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Research and Innovative Methodology on Closed-Loop Analysis & Improvement Mechanism Based on Cost of Quality System

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Keywords

Monthly comparative analysis
Quality control costs
Quality failure costs
Quality improvement area
Total quality cost

Abstract.

The concept "cost of quality (COQ)" is well-known and widely used in all kinds of economic activities, especially manufacturing industry. However, the installation of COQ has always been the major research subject and little study is carried out in terms of tracking and improvement mechanism after building COQ system. The aim of this paper is to present novel research and innovative methodology of a closed-loop analysis & improvement mechanism when establishing COQ system in manufacturing industry. Economically, quality failure costs that consist of external failure costs and internal failure costs are reduced significantly through increasing targeted investment in quality control costs that consist of prevention costs and appraisal costs in practice. The innovative methodology verifies that enterprise can achieve dramatic increase of economic and social benefits through building COQ system and implementing closed-loop analysis & improvement. In addition, the innovative methodology provides theoretical support and methodological reference for enterprises in manufacturing industry to build COQ system and carry out closed-loop analysis & improvement.

1. Introduction

Because manufacturing enterprises are facing global severe competition, the significance of quality has been acknowledged as a critical factor for their survival and development, especially in the face of the benefits drying up gradually due to both rising cost of raw material and falling price of products. Muhammad and Randolph [16] emphasize that in recent years, customer expectations for quality at low cost have only intensified. As manufacturers strive to achieve these goals they eventually reach a point where trade-offs must be made between increasing quality and lowering costs. Thus, Marcin

[13] points out that customer retention has become one of the priorities, especially for small and medium enterprises (SMEs), if one is to survive the severe competition on a global market. Rahardjo et al. [19] conclude that optimal production costs are always needed as costs that represent value for customers. Costs related to quality are costs that if managed properly provide a competitive and comparative advantage for the organization. Though world famous manufacturing enterprises fully recognize quality as the crucial factor for them to be able to develop sustainably and carry out systematic COQ management in order to achieve competitive advantages, many enterprises, in particular, SMEs in manufacturing industry conduct simple statistics of individual internal and external failure costs, such as scrap and warranty compensation for budget-minded purpose without building COQ system into quality management system, let alone conducting related analysis & improvement. Maja and Jovan [12] think that the main problem related to the COQ field is the low level of applicability in practice, regardless of the relevance given to this field in theory. As a result, it is common that total quality cost remains high. So, Iuliana et al. [9] propose that the purpose of considering COQ in the industry practices is to demonstrate and highlight the benefits of improving quality and to relate it to customer satisfaction, as well as to link these benefits with a matching cost in order to be able to reduce total costs and increase benefits. Teli and Chanewar[18] point out that organizations which are aware of costs related to quality , make decisions which are different form organizations which are not aware of costs related to quality. Modhiya and Desai [15] find it is not always easy to install and implement COQ system because of the lack of literature sources regarding the methodology of installation and implementation of quality cost systems that approach the business practices of each organization. Anna and Agnieszka [2] specify that the optimum cost of quality is the one that balances investments in prophylaxis and assessment with expenses caused by the occurrence of mistakes. Sailaja et al. [17] use the strength of analytic hierarchy process (AHP) technique together with the fuzzy logic concept and fuzzy multi-objective optimisation and ratio analysis (MOORA) technique to develop a hybrid model with an objective to overcome the limitations of present quality cost systems as an effective tool for decision making in any manufacturing firms. In this study, making use of COQ theory and the innovative methodology illustrated as below, this paper elaborates how to install and implement the mechanism of effective closed-loop analysis & improvement in manufacturing enterprise after building COQ system. Both theoretical support and methodological reference are provided for manufacturing enterprises to build COQ system and conduct closed-loop analysis & improvement so as to reduce total quality cost, increase economic benefits and also enhance competitiveness.

2. Cost of Quality

There are many researches concerning COQ. From the point of view of Djekic et al. [7], COQ is an indicator related to the achievement, or non-achievement, of quality. Martinez and Selles [14] regard quality cost management as one of the most important aspects of the development of a quality management system. Different from the above, Machowski and Dale [11] think there is no general agreement on a single broad definition of COQ. However, this paper adopts classical understanding which is widely acknowledged that COQ is the sum of conforming costs and non-conforming costs. With the research of Andrea and Vince [1], quality guru, Dr. Armand Feigenbaum firstly devised a quality costing analysis in 1943, when he and his team developed a dollar-based reporting system. Later, in 1956, Dr. Armand Feigenbaum proposed the well-known COQ categorization of prevention, appraisal and failure (internal and external) costs.

