A system dynamics approach to model cost of quality in a supply chain

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Abstract:

The objective of this paper is to build a cost of quality (COQ) model operating within supply chain (SC), which also incorporates opportunity cost (OC). The model allows studying the relationships between the COQ elements (including OC) at different quality levels. System dynamics is used as the main approach in this study. The COQ model is built based on the Prevention-Appraisal-Failure (PAF) concept while Opportunity Cost (OC) is integrated into non-conformance cost category. The simulation using Vensim software is carried out to study the effects of the COQ elements and OC on the numbers of new customers in the SC. The findings of this research show that the number of new customers in SC decreases when OC is considered in the model; however, an investment in conformance costs is recommended to increase the number of new customers, which consequently will reduce the non-conformance costs. However, in reality, tracing opportunity cost is challenging, because it depends on the customer satisfaction which is not easy to capture and quantify. The study derives the level and the dynamics of the customer satisfaction from a survey and may thus suffer from some inaccuracies.

Keywords: Supply Chain, Cost of Quality, PAF Model, Opportunity Cost, System Dynamics.

1. Introduction

Quality has been long recognized as an important factor in the decision making of the consumers when selecting among the variety of the products on the market. But it is not only high quality which customers require, it is high quality for low price which attracts them and which will thus ultimately enable companies to outshine the competition. In order to gain the customers on their side organizations and businesses' owners must therefore consider not only the level of quality of the products they are producing and offering to the market but also the cost for which such quality can be achieved. Integrating tools such as Cost of Quality (COQ) in their accounting systems can hence help companies to minimize cost and at the same time to attain better customer satisfaction. However, the concept of identifying COQ elements and implementing COQ model is not very straightforward and there have been some differences about what these costs comprise (Machowski & Dale, 1998). Tsai (1998) states that there is no general technique on how to allocate expenses to COQ elements and no satisfactory method to trace quality costs to their sources. Quality costs are defined by the British Standard (BS 6143 Part 2, 1990) and American Society for Quality Control (ASQC, 1971) as those costs that assure and ensure quality plus the loss incurred when quality is not achieved. In the past, quality costs were mainly connected with inspection and testing, and usually these costs were part of overhead costs. 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 them with a matching cost in order to be able to reduce total costs and increase benefits. Therefore, the cost of quality can be considered as a tradeoff between the cost of conformance and the cost of non-conformance (Schiffauerova & Thomson, 2006). After Juran (1951) discussed the cost of quality, many researchers have proposed different approaches and models to measure COQ. Several authors, such as Plunkett & Dale (1988), Kumar et al. (1998), and Schiffauerova & Thomson (2006) provided a review of various COQ models and approaches. In literature, the Prevention-Appraisal-Failure (PAF) model is considered to be the one most commonly used. PAF model has obtained general acceptance amongst different researchers and organizations, such as ASQ. COQ integrates the implications of poor quality, quality improvement efforts and hidden quality costs and translates them to understandable monetary terms to all stakeholders of the organization (Castillo-Villar et al., 2012). COQ measurement is mostly implemented for a specific organization or business, and although there are numerous cases of COQ measurement and its implementation in organizations individually, there are few studies which attempt to measure COQ in the whole supply chain (SC) network. Srivastava (2008) was the first author who combined COQ in SC performance measurement. He defined COQ in SC as: "the sum of the costs incurred across a SC in preventing poor quality of product and/or service to the final consumer, the costs incurred to evaluate and ensure that the quality requirements are being met, and any other costs incurred as a result of poor quality" (p.194). Srivastava was able to measure COQ in SC of a pharmaceutical company.

Opportunity cost (OC) is conventionally defined as the difference between an investment one makes and another one which he/she chose not to make, i.e. benefits that are not earned as a result of pursuing another alternative (Son, 1991). Most of traditional costing systems represent quality costs as those costs are easily seen and monitored. Nevertheless, OC does not characterize true money, thus it is excluded from the company's book. So far OC did not gain much interest in the COQ research literature, because most empirical studies have failed to find a way how to express them. Most quality costs are in fact hidden and not easy to be measured (Krishnan, 2006; Wood, 2007). However, ignoring OC leads to a value of zero in the accounting systems, and this is definitively not an accurate estimate for these costs (Chiadamrong, 2003) and can result in wrong conclusions and losses for the company.

In the literature, the effects of the opportunity costs are rarely considered in the COQ models. Moreover, COQ is usually measured and analyzed within one company and the effects of SC are thus ignored. The consideration of both OC and the SC effects in the COQ model makes this research very original. The overall objective of this paper is to incorporate the OC into the PAF model and to evaluate the costs in the SC. The OC represents customer's satisfaction and it will be represented as a monetary term in the model. The created model will be used to investigate the feasibility of investing in the cost of conformance, prevention and appraisal (PA), and the effect of this investment on the cost of non-conformance, failure (F) and OC. A case study for a manufacturing SC located in North Africa will be used to collect the data to better understand the relationships, and to describe and validate our model. The rest of this paper is structured as follows: Section 2 provides a literature review on the COQ. Section 3 discusses the research methodology. Section 4 discusses the results. In Section 5, the relevant conclusion is explained, and finally, suggestion for future studies are provided in Section 6.

