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Costs of Quality: Exploratory Analysis of Hidden Elements and Prioritization using Analytic Hierarchy Process

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Abstract

Cost of Quality analysis is emerged as an effective tool for the industrial managers for pinpointing the deficiencies in the system as well as for identifying the improvement areas by highlighting the cost reduction opportunities. However, this analysis will be fully effective only if it is further extended to identify the cost incurred in ensuring quality in all areas of the supply chain including the hidden costs and costs of missed out opportunities. Most of the hidden elements of quality costs are difficult to track and not getting accounted by the traditional accounting tools. An exploratory analysis is made in this research to identify the hidden elements of quality costs in manufacturing industry. Further, the identified cost elements are classified into various groups for better analysis and, finally, prioritized to identify the vital few among them. Analytic Hierarchy Process (AHP) technique which is one of the most popular Multi Criteria Decision Method (MCDM) and Pareto analysis were used in this study for prioritizing the hidden quality cost elements based on their degree of impact on overall cost of quality. By this analysis, the key cost elements which are to be addressed to reduce the overall cost of quality are identified.

Keywords: Cost of Quality; Hidden Quality Costs; Opportunity Costs; AHP; Pareto Analysis.

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1. Introduction

Quality has become the key strategy to survive in the highly competitive and customer-driven market which demands highest quality at lower price. Hence, industrial experts are keen on exploring the possibilities of quality management with cost reduction opportunities. The need to improve an organization's financial position directly correlates with the process of making and measuring quality improvements (Zulnaidi, Y. ,2010). Cost of quality (COQ) analysis is identified as one of the effective tools for tracing the improvement opportunities (Mohandas,V.P. & Sankaranarayanan, S.R.,2008; Zimwara, D.et al ,2013) as it supports the top management to get the highlights of quality related activities in monitory terms, to track, estimate and demonstrate the cost of non-conformance and its causes and impacts, to identify improvement opportunities, to set action priorities and to monitor the performance over time (Gidey, E et al,2014). The cost of quality analysis triggers changes and provides proof why changes should be made (Cosmin, D et al, 2013). The costs of poor quality will tend to zero, if all the activities are performed without any deficiencies every time (Arvaiova, M et al, 2008).

Over the last six decades, many studies were in place worldwide and the understanding of quality cost concept has developed many folds (Schiffauerova, A., & Thomson, V., 2006; Omar, M. K., & Murgan, S., 2014). Earlier models were having production oriented point of view, taking only costs of deviations from specification into account (Sorqvist, 1997). The area has become wider with the additional dimensions added to the term quality (Suthummanon, S., & Sirivongpaisal, N., 2011). Traditional quality cost models based on the Prevention-Appraisal-Failure cost categories (P-A-F) are widely accepted by the quality practitioners (Wang et al, 2010) even with their limitations that they are confined within the tangible and directly measurable costs and are failed to address many of the cost areas (L.H.Tye et al, 2011) such as lost sales, loss of customer good will, loss due to low morale of work force etc. (Snieska, V, 2013). Many of the cost elements were not identified, quantified or analyzed further in this approach (Jafari, A., & Rodchua, S., 2014) and do not adequately evaluate the invisible or hidden quality related activities. Hidden costs are hidden profits and will provide a tremendous opportunity for improvement (Krishnan, S. K et al, 2000) on proper tracking and analysis.

Increasing complexity of organization, product, variety, and dynamic market situations forces industrial practitioners to enhance the concept of COQ with identification of more intangible and opportunity factors (Cheah, S. J. et al, 2011). Accounting and analyzing hidden quality costs is essential for a complete picture of losses due to poor performance and it would disappear entirely if every activity were performed without deficiency every time (Shanshan, S. ,2013). Improvement attempts with the incorporations of additional cost categories were made by several researchers like Akyol, D. E (2005), Teeravaraprug , J (2004), Yang, C.C (2008) and Sellés, M. E, et al (2008).

In spite of the academic interest on this subject, not many industries are found practicing these theories for the organizational improvement.

1.1. Hidden elements of Cost of Quality

The studies in this field are limited to a few dimensions of hidden quality costs in the manufacturing process. The elements identified by Sandovel- Chavez (1998) were effectively utilized by Cheah, S. J. et al (2011) for an action research in identifying the quality cost elements in continuous process manufacturing company with a highlight of resistance against implementation. Comprehensive researches with identification of all hidden elements of quality cost including opportunity losses are rare. In the current industrial scenario in which more and

more companies are aiming at TQM status with an objective of continuous improvement of the quality of goods and services, the lack of practical and comprehensive studies to identify and quantify the costs incurred in such quality improvement programs are noteworthy.
Hence, in this research, an attempt is made to analyze cost of quality in a broader sense by tracking all the hidden elements of costs incurred in ensuring the quality of each and every function associated in the total supply chain – right from the customer requirement analysis to after sales customer support quality of a product in a manufacturing firm.

