A Case Study of the Costs of Quality: Water Utilities

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Abstract: Cost of Quality has long been applied to manufacturing entities only. This research expands on that effort and applies the COQ methodologies to water utilities. Three water utilities were chosen for the initial study—El Paso, Lubbock, and San Antonio, Texas. A Prevention, Appraisal, and Failure Cost Compendium was developed to assist in categorizing costs. The study used manufacturing meta-analysis COQ percentages as a basis for comparison with water utility organizations. Three water utilities —El Paso Water Utility (EWU), Lubbock Water Utility (LWU), and San Antonio Water System (SAWS), were chosen to be included in this study because they represented three different populations, three different water source combinations, and three different county water usages. Using non-parametric statistics between manufacturing organizations and water utility organizations, the results show that prevention, failure, and total COQ are statistically different, yet appraisal costs are the same. A sensitivity analysis and a Pareto analysis performed on the data resulted in actionable analytics for researchers. We assert that COQ is a useful tool for water utilities to assist in making monetary resource decisions.

Keywords: Cost of Quality, Water Utilities, Opportunity Cost, Economic Analysis

EMJ Focus Areas: Economics of Engineering, Operations Management, Quality Management, Systems Engineering

The COQ philosophy has been applied to manufacturing since the early 1950s and is widely attributed to the work of Joseph Juran and A.V. Feigenbaum. The cost of quality can be defined as the total of all resources spent by any organization to assure that quality standards are met on a consistent basis (Bohan and Horney, 1991). This definition will be used as the operational definition of COQ in this research. The primary model associated with COQ is that of Prevention, Appraisal, and Failure or the PAF model. This model is a milestone in the COQ evolution and was initially developed by Feigenbaum (1956). The PAF costs are classified as follows (Chase, Aquilano, and Jacobs, 1998):

- Appraisal Costs – the costs of the inspection, testing, and other tasks to ensure that the product or process is acceptable.
- Prevention Costs – the sum of all the costs to prevent defects, such as identifying the cause of the defect, to implement corrective action to eliminate the cause, to train personnel, to redesign the product or system, and for new equipment or modifications.
- Failure Costs
  - Internal Failure Costs – The costs for defects incurred within the system: scrap, rework, repair.
  - External Failure Costs – The costs for defects that pass through the system: customer warranty replacements, loss of customer goodwill, handling complaints, and product repair.

As the business environment has evolved to become increasingly competitive and global, any competitive advantage a company attains helps it in gaining market share and ensuring future operations. This is where quality becomes a differentiating factor between products. The water utility environment does not necessarily have the same pressures since its operation is inherently local and in many cases monopolistic, but water utilities must maintain a quality water system in order to provide water to sustain the local population. Without a quality water system, the local population will move to a different location or buy bottled water, and the utility will eventually find itself without demand or requiring government oversight; therefore, while it may not face global competitive pressures, those pressures from local inhabitants and government regulations can be just as imposing. This is where quality costs become significant in maintaining a potable water system.

Quality costs are a direct input to the total cost of operating a water utility. The total costs are used to determine the water rates charged to customers. If these costs become too high, then the costs are passed onto the customers thereby increasing rates. Increased rates result in unsatisfied users, which causes the water utility to be even more cost conscious in attempting to maintain rates. It will also be a catalyst for users to find alternatives to the water utility's service. Maintaining low water rates is a mandate for water utilities in order to provide universal access to the service.

In addition to these basic local water utility issues, there have been international environmental quality commissions and committees studying issues related to maintaining environmental quality. The Carnegie Commission on Science, Technology, and Government (1992), in particular, concluded that there needs to be better integration of economics, social, and political studies of environmental issues with the natural sciences. They also considered the research and development system to be diffuse, reactive, and focused on short-range, end-of-the-pipe solutions (Mays, 1996). This research study brings a long-range approach for understanding the effects of different management philosophies. It also integrates economics with water management to the water utility industry.

Future population growth is a key factor related to the sustainability of water supplies. Growing populations and incomes are imposing ever-increasing demands for water for agricultural, industrial, and residential uses on limited surface and groundwater supplies (Mays, 1996). As the local population grows, water availability per capita decreases, thereby making the resource scarcer. It, therefore. becomes increasingly important to sustain water supplies. Part of maintaining water supplies is the cost of providing the system to distribute water to the end user. If system costs increase, then the total cost of providing water

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increases leading to an increased cost to the consumer. A portion of the costs are quality costs associated with the treatment and distribution of water. By maintaining or even decreasing these costs, the utility will be able to provide quality potable water at reasonable rates.

Introducing COQ to the water utility environment will provide benefits to researchers and practitioners in three ways. First, it will provide a methodology for classifying quality costs. Second, it will enable the water utility organizations to monitor quality costs, leading to the third benefit of being able to provide a potable and sustainable water supply at a reasonable rate to consumers.

COQ Literature Summary

Exhibit 1 provides a historical timeline of the major COQ research. Please refer to each article for further information. Exhibit 2 summarizes the historical development of the COQ model with the major contributions of various authors from Juran through the Beruvides and Chiu model. Exhibit 3 represents the current COQ model (Beruvides and Chiu, 2004). For clarification it is important to discuss the individual components in this exhibit. The Juran Point is the intersection of the failure costs and the prevention/appraisal costs. Opportunity Costs equal the "total COQ costs expressed as revenue lost and profit not earned," (Beruvides and Sandoval-Chavez, 1997). The economic Inflection Point Region is the region where additional investment in prevention and appraisal no longer yields positive benefits. MCIP is the Minimum Cost Inflection Point, which is the minimum cost spent for maximum benefit. The critical concept is that increases in prevention and appraisal costs decrease failure costs and the total cost of quality until the MCIP is reached. Any additional prevention or failure expense after the MCIP decreases failure costs but also increases total COQ.