2.1. COQ categorization

Dr. Armand Feigenbaum [4] summarizes and develops systematic COQ definition and measurement. In general, COQ can be divided into two categories as below Figure 1. The first category consists of costs necessary for achieving high quality, which are called quality control costs and two types are included: prevention costs and appraisal costs. The second category consists of the cost consequences of poor quality, which are called quality failure costs. These include external failure costs and internal failure costs. Meanwhile, it is necessary to point out that quality control costs are incurred to prevent quality failure costs.

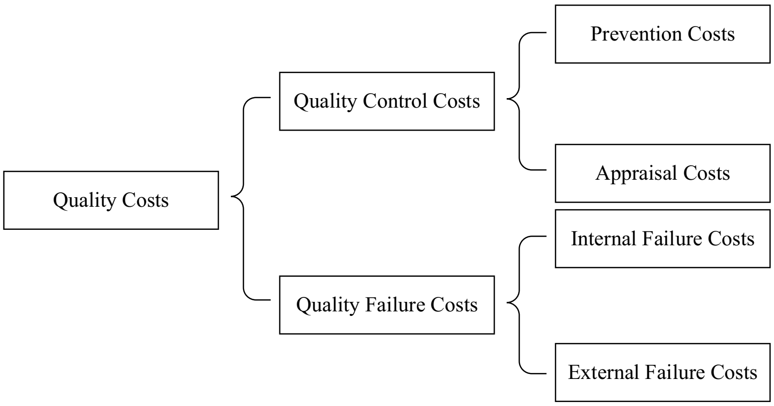

Figure 1: COQ Categorization [4].

2.2. COQ curves

The American Society for Quality Control (ASQC) [4] adopts Feigenbaum's and Juran's COQ scheme, which is classical and prevailing in the area of quality. According to the scheme, mathematical linkage between COQ and product quality level is illustrated with so-called COQ curves as below Figure 2.

Figure 2 displays cost per good unit of product as the ordinate versus quality level as the abscissa, of which far left and far right represent two extreme levels respectively: 100% defective and 100% good. As the quality control costs, curve 1 is the sum of prevention costs and appraisal costs. Curve 2 shows quality failure costs that consist of internal and external failure costs. Surely, curve 3 indicates total quality cost and also the sum of four types of costs. As can be seen from Figure 2, when extreme 100% defective, the quality control costs has fallen to near zero, which means the organization

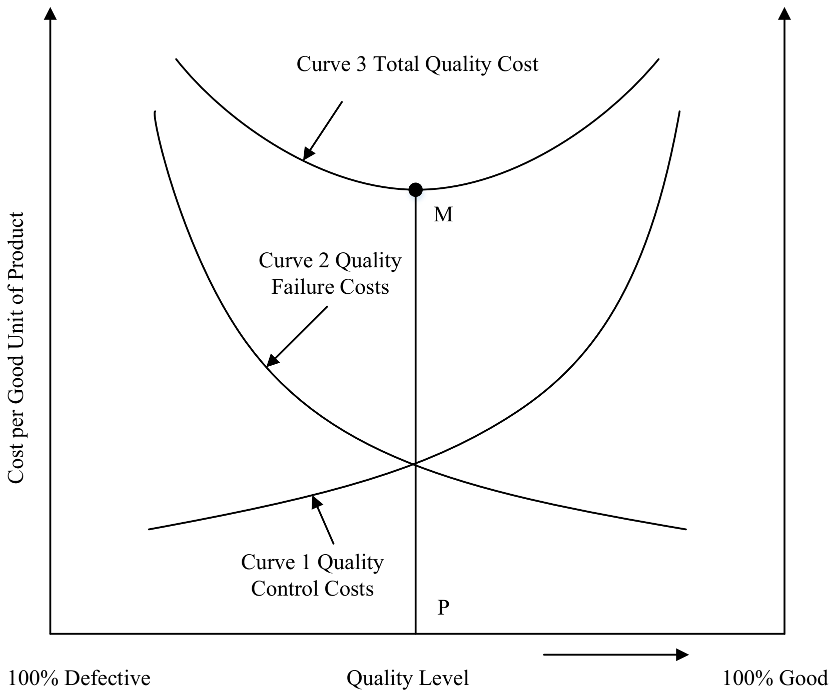

Figure 2: COQ Curves [4].

