The impact of Tolerance Limit on Cost of Quality

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Abstract – In this paper, the recommended extensions by Chiadamrong [1] was successfully adopted and significant modifications was proposed when computing costs of quality model in a manufacturing system In the literature shows that there is strong connection exist between the tolerance designs with the quality characteristic of a product and the cost associate in achieving the specific quality of the product. With the intention of utilizing the reciprocal power model in determine the relation between the tolerance and the cost, the tolerance has to be converted and set to a standard value at different confidence level. The proposed costs of quality model was tested using real life data obtain from the industry and through simulation works, the results was generated.

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Keywords – **cost of quality, simulation, tolerance limit**

I. INTRODUCTION

The importance of cost of quality has been reported in many research works, Giakatis *et. al.* [2] reported that cost of quality represents considerable portion of company's total costs. Even though the importance and impact of implementing cost of quality systems on increasing profit of any organization is obvious, Yang [3] reported that the literature on cost of quality systems implementation indication that most of companies do not know the true cost of their own quality. This is due to the fact that many of the significant quality related costs cannot be captured by most types of accounting systems. Chen and Yang [4] related the difficulties to measure cost of quality to the fact that there is a lack of adequate methods for determining the financial consequences of poor quality. It can be concluded that, without having any effective method is measuring cost of quality, there will be no effective way to control the quality. Therefore the prerequisite in order one to used the quality cost system and experienced the benefits of implementing costs of quality, one has to quantify the cost of quality first (Krishnan et al., [5]).

In current growing industry, manufacturers are focused in producing products which are better in quality with lower cost and flexible towards the changes in manufacturing conditions along with customer demand. As the customers' demands can vary beyond expectations; productivity, quality and flexibility have become crucial elements for manufacturers to measure the performance of their manufacturing systems. From the previous study reported in the literature shows that there is strong connection exists between the tolerance designs with the quality characteristic of a product and the cost associate in achieving the specific quality of the product. This is due to the fact that throughout the designing of the tolerance the manufacturing designer has to keep in mind that the tolerance design must be able to detail the performance level in certain criteria in order to meet the prerequisite of the quality characteristic.

Manufacturing engineer prefer to aim for wider tolerance limit since wider tolerance limit reduce the level of difficulty in producing and processing a product. Therefore the manufacturing cost (quality related cost) involved in producing the product will be reduced significantly compare to the cost associate in designing tighter tolerance limit as mentioned in the functional requirement point of view. But one must bear in mind; wider tolerance limit will incurred high variability in quality characteristic of the product which will lead to poor quality and high quality loss. In the mean time, tighter tolerance limit will produce lower variability in quality characteristic of the product which will lead to good quality product, lower quality cost but increases significantly the manufacturing cost. Therefore the challenge face by the manufacturing engineer when designing tolerances design is to satisfy both factors, the product produce should not have larger variability and in the same time the manufacturing cost associate in producing the product should be at a minimum level.

The relation between the cost and the tolerance are inversely proportional. With the intention of utilizing the reciprocal power model in determine the relation between the tolerance and the cost, the tolerance has to be converted and set to a standard value at different confidence level.

This paper takes a special interest in the model and process described by Chiadamrong [1] where it attempts to extend and improvised the deficiency of the developed model. This paper is organized in the following way; model development of cost of quality model, followed by the problem and solution methodology, results and discussion and finally conclusion.

II. THE QUALITY COST MODEL

In this section, we briefly explain the cost of quality model developed in a manufacturing environment which we believe to be more realistic and accurate cost than current accounting approach.

A. Notations

COA (i)	Cost of accepting the sample of product i
COR (i)	Cost of correcting the sample of product i
NP_{nrm} (i)	Number of normal product of product i
NP_{rwk} (i)	Number of rework product of product i
$E(C_{AQ})$	Expected acceptance sampling cost
$E(C_{PIQC})$	Expected production invisible quality cost
$E(C_{mat})$	Expected material cost
$E(C_{m/c})$	Expected machine cost
$E(C_{lb})$	Expected labor cost
$E(C_{m/h})$	Expected material handling cost
$E(C_{fr})$	Expected failure repairing cost
$E(C_{OC})$	Expected opportunity cost
$E(C_{setup})$	Expected setup cost
$E(C_{idle})$	Expected idle cost
$E(C_{inv})$	Expected inventory cost
$E(C_{wc})$	Expected waiting cost
$E(C_{efc})$	Expected external failure cost
$E(C_{VQC})$	Expected visible quality cost
$E(C_{Prevention})$	Expected setup cost
$E(C_{Appraisal})$	Expected appraisal cost
$E(C_{Failure})$	Expected failure cost
$E(C_{pr})$	Expected preventive maintenance cost
$E(C_{pc})$	Expected process control cost
$E(C_{pi})$	Expected product inspection cost
$E(C_{dev})$	Expected cost of deviation
$E(C_{COQ})$	Expected total costs of quality

B. Description of the model

The process considered by this paper consists of several operations linked together forming a network of processes in series which is a typical configuration in many manufacturing environments. The product passes through two different processing stations in parallel and in series. Inspection on the product is performed immediately after each processing station. An incoming inspection is done upon receiving the lot from the previous manufacturing unit for both processing station to investigate on the incoming quality of the product before it is send for processing. During the incoming inspection, tests are carried out to ensure the quality of the product whether the lot of the product should be accepted or rejected. For the rejected lot, the lot will be sent for 100% inspection, where the lot is inspected thoroughly and the defect products will be either reworked or scrapped.