Methodology and Results

Prevention, Appraisal, Failure Cost Compendium

The first step to conducting this research was to categorize water utility costs into the traditional prevention, appraisal, and failure classifications. To this end, a compendium of classifications across international standards (Exhibit 4) was developed.

It is interesting to note that while the ISO 9004 standard does not specifically refer to the economics of quality, it implicitly provides costs to be categorized across the PAF model. The four standards used to develop this compendium were:

1. ISO 9004:2000: Quality management systems – guidelines for performance improvements
2. ISO 9004:1987: Quality management and quality system elements – guidelines
3. BSI 6143: Part 2: 1990: Guide to the economics of quality: Part 2. Prevention, appraisal, and failure model
4. AS 2561-1982: Guide to the determination and use of quality costs

Water Utilities for Comparison

Three water utilities, El Paso Water Utility (EWU), Lubbock Water Utility (LWU), and San Antonio Water System (SAWS), were chosen to be included in this study because they represented three different populations, three different water source combinations and three different county water usages. The three utilities together represent 10% of large water systems and approximately 11% of the population in Texas. Exhibit 5 summarizes some of the relevant water utility demographics for these three water utility organizations.

The research methodology used for this study included five major steps: (1) a manufacturing meta-analysis was completed, (2) water utility data were collected, (3) water utility data were categorized, (4) statistical analyses of the data were performed, and (5) a sensitivity analysis was completed. Each of these steps is described in more detail.