1.2. Significance of Prioritization of Hidden Cost Elements

In an industrial situation which focuses on result oriented objectives, elaborative and time consuming analysis of non-significant cost elements is not practically advisable. Hence the most significant cost elements which are vital in controlling the overall costs of quality need to be identified so that the industrial managers can effectively focus on analysis of only these vital elements for further improvements in quality and cost reduction.
Since multiple conflicting or interdependent criteria needs to be evaluated in this decision-making process, Multi Criteria Decision Analysis (MCDA) techniques have to be used to resolve this issue. Various MCDA techniques such as weighted sum model (WSM), weighted product model (WPM), Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Elimination and Choice Translating Reality (ELECTRE) can be used in decision-making problems depending upon the complexity of the situation (Aruldoss, M., et al 2013, Velasquez and Hester , 2013).
The Analytic Hierarchy Process (AHP), introduced by Saaty (1980), which is one of the most popular MCDM techniques, is used in this study for prioritization of cost elements. The reason behind the selection of AHP lies in the fact that it can handle the objective as well as subjective factors and the criteria weights and alternative scores are elicited through the formation of pair-wise comparison matrix. The advantages of AHP over other multi criteria methods are its flexibility, intuitive appeal to the decision makers, and its ability to check inconsistencies (Ramanathan 2001). While providing a useful mechanism for checking the consistency of the evaluation measures and alternatives, AHP reduces bias in decision-making. The AHP method supports group decision-making through consensus by calculating the geometric mean of the individual pairwise comparisons (Hwang, C. L., and K, Yoon 1981). AHP approach is much more straightforward, easily understandable, more flexible, convenient, and accurate. Its use of pairwise comparisons can allow decision-makers to weight coefficients and compare the importance of each criterion with relative ease and clarity (Macharis et al. 2004). It is scalable, and can easily adjust in size to accommodate decision-making problems due to its hierarchical structure and is uniquely positioned to help model situations of uncertainty and risk since it is capable of deriving scales where measures ordinarily do not exist (Millet & Wedley 2002).And although it requires enough data to properly perform pairwise comparisons, it is not nearly as data intensive as other methods. The Analytic Hierarchy Process (AHP) decomposes a difficult multi criteria problem into a systematic hierarchy procedure in a powerful but simple way using the ability of individuals or groups to make pairwise comparisons in an efficacious manner. AHP is not demanding any pre-assignment of weight factors to the criteria as in the case of other MCDA techniques and the computations are also much easier than TOPSIS or ELECTRE. Hence AHP is selected as the MCDA tool for analysis of priorities of cost elements in this study.

The main objectives of this study are as follows:

1. Comprehensive analysis of various hidden elements of Cost of Quality and classification.
2. Ascertaining the degree of importance of each hidden cost element and identification of most significant elements in reducing the overall quality cost.

2. Research Methodology

The research methodology adopted is as follows:-

Personal interviews and discussions conducted with the employees for analyzing the activities which controls and ensures quality of processes, product and delivery. The details on quality improvement activities, quality deviations and insufficiencies in procedures in meeting customer requirements and the costs associated with each of them are identified. Missed out opportunities in each process heading to losses were also identified and critically analyzed to find out all the associated quality cost elements. These cost elements are then grouped into direct and hidden quality cost category.
AHP techniques were used to ascertain the degree of importance of each element and were prioritized based on their impact on controlling overall Cost of Quality, to identify the vital few among them.

2.1 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is the widely accepted technique developed by Prof. Saaty, T. L. (1980) used for multi criteria decision-making, in which the relevant factors of a decision are arranged in a hierarchic structure and decisions are arrived based on paired comparison of expert's opinions on each criterion. It is very popular due to its simplicity, ease of use and flexibility (Vaidya, O. S., & Kumar, S. ,2006) and a very reliable tool to facilitate systematic and logical decision-making process and determine the significance of a set of criteria and sub criteria(Bhatt, R etal,2010).

Basic components of AHP are (1) breaking down a complex, unstructured situation into its component parts; (2) arranging these parts, or variables into a hierarchic order; (3) assigning numerical values to subjective judgments on the relative importance of each variable; and (4) synthesizing the judgments to determine which variables have the highest priority and should be acted upon to influence the outcome of the situation.

The AHP determines the preferences among the set of criteria in each level of a hierarchy by employing pair-wise comparisons of these criteria with respect to their impact to a criteria in the next higher level. Starting at the top of the hierarchy and working down, a number of square matrices called preference matrices are created in the process of comparing criteria at a given level. Judgments of preference are made on pairs of criteria in the structure using Saaty's scale of AHP (Saaty 1996) which is reproduced in Table 1.

Table 1. The Saaty Rating Scale of AHP

Intensity of importance	Definition	Explanation of scale
1	Equal importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgment slightly favor one over the other.
5	Much more important	Experience and judgment strongly favor one over the other.
7	Very much more important	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice.
9	Absolutely more important.	The evidence favoring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed.