2. Background and literature review

The importance of quality derives from the fact that it greatly affects customer's decision about the purchase of any product. The differences among various products can thus be identified by the quality and its cost. Over the past thirty years there has been an aggressive battle among companies trying to provide quality for the lowest possible cost, and, consequently, only those who succeeded survived. In today's market, the quality differences became a critical element in competition (Bowbrick, 1992). Therefore, a clear definition of the COQ for any product is necessary for effective operation and competition (Ben-Arieh & Qian, 2003). Even though the definition of quality costs is crucial for measuring the quality itself, there is no unique and generally accepted definition, as different authors define quality costs in different ways (Chiadamrong, 2003; Dennis, 1999; Evans & Lindsay, 1999). Accordingly, sum of the total quality costs represents only a small portion of the total cost. According to Srivastava (2008), COQ or quality costs can be defined as a measurement system that translates quality related activities into a monetary language for managers, i.e. it is the sum of costs incurred to ensure that the quality requirements are being met. There are different estimations of total costs of quality in the literature, for example, Kent (2005) estimated them between 5-15% of turnover for companies in Great Britain. Crosby (1984) between 20-35% of sales for manufacturing and service companies in the USA, and Feigenbaum (2001) at 10% of revenues. Since these are relatively small percentages, managers tend not to give importance to the quality costs (Chiadamrong, 2003). Nevertheless, Schiffauerova & Thomson (2006) have highlighted the savings achieved through the COQ employment in various companies. As examples of published success stories, ITT Europe headquartered in Belgium has saved over $150 million during five years of coping with quality cost control (Groocock, 1980). Hagan (1973) and Morse et al. (1987) described huge savings related to reducing COQ for ITT New York, United Technologies Corporation. Essex Telecommunication Products Division established COQ measurement and reported that after five years of implementation the productivity increased by 26%. Thompson & Nakamura (1987) have collected and reported COQ data from several development projects at AT&T Bell Laboratories, Transmission System Division and confirmed that managing COQ in the R&D process is a viable way to improve product development. In general, it is expected that the total cost of quality will decrease if the organizations implement a strong quality cost system, and the external failure costs will decrease too as a percentage of total COQ. Schiffauerova & Thomson (2006) claimed that a number of organizations and companies have recently been keen on getting information on the theoretical background of quality related costs, and are seeking practical evidence about the implementation of quality costing system as well. Several research studies reviewed the COQ models and approaches, which were used in the literature, such as Plunkett & Dale (1988), Kumar et al. (1998), Schiffauerova & Thomson (2006) and Plunkett & Dale (1988). They are all generally in agreement with classifying COQ models into the following generic groups which are: PAF (prevention-appraisal-failure) or Crosby's model, opportunity cost models, process cost models and ABC models. The next section will describe the PAF models and its concept.

2.1 PAF models

Feigenbaum (1961) was instrumental in proposing quality terms, and he also classified the quality costs into three widely accepted broad categories, which are prevention, appraisal and failure (PAF). The PAF model involves the costs coming from three sources of activities, which are defined in the British Standard (BS 6143, 1990) as follows: Prevention costs (P) are the investment made to prevent and reduce the risk of nonconformity or defect, such as, quality planning, process control costs, and training and general management costs. Appraisal costs (A) are the cost of efforts made to achieve conformance to requirements including, for example, test and inspection costs, and instrument maintenance costs. Failure costs (F) are the efforts exerted to correct a non-conformity that has occurred before or after delivery to the customer. Failure costs are thereby classified as internal failures and external failures, where internal failure costs are incurred within an organization due to nonconformities or defects at any stage of the quality loop, such as, costs of scrap, rework, retest, re-inspection and redesign, whereas external failure costs represent costs which arise after delivering poor quality to a customer/user due to non-conformities or defects, such as, cost of repairs, returns, dealing with complaints, and compensations.

Juran's model is the most common model in the literature, which is widely used in manufacturing industry due to its easy interpretation (Jaju et al., 2009). He claims that in order to obtain the lowest rate of COQ, failure costs should be equal to prevention and appraisal costs (Juran, 1951). This can be realized in the trend graph in Figure 1. However with the increase in the organization complexity these costs are increasing as well, and their cost elements may become unclear and more difficult to be captured. Cheah et al. (2011), Campanella (1999), Krishnan (2006) and Wood (2007) supported the view that most quality costs are in fact hidden and are not easy to be measured.