Exhibit 1. COQ Historical Timeline

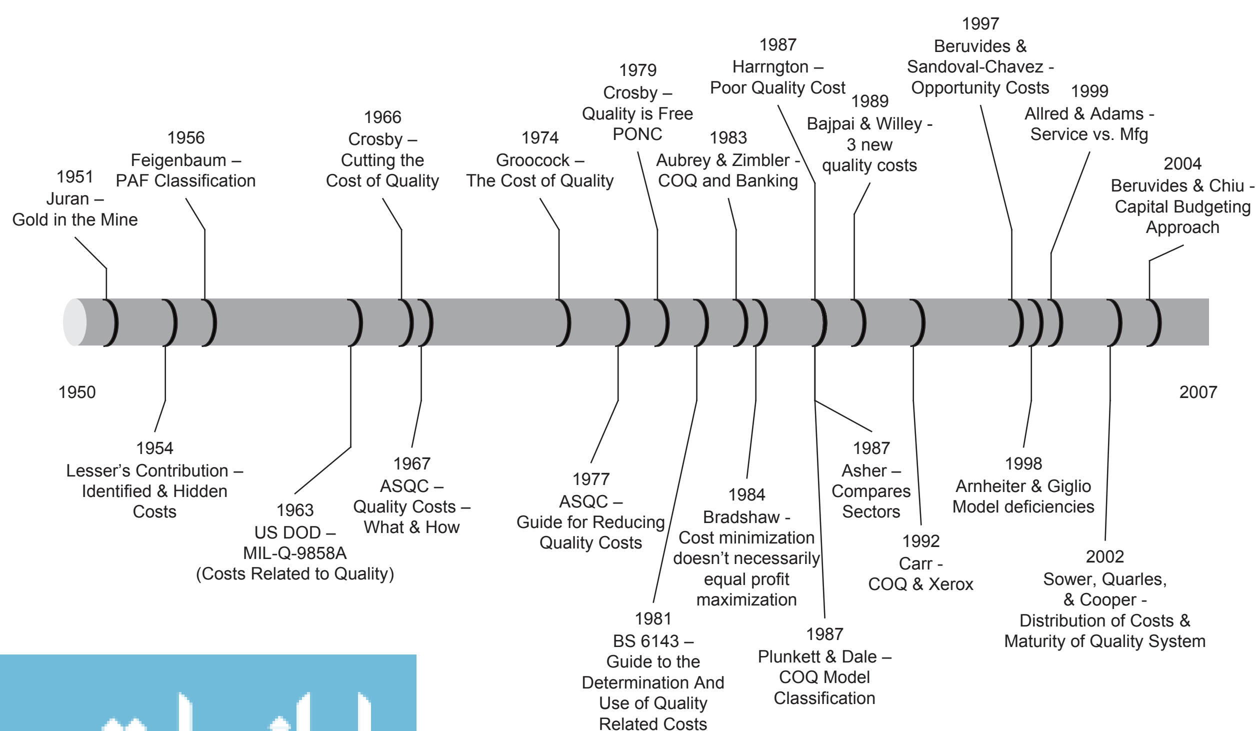

Exhibit 2. COQ Model Summary

Author	Contribution
Juran – Original COQ Model (1951)	Credited with developing the first COQ model. First introduced quality costs as avoidable and unavoidable and used a non-conformance approach in describing COQ behavior. He further identified the costs as tangible and intangible.
Lesser – Identified and Hidden Costs Perspective (1954)	Lesser classified quality costs as *identified costs* and *hidden costs*. These cost classifications were very similar to Juran's. Lesser directly relates the costs of quality to the profit and loss statement categories of direct material, direct labor, overhead, and engineering
Feigenbaum – PAF Model (1956)	Feigenbaum introduced the Prevention-Appraisal-Failure (PAF) model. This is the first instance in the cost of quality literature that a relationship exists between the investment of prevention costs with those of failure and appraisal.
Harrington – Poor Quality Cost Model (1987)	The major philosophical difference is that Harrington focuses the cost of not having quality versus measuring quality costs. Harrington also includes white collar errors throughout the organization as costs of quality.
Godfrey-Pasewark – Accounting COQ Model (1988)	Godfrey and Pasewark developed a model based on three interrelated components: defect control costs, failure costs, and cost of lost sales. The main thrust of their argument is that, "these costs are related so that a change in one type of cost can result in change in another type."
Carr - COQ Service Model (1992)	This model was developed in the Xerox United States Marketing Group (USMG). The model developed by the USMG included three categories: costs of conformance, costs of nonconformance, and the costs of lost opportunities.
Juran's Revised Model	This is an update to Juran's original model. The major difference between the two models is that costs can be finite in achieving 100% quality of conformance. This new model also proposed that the minimum total quality costs occur at the 100% conformance level.
Beruvides and Sandoval-Chavez – COQ and Opportunity Costs (1997)	This model builds on Juran's revised model and Carr's service model. The new model that includes Opportunity Costs as a separate cost category. The results of the research, "found opportunity costs to account for 83% of the total revenue lost and 56 % of the total profit earned. The opportunity losses were found to be greater than the PAF expenses."
Beruvides & Chiu – Capital Budget Approach to COQ & the EIP (2002)	This model builds on both Juran's works and the Beruvides and Sandoval-Chavez COQ opportunity cost model. It analyzes the apparent trade-off between prevention/appraisal costs and failure costs. By taking a capital budgeting approach, the model uses a cost-benefit analysis and opportunity costs to develop a net present worth equation to identify the EIP (Economic Infection Point). The EIP identifies the point where it is not economically advisable to continue investing in a specific quality initiative.

Exhibit 3. Beruvides and Chiu (2002) COQ Model

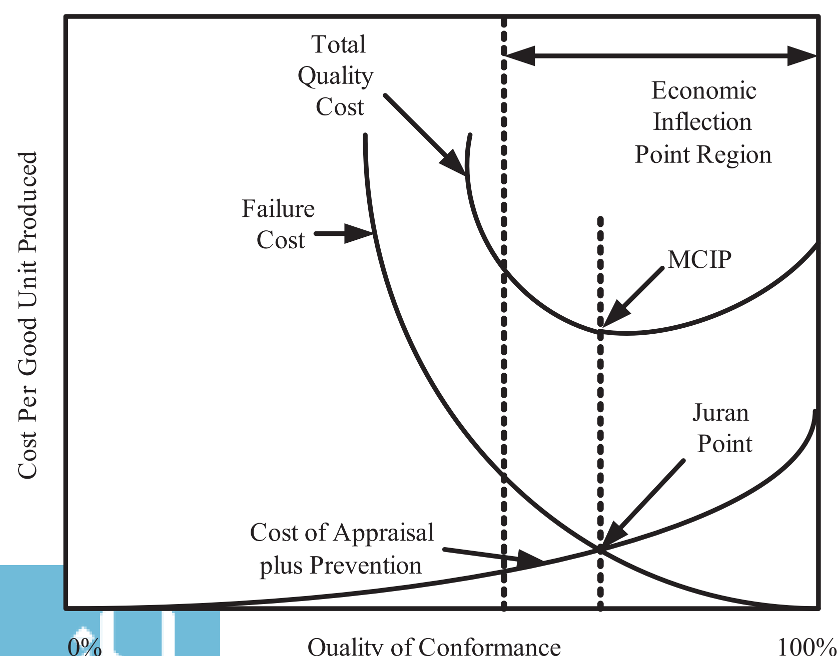

Exhibit 4. PAF Cost Compendium

Costs of Quality

Prevention Costs	Appraisal Costs	FAILURE COSTS	
		INTERNAL FAILURE COSTS	EXTERNAL FAILURE COSTS
a. Acquisition analysis and reporting quality data	a. Analysis & reporting of test and inspection results	a. Control of nonconforming product	a. Complaints
b. Acquisition analysis and reporting quality data	b. Approvals and endorsements	b. Defect diagnosis	b. Concessions
c. Assuring vendor/subcontractor quality	c. Benchmarking	c. Disposition determination	c. Control of nonconforming product
d. Calibration & maintenance of production equipment used to evaluate quality	d. Conducting data analysis to facilitate continual improvement of processes	d. Downgrading	d. Loss of sales
e. Calibration & maintenance of quality measurement & test equipment	e. Design & Development review, verification, and validation.	e. Downgrading	e. Management of customer property
f. Control of monitoring and measuring devices	f. Design appraisal	f. Downtime	f. Poor service delivery
g. Corrective action	g. Field performance testing	g. Downtime	g. Product liability
h. Design & Development of quality measurement and test equipment	h. Financial Measurement	h. Fault of subcontractor	h. Products rejected & returned
i. Documentation of quality policy & quality objectives	i. Inspection and test equipment	i. Modification permits and concessions	i. Recall costs
j. Ensuring that the sequence & interaction of processes are designed to achieve the desired results	j. Inspection and testing	j. Reducing process and product failures	j. Reducing product failures, cost of compensation under guarantee and warranties, costs of lost customers and markets
k. Loss prevention	k. Laboratory acceptance testing	k. Reinspection & retesting	k. Warranty claims
l. Operating Plan	l. Management Review	l. Replacement, rework, and repair	
m. Planning of product recall	m. Materials consumed during inspection & testing	m. Replacement, rework, or repair	
n. Preventing problems	n. Measurement & monitoring of system performance, processes, satisfaction, and product	n. Scrap	
o. Process Control Engineering	o. Methods of monitoring	o. Troubleshooting and defect/failure analysis	
p. Product recall and liability insurance	p. Monitoring input & output to verify that individual processes are linked & operate effectively & efficiently	p. waste in material and time	
q. Purchasing Process	q. Pre-production verification		
r. Quality Auditing	r. Process Validation		
s. Quality improvement programs	s. Receiving inspection		
t. Quality Planning	t. Record Storage		
u. Quality Policy	u. Risk Assessment		
v. Quality review and verification of design	v. Self-Assessment/Audit		
w. Quality training	w. Stock evaluation		
x. Resources needed to prevent damage, deterioration or misuse (preservation of product)			
y. Reviewing & verifying designs			
z. Supplier Assurance			