has almost abandoned quality control with little quality input. At the same time, the quality failure costs are so extremely huge that the organization would be unable to survive. All these urge the organization to put increasing emphasis and investment on quality. Then, quality control costs, the sum of prevention and appraisal costs, have been increased continuously as indicated by the curve 1 in Figure 2. It is followed that quality failure costs go down sharply as shown by the curve 2 and quality level is improved continuously. The minimum and also optimal point at the curve 3 of total quality cost is defined as point M in Figure 2 and the corresponding point on the abscissa of quality level is defined as point P. From the point of view of quality control micro mechanism, qualitative method is used to further illustrate the mathematical linkage among the above costs. One of the typical appraisal investments, calibration cost is taken as the example. When the reduction of it happens, it is obvious that the quality of products is impacted directly and the increase of failures is triggered instantly. Then, internal failure costs including excess raw materials, extra processing, re-test, delay delivery will be led to soon. Ultimately, customers are dissatisfied and sale orders are lost, which means huge external failure cost. It goes without saying that the reduction of quality control costs, no matter prevention investment or appraisal investment, leads to the increase in internal or external failure costs. After crossing point P, quality control costs, the sum of prevention and appraisal costs, will rise noticeably to further improve quality level but quality failure costs, by contrast, decline unnoticeably.

Now the partial area around point M is enlarged and divided into three sub-areas so as to analyse the curve of total quality cost individually and clearly shown in the

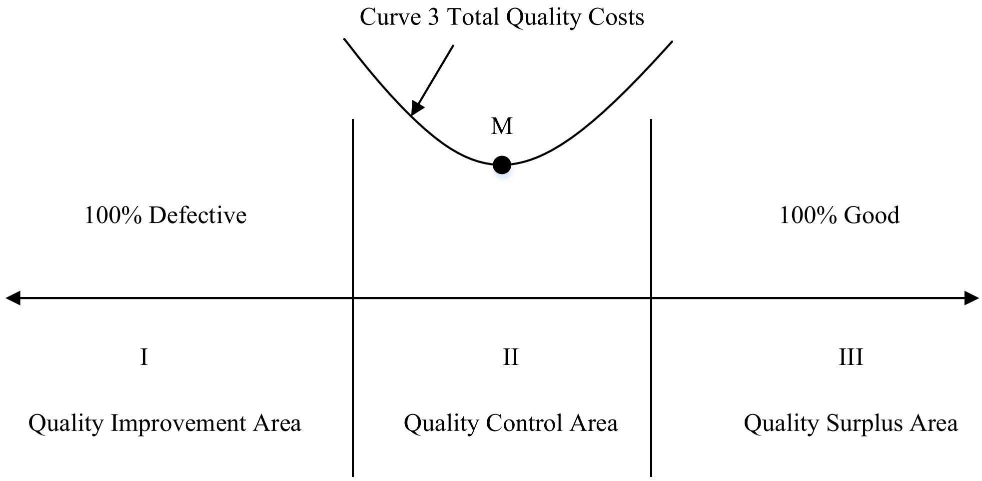

Figure 3: COQ Curve Sub-areas [4].

above Figure 3. According to the explanation the above, quality failure costs are much more than quality control costs in area I, which is the most severe area in terms of poor quality. In the meantime, Dr. Armand Feigenbaum [3] points out that the earlier defects are found, the less costly they are to correct. In other words, it takes much less expense to detect and correct defects during product design and production than at the customer site as shown in Figure 4. Hence, the organization that highlights quality importance shall invest heavily in prevention and appraisal costs in order to prevent internal and external failure costs. For that reason, it is necessary to detect and prevent defects before delivery. Therefore, when being in area I where quality failure costs are much more than quality control costs, the priority of organization is *rise* and *fall* as to COQ management, namely the investment of prevention and appraisal costs shall *rise* to strengthen preventive measures and enhance detection capability, then quality failure costs shall *fall* rapidly and greatly. The above is the major theoretic foundation based on which the innovative methodology of COQ management is implemented. Of course, the actual operation in the organization is not to increase prevention and appraisal costs blindly but to provide targeted input for the investment of prevention and appraisal through closed-loop analysis & improvement mechanism highly being data-driven by effective COQ statistics in order to achieve rapid and great failure costs reduction. Thus, area I in Figure 3 is named as Quality Improvement Area.

In the end, area II and area III are called quality control area and quality surplus area with related priorities of maintaining current quality level and optimizing prevention and appraisal costs respectively.