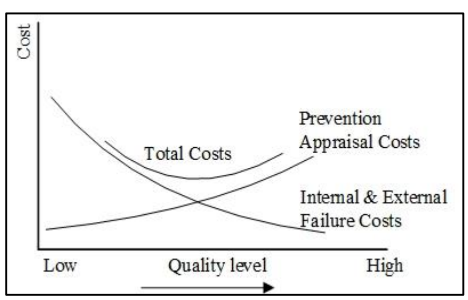


Figure 1. Juran's model for COQ (Source: Adopted from (Juran, 1951))

2.2 Opportunity cost

Hidden costs have recently become of interest to the research community. In the literature, there are different kinds of the hidden costs. Loss of goodwill represents one of the hidden costs, which is an opportunity cost (OC) that occurs when a product or a service dissatisfies a customer. Therefore, an organization loses money when its customers are not buying its products/services again (Chiadamrong, 2003). Chiadamrong claims that, opportunity cost can be divided into four main categories which are idle cost, batch waiting, process waiting and loss of goodwill. The first three costs can occur within the organization itself. They can be incurred when manufacturing equipment is underutilized, which usually means that the company inefficiently utilizes available resources. In this case the opportunity costs may be represented as loss of profit, because the opportunity of making and selling more products in fact exists but it is not exploited. In such case the opportunity cost can be calculated according to the company's accounting history. Loss of goodwill can happen when a customer is not satisfied, which may have serious consequences in terms of not only losing a specific customer and all his/her future sales, but also losing the reputation, and with that more customers as well. Loss of organization's image is a serious issue, which costs much more than expected. Ignoring loss costs influences different organization managers to make wrong decisions (Heagy, 1991). Costs of losing goodwill are obviously difficult to calculate and not many researchers have attempted to do so. Carr (1992) claimed that Xerox was the first company to use OC to determine the COQ. The program which was implemented by the US Marketing Group (USMG) of Xerox, USA, was able to reduce overall COQ by $54 million. Carr explains that the key reason for Xerox's successful program was a primary focus of the company on improving business practices with the ultimate goal to attain complete customer satisfaction. According to Giakatis et al. (2001), some attempts were made to measure the components of quality costs behind other expenses. In their case study the opportunity cost, which is the sum of the operating loss and the idle loss was found to be 35% of the actual cost. Moen (1998) developed a cost model that focuses on a new customer and poor quality. His model aimed to provide better understanding of the cost of poor quality, which enables management to make strategic decisions on how to improve their customers' satisfaction. In his model, Moen (1998) found that the intangible loss for the product is $57.99. Snieska et al. (2013) used a pilot study to investigate the external failure cots at a medical supply service company in Lithuania. They used quality function deployment modified planning matrix (developed by Moen 1998), and loss calculation method due to unsatisfied customers lost (implemented by Jones & Williams, 1995). Snieska et al. (2013) found the hidden external failure quality costs ($HEFQC_c$) equal to 7.84Lt (Lithuanian currency). In this research we try to incorporate the opportunity cost in terms of customer satisfaction in the SC quality costs analysis. We define opportunity cost as a value and suggest a model which integrates it with the total COQ under costs of non-conformance. Since we were able to incorporate the OC in our model, we could also simulate it with the other quality costs. This allowed us to analyze the effect of OC on quality level and number of new customers in the supply chain.

3. Methodology

The proposed COQ model in a manufacturing supply chain was established based on the most commonly used model in the literature, which is PAF model described in the previous section. In order to analyze the components of quality cost, it is necessary to understand how each of them interacts with the other ones. For example, when an investment is made in PA (conformance) costs the F (non-conformance) cost decreases. Organizations' quality control managers might want to know how much of an investment in conformance costs is necessary to reduce the costs of non-conformance. In addition, they may also be interested in finding out what is the optimum spending on PA in order to reduce spending on total COQ, because such information is significant when any investment in quality is required. Furthermore, the quality control managers have to know about OC and consider it in their analyses. Here the notion of OC relevant to the COQ in the SC was established while taking inputs mainly from existing literature, expert insights and industry realities. To better understand the purpose of this work, Figure 2 shows the COQ for two cases. The first one is when OC is not considered (see full line COQa) and the second one is when OC is integrated to COQ and all the costs are minimized together (see dotted line COQb). Our proposed model will investigate the differences between these two cases in a system dynamic model.

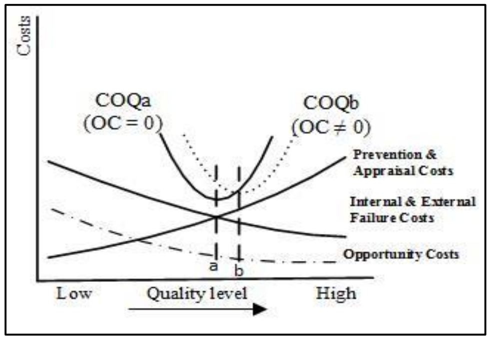


Figure 2. COQ before and after incorporating OC

3.1 Data collection

In order to collect the data a case study in a manufacturing SC was carried out. The name of the company and the data provided remain confidential. The SC involved is an automobile manufacturing SC mainly consisting of metal casting, inspection, lubrication, machining and heat treatment. Example of the company produced parts are heat sink, end bell, drum brakes, disk brakes, dies, covers, or flywheels. Most of the data was obtained from main components of the SC general layout, i.e. one supplier, one manufacturer, customers, and customers from the SC competitors. The supply chain provides different families of products in which both the suppliers and manufacturer are involved. However, only one family of products was considered in our study, while the others were not included. The products are manufactured by sandcasting and die casting in the supplier section. Machining processes are done at the manufacturer. The supplier works at a certain quality level, uses some quality instruments such as the inspection processes carried out through the selection of random samples at specific production times for each supplied lot. The supplied lots should maintain certain quality level in order to be accepted and supplied to the manufacturer. There is a ratio of defects which can be accepted by the manufacturer for the supplied parts. The manufacturer returns products which fail to meet some quality tests to the supplier, the rejected parts are then remanufactured at the supplier and resupplied again. The manufacturer implements the same procedures for the quality measures as the supplier does.