Let $C = \{Cj \mid j = 1, 2 \ldots n\}$ be the set of criteria. The result of the pair wise comparison on n criteria can be summarized in an $(n \ X \ n)$ judgmental matrix A in which every element aij $(i,j = 1,2,..., n)$ is the quotient of weights of the criteria. $aij = 1/aji$, for $i \neq j$, and $aii = 1$, for all i.
The judgmental matrix A is a positive reciprocal pair wise comparison matrix.
Then the geometric mean of each raw of matrix to be found and normalize it to get the eigen vector, ω. If the judgments are collected from m expert individuals, then for every individual it can be obtained a normalized vector of individual priorities, $\omega = [\omega ij]$, where i refers to i^{th} individual and j refers to the j^{th} element .The aggregation can be done using geometric mean of individual priorities.
ω vector satisfies the equation $A\omega = \lambda max \omega$ and $\lambda max \geq n$.
λmax is the principal eigen value of matrix A and the difference, if any, between λmax and n is an indication of the inconsistency of the judgments. If $\lambda max = n$ then the judgments are consistent.
The consistency of the judgmental matrix can be determined by a measure called the Consistency Ratio (CR), defined as: $CR = CI \ / \ RI$ where CI is the Consistency Index and RI is the Random Index.
Consistency Index can be calculated from $(\lambda max - n)/(n-1)$.
The RI values for matrices of different sizes are shown in Table 2.
In general, a consistency ratio of 0.10 or less is considered acceptable. If the value is higher, the judgments may not be reliable and have to be elicited again.

Table 2. The average consistencies of random matrices (The Random Index-RI-values)

Size	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	**0.00**	**0.00**	**0.58**	**0.90**	**1.12**	**1.24**	**1.32**	**1.41**	**1.45**	**1.49**

The composite weights of the criteria are then determined by aggregating the weights throughout the hierarchy. This is done by following a path from the top of the hierarchy to each alternative at the lowest level and multiplying the weights along each segment of the path. The outcome of this aggregation is a normalized vector of the overall weights of the options.

3. Data Collection and Analysis

3.1 Tracking & Classification of Hidden Elements of Costs of Quality

Detailed study is conducted in a manufacturing firm under electronic industrial sector. Each activity in the supply chain of this manufacturing firm is analyzed to identify the cost elements which are incurred in ensuring quality in each activity but not normally accounted in traditional quality cost analysis are identified and classified into various groups as listed in Table 3.

Table 3. Hidden cost elements with categorization

Hidden Cost of Quality Elements	Quality Cost Category
Customer requirement review	Prevention Cost- A1.1
Engineering design changes	Prevention Cost – A1.2
Process validation costs	Prevention Cost- A1.3
Audits at vendor premises	Appraisal Cost- A2.1
Customer audits	Appraisal Cost- A2.2
Engineering or design mistakes	Internal Failure Cost- A3.1
Rejection Consequent costs	Internal Failure Cost- A3.2
Material Planning errors	Internal Failure Cost- A3.3
Production planning errors	Internal Failure cost- A3.4
Litigation cost on failed supplies	External Failure Cost- A4.1
Billing errors and rework on bills	External Failure Cost- A4.2
Excess man power costs	External Failure Cost - A 4.3
Extra Shipping Costs	Opportunity Cost-Internal - B1.1
Capacity Under utilization	Opportunity Cost -Internal - B1.2
Delayed payments & Penalties	Opportunity Cost-Internal -B1.3
Customs demurrage charges	Opportunity Cost -Internal - B1.4
Bank transaction losses	Opportunity Cost - Internal - B1.5
Liquidate damages (LD)	Opportunity Cost - External - B2.1
Interest on Sundry debtors	Opportunity Cost- External- B2.2
Lost sales	Opportunity Cost- External - B2.3

3.1.1 Hidden Prevention Costs

Prevention costs are the costs incurred in all pro-actie measures for ensuring quality. Even though all the direct prevention costs are captured in the traditional system, some of the incurred costs which are not directly attributable to any product were not accounted. These are grouped under hidden prevention costs.

Customer requirement review: Customer order inputs are analyzed in these reviews and transformed to easily interpretable work orders to avoid any mistakes in the final product. Cost associated with this proactive measure is an indirect cost which was not being captured in the traditional system.

Engineering design Changes: Engineering design changes are resulted in some of the customer orders reviews. Costs of identification and implementation of design changes are another hidden cost.

***Process validation costs*:** Before the execution of a new customer order, the production process is validated with the key parameters identified as per customer specifications and a sample lot produced is tested for its conformance. These process validation costs are another hidden cost captured in this study.

3.1.2 Hidden Appraisal Costs

Appraisal costs are costs incurred in all types of audit or inspection activities to detect the quality deviations. The direct appraisal costs like cost of raw material inspection, inline tests, QC checks and audits are accounted in traditional quality cost system. But the inspection activities carried outside the manufacturing premises were not captured.

***Audits at vendor premises*:** Costs associated with process and product audits conducted at vendor's premises to hasten the receipts of good quality materials are captured in this study and accounted as the hidden appraisal cost.

Customer audits: Cost incurred against surveillance inspections by the customers is another hidden appraisal cost since these are not preplanned and not linked with any supplies and captured in this study.

3.1.3 Hidden Failure Costs

Hidden Failure Costs are much more significant than the other two categories as it is the outcome of errors which can be eliminated totally through proper root cause analysis and corrective measures.

Hidden Internal Failure Costs**:** These are hidden costs associated with internal failures.

Engineering or design mistakes: Impacts of the engineering or design mistakes identified at a later stage of production are manifold. Apart from the costs of scraps which are quantified against the direct internal failure costs of traditional system, the cost incurred in restarting the whole manufacturing process after corrective actions need to be accounted. This involves costs incurred in changes in manufacturing documents, re-scheduling the production, loading of additional raw materials, setup changes of machines and also the additional manufacturing costs.