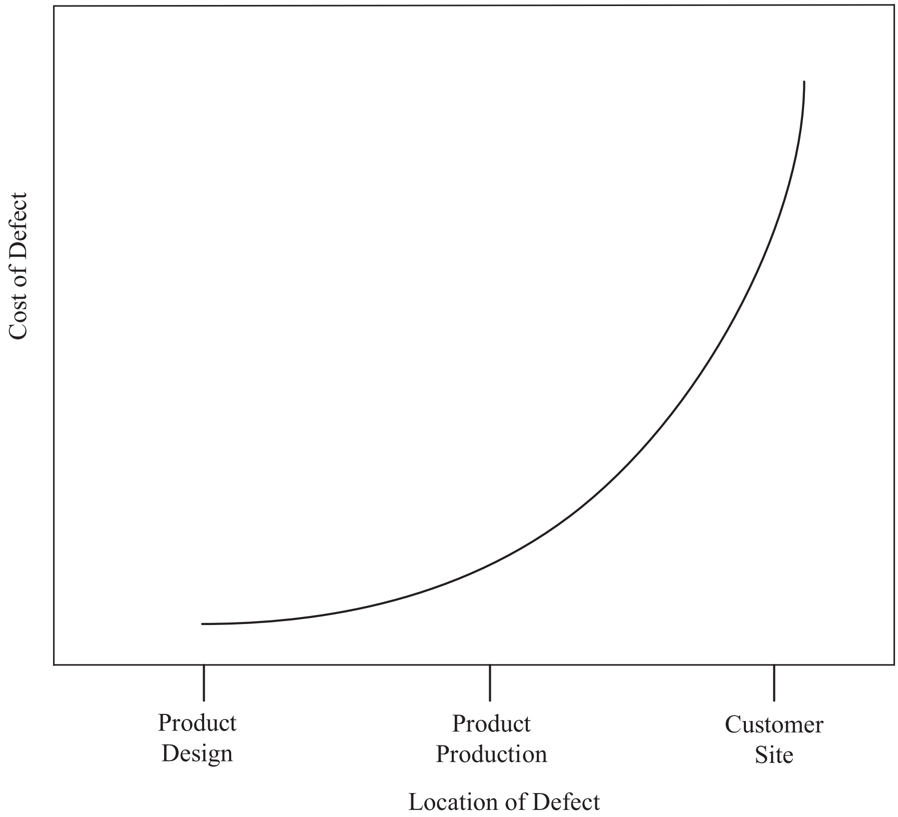

Figure 4: Cost of Defect [4].

3. Innovative Methodology implementation in Enterprise

3.1. Enterprise introduction

For confidentiality reasons, the name of the enterprise is not disclosed with the replacement of Company D. Company D is a listed auto parts & components company, which was founded in 1990s majoring in a single auto component at that time. So far, it has been made up of 5 individual business divisions manufacturing different auto parts & components. During listing process in recent years, it enhances its governance system constantly including introducing quality professionals to campaign COQ management.

3.2. COQ management description

Company D did not build COQ system before the campaign. Though there were scrap statistics reporting system covering all from business divisions, workshops, production teams to operators, at most the system was regarded as manufacturing scrap of internal failure costs. Also, Company D reported one of business division's warranty cost just because of its product's costly compensation after sales, which could be summarized into warranty of external failure costs. As for prevention and appraisal costs, there were no related statistics and reports. Through analysing the data mentioned the above, it was concluded definitely that typically, the COQ status of Company D was in area I, namely Quality Improvement Area.

Douglas and Connie [8] advocate that quality planning is a strategic activity and it is just as vital to an enterprise's long term business success. COQ implementation is certainly no exception. Based on then status analysis, initiatives and objective below were planned and developed as to COQ campaign at first:

- Build COQ system.
- Establish closed-loop analysis & improvement mechanism to carry out investment in prevention and appraisal costs rapidly and effectively, and then realize rapid and great failure costs reduction.
- Percentage of total quality cost to sales revenue shall fall by half in three years.

3.3. COQ system building

In the beginning, a cross function team of COQ campaign in Company D is set up including quality, financial, production, purchasing, marketing, research & development (R&D). Soon, the training is conducted in terms of COQ management. Apart from deeper understanding of typical terms, definitions and principles, it is highlighted that COQ is highly effective in improving the quality of work in the most profitable way.

Based on the business and industry feature of company D, detailed COQ framework is identified and compiled from every category, every element to every subject with clear definitions including scope, statistical approach, functions involved. In practice, a company-level document named COQ Control Procedure is developed to depict its COQ categorization, detailed definition of every subject and responsibilities of involved functions. The traditional and typical COQ subject, incoming inspection of appraisal costs is taken as an example for explanation. The expense used for incoming inspection comprises sample parts expense, depreciation of tools and equipment for incoming inspection, wages of staff being engaged into incoming inspection and expense of office supplies for incoming inspection. Meanwhile, financial function is defined as the statistic and report department. Due to limited space, items of category, element and subject are shown in Table 1. It should be noted that different organizations have different business natures and then make different decisions in terms of COQ categorization and related definitions.