3.1.1 SC data collection and classification

The documented data was collected in tight collaboration with the SC entities. The data involves the records for the period of four years, between 2010 and 2014, and comes mainly from operation, quality, sales, and customer service departments in the SC. In this study, the quality costs were categorized based on the PAF model classification.

3.1.2 Survey data

In order to capture OC a survey was conducted. It targeted the SC customers and customers of competitive organizations. 116 customers of the supply chain, and 76 customers of competitive organizations participated in the survey. For the survey, the total targeted number of the SC customers and customers of competitive organization was 250, where each of them was contacted separately by email. Opportunity cost related to customers' goodwill was calculated using quality function deployment modified planning matrix method, which was used by Moen (1998) and Jones & Williams (1995) to calculate loss due to unsatisfied customers.

3.2 Casual loop diagram

System dynamics (SD) relies on causal loop diagram as a simple map to define the dynamic relationship amongst various factors, where it is capable to consider the effect of each variable on the other ones simultaneously. Based on the COQ relations, we established a causal loop diagram (CLD) to analyze the OC of the SC. Figure 3 illustrates the CLD based on the SC COQ viewpoint. The CLD shows how various factors influence the number of new customers in the system. The main positive reinforcement loop shows the effects of the increase of the number of new customers on the number of the total customers, and sales, and on both supplier and manufacturer production. There are three cost factors that have negative effect on the number of new customers, which are the price of the product, OC, and failure cost. The appraisal cost has a positive effect on the new customers, and as it increases the number of new customers in the SC increases.

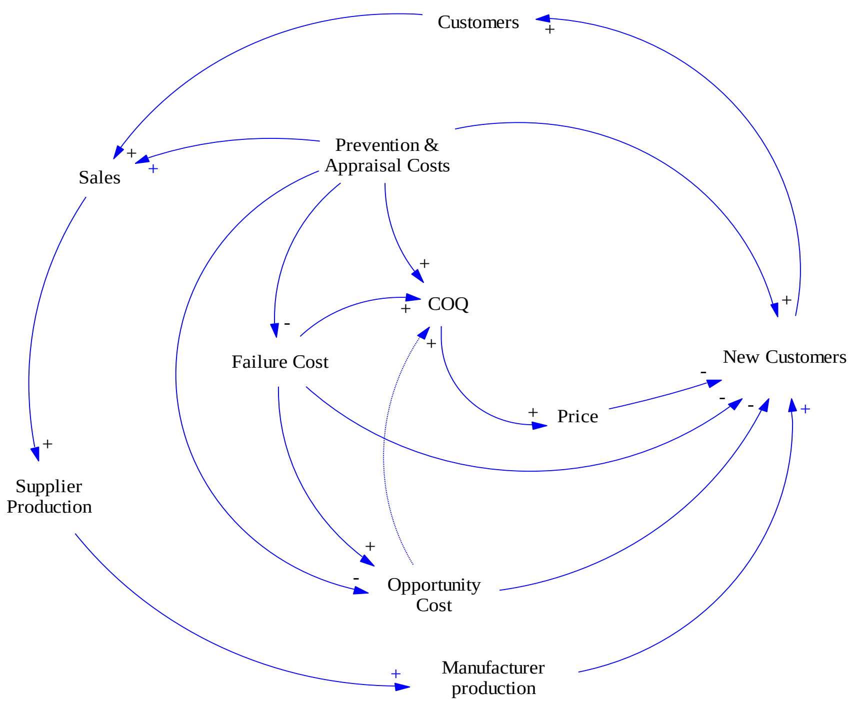


Figure 3. Causal loop diagram of the supply chain incorporating COQ

The CLD implies that investment in prevention and appraisal would increase conformance, which will consequently minimize failure and opportunity cost. The relationship between COQ and new customers in CLD was built according to the SC historic data and the results from the questionnaire.

3.3 SD model

Several tools, such as control charts, histogram, and statistical process control (SPC) have been originally considered for the analysis of COQ and for the assessment of their effect on quality measures. However, these tools do not consider the dynamics of the interaction among different cost factors. Since prevention, appraisal, failure costs and opportunity costs are interrelated and affect one another, they should not be treated independently. Investment in any of conformance cost can change the other non-conformance cost. Thus, a dynamic approach was judged to be adequate in order to better analyze and comprehend the influence of cost factors, and to highlight the most influential cost factors in achieving the expected quality level and high customer satisfaction. Figure 4 shows the generated SD model. In order to build this model**,** an extensive interaction with the supply chain individuals was necessary, which helped us visualizing our model. The SD model integrates supplier, manufacturer, customers, and COQ. In the model, if the number of new customers increases the sales increase and the manufacturer supplies the needed products to the customers. In addition, the sales trigger the supplier to produce products which are demanded from the manufacture.