Exhibit 5. Water Utility Summary

City	County Population	Water Pumped (B Gal)	Municipal Water	Irrigation Water
San Antonio	> 1 million	62.86	77.20%	8.10%
El Paso	~ 750,000	35.20	47.00%	48.50%
Lubbock	~ 260,000	13.00	15.10%	82.20%

Manufacturing Meta-Analysis

In order to achieve a satisfactory comparison variable, a total of 92 COQ manufacturing industry study results were initially obtained. For a variety of reasons ranging from no COQ percentage information provided in the study, incomplete information, duplicity, to the wrong COQ calculation variable (i.e., percentage of operating costs instead of percentage of sales), the number of studies was reduced to 38. Exhibit 6 summarizes the results of the meta-analysis of the 38 manufacturing studies reporting a usable COQ percentage.

Water Utility Data Collection

Monthly financial data was collected from each of the three water utility organizations studied. Lubbock provided 33 observations, El Paso 45, and San Antonio 12 after the removal of outliers. Outliers were removed based on a two step process. First, a dot plot of the data was visually examined to identify potential outliers. Second, if the data point was calculated to be greater than three standard deviations away from the mean, it was considered an outlier and removed from the study. For San Antonio specifically, annual data could not be reconciled to annual report or budget results, and therefore was excluded. The data were then categorized as Prevention, Appraisal, and Failure (PAF) costs based on annual reports, budgets, utility input and the PAF Cost Compendium. Exhibit 7 summarizes these results.

Water Utility Data Categorization

Data categorization is the single most important step of this research. While this is not an exact science, every care has to be taken to ensure the proper categorization of costs into the Prevention, Appraisal, and Failure categories. To ensure the best assignment to the PAF, the researcher consulted the water utility contacts, water utility budgets and annual reports, and the PAF Cost Compendium presented in Exhibit 5. It must be stressed that COQ is an economic issue, not just a quality issue; therefore, costs that may seem to have nothing to do with quality are part of the COQ. The percentage allocations to the PAF category were determined by using three data points. The first was the number of employees that work in a Prevention, Appraisal, or Failure capacity; the second was using the listing of major accomplishments provided by the water utility as a method for capturing the percentage cost allocated to the PAF activity. The third data point was the departmental descriptions or definitions. The cost categorization will be discussed for each of the three water utility organizations studied.

El Paso Water Utility

Exhibit 8 categorizes the El Paso Water Utility (EWU) PAF costs. These were developed by consulting EWU personnel and the EWU budgets. One interesting note is that some expense accounts

Exhibit 6. Meta-Analysis Descriptive Statistics

	Cost of Quality Category			
	Prevention	Appraisal	Failure	Total COQ
Manufacturing Studies	33	33	35	34
Average COQ %	10.2%	29.3%	60.7%	11.4%

Average COQ % represents the average of the P,A,F or Total COQ costs in the Manufacturing Studies
PAF Costs represent P,A, or F as a percentage of the Total COQ
Total COQ represents the Total COQ as a percentage of Sales

Exhibit 7. Water Utility Data Collection Summary

		Cost of Quality Category			
	Months of Data	Prevention	Appraisal	Failure	Total COQ
SAWS	12	27.3%	31.0%	41.7%	N/A
EWU	45	22.0%	28.8%	49.1%	25.9%
LWU	33	15.5%	29.0%	55.5%	20.8%

PAF Costs represent P,A, or F as a percentage of the Total COQ
Total COQ represents the Total COQ as a percentage of Sales

Exhibit 8. El Paso Water Utility PAF Categorization

Prevention	Appraisal	Failure
Public Service Board - 7.7%	Developer Services - 12.5%	Workers Compensation - 100%*
Human Resources - 50.0%	Water Division Office - 33.3%	Legal Services - 13.3%
Insurance - 100%	Water Production - 28.1%	Water Production - 28.1%
Security Services - 100%*	Instrumentation & Control - 100%*	Water Distribution - 75.0%
Environmental Compliance - 100%*	Laboratory Supplies & Testing - 100%*	Maintenance of Equipment - 100%*
Water Conservation - 100%*	Laboratory Services - 100%*	Maintenance of Structures & Improvements - 100%*
Water Conservation Expense - 100%*	Customer Service - 50.0%	Customer Service - 50.0%
	Meter Testing & Repair - 50.0%	Meter Testing & Repair - 50.0%
		Fleet Maintenance - 100%*

are identified in multiple departments and categorized as one particular PAF category even when the rest of the department is categorized as a different PAF category. One example of this is Workers Compensation—because it represents an injury to an employee on the job regardless of how the rest of the department is categorized. The percentages allocated to each PAF cost in Exhibit 8 represent that percentage of the expense account or departmental expense listed in the table. For example, 50% of the Human Resources departmental expenses were allocated to Prevention, and 100% of the Workers Compensation expense line item was allocated to Failure. The 100% allocation means that all of that expense line item or departmental expense was allocated to that specific PAF category.