A EWMA-type of control chart is used to monitor the process over a period of time and it is assumed that a state of statistical control has been established for a certain period that is sufficient enough to provide constant estimation of various time and cost parameters. Two types of inspection error are considered during the manufacturing process. A Type I error (misclassification a good product as a bad product) and Type II error (misclassification a bad product as a good product). It is assumed that the misclassification error is identical from one processing station to another processing station and it is independent.

An acceptance sampling is performed in between the process of finished product and shipping (output). The purpose of implementing this inspection is to check the quality of the finished product before it is passed for shipping and this is done by setting few criteria that the finished product must meet.

We assumed non-destructive tests throughout the manufacturing process where the numbers of product are remains as N sample products.

C. Production Invisible Quality cost calculation

These are the activities that have significant affect from poor quality and these activities are expressed in the form of monetary value. This component consists of material costs, machine costs, labor costs, material handling costs, failure repairing costs and finally preventive maintenance costs. The expected material costs consist of direct and indirect material. The part that detected to be defective is sent for reworking and the material that cannot be reworked is sent to scrap and resold. There are possibilities in rejecting a good part of materials which corresponded to misclassification error. The expected machine costs consist of the costs of utilities (power and fuel), cost of operating the product, insurance and property for manufacturing equipment operation. The expected labor costs are basically the cost associate to direct and indirect labor which is involved in production activities. Besides that, this cost also includes the wages and salaries that are given to direct and indirect labor. The expected material handling costs consists of the cost involved in transporting the product from one station to other station according to the consecutive order. The expected failure repairing costs occur due to machine breakdown caused by products that jammed in the machine during manufacturing process. The machine has to be stopped in order to remove the jammed product from the machine and then the machine has to be reset or repaired. The expected production invisible quality cost;

$$E(C_{PIQC}) = E(C_{mat})+E(C_{m/c})+E(C_{lb})+E(C_{m/h})+E(C_{fr}) \quad (1)$$

D. Visible Quality cost calculation

Visible quality costs are simply the costs based on Feigenbaum [6] and known as the P-A-F model which consist of prevention, appraisal and failure costs. The expected prevention costs consist of process control and preventive maintenance cost. The expected process control costs are the cost associated when monitoring the manufacturing process in an effort to reduce variation and build quality into the product. The design of a control chart has economic consequences that are the costs of sampling and testing, sub-group inspection costs, costs associated with investigating out-of control signals and possibility in correcting assignable causes and the costs of adjusting the machine back to normal conditions so that the production can be continued. When there is a signal showing that the product specification is out of control limit, costs of scrapping or reworking are incurred. The expected preventive maintenance costs are associated with a list of planned maintenance actions need to be taken in order to prevent machine breakdowns and failures. This activity is very important in order to make sure that the machine is always in a good condition and preventing it from producing non-conforming products. The expected appraisal cost consists of acceptance sampling cost and product inspection cost. The expected acceptance sampling costs are contributed by the acceptance sampling inspection carried out during the manufacturing process. The expected product inspection costs are the costs of checking the conformance of the product throughout its various stages in manufacturing system. The expected failure costs consist of cost of deviation. The expected cost of deviation is the costs associated when the product deviate from their design target m, and also the costs deviate due to late delivery schedule. The costs of deviation are utilizing the Taguchi concept where the costs of deviation are divided to three main areas that are scrap zone, acceptable zone and the rework zone.

$$E(C_{VQC}) = E(C_{Prevention})+E(C_{Appraisal})+E(C_{Failure}) \qquad (2)$$

E. Opportunity cost calculation

Opportunity costs are the potential profit that lost or scarified when the choice of action requires giving up an alternative course of action. This component consists of setup costs, idle costs, inventory costs, waiting costs and finally external failure costs. The expected setup costs are the cost associated in preparing and setting up the machine for new production run. The expected idle costs are the costs associated due to the inefficiency consuming the available resources. The expected inventory costs consist of the cost of carrying or shortages inventory. The main element that contributes to inventory cost is the amount of raw material supplied and finished products. In the same time the space taken to keep the inventory should also be taken into account. The expected waiting costs are the cost associated with parts that are waiting for service somewhere in the manufacturing processes. Waiting cost can be divided into two components, which are during in process (waiting for the part to be complete) and also during the completion of the process (waiting for the whole batch to be completed). The waiting cost includes the work-in-process cost inventory. The expected external failure costs are the cost encounter when the quality of the product did not meet the specification set after the product is ship to the customer. It constitute to loss of opportunity cost. In particular, when the defective product is returned or rejected, it will affect the company reputation where the company might face loss of sales. The expected opportunity cost.