A correlation analysis was employed to present the impact of the COQ on sales and the number of new customers. Based on the correlation, we constructed the model, which implies that the investment in conformance costs (PA) will increase the number of the new customers and consequently it will increase the number of total customers. On the other hand, any increase in non-conformance costs (F & OC) reduces the number of new customers. The shape of the lookup function was created based on the Juran's (1951) COQ model with different cost values for each COQ factor. By changing the variables of the expected COQ factor, the model was simulated and run at different COQ scenarios in order to provide a general picture of the OC and its effect on the number of new customers. In order to obtain more accurate results we have constrained our SD model. These constraints will limit the external usability of the model. The model assumptions are as follow:

1. Customer demand is equal to the desired units from the manufacturer.
2. All supplied parts from the supplier are accepted at the manufacturer.
3. The SC products are 100% inspected before the products are delivered to the customers.
4. Non-conformance costs have the same trend (lookup function) in the model.

3.4 Model validation

There is no single or general test which can be used to "validate" a system dynamics model. Confidence in a system dynamics model increases gradually as the model passes more tests. Testing of a model can be obtained by comparing the model to the empirical reality, which means to test the model in various forms other than numerical statistics for the purpose of confirming or refuting the model (Forrester & Senge, 1996). The following sections describe the validation of our model.

3.4.1 Model structure and behavior

The validity of our model can be obtained by testing the model structure and its behavior against the structure of the real system (Barlas, 1994). As the model structure must follow the structure of the real system and its functions, the structure of our model was discussed with the SC production and quality engineers (the same SC for which we gathered our data) to ensure its suitability for the existing SC and they agreed on the structure of the SD model. Furthermore, since this research was inspired by Juran's (1951) model, the results of the COQ model were compared with Juran's model in order to confirm that the behavior of the COQ is compatible with his model (see Fig 7. and 8).