Raw material planning errors**:** The raw material planning errors create shortage of raw materials and ends in procurement at higher costs due to the lack of sufficient lead time for ordering and other hidden costs like the cost of documentation and follow-ups. Minimum order quantity (MOQ) limitations result in excessive inventory carrying cost. In addition to this, components normally processed with automated process in bulk reel form had to be processed as small loose quantities with manual loading and assembly operations leads to extra machine and man hour costs.

Production planning errors: These errors lead to stoppage of process flow, re-scheduling and re-loading of production activities and delay in customer order execution. The costs associated include wastage in man and machine hours, documentation costs and late demurrage charges imposed by the customer.

Consequent costs of material rejections: Apart from the inspection costs, hidden dimensions of post rejection procedures also have to be accounted. Most of the time, the transportation costs for the rejected materials are born by the supplier and re-inspection costs are getting accounted against traditional appraisal costs; but the cost incurred against the documentation procedures, packing, follow-up and re-edition are not accounted in the traditional system, which are accounted as hidden internal failure cost .

Hidden External Failure Costs**:** These are hidden costs associated with failures in post-dispatch activities.

Billing errors and rework on bills: The errors in the bills result in withdrawal of the wrong bills from customer, work repetition in raising new bills with wastage of man hour, additional documentation and follow-ups and also causes customer dissatisfaction which leads to delay in payment realization and loss against interests.

3.1.4 Opportunity Costs

Another hidden area is the opportunity cost of a missed out opportunity. Applied to a business decision, opportunity cost might refer to the profit a company could have earned from its resources- man power, machine and material- if these assets had been utilized in a different and efficient way. Opportunity costs can be grouped into two Internal and External opportunity costs.

Internal Opportunity Costs: Loss of missing opportunities which are confined within the firm is categorized as internal opportunity costs. Extra shipping costs, under utilization of machines, loss due to delayed payments to the vendors, customs demurrage charges and penalties imposed by banks are coming under this group.

Extra shipping costs: Costs incurred in emergency dispatch modes such as air courier, personal delivery etc (.) adopted to cop up the delays in deliveries and to meet customer urgencies are accounted as costs due to missed out opportunity of dispatches in time.

***Under utilization of machine capacity*:** The research revealed the under utilization of manufacturing equipments against the specified machine capacity as a result of raw material shortages, shortage of trained manpower, insufficient customer order etc. which is measured under this study from the information of installed machine capacity per hour and the actual utilization of machines. Apart from this, whenever the machines are restarted after a stoppage, warming up and setting up is required before the start of manufacturing process. Also, the first output lot after each restart has to be inspected against all critical parameters to ensure the absence of process variations. All these are inputs for opportunity costs incurred.

Loss due to delayed payments*:* Adherence to payment terms of the suppliers is a critical factor for ensuring timely delivery as well as service quality and any slippage in the same leads to impose of more stringent payment terms and loss of credit facility. From the analysis of changes in the payment terms of the suppliers, the loss incurred due to this missed opportunity can be tracked.

Customs demurrage charges*:* Customs demurrage charges due to the mistakes as well as ambiguity in the documents produced before customs authorities is another hidden quality cost captured for this study.

Loss incurred in bank transactions: Penalties levied by the bank due to the insufficiency in documents produced for a foreign transaction and loss incurred due to the foreign exchange variations due to the absence of a forward rate contract with the bank are captured as hidden costs.

External Opportunity Costs*:* Opportunity costs for which the customer is involved is termed as external opportunity costs.

Interest on sundry debtors*:* Any bills exceeding the target realization period are considered as sundry debtors and interest amount to this value is another opportunity loss which could have been avoided if the payment realization of these bills were made in time.

Late demurrage charges: Non-adherence to delivery schedules given by customers revoke penalty clause on late deliveries (LD). The delayed dispatch cases are analyzed for tracing this opportunity cost data.

Lost sales: The reduction in sales volume on account of lost sales due to repeated quality issues and delay in services are another opportunity cost which can be estimated by analyzing the average business volume of the customer for a particular span and from the reduction in business volume.

3.2 Prioritization of Hidden Quality Cost Elements

Each hidden cost element in this study is having a distinct influence on the overall cost of quality and plays a vital role in improving the profit margin of the firm. But in a practical application, analysis of each and every cost element is not advisable since it is highly time consuming and unproductive. Hence the theory of “vital few” has to be applied to identify the most significant cost elements so that the insignificant elements can be avoided from further analysis of quality improvement programs. Hence an attempt is made in this study to prioritize hidden quality cost elements using Analytical Hierarchy Process (AHP) techniques.

Based on the hidden quality cost elements collected from the manufacturing firm, the hierarchical model with prioritization of quality costs as goal is developed. The goal is broken down to cost categories and further to cost elements to form the 3 level AHP model for assessment.

Level 1 comprises of the two hidden cost categories – indirect quality costs and opportunity costs. Level 2 forms the sub-categories under these two sets. Indirect Quality Cost is with 4 sub-categories- Hidden Prevention Cost, Hidden Appraisal Cost, Hidden Internal Failure Cost and Hidden External failure Cost where as the second category, Opportunity Cost is with 2 subcategories- Internal Opportunity Cost and External Opportunity Cost.