$$E(C_{OC}) =E(C_{setup})+E(C_{idle})+E(C_{inv})+E(C_{wc})+E(C_{efc}) \qquad (3)$$

Hence, the total cost of quality can be represented by summing up all the cost components (1) through (3) and is presented by equation 4.

$$E(C_{COQ}) = E(C_{PIQC})+E(C_{OC})+E(C_{VQC}) \qquad (4)$$

III. THE PROBLEM AND SOLUTION METHODOLOGY

The manufacturing system considered by this paper consists of three successive stations where they are operating to produce a single product. A simulation model of the manufacturing system was built in @Risk spreadsheet simulation software in order to determine the efficiency of the proposed cost of quality model. When building the proposed model in the simulation. There were few assumptions applied to the model. The assumptions made are as follow: Proportion of non-conforming unit (defect rate) is assumed to be normally distributed. Type I and Type II error are normally distributed. The probability of accepting the sample is binomially distributed. The time taken to process the parts for both stations is assumed to be the same. The process is considered as non-destructive process. Products which have completed one station are transported to the next station using forklift trucks. It is assumed that the acceptable quality level for inspecting the batch size is 0.5% for the first station and 0.1% for the second station.

In this paper a real life industry data was used. By using the mathematical model proposed from (1) to (4), the expected total costs of quality can be calculated.

IV. EXPERIMENT DESIGN

In designing the experiment, we are interested in applying the quantified costs of quality model which has been developed. The planning horizon for the manufacturing process is assumed to be monthly (T=1 month). Hence the simulation time is 43200 minutes. The simulation is replicated 30 times so that every trail will run for 1440 times of simulation runs (see Table 1) represents the daily manufacturing activities during the planning period. At the entering inspection point, the acceptable quality level (AQL) was set by the quality control department to be 0.5% of the lot size where the maximum allowable defect products are subjected to 5 defect products. On the other hand, for the outgoing inspection point, the acceptable quality level was set by the quality control department to be 0.1% of the lot size where the maximum allowable defect products are subjected to 2 defect products. It is assumed that the company receives a lot size of 5000 products. The simulation work is then carried out to calculate the costs associated with quality. In addition, since verification of the model is very important issue to be done when dealing with simulation work, we have used the real life data obtain from real life industry and run the simulation model and the result obtains from the simulation model is compare with the manual calculation. Both results exactly matched and that indicates that the simulation model is free from any illogical error and has been verified. Once the simulation model has been verified, next the model has to be validated. The simulation model can be validated by comparing the result with previous study by other researchers. The result generated from the simulation model is corresponding with the previous study. Hence the simulation model has been verified and validated. Table I is presented at the end of this paper.

V. RESULTS AND DSCUSSION

Since we are using simulation tool to allow the user to subject the manufacturing level with different quality level and tolerance design that can be used to investigate the impact on cost of quality, hence we consider that it will be great idea to place it here. Higher optimization indicates to higher quality level. Table II shows the result generated from the simulation tool on the quality related cost with respect to different tolerance limit at different quality level.

The conformance cost in Table II are the cost associate in improving quality level of the product and this cost consist of prevention and appraisal cost whereas the nonconformance cost are the cost associate in correcting the defect product which fail to meet the standard requirement and this cost consist purely on failure cost (production invisible quality cost, opportunity cost and finally cost of deviation). The result generated in Table II shows that as the tolerance limit become tighter the cost of quality associate in meeting this specification increases significantly.

The failure rates of the product at different processing station were generated using the simulation tool. The result shows that as the tolerance limit becomes wider the number of defect product generated also increases. This is because wider tolerance are subjected to high variation on the product hence the quality of the product produced are poor although the cost associate to it are less. The condition is different when it involved smaller tolerance limit, the number of defect product generated are smaller. Since the variation of the product from the specification limit set are small. Therefore the quality of the product produced is good but the cost associate to it is very high since it requires more quality control activity.

To have a clearer view on how these tolerance limits interact with each other, a graphical form is presented so that readers can see the interaction between the tolerance and cost of quality. The graphical form of the result is presented in Fig. 1 at the end of this paper.