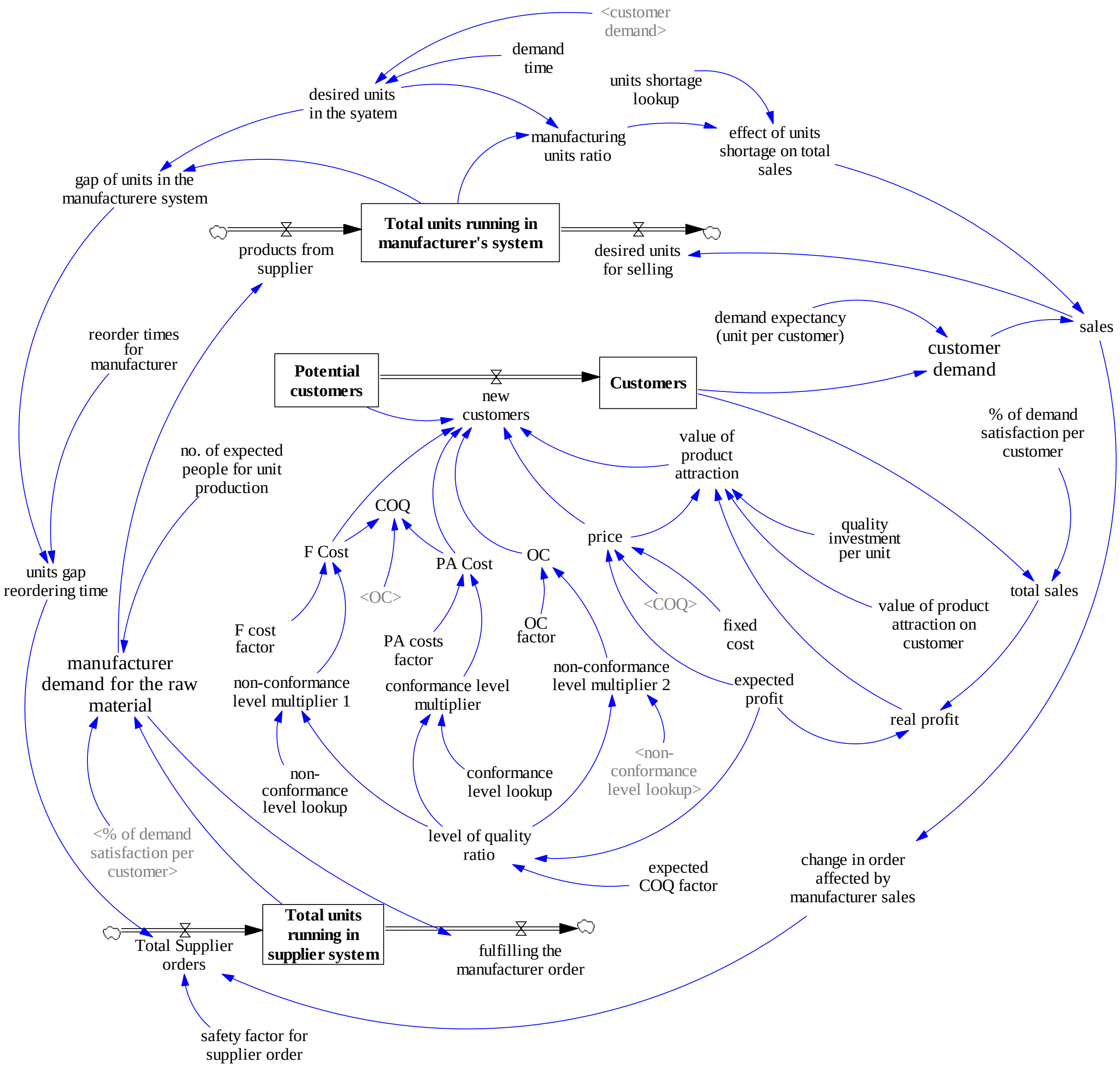
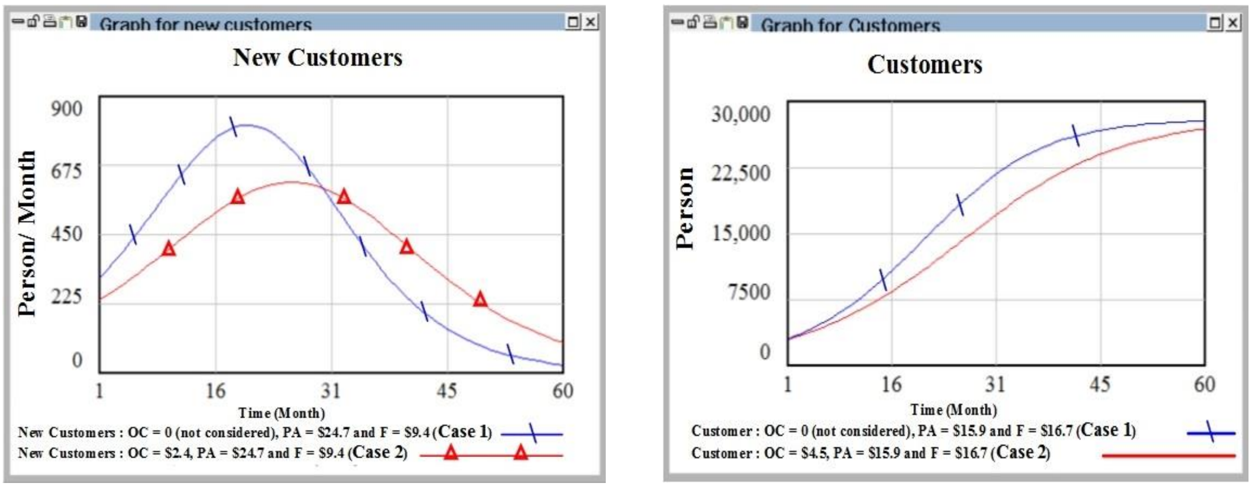


Figure 4. System Dynamics (SD) model

3.4.2 Parameter-verification test

According to Forrester & Senge (1996), the parameters of a system dynamic model can be tested and verified against observations of the real life, similarly as the structure of the model which we compared to the real system. The constant factor which we considered in our model as shown in Figure 4 is the quality level factor. It affects directly the quality level and consequently it influences COQ variables, PA, F, OC and the price of products. Figure 5 (a) shows the observation for two cases, where Case 1 represents the number of new customers when opportunity cost is not considered (OC = 0) in the SC, and Case 2 (adjusted case) represents the expected number of new customers when opportunity cost is integrated to the COQ. For the parameter-verification test, it was found that the average number of new customers in Case 1 is higher than in Case 2, which consequently affects the number of customers as shown in Figure 5 (b). This corresponds to the situation observable in the real life, where the consideration of OC reflects the lower satisfaction of customers and hence their lower numbers in the SC.



a b

Figure 5. The observations for number of new customers and customers in the SD model (with & without OC)

4. Results and discussion

In this research, correlation analysis is conducted to determine the impact of the cost of quality components on the number of new customers. The SC historical data collected over a period of four years (2010 - 2014) were used to calculate the correlations. The results confirm that as PA costs increase, quality improves and failure cost decreases. Also, the results display a strong relationship among the PA, new customers and sales. The correlation results were also used to construct the CLD and SD models.

Even though the SD model represents the whole supply chain, in the analysis we focused on the effects of the quality level on the COQ parameters, PA (conformance costs), and OC and F (non-conformance costs), and consequently on the number of new customers of the SC. The COQ parameters were simulated and investigated simultaneously. The time frame which was used in the simulation is five years as shown in Figure 6. We designed three cases which can be observable from this figure and which are described below:

Case 1: Case 1 refers to the current situation for the SC, where the quality level is 73% and PA = \$24.7, F = \$9.4, OC = 0, and COQ = \$34.1. With this working quality level the SC was expected to gain an average of 413 new customers per month.