Level 3 is with cost elements in each sub-category.

The final hierarchical model with all elements in each level is as shown in Figure 1.

Eight experts are selected from key functions in the manufacturing firm under study as participants: two each from Quality Assurance, Manufacturing and Finance and one each from Marketing and Materials Management functions. Survey questionnaires using Saaty's scale were circulated among these experts to get feedback on priorities assigned by them against each cost category, subcategory and element.
With the help of AHP approach, pair-wise comparisons of priorities of elements in each level are calculated using eigenvector method and aggregation of individual priorities (AIP) done by geometric mean of pair-wise comparison results collected from the experts (Forman, E., & Peniwati, K. (1998).

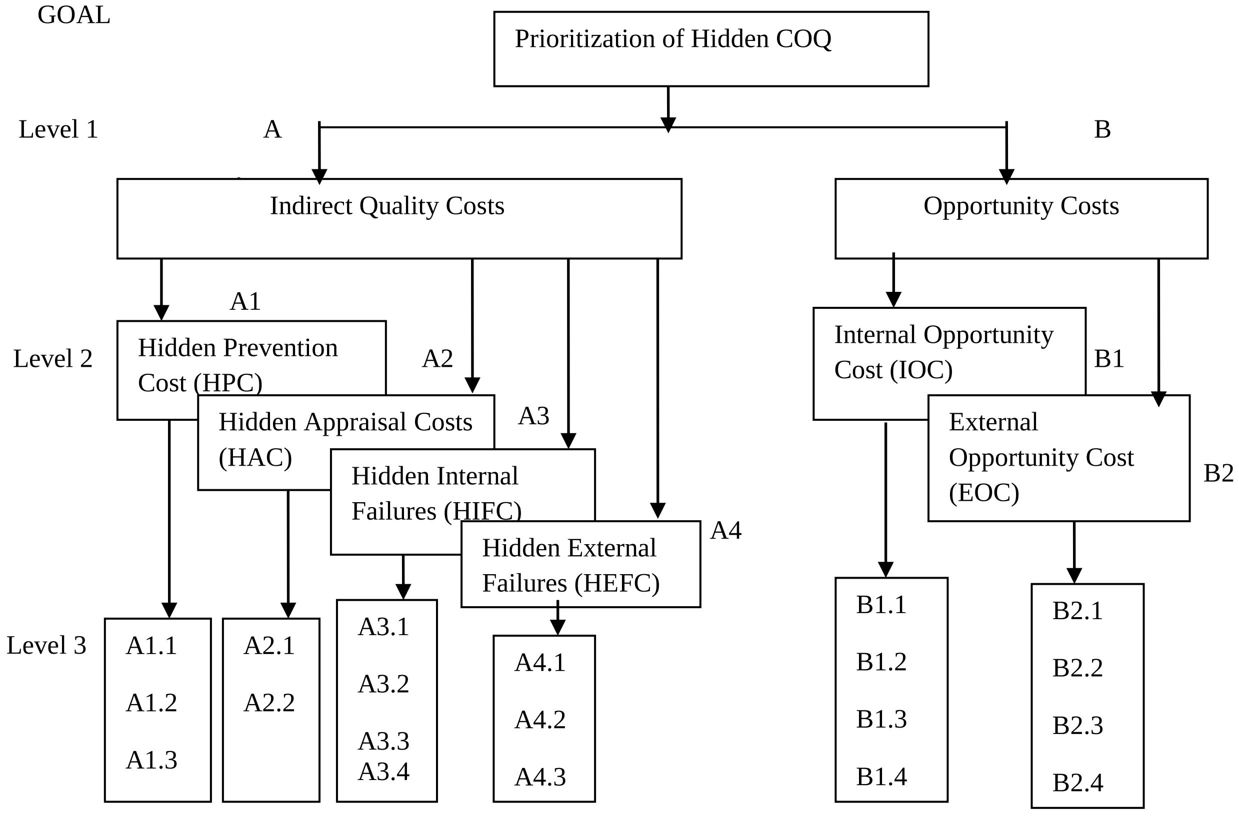

Figure 1. Final Hierarchical model

Cost elements A1.1, A1.2, A2.1, B1.1, B2.1 etc. in each sub-category as listed in the Table 3.

Steps involved in this study are:

1. Administration of pairwise comparison survey forms based on Saaty's scale (Saaty, 1980) to experts from different functional areas to collect their judgments on priority of parameters with respect to its impact on controlling the higher level parameter in the hierarchy.

2. Formation of the judgmental and reciprocal matrices to find out the relative value vectors(RVV) and normalization to get the Eigen vector (w).Calculation of the priority vectors (local weights) of each element-hierarchical level-wise. Sum of these local weights at each level will be 1.

3. Checking the consistency of the judgments by finding out consistency index and consistency ratio using principal eigen value method.

4. Aggregation of individual priorities at each level of hierarchy using geometric mean method.

5. Assessing the global priority of each cost element and rank them based on the priorities to get the most important elements with maximum impacts on overall cost of quality.