From Fig. 1, it shows that the costs are exponentially distributed with the tolerance limit. The coat associates to conformance activity are lower compare to the cost subjected to non-conformance activity. Therefore the model can be assumed still reliable since the cost associate in improving the quality is lower compare to the cost associate in repairing poor quality. From the figure it shows that the costs are decreasing significantly as the tolerance limit increases. One must bear in mind there is no point dealing with wider tolerance just to save the cost but the fact that the product produced is subjected to poor quality level. Therefore we have to determine the optimum tolerance limit where it satisfies the condition that the output quality of the product should be good and in the same time the cost associate to it are at minimum level.

The proposed model were run to determine the optimum level of the tolerance limit, the result generated shows that the optimum level could be achieve at the tolerance limit, 20. At this level, the quality of the product produced is considerably good and the cost (quality related cost) associate in producing it is at the minimum level.

VI. CONCLUSION

In this paper, we have successfully adopts the recommended extensions by Chiadamrong [5] and proposes significant modifications such as the element of misclassification error and tolerance design towards more reliable modeling approach for computing costs of quality in a manufacturing system. From the result obtain we can conclude that tolerance limit have significant impact on the output of the cost of quality.

As for suggestion the proposed model may be subjected for testing using different case of managerial quality control decision scenarios to investigate the impact of quality control decisions on cost of quality for the future work. Besides that the proposed model can be expanded to large scale simulation run

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TABLE I

THE SIMULATION RUNS OF THE PROPOSED MODEL

Classified element of COQ	Tolerance limit						
	5	10	15	20	25	30	35
Production invisible quality cost	1440 runs	1440 runs	1440 runs	1440 runs	1440 runs	1440 runs	1440 runs
Opportunity cost	1440 runs	1440 runs	1440 runs	1440 runs	1440 runs	1440 runs	1440 runs
Visible quality cost	1440 runs	1440 runs	1440 runs	1440 runs	1440 runs	1440 runs	1440 runs
Total cost of quality	1440 runs	1440 runs	1440 runs	1440 runs	1440 runs	1440 runs	1440 runs

TABLE II

TOTALCOSTS OF QUALITY AT DIFFERENT TOLERANCE LIMIT

	Tolerance limit						
Cost of quality (MU)	5	10	15	20	25	30	35
Conformance cost	120854.92	35164.35	18841.06	11262.4	7988.15	6087.24	4854.63
Nonconformance cost	137695.15	41489.22	22175.79	14050.39	10534.15	8449.50	7141.65
Total cost of quality	258550.07	76653.57	41016.85	25312.82	18522.30	14536.74	11996.28

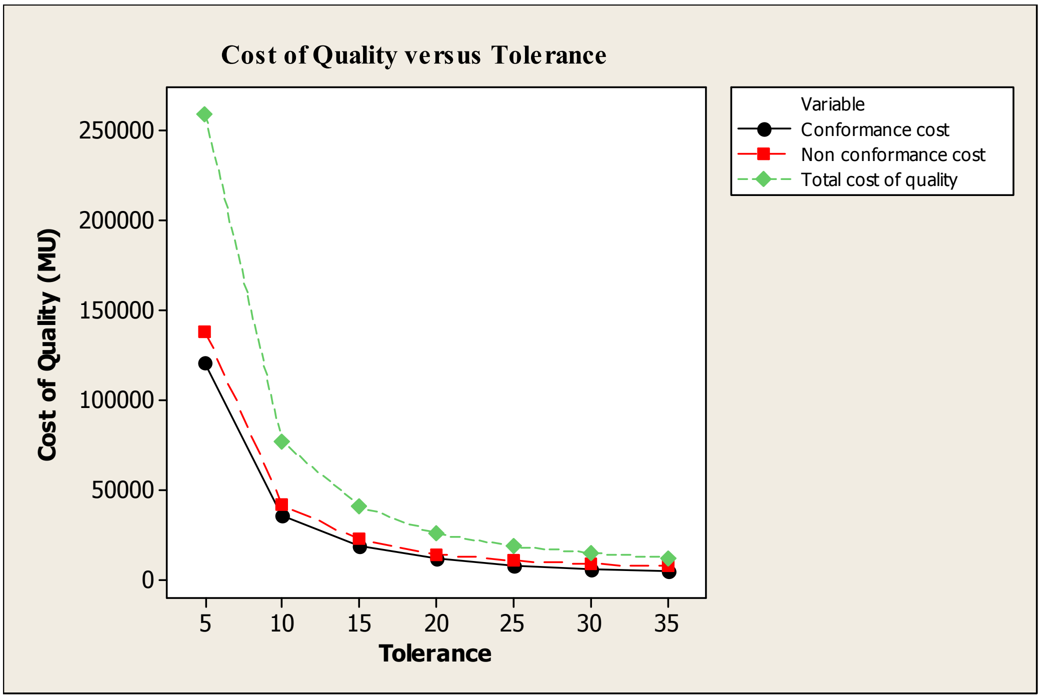

Fig. 1: Total cost of quality of the manufacturing system