Case 2: Case 2 is the situation when OC is considered to be equal to \$2.4, which is the value obtained from the survey analysis. In this case, the quality level, PA, and F costs are fixed at the same values as in Case 1 and the new COQ = \$34.1 + \$2.4 = \$36.5. Here we observed a decline in the number of new customers, which is because of the added OC variable to the model, which made the number of the (expected) new customers for the SC more realistic. In this case, the SC should expect around 399 new customers per month, which is less by 4% than the previous expectation in Case 1.

Case 3: Case 3 is the adjusted case of Case 2, which is intended to meet the same number of new customers as in Case 1. The purpose of presenting this case is to highlight the tradeoff among the COQ factors. We found that the quality level should be increased to reach 77% to gain the same number of new customers as presented in Case 1. As a consequence of the increase in quality level the model adjusts the costs of conformance (PA) to be increased by around $2 to reach $27.0, whereas the cost of non-conformance (F) on the other hand declined by around $1.5 to become $7.8, and the OC cost has also decreased to approach $2.0.

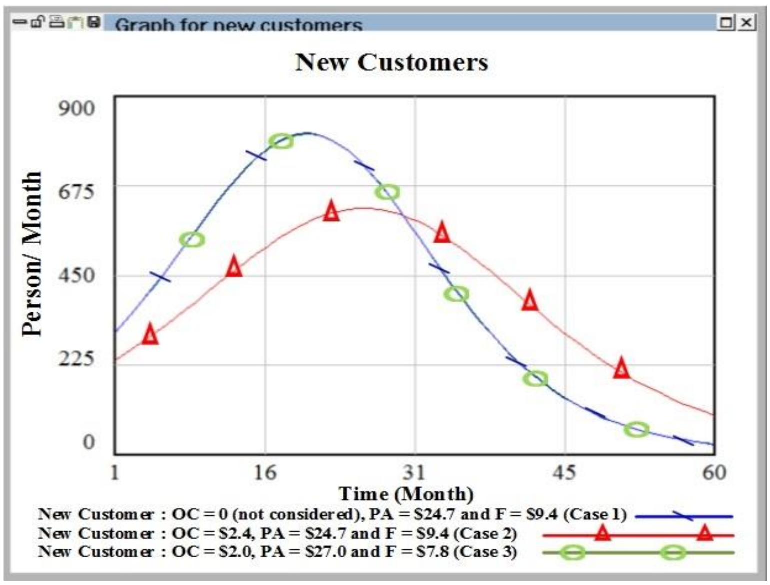


Figure 6. COQ observations for the number of new customers

5. Conclusion

In this paper the cost of quality was considered and measured within the supply chain, where individual COQ parameters were studied using system dynamics. The model was built based on the PAF approach, but its unique feature was the consideration of OC and its integration into the model. The model provided a simultaneous analysis for all the COQ factors which enabled us to build a more general framework for the behavior of all the cost factors. We proposed how each of the COQ factors can affect the number of new customers in the whole SC. In order to highlight the importance of the OC in the COQ analysis we investigated two separate cases, one which did not consider OC and one which incorporated it into the COQ calculations. In order to study the effect of incorporating OC to the PAF cost model, a real manufacturer supply chain was considered. The model investigated the efficacy of spending on the costs of conformance. For the current working level (OC is considered) the study showed that spending more on conformance costs, PA, and increasing them is beneficial. Although it will increase the total COQ by 7.9% it will also increase the number of new customers by around 4%. The model was able to demonstrate different COQ scenarios at different quality levels. In general, it has been proved that increasing costs of conformance (PA) in the supply chain can directly decrease costs of non-conformance (F and OC), which makes therefore the outcomes of this research correspond to the definitions of Juran (1951).

We recognize the limitations of this work in that it may not perfectly capture the integration of OC in the model. However, we concluded that it was the most realistic approach to allow us to incorporate the OC in the model. The study considered the customer satisfaction from a survey and may thus suffer from some inaccuracies.

6. Suggestion for future studies

Just like COQ was modeled in the SC as one representation, it can be also modeled at the manufacturer and supplier separately and the total effect of OC on the whole model can be studied. Also, further research could address a multi-product COQ, i.e. different lookup functions can be assigned for different products, at the supplier's and manufacturer's sites. The complexity of such a combination model would be great and will perhaps be possible to be dealt with again through System Dynamics, which will consider different functions simultaneously and provide a variety of COQ collections over a time period.

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8. References

ASQC. (1971). *Quality Costs – What and How*. Milwaukee, WI, ASQC Quality Press.

Barlas, Y. (1994). Model validation in system dynamics. In *Proceedings of the 1994 International System Dynamics Conference* (pp. 1–10). Sterling, Scotland.

Ben-Arieh, D., & Qian, L. (2003). Activity-based cost management for design and development stage. *International Journal of Production Economics*, *83*(2), 169–183.

Bowbrick, P. (1992). *The Economics of Quality, Grades and Brands*. Routledge, London.