Though Company D did not build COQ system before the campaign, its basic data related to COQ system were complete comparatively and just not categorized, summarized in accordance with the subjects of COQ system. Hence, it is fluent for data collection, statistics and summary of every subject, and also to report whole COQ system when it is established and integrated into existing accounting system in four months.

3.4. Closed-loop analysis & improvement mechanism

As the novelty and innovation, the methodology is not constrained by the traditional categorization of COQ. After building and running COQ system, following priority is

Table 1: COQ Framework.

Category	Element	Subject
Prevention Costs(PC)	Market PC	Research & Survey
		Contract Audit
		Customer Maintenance
	Design PC	Research & Development (R & D)
		R & D Audit
		Test
		Testing Equipment
	Purchase PC	Supplier Development
		Supplier Training
	Production PC	Training
		Equipment Maintenance
	Quality Management PC	Wage
		Training
		Correction
		Team Building
		Bonus
		3rd Party Certification
Appraisal Costs (AC)	Purchase AC	Incoming Inspection
		Audit
		Incoming Inspection Equipment Maintenance
	Production AC	Internal Inspection
		External Inspection
	Inventory AC	Inventory Inspection
	Pre-delivery AC	Pre-delivery Inspection
	External AC	Material
		3rd Party Calibration
Internal Failure Costs(IFC)	Design IFC	Re-design
		Re-work
		Scrap
	Purchase IFC	Purchase Return
		Downtime
	Inventory IFC	Overdue Inventory
		Inventory Maintenance
		Capital Turnover
	Production IFC	Rework, Repair and Concession
		Scrap
		Downtime
		Trouble-shooting and Correction
	Before -in-service IFC	Before-in-service IFC
External Failure Costs(EFC)	Warranty	Compensation
		Service
	Degrade	Degrade
	Recall	Recall
	Severe Quality Issue	Compensation
		Liability Claim
	Intangible Loss	Intangible Loss

Table 2: COQ Subject Statistical Comparison.

Month	Subject	Month-on-Month	Year-on-Year	Target Comparison
Nov.	Single Month Trend Chart on Scrap	-3.88%	*13.79%*	-1%
	Year-to-Date Trend Chart on Scrap	N/A	-19.47%	-9%

not just to collect and summarize the data of every COQ subject repeatedly but to establish data-driven closed-loop analysis & improvement mechanism that is used to seek improvement opportunities, which are taken into project management consisting of root cause analysis, schedule monitoring, effectiveness verification, etc. Additionally, deeply impressed with the views of Braun and Han [6], and also Liker [10], it is emphasized that simple charts and universal management tools such as bar or pie charts, Pareto diagrams, Gantt Charts, etc. shall be utilized at all steps in the campaign in order to assure clear data visualization and operation both available and understandable for all participants, including operators.

Firstly, statistics are conducted concerning every subject of COQ on the basis of the monthly comparative analysis by month-on-month (only single month) and year-on-year (both single month and year-to-date), as well as target comparison (also both single month and year-to-date). In the meantime, negative variation of 10% is set as the trigger-limit to identify improvement opportunity, which will be the input of improvement projects after project feasibility analysis. The model of comparative statistics is shown in Figure 5, Figure 6 and Table 2 (Scrap in November as example is presented for better illustration).

From Table 2, it is evident that the italic figure of 13.79% meets the above rule of being more than the trigger-limit of 10% as negative variation, which means that project feasibility shall be launched with respect to the scrap improvement on November.

At the same time, in terms of failure costs, apart from the above monthly comparative analysis, every subject's statistics is carried out making use of Pareto diagram in a variety of dimensions depending on different failure costs subjects. For every statistical outcome with Pareto diagram, top 3 issues as improvement opportunities are screened into project feasibility analysis. For example, the scrap every month is statistically analysed in accordance with failure modes, processes and operators visualized with Pareto diagram, and then top3 issues could be listed from the perspective of failure modes, processes and operators for further project feasibility analysis.