San Antonio Water System

Exhibit 9 categorizes the San Antonio Water System (SAWS) PAF costs. These were developed by consulting SAWS personnel, comprehensive annual financial reports, annual budgets, and the PAF Cost Compendium. In addition, any information available regarding employee positions or major accomplishments was used to determine the PAF cost category allocation. Similar to EWU, some expense accounts are extracted from multiple organizational units or departments and allocated to a specific PAF category even if the rest of the unit or department was captured in a different PAF category. For example, Security was considered a prevention cost in all organizational units; therefore, 100% of the Security expense was allocated to the prevention PAF category. The same philosophy for El Paso and Lubbock was applied to San Antonio with respect to cost categorization. The San Antonio data included over 7,300 individual expense accounts; therefore, Exhibit 9 represents a summary of those accounts.

Lubbock Water Utilities

Exhibit 10 categorizes the Lubbock Water Utilities (LWU) COQ costs. These categorizations were determined by consulting the LWU personnel and budgets, lead sheets, comprehensive annual financial reports, and the PAF cost compendium. The percentages allocated to each PAF cost in Exhibit 10 represent that percentage of the expense account line item or departmental expense listed in the table. The 100% allocation means that all of that Expense Line Item or Department was allocated to that specific PAF category. With all of the costs classified into the Prevention, Appraisal, and Failure categories, the next step of the research was to test the primary hypotheses and conduct a sensitivity analysis with the available data.

Exhibit 9. San Antonio Water Utility PAF Categorization

Prevention	Appraisal	Failure
Community Outreach Conservation - Agriculture Conservation - Commercial Conservation - Office of the Director Conservation - Residential Conservation Sect Conserve - Communications Customer Svc Training Desalination EAA Activities Education Outreach Edwards Acquisitions Edwards Aquifer Optimization Program Edwards Groundwater Groundwater Resource Protection Indoor Conservation Administration Infrastructure Planning Dept Instrumentation Maintenance - ASR Outdoor Conservation Administration Planning and Research Quality Control Supervisor Recharge Resource Protection Div Resource Quality Management Dept Safety and Environmental Health Security Source Water and Watershed Education Water Quality (WRAP1) Water Quality (WRAP2) Water Resources - Public Outreach Youth Education	Call Center Collection System Monitoring Conservation - Leak Detection Conservation - Residential Indoor Audits Conservation - Residential Outdoor Audits Construction & Inspection - ASR Construction & Inspection - Gonzales Construction Monitoring Control Center Customer Care Manager Design Field Investigation Field Services Div Flow Monitoring Industrial Compliance Internal Audit Dept Laboratory - Water Leak Detection Program Meter Reading Odor Control Program (Inactive) Operations Center Performance Indicators PGA Monitoring Pipeline Inspection Recycled Water Div Resource Compliance Div Resource Protection & Compliance Dept Risk Management Surface Water Resource Protection Sect Survey	Bad Debt Collections Call Center Claims Concrete & Asphalt Svcs - Water Corporate Complaints Customer Care Manager Customer Contact Div Emergency Service Section Equipment Maintenance Div Field Meter Repair Field Service Final Bills Internal Collections Manager - Field Services Manager - Revenue Collections Meter Shop Meter Technician Supervisor Other Requirements - AL/GL Contingent Liab. Other Requirements - WC Claims Project Management Reading Review Replacement & Improvements Div Revenue Protection Special Services System Control (Inactive) Tank Maintenance Section Telephone Collections Work Order Agents

Exhibit 10. Lubbock Water Utility PAF Categorization

Prevention	Appraisal	Failure
Conservation & Education – 83% Production – 10% Water Reservoir – 25% Engineering – 14% Pipeline Maintenance – 17% Insurance – 100%*	Conservation & Education – 17% Production – 10% Treatment – 10% Metering & Customer Service – 25% Pumping & Control – 10% Engineering – 14% Laboratory Services – 100%*	Production – 20% Treatment – 6% Water Reservoir – 7% Metering & Customer Service – 75% Pumping & Control – 20% Equipment Maintenance – 100%* Pipeline Maintenance – 50% Overtime – 100%* Workers Compensation – 100%* Long Term Disability – 100%*

Statistical Analysis

In order to compare the means of the COQ percentages by category from meta-analysis data with the COQ percentages by category from the water utility organizations, a Smirnov Non-Parametric Test of Two Independent Samples was selected. This test was chosen because it accommodated two continuous distributions with different sample sizes, it accommodated independent samples, and the results are easily interpreted. For this test, the parameters include N1 for the number of data points for the manufacturing meta-analysis and N2 for the number of data points for the water utility organization(s). Additionally, T1 is the test statistic compared to the critical value $\omega_{.95}$ from table A20 (Conover, 1999). Four hypotheses were developed and tested as follows:

Hypothesis 1: The Water Utility percent Prevention quality costs are equal to the Manufacturing firm percent Prevention quality costs.

Hypothesis 2: The Water Utility percent Appraisal quality costs are equal to the Manufacturing firm percent Appraisal quality costs.

Hypothesis 3: The Water Utility percent Failure quality costs are equal to the Manufacturing firm percent Failure quality costs.

Hypothesis 4: The Water Utility ratio of Total COQ costs to Total Costs ratio is equal to the Manufacturing firm ratio of Total COQ costs to Total Costs.

These hypotheses were tested to identify if there was a significant difference between the manufacturing firm meta-analysis COQ percentages and the water utility organization COQ percentages. A sensitivity analysis was also conducted to identify any variables that may affect the Water Utility Organization outcomes more than others. Thus, the primary hypotheses will be discussed starting with the first Hypothesis.