BS 6143. (1990). *Guide to Determination and Use of Quality Related Costs*. British Standards Institute, London, 1981, p.16.

Campanella, J. (1999). *Principles of Quality Costs. Principles, Implementation and Use,* (3rd ed.). ASQC, Milwaukee.

Carr, L. P. (1992). Applying cost of quality to a service business. *Sloan Management Review*, *33*(4), 72.

Castillo-Villar, K. K., Smith, N. R., & Simonton, J. L. (2012). A model for supply chain design considering the cost of quality. *Applied Mathematical Modelling*, *36*(12), 5920–5935.

Cheah, S.-J., Shah, A., Shahbudin, M., Fauziah, & Taib, M. (2011). Tracking hidden quality costs in a manufacturing company: an action research. *International Journal of Quality & Reliability Management*, *28*(4), 405–425.

Chiadamrong, N. (2003). The development of an economic quality cost model. *Total Quality Management and Business Excellence*, *14*(9), 999–1014.

Chiadamrong, N., & Thaviwatanachaikul, C. (2002). Analysis of Quality Costs for Statistical Quality Control Planning. *Asian Journal of Science and Technology for Development*, *19*(1), 39–54.

Crosby Philip, B. (1984). *Quality without Tears: The Art of Hassle-Free Management*. McGraw-Hill, New York.

Dennis Beecroft, G. (1999). The role of quality in strategic management. *Management Decision*, *37*(6), 499–503.

Evans, J. R., & Lindsay, W. M. (1999). *The management and control of quality.*

Feigenbaum, A. V. (1961). *Total quality control:* McGraw-Hill New York.

Feigenbaum, J. A. (2001). A statistical analysis of log-periodic precursors to financial crashes. *Quantitative Finance*, *1*(3), 346–360.

Forrester, J. W., & Senge, P. M. (1996). Tests for building confidence in system dynamics models. *Modelling for Management: Simulation in Support of Systems Thinking*, *2*, 414–434.

Giakatis, G., Enkawa, T., & Washitani, K. (2001). Hidden quality costs and the distinction between quality cost and quality loss. *Total Quality Management*, *12*(2), 179–190.

Groocock, J. M. (1980). Quality cost control in ITT Europe. *Quality Assurance*, *6*(3), 37.

Hagan, J. T. (1973). Quality costs at work. In *ASQC Technical Conference Transactions* (Vol. 307).

Heagy, C. D. (1991). Determining optimal quality costs by considering cost of lost sales. *Journal of Cost Management*, *5*(3), 64–72.

Jaju, S. B., Mohanty, R. P., & Lakhe, R. R. (2009). Towards managing quality cost: A case study. *Total Quality Management*, *20*(10), 1075–1094.

Jones, P., & Williams, T. (1995). *Business Improvement Made Simple.* Information Press.

Juran, J. M. (1951). *Quality Control Handbook* (1st ed.). McGraw-Hill). New York.

Kent, R. (2005). *Manufacturing strategy for window fabricators 14–the cost of quality, Tanagram Technology*.

Krishnan, S. K. (2006). Increasing the visibility of hidden failure costs. *Measuring Business Excellence*, *10*(4), 77–101.

Kumar, K., Shah, R., & Fitzroy, P. T. (1998). A review of quality cost surveys. *Total Quality Management*, *9*(6), 479–486.

Machowski, F., & Dale, B. G. (1998). Quality costing: An examination of knowledge, attitudes, and perceptions. *Quality Management Journal*, *5*(3).

Moen, R. M. (1998). New quality cost model used as a top management tool. *The TQM Magazine*, *10*(5), 334–341.

Morse, W. J., Roth, H. P., & Poston, K. M. (1987). *Measuring, planning, and controlling quality costs*. Institute of Management Accountants.

Plunkett, J. J., & Dale, B. G. (1988). Quality costs: a critique of some "economic cost of quality"models. *The International Journal of Production Research*, *26*(11), 1713–1726.

Schiffauerova, A., & Thomson, V. (2006). A review of research on cost of quality models and best practices. *International Journal of Quality & Reliability Management*, *23*(6), 647–669.

Snieska, V., Daunoriene, A., & Zekeviciene, A. (2013). Hidden Costs in the Evaluation of Quality Failure Costs. *Engineering Economics*, *24*(3), 176–186.

Son, Y. K. (1991). A cost estimation model for advanced manufacturing systems. *The International Journal of Production Research*, *29*(3), 441–452.

Srivastava, S. K. (2008). Towards estimating cost of quality in supply chains. *Total Quality Management*, *19*(3), 193–208.

Tsai, W.-H. (1998). Quality cost measurement under activity-based costing. *International Journal of Quality & Reliability Management*, *15*(7), 719–752.

W. G. Thompson Jr, & Nakamura, S. (1987). Measuring costs of quality in the development process. In *IEEE International Conference on Communications* (Vol. 87, p. 1770).

Wood, D. C. (2007). *The executive guide to understanding and implementing quality cost programs: reduce operating expenses and increase revenue*. ASQ Quality Press.