The statistical summaries mentioned above are necessary for COQ improvement campaign. In practice, including following project improvement, other universal tools such as fish-bone diagram, C&E, as well as failure tree, etc. are used for analysis when necessary. It is required that through synchronized statistical analysis, the statistics shall fully cover company, business divisions, workshops, teams, individuals to make sure collected and analysed data complete and objective so as not to miss improvement opportunities. As previous indicated, it is certain that not all improvement opportunities

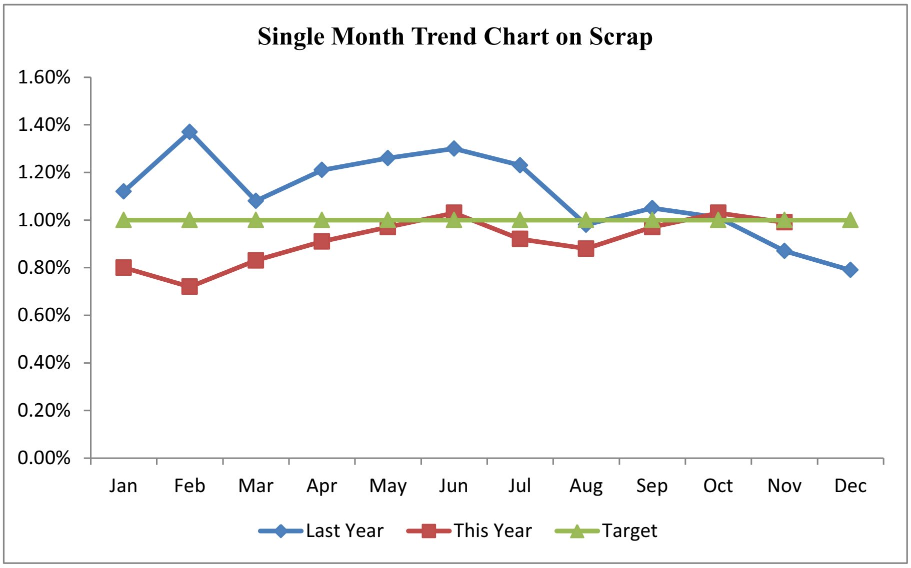

Figure 5: Single Month Trend Chart Model.

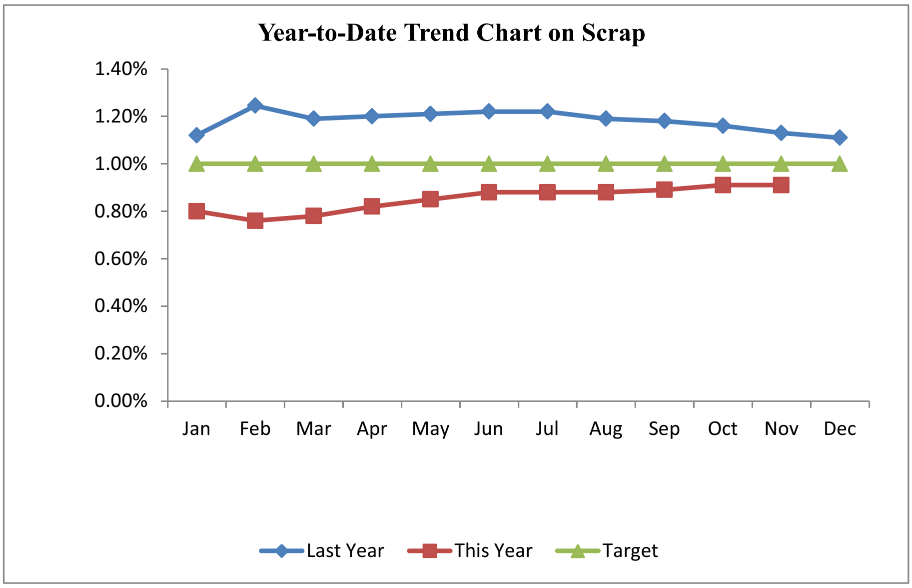

Figure 6: Year-to-Date Trend Chart Model.

are defined as projects, which will be further classified into two levels, namely division level and company level. Based on related benefit and expense, all detected improvement opportunities and projects are weighed to ensure the effectiveness and efficiency in the light of Risk Prioritization Rule (RPR). Essentially, different RPRs have different limitations due to the complex nature of the different organizations. It is recommended here that the RPR company D adopts emphasizes that the risk assessment shall be executed from severity, financial, resource and schedule..