The best comparison between the manufacturing meta-analysis COQ and the water utility COQ was to compare the ratio of Total COQ to Sales between the meta-analysis and the water utilities. The meta-analysis data was overwhelmingly based on COQ to Sales and the water utility data ratio was easy to compute. The individual Prevention, Appraisal, and Failure components were calculated based on total operating costs. The results for each hypothesis tested are summarized in Exhibit 11.

Analysis

Exhibit 12 summarizes the means of the water utility and meta-analysis research data. The Total Water Utility line item represents the mean of all of the water utility data points. The average Prevention COQ percentage for the Water Utilities was twice that of the manufacturing meta-analysis Prevention COQ percentage. The Total COQ percentage was also two times the Total COQ percentage obtained from the meta-analysis of the manufacturing studies. The theory is that increased prevention and decreased Failure results in decreased Total Cost of Quality.

The results from the hypotheses tests are detailed in Exhibit 11. Notice that all of the tests reject the null hypothesis except for San Antonio in Hypothesis 2. The rest of this section will discuss the results for each Hypothesis test starting with Hypothesis 1. The meta-analysis manufacturing study COQ percentage for Prevention mean is 10.2% and the water utility COQ percentage for Prevention means range from 15.5% to 27.3%. Based on the Smirnov non-parametric test, the Lubbock Water Utility mean of 15.5% had the smallest gap. The result of this analysis is to reject that the meta-analysis manufacturing study COQ percentage for Prevention is equal to water utility COQ percentage for Prevention.

The results from the Hypothesis 2 test are not as clear cut as Hypothesis 1. From Exhibit 11, the meta-analysis mean is 29.3%, while the water utility mean is 29.2%; SAWS = 31.0%, EWU = 28.8%, and LWU = 29.0%. In general, the gaps between the meta-analysis and the water utilities are much narrower. Based on this test, the SAWS null hypothesis is the only one that cannot be rejected. The other tests narrowly reject the null.

The results from the Hypothesis 3 test are to reject the null hypothesis. In reviewing Exhibit 12, there is a distinct difference between the means of the meta-analysis manufacturing study COQ percentage for Failure (60.7%) and the water utilities COQ percentage for Failure (50.5%). Based on the Hypothesis 3 non-parametric test results, Water Utilities percentage Prevention and percentage Failure differ from meta-analysis of manufacturing COQ.

Hypothesis 4 tests the manufacturing company meta-analysis total COQ ratio with the water utilities total COQ ratio. Since the test statistic T_1 is greater than the critical statistic $\omega_{.95}$ the null hypothesis is rejected. The water utility Total COQ ratio to Sales is not equal to the manufacturing studies Total COQ ratio to Sales. The results from the hypothesis tests show that the Total COQ percentage for Water Utilities is not equal to the Total COQ percentage for the manufacturing study meta-analysis. What can also be inferred is that the water utilities Total COQ is a higher percentage than the manufacturing study meta-analysis Total COQ. If the two were equal, the gap between the distributions would be less than the $\omega_{.95}$ level. This provides a clear indication

Exhibit 11. Research Hypotheses

Null-Hypotheses	Test Statistics	Results
Hypothesis 1: The Water Utility percent Prevention quality costs are equal to the Manufacturing firm percent Prevention quality costs.	$H0a_{1j}: p_{1j}=p_{14}$ $H1a_{11}: p_{11}\neq p_{14}$ $H1a_{12}: p_{12}\neq p_{14}$ $H1a_{13}: p_{13}\neq p_{14}$	Smirnov Non-Parametric Test of Two Independent Samples **Reject $H0a_{10}$:** $T_1 > p$; $T_1 = 0.70$, $\omega_{.95} = 0.28$ **Reject $H0a_{11}$:** $T_1 > p$; $T_1 = 0.88$, $\omega_{.95} = 0.46$ **Reject $H0a_{12}$:** $T_1 > p$; $T_1 = 0.77$, $\omega_{.95} = 0.31$ **Reject $H0a_{13}$:** $T_1 > p$; $T_1 = 0.64$, $\omega_{.95} = 0.33$
Hypothesis 2: The Water Utility percent Appraisal quality costs are equal to the Manufacturing firm percent Appraisal quality costs.	$H0a_{2j}: p_{2j}=p_{24}$ $H1a_{21}: p_{21}\neq p_{24}$ $H1a_{22}: p_{22}\neq p_{24}$ $H1a_{23}: p_{23}\neq p_{24}$	Smirnov Non-Parametric Test of Two Independent Samples **Reject $H0a_{20}$:** $T_1 > p$; $T_1 = 0.38$, $\omega_{.95} = 0.28$ **Accept $H0a_{21}$:** $T_1 > p$; $T_1 = 0.37$, $\omega_{.95} = 0.46$ **Reject $H0a_{22}$:** $T_1 > p$; $T_1 = 0.37$, $\omega_{.95} = 0.31$ **Reject $H0a_{23}$:** $T_1 > p$; $T_1 = 0.39$, $\omega_{.95} = 0.33$
Hypothesis 3: The Water Utility percent Failure quality costs are equal to the Manufacturing firm percent Failure quality costs.	$H0a_{3j}: p_{3j}=p_{34}$ $H1a_{31}: p_{31}\neq p_{34}$ $H1a_{32}: p_{32}\neq p_{34}$ $H1a_{33}: p_{33}\neq p_{34}$	Smirnov Non-Parametric Test of Two Independent Samples **Reject $H0a_{30}$:** $T_1 > p$; $T_1 = 0.50$, $\omega_{.95} = 0.27$ **Reject $H0a_{31}$:** $T_1 > p$; $T_1 = 0.74$, $\omega_{.95} = 0.45$ **Reject $H0a_{32}$:** $T_1 > p$; $T_1 = 0.51$, $\omega_{.95} = 0.30$ **Reject $H0a_{33}$:** $T_1 > p$; $T_1 = 0.48$, $\omega_{.95} = 0.33$
Hypothesis 4: The Water Utility ratio of Total COQ costs to Total Costs ratio is equal to Manufacturing firm ratio of Total COQ costs to Total Costs.	$H0a_{40}: p_{40} = p_{44}$ $H1a_{40}: p_{40} \neq p_{44}$	Smirnov Non-Parametric Test of Two Independent Samples **Reject $H0a_{40}$:** $T_1 > p$; $T_1 = 0.80$, $\omega_{.95} = 0.28$ **Reject $H0a_{42}$:** $T_1 > p$; $T_1 = 0.82$, $\omega_{.95} = 0.30$ **Reject $H0a_{43}$:** $T_1 > p$; $T_1 = 0.76$, $\omega_{.95} = 0.33$
Variable Definitions	ith variable; jth variable:	i=1 Prevention i=2 Appraisal i=3 Failure i=4 Total COQ j=0 All Water Utilities j=1 SAWS j=2 EWU j=3 LWU j=4 Manufacturing Meta-Analysis

