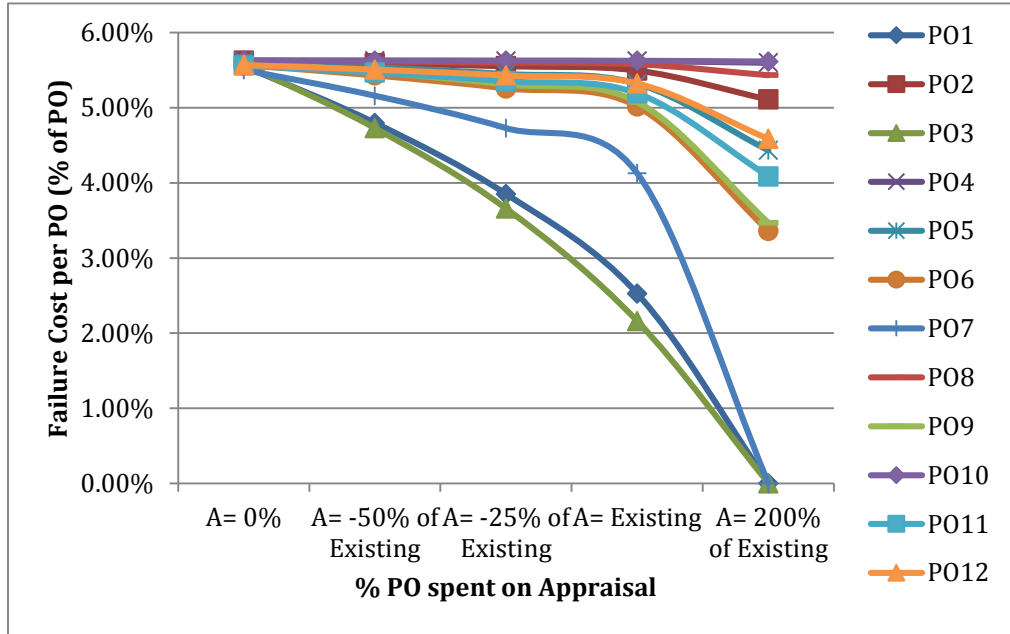


Figure 6- Increasing Appraisal vs. Failure Cost per PO

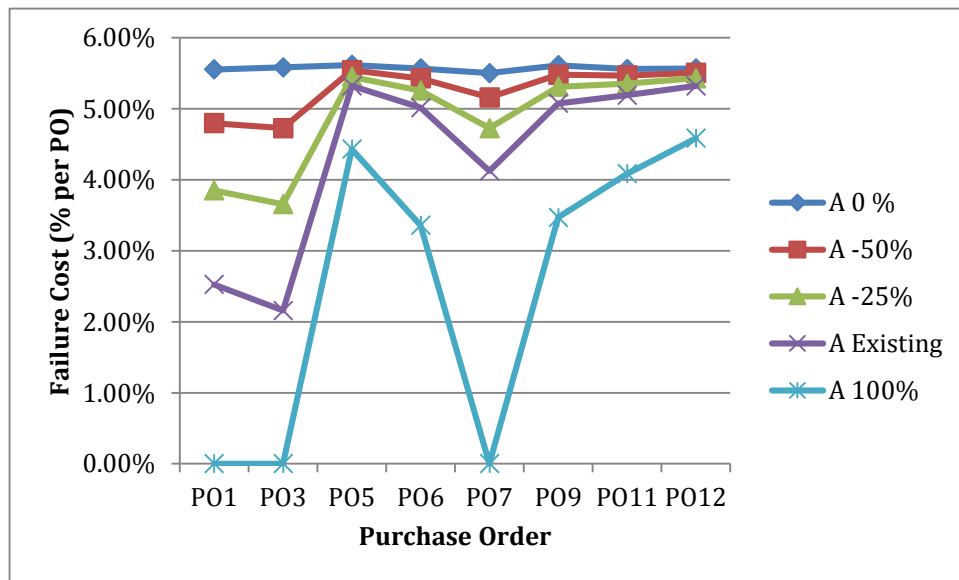


Figure 7- % of PO spent on Appraisal cost vs. Failure costs

Figures 6 and 7 show the relationship between failure cost and appraisal cost to be negative which is what is expected when considering Juran's model. This observation leads to the conclusion that increasing appraisal cost does in fact decrease failure. However, these results suggest that the lowest COQ occurs when appraisal costs are 0 despite the decrease in failure costs. This leads to the conclusion that too much of the PO value is spent on Appraisal and that perhaps appraisal is generally more expensive than failure costs in the procurement of construction materials.

4. CONCLUSION

In order to minimize COQ, these results suggest that prevention should be increased to 4% and appraisal to be decreased to 0%. However, a company in the construction industry must consider the factor of reputation. Construction companies are awarded contracts after an extensive bidding process that usually considers previous projects and reputation for success. Although in this case incurring some failures may prove to be less expensive than appraisal costs, there is the matter of opportunity cost that needs to be considered for contracts lost due to the reputation of incurring too many failures. Therefore decreasing appraisal to a point where failure costs are too high is unwise, despite minimizing COQ. For this reason, a limitation of this study is the inability to determine the opportunity cost of decreased appraisal at the expense of increasing failures and potentially losing future contracts.

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