Secondly, project leader is designated to implement issue definition for the identified improvement opportunity that is approved as project through project feasibility analysis and take action in accordance with 7-step. It needs to be highlighted that with COQ analysis outcome mentioned the above, the point of first step is to specifically define the issue and propose reviewed improvement target relative to COQ reduction as well as deadline of every step. After filling in the model shown in Figure 7, project leader submits it to the Information Management Platform for special track and monitor. All projects will be formally reviewed when applying for project closing from following aspects:

- Actions being implemented or not.
- Target relative to COQ reduction being achieved or not.
- Failures recur or not.
- Verified actions being developed into related written documents or not.

Project leader returns to the phase of COQ comparative statistics for re-analysis when failing in project closing review.

Project Name:********* Update Time:**/**/****
Project Leader:*** Current Status: Step*
Starting Time:**/**/****

1. Issue Definition	
Description	
Target	
Deadline	**/**/****
2.Risk Assessment	
Containment(When necessary)	
Deadline	**/**/****
3.Short-term Measure	
Deadline	**/**/****

4.Determine Issue & Failure Cause	
Possible Cause	
Root Cause	
Deadline	**/**/****
5.Effect Verification	
Deadline	**/**/****
6.Measures Consolidation and Track	
Deadline	**/**/****
7.Project Closing	
Approved by	
Deadline	**/**/****

Figure 7: 7-Step Model.

In short, the methodology of COQ management in Company D is not simple data collection or statistics but a highly data-driven closed-loop analysis & improvement with the philosophy of PDCA as below Figure 8:

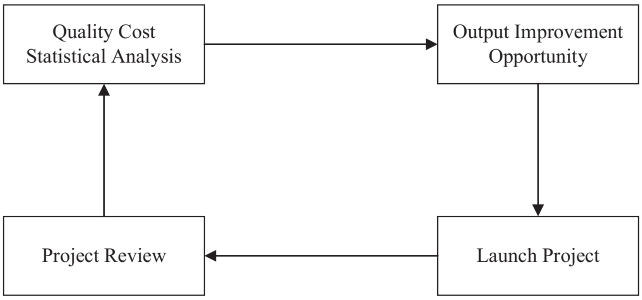

Figure 8: Closed-loop Analysis & improvement.

In company D, the closed-loop analysis & improvement mechanism is named as "Prevent Recurrence Mechanism", which also focuses on that through root cause analysis (RCA), preventive actions are implemented effectively to prevent recurrence of failures. Of course, what matters is not the name of mechanism but to be persistent in closed-loop improvement with PDCA philosophy and root cause analysis when improvement.

3.5. Effect

As the effect illustrated in Figure 9, it is obvious that for two consecutive years,

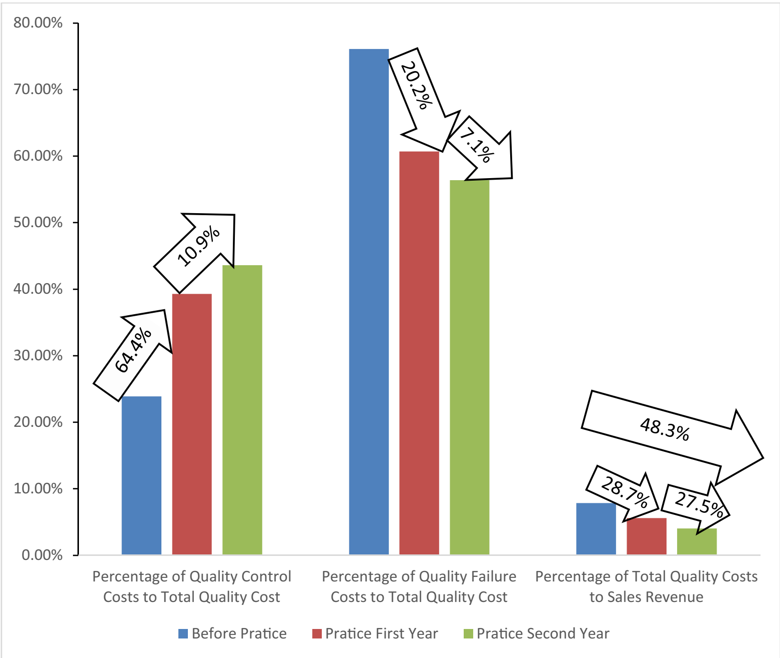

Figure 9: COQ Comparisons Before-and-After Campaign.

percentage of quality control costs to total quality cost rises and on the contrary, percentage of quality failure costs to total quality cost falls. Especially in the case of quality control costs rising, percentage of total quality cost to sales revenue falls sharply year by year with decline of 28.7% the first year and 27.5% the second year, which means that total decline of 48.3% in two years nearly meets the objective of falling 50% a year in advance. All variation trends of quality control costs, quality failure costs and total quality cost are highly in line with related curves in area I of Figure2, which fully proves COQ management theory illustrated previously.