The AHP method gives the local as well as global weights of each element with reference to its impact in reducing cost of quality. The number of pairwise comparison in each level will be **n (n-1)/2** where **n** is the number of elements in that hierarchical level.
The pairwise judgmental matrices, the corresponding Eigen vectors (ω), Principal eigen value (λmax), Consistency Index (CI) and Consistency Ratio (CR) in each level are found. The value of CR in all judgments were found to be less than 1, which indicates the true consistency of judgments in this study.

The Eigen vector found in each pairwise comparison is the local weights of priority assigned to each element in the hierarchical level. Global weights (Composite priority weights) of these elements are calculated by multiplying the corresponding local weights in each level and ranked in the descending order. The values of local weights in hierarchical level and composite priority (global) weights are given in Table 4.
Detailed calculations are shown in Appendix- A (Tables A1 to A9). Survey questionnaire sample format are is given in Appendix-B.

Table 4. Composite priority weights (global) of all parameters of Hidden Cost of Quality

Level 1 1 Category	Local weights	Level 2 sub categories	Local weights	Level 3 Cost Elements	Local weights	Global weights
A. Indirect Cost of Quality	0.135	A1. Hidden Prevention Cost	0.046	A1.1-Customer requirement review	0.091	0.0006
				A1.2-Engineering design changes	0.597	0.0038
				A1.3-Process validations	0.313	0.0020
		A2. Hidden Appraisal Costs	0.091	A2.1-Audits at Vendor premises	0.259	0.0032
				A2.2-Customer audits	0.741	0.0091
		A3. Hidden Internal Failure Costs	0.563	A3.1-Engineering \ design mistakes	0.642	0.0489
				A3.2-Consequents of raw material rejections	0.048	0.0036
				A3.3-Material planning errors	0.108	0.0082
				A3.4-Production planning errors	0.202	0.0154
		A4. Hidden External Failure Costs	0.299	A4.1-litigation costs	0.749	0.0303
				A4.2-Billing errors	0.067	0.0027
				A4.3-Extra field assistance	0.185	0.0075
B. Opportunity Costs	0.865	B1. Internal Opportunity Costs	0.202	B1.1-Extra shipping costs	0.031	0.0054
				B1.2-Capacity under utilization	0.395	0.0690
				B1.3-Delayed payments	0.275	0.0481
				B1.4-Customs demurrage charges	0.106	0.0185
				B1.5- Loss in bank transactions	0.193	0.0338
		B2. External Opportunity Costs	0.798	B2.1-Late demurrage (LD)	0.058	0.0397
				B2.2-Interest on sundry debtors	0.659	0.4544
				B2.3-Lost sales	0.284	0.1959

4. Results and Discussions

The analysis revealed that in the first level, opportunity cost category is having more impact (86.5%) on cost of quality than the direct hidden costs (13.5%). In the second level, among the sub-categories of direct hidden cost category, internal failure costs are found more significant than the other sub-categories. Similarly, among the sub-categories of opportunity cost category, external opportunity costs were found over powering the internal opportunity costs. The local and the global weight at the elementary level provide the prioritization of each cost element and their order of priority.