Exhibit 12. Summary of Means

	Summary of Means			
	Prevention	Appraisal	Failure	Total COQ*
Meta-Analysis	10.2%	29.3%	60.7%	11.4%
Total Water Utility	20.3%	29.2%	50.5%	23.8%
LWU	15.5%	29.0%	55.5%	20.8%
SAWS	27.3%	31.0%	41.7%	N/A
EWU	22.0%	28.8%	49.1%	25.9%

*Ratio of Total COQ to Sales

that the water utility organizations costs of quality are not equal to the manufacturing meta-analysis costs of quality.

Sensitivity Analysis

A sensitivity analysis was also performed to identify the most impactful cost categories on the water utility organizations costs of quality. The sensitivity analysis was conducted in two ways. In the first method, the operating characteristics of the water utilities themselves were compared; in the second method, a Pareto analysis on the financials of the company to identify any specific cost categories that may affect water utility COQ was performed.

One of the benefits of the data obtained in this research is that it has a "built-in" sensitivity analysis. "Built-in" means that the three different utilities have different water usage patterns, population sizes served, population growth rates, usage per capita, and miles of water lines in place. Exhibit 13 summarizes a number of operating characteristics across the three water utilities.

The sensitivity analysis focused on the following factors: Distribution Loss, Water Delivered Per Employee, Water Customer Accounts per Employee, Rainfall, and Population Growth. Distribution Loss can have a significant impact on the COQ for a water utility. This is because each gallon of water lost between the utility and the customer equals lost revenue; therefore, if this number increases significantly, the utility loses that incremental percentage of revenue. A 1% increase in the distribution loss for a water utility equates to $1M per year for EWU or $1-$2M for SAWS. The key with distribution loss is to find an optimal target that minimizes maintenance costs and distribution loss. The AWWA Benchmarking Report Distribution Loss median value is 9.1% with a 25th percentile of 5.7% and 75th percentile of 13.4%.

Water Delivered Per Employee and Water Customer Accounts per Employee are employee efficiency measures. Generally, the higher the number is—the more efficient an organization. Based on this metric, the LWU is more efficient than either EWU or SAWS. The AWWA Benchmarking Report provides 25th percentile, Median, and 75th percentile measures of 322, 467, and 629 respectively. These metrics would suggest LWU should have a better COQ measure—but this is not the case, so this may not be a very sensitive indicator of PAF costs. Similar results were seen with the Water Delivered Per Employee measure. The AWWA Benchmarking Report provides 25th percentile, Median, and 75th percentile measures of 0.18, 0.25, and 0.39 respectively. Once again, Lubbock is 1.5 times to over twice as much as the other utilities.

A population growth comparison was included to determine if faster or slower growth impacted PAF costs significantly. The population growth rate also seemed to have a negligible effect on PAF. San Antonio had the highest growth rate of all three utilities, yet its COQ to Operating Costs was less than the other two. San Antonio's total expenditures have increased in general, but that does not necessarily have an increased impact on the PAF.

A Pareto analysis helps identify areas which may affect the overall costs of quality by identifying those expenses which are the largest. In such an analysis, a small increase in a large expense category will have significantly more impact than a large change in a negligible expense category. Exhibit 14 contains the top cost categories for SAWS and EWU. These categories represent 93.5% of SAWS and 86.2% of EWU operating costs. What can be gained from this analysis is that salaries as an expense item are by far the number one cost; therefore, changes to this category will have a significant impact on the COQ for a water utility. Other interesting accounts that will have an immediate impact on the PAF costs for a water utility are items such as Maintenance of Mains or Turf Rebate Program for EWU and Uncollectable Accounts, Overtime, or Vehicle Maintenance—Corrective for San Antonio. LWU also has similar cost categories that help to identify the main cost centers. Changing these costs will have a dollar for dollar impact on COQ for a water utility. In addition to the operating characteristics and a financial Pareto analysis, comparing the water utilities to each other to identify differences will help to determine in what areas they are different and may be more influenced by certain actions.