Because of being originated from improvement actions that are highly based on COQ statistics and closed-loop improvement, increased prevention and appraisal costs are tremendously specific to the newly investment in error-proofing systems and measurement instruments used for detecting, preventing defects in advance in order to improve quality assurance capability and product quality rapidly, as well as reduce failure costs greatly.

Also through the COQ campaign, a large quantity of improvement opportunities are identified and improved in the following management functions to further improve the suitability, adequacy and effectiveness of company quality management system.

- R & D
- Purchasing
- Manufacturing Engineering
- Logistic
- Sales & Marketing

All these efforts and performances in two years make sure that company D achieves big competitive advantage and enhances tremendous customer satisfaction with sufficient evidences as below:

- Resulting in significant increase in market share, for example, market share in a global diesel engine OEM from 15% up to 100%.
- Having become suppliers of Benz, Volvo, Nissan, BMW, etc.

Additionally, with increased appraisal costs, there is a great deal of investment in measurement instruments including lots of precision measurement and testing apparatuses. Simultaneously, in company D, a Laboratory Center is installed, in which all these apparatuses are managed in accordance with ISO17025 while building COQ system. Two years later, Laboratory Center obtains the certificate of conformity issued by China National Accreditation Service for Conformity Assessment (CNAS), also the member of International Accreditation Forum (IAF) and International Laboratory Accreditation Cooperation (ILAC), which not only brings company D greater social benefit but also boosts customer loyalty.

In summary, the economic model from practical COQ campaign is developed as below Figure 10. Being different from the above Figure 2, this model illustrates the trends of prevention, appraisal, internal failure and external failure costs economically. As a matter of fact, the economic model further validates COQ theory vividly.

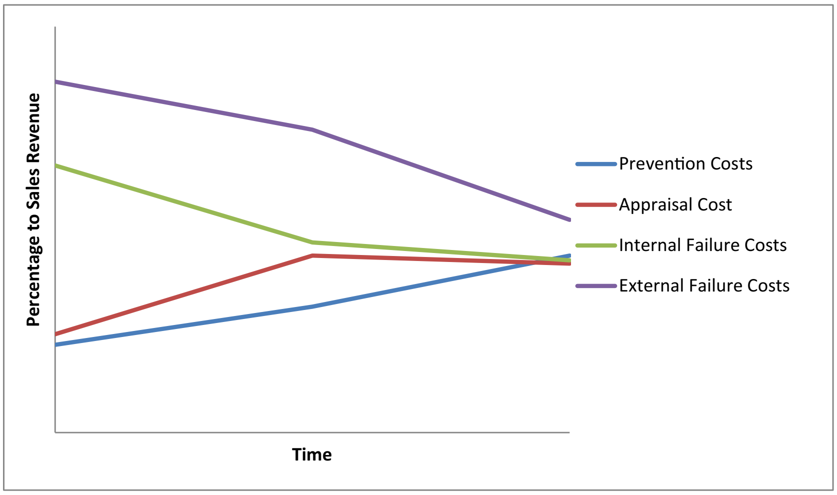

Figure 10: Economic Model from Practical COQ.

In addition, summarized social performance is displayed as below Figure 11.

Figure 11: Social Performance from Practical COQ.

4. Conclusion

The theory of COQ provides theoretical framework and reference for organization to build COQ system. As shown in the above literature review, there are lots of similar researches concerning COQ. However, the methodology this paper elaborates has its own novelty, innovation and advantage. As to the campaign in company D, after building COQ system, what is focused on is not the typical statistics and report of COQ but the effective tracking and improvement mechanism embodying closed-loop management philosophy so as to seek optima approach for the company to control COQ. Namely, wastes of man, machine, material, method, measurement and environment are identified and eliminated continuously in the company. Ultimately, all these activities maximize the value of COQ control through ensuring targeted increase of prevention costs and dramatic decline of failure costs in the company. Economically, the percentage of total quality cost to sales revenue falls by half basically a year in advance. Because of the great economic and social performance, top management of company D is so impressed with the benefits that it provides tremendous support to the cross function team which makes continuous efforts to further optimize COQ system. When planning in the beginning of the campaign, it is emphasized to use universal, clear and simple management tools as work models at every step in the whole campaign to make sure all management and improvement activities quick and efficient, all operations simple and easy, as well as all visualizations clear and concise. Because of its practicability and acceptability, it is of great value to be applied and popularized to other enterprises in the industry.

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