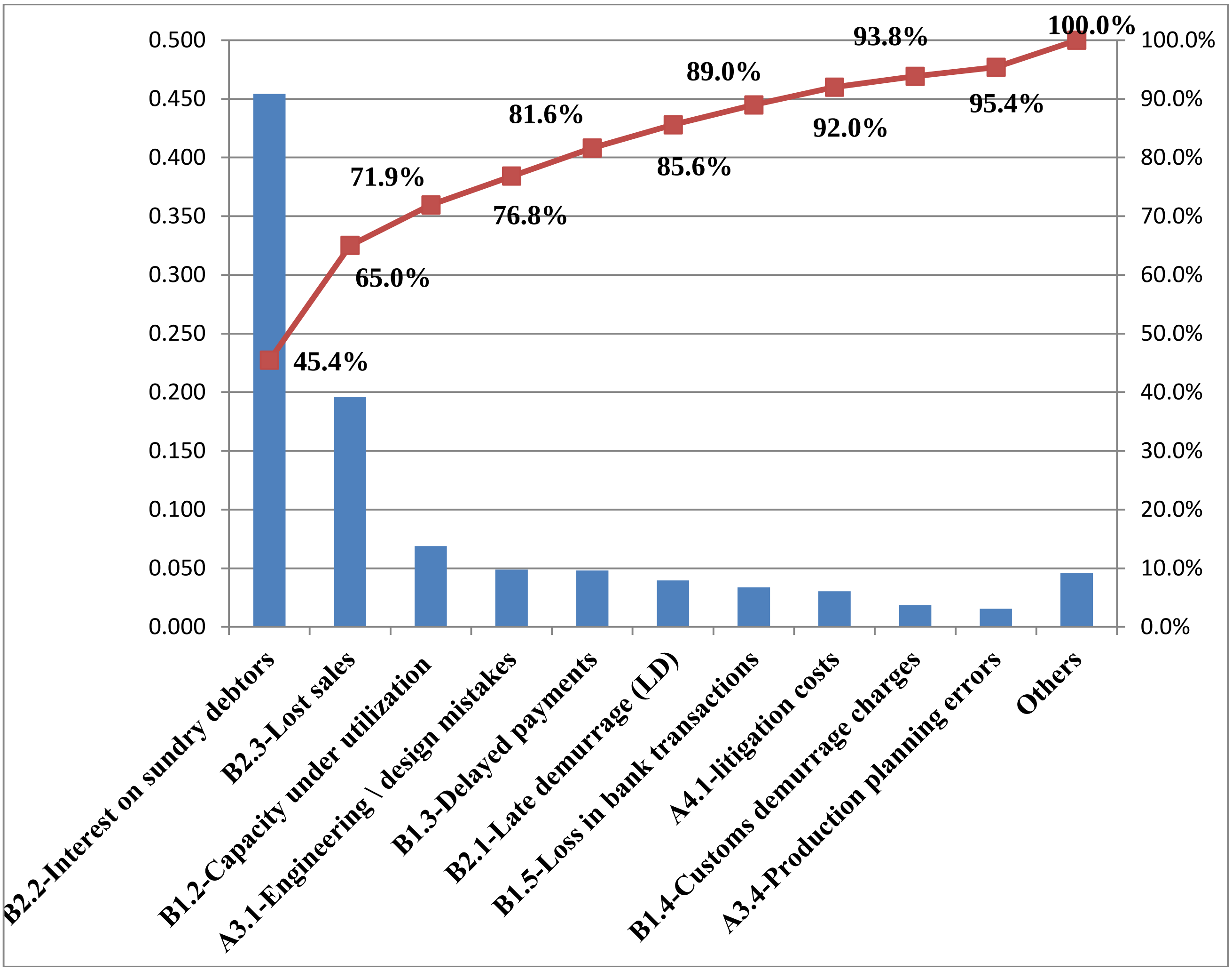

Figure 2. Pareto chart on impact of hidden cost elements on cost of quality.

As per AHP analysis of prioritization of hidden cost of quality elements, the five top priority cost elements are B2.2-Interest on sundry debtors, B2.3-lost sales, B1.2- loss due to underutilization of machine capacities, A3.1- loss due to engineering and design mistakes and B1.3 – loss due to delayed payments to the raw material suppliers, respectively. 81.63% of the hidden cost of quality is comprised
of these five top priority hidden cost elements. The Pareto analysis also supports the same findings. Pareto chart in Figure 2 shows that more than 80% of the total quality costs come from 20% of the hidden quality cost elements.

A systematic monitoring and root cause analysis of these top priority cost elements will provide a clear focus on the areas where the quality improvement activities to be strengthened and by eliminating these losses, the organization can improve its profit margin.

5. Conclusion

Cost of quality (COQ) analysis is an effective tool for the industrial managers for pinpointing the deficiencies in the system as well as for identifying the improvement areas by giving a clear insight to the cost reduction opportunities in terms of monitory benefits. The analysis will be

effective only if the hidden costs including opportunity losses also are measured and quantified. Opportunity losses are the financial advantage which would have been gained by the company, if every activity were performed without deficiency every time. Most of the opportunity costs are hidden and difficult to track and hence not accounted by the traditional accounting tools.
Due to the practical difficulties in measurement and analysis of cost elements, most of the firms usually focus only on addressing the tangible and easily retrievable costs and hence the intended result of quality improvements with less incurred cost and efforts are not fully met. Whereas, if the most significant cost elements which contribute to the major share of quality costs are dentified , then the analysis can be focused on these most significant elements without compromising the results.
In this study, an attempt is made to identify the most significant cost elements out of the whole set of hidden cost elements in a manufacturing organization, based on their importance in controlling overall cost of quality. For this purpose, an enhanced quality cost model with detailed and systematic tracking of each functional element which is having significant contribution to the overall quality management of the manufacturing firm is done. An exploratory study is conducted to identify all possible hidden quality cost elements and categorized them into indirect quality costs and opportunity costs. Around 20 hidden cost elements which have significant impact on the overall quality cost are tracked in this study.
Further the degrees of importance of each of these quality cost elements were ascertained using the expert opinions and AHP techniques. Questionnaires based on Saaty's scale were prepared and administered over a selected group of experts to collect their judgment on priority of each cost element. Consistencies of judgments were also ensured by measuring principal Eigen value as well as consistency index and consistency ratios.
The cost elements are prioritized based on their global importance and the most significant elements which contributes to more than 80% of the hidden costs of quality in a manufacturing firm is identified. Thus, out of 20 quality cost elements identified, only 5 found most important, leaving the remaining as insignificant.
The results of this expert opinion based on AHP approach helps the industrial managers to narrow down the complex problem of prioritization of quality cost elements and to address the top priority cost elements in their quality improvement programs for achieving quality with assured cost reduction.
This study and method are applicable to any manufacturing firm for classification and prioritization of the complex cost structure in the real industrial environment.

6. Limitation and future scope of this study

Calculations in AHP becomes time consuming and tedious with increase in the number of criteria to be compared .Software application packages like Matlab or Expert Choice will be useful to overcome this limitation.
The expert opinions in this study are collected in the Saaty's ratio scale where as it can be made more accurate by using a linguistic scale and by performing fuzzy arithmetic operations to identify the priority weights. Also the decision-making is a complex situation wherein the cost elements are much interdependent. The study can be further extended to address these two points also.