Exhibit 13. Water Utility Operating Characteristics

	Lubbock	San Antonio	El Paso
Average COQ Measures			
Total COQ to Sales	19.93%		27.60%
Total COQ to Operating Expense	33.61%	29.25%	35.59%
Prevention	15.80%	27.33%	22.54%
Appraisal	30.12%	30.97%	28.61%
Failure	56.41%	41.69%	48.85%
Distribution Loss - % of Water Pumped		6.56%	9.14%
Total Employees (2007 Budgeted)	154	1685	607
2007 Water Delivered Per Employee (Millions of Gallons Daily)	0.24	0.10	0.16
2007 Operating Expense/Employee	$174,855	$104,424	$200,725
Water Customer Accounts per Employee	705.54	440.90	321.89
% Usage (texasep.org, twdb.state.tx.us, 2005)			
Municipal	15.1%	77.2%	47.0%
Irrigation	82.8%	8.1%	48.5%
Groundwater % of Supply (texasep.org)	24%	98%	25%
Rainfall (Inches) - (National Weather Service)	19.32	21.34	11.43
Estimated Population - January 2008 (Texas State Data Center)	263,675	1,593,859	749,721
2000-2008 % Population Growth (Texas State Data Center)	8.7	14.4	10.3
Miles of Water Lines/Customer (LWU, SAWS, EWU)	0.013	0.013	0.012
Miles of Water Lines in Place (LWU, SAWS, EWU)	1,375	4,673	2,432

Exhibit 14. Water Utility Pareto

EL PASO WATER UTIILITY			SAN ANTONIO WATER SYSTEM	
Account Number	Account Description - name	% of Total Expense	Account Description	% of Total Expense
7020	O & M Salaries and Wages	35.6%	Total Salaries	32.16%
7060	Electricity Expense	15.7%	511260 Utilities - Electric and Gas	9.96%
7850	Maintenance of Equipment	6.0%	511312 Contractual Professional Services	9.32%
7500	Chemicals	6.0%	511261 Water Options and Payments	7.16%
7080	Water Purchased for Resale	4.4%	511162 Employee Retirement	5.99%
7010	Capital Salaries & Wages	3.5%	511540 Dependent & Retiree Med Coverage	5.75%
7530	Sludge Hauling Fees	2.7%	511265 Groundwater District Payments	3.98%
7880	Maintenance of Mains	2.3%	511220 Maintenance Expense	2.90%
7710	Natural Gas Expense	2.0%	511160 Employee Insurance	2.64%
7860	Maintenance of Services	1.6%	511430 Maintenance Materials & Supplies	2.15%
7420	Postage	1.4%	511422 Chemicals	1.86%
7790	Software Expense	1.4%	511451 Motor Fuel	1.11%
7720	Professional Services	1.3%	511320 Legal Services	1.10%
7120	Transportation	1.2%	511140 Overtime	1.07%
7210	Turf Rebate Program	1.1%	511381 Software and Hardware Licensing	0.95%
		86.2%	511560 Uncollectible Accounts	0.87%
			511420 Operating Materials & Supplies	0.86%
			511270 Mail and Parcel Post	0.80%
			511210 Operating Expense	0.80%
			511428 Program Materials	0.75%
			511570 General Liability & Fire Insurance	0.74%
			511224 Vehicle Maintenance - Corrective	0.58%
				93.5%

Conclusions and Future Research

This research provides scholarly and practicing engineers a methodology for applying the COQ model to the public utility sector. It also provides empirical evidence that a difference exists between manufacturing company and water utility costs of quality. This first research study provides an initial framework for scholarly research in applying the Costs of Quality concepts in researching the public utility sector. An updated literature review, COQ historical timeline, Prevention, Appraisal, Failure cost compendium, and manufacturing firm meta-analysis provide a launching point for future COQ research in this area. The initial water utility PAF categorization also provides a roadmap for the process of allocating departmental and expense line times. The practical implications from this research can be summarized as follows:

- The PAF Cost Compendium provides a combined view of four of the primary COQ standards that makes it easier to begin a cost categorization effort regardless of industry.
- The methodology used in this research can be applied to analyze other water utility organizations in the United States and internationally.
- Manufacturing and water utility organizations total COQ ratio and PAF cost ratios are statistically different. This implies that the two different industries' cost structures are inherently different.
- Appraisal costs were very similar as illustrated in the sensitivity analysis, including the manufacturing meta-analysis percent appraisal. This implies that the two sectors spend about the same on appraisal activities.
- The sensitivity analysis of the three water utilities, by using a Pareto Analysis, identified that salaries are the single largest expenditure. Depending on the industry, this may be expected.
- Distribution loss can have a significant impact on the failure costs of a water utility.

Based on the results of this research, the following recommendations are made for areas of future research. Additional COQ studies should be conducted on water utilities to substantiate and strengthen the findings. A detailed process map of the methodology used in this study could be developed to provide a very specific algorithm for conducting future research efforts. The methodology should be applied to other public utilities including waste water, storm water, and electric utilities, and then compared to these results. A study should be conducted to determine if there is a significant difference between private and publicly owned utilities. In addition, the EPA has introduced the four pillars of sustainable infrastructure for water and wastewater systems: better management, full cost pricing, efficient water use, and watershed approaches. The first three pillars have Cost of Quality applicability.

As world and local populations grow, the amount of water available per capita continues to decrease. The water utility system is also suffering a significant capital funding gap, and in this economic environment, shortages of funding. This COQ research, when properly applied, could help allocate funding requirements from COQ failure activities to capital improvement programs or impactful prevention programs. As the utilities are continually pinched by said funding shortages, an aging infrastructure, and increasing demand, providing a methodology to help allocate monetary resources effectively will become increasingly important. COQ methodologies are an effective tool a utility can utilize to manage expenses and ensure a sustainable water supply into the future.

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