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Appendix A:

Calculations of the pair wise priority vectors shown in Table A1 to A9

Table A1: Pair wise comparison of Indirect Quality cost (A) to Opportunity Cost (B) – Hierarchical level 1

.	A	B	RVV	Eigen Vector (ω)	λmax	CI	CR
A	1	0.157	0.396	0.135	2	0	0
B	6.39	1	2.528	0.865			

Table A2. Pair wise comparison of Hidden cost sub categories - Hierarchical level 2

	A1	A2	A3	A4	RVV	Eigen Vector (ω)	λmax	CI	CR
A1	1.000	0.354	0.143	0.126	0.283	0.0461	4.1908	0.0636	0.0706
A2	2.825	1.000	0.144	0.240	0.559	0.0912			
A3	6.971	6.943	1.000	2.930	3.451	0.5633			
A4	7.950	4.169	0.341	1.000	1.834	0.2993			

.

Table A3. Pair wise comparison of Opportunity cost sub categories - Hierarchical level 2

	B1	B2	RVV	Eigen Vector (ω)	λmax	CI	CR
B1	1	0.253	0.503	0.202	2	0	0
B2	3.95	1	1.987	0.798			

Table A4. Pair wise comparison of Hidden Prevention cost elements - Hierarchical level 3

	A1.1	A1.2	A1.3	RVV	Eigen Vector (ω)	λmax	CI	CR
A1.1	1.000	0.203	0.217	0.353	0.091	3.085	0.043	0.074
A1.2	4.919	1.000	2.551	2.324	0.597			
A1.3	4.618	0.392	1.000	1.219	0.313			

Table A5. Pair wise comparison of Hidden Appraisal cost elements - Hierarchical level 3

	A2.1	A2.2	RVV	Eigen Vector (ω)	λmax	CI	CR
A2.1	1.000	0.349	0.591	0.259	2	0	0
A2.2	2.862	1.000	1.692	0.741			

Table A6. Pair wise comparison of Hidden Internal failure elements - Hierarchical level 3.

	A3.1	A3.2	A3.3	A3.4	RVV	EigenVector (ω)	λmax	CI	CR
A3.1	1.000	8.360	6.346	4.789	3.992	0.642	4.220	0.073	0.0814
A3.2	0.120	1	0.265	0.245	0.297	0.048			
A3.3	0.158	3.777	1	0.341	0.671	0.108			
A3.4	0.209	4.076	2.931	1.000	1.257	0.202			

Table A7. Pair wise comparison of Hidden External failure elements - Hierarchical level 3.

	A4.1	A4.2	A4.3	RVV	EigenVector (ω)	λmax	CI	CR
A4.1	1.000	8.360	5.448	3.571	0.749	3.088	0.044	0.076
A4.2	0.120	1.000	0.268	0.318	0.067			
A4.3	0.184	3.728	1.000	0.881	0.185			

Table A8. Pair wise comparison of Internal Opportunity Cost elements - Hierarchical level 3

	B1.1	B1.2	B1.3	B1.4	B1.5	RVV	EigenVector ω	λmax	CI	CR
B1.1	1.00	0.116	0.13	0.169	0.158	0.14	0.031	5.245	0.061	0.054
B1.2	8.58	1	2.55	2.930	1.465	1.81	0.395			
B1.3	7.38	0.392	1	3.031	2.169	1.26	0.275			
B1.4	5.90	0.341	0.33	1	0.500	0.48	0.106			
B1.5	6.34	0.683	0.46	2.000	1	0.89	0.193			

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Table A9. Pair wise comparison of External Opportunity Cost elements - Hierarchical level 3.

	B2.1	B2.2	B2.3	RVV	Eigen Vector (ω)	λmax	CI	CR
B2.1	1.000	0.120	0.148	0.261	0.058	3.100	0.050	0.086
B2.2	8.360	1.000	3.178	2.984	0.659			
B2.3	6.760	0.315	1.000	1.286	0.284			

Appendix B:
Survey on pair wise comparison of criteria

Please mark your opinion on the importance of the cost category/ sub category/ cost elements in the pair wise comparison table given below:

Q1: Impact of Indirect Quality Costs Vs Opportunity Costs on overall Cost of Quality

Cost Category	More importance than								Equal	Less importance than								Cost Category
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Indirect Quality Costs- A																		**Opportunity Costs- B**

Q2: Impact of sub categories on Indirect Quality Costs

Cost Sub Category	More importance than								Equal	Less importance than								Cost Sub Category
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Hidden Prevention Cost – A1																		**Hidden Appraisal Costs – A2**
Hidden Prevention Cost – A1																		**Hidden Internal Failures – A3**
Hidden Prevention Cost – A1																		**Hidden External Failures – A4**
Hidden Appraisal Costs – A2																		**Hidden Internal Failures – A3**
Hidden Appraisal Costs – A2																		**Hidden External Failures – A4**
Hidden Internal Failures – A3																		**Hidden External Failures – A4**

Q3: Impact of sub categories on Opportunity Costs

Cost Sub Category	More importance than								Equal	Less importance than								Cost Sub Category
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Internal Opportunity cost - B1																		**External opportunity Cost - B2**

*** (Similar survey questionnaires are used for comparing the importance of cost elements in the further hierarchical level also) ***.