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A conceptual framework of quality cost chain in strategic cost management

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Abstract

Purpose – This study aims to discover a practical and effective way to apply the quality cost concept in Strategic Cost Management (SCM) framework. The interaction of preventive, appraisal and failure (PAF) activities in a company's internal value chain will be the starting point of SCM implementation.

Design/methodology/approach – This study begins by establishing value chain and quality costs as the scope of conceptual analysis. Discussions on the interrelationships between activities, quality and costs were gathered to clarify conceptual and practical gaps in the scope of the study. The PAF quality cost model is applied to find viable, practical solutions. The costs of activities will serve as performance indicators.

Findings – The PAF quality cost model depicts opportunities to lower costs and increase profit in a business simultaneously; current poor quality costs are the benchmark. Identifying PAF activities and costs in the business value chain and linking it with others is crucial in evaluating SCM applications. These linkages will generate a Quality Cost Chain (QCC). The leading indicator of improvement is a higher ratio between new possible failure costs (FC) and the combination of prevention and appraisal costs (PAC) than the current value, followed by a lower total quality cost (TQC). The subsequent attention is a lower ratio between the appraisal cost (AC) and prevention cost (PC). Mathematically, for assessing the operability of new quality-related activities, $\Delta PAC_{new} < \Delta FC_{new}$, $TQC_{new} < TQC_{current}$, $(FC/PC)_{new} > (FC/PC)_{current}$ and $(AC/PC)_{new} < (AC/PC)_{current}$ are proposed as feasible conditional-quantitative improvement criteria.

Research limitations/implications – This study only discusses the relationship between quality costs and activities related to quality management in the PAF quality cost model, not cost behavior. This limitation opens up opportunities for future research that intends to link QCC with cost behavior in the context of managerial accounting and Strategic Cost Management. The use of QCC in certain industrial areas is the next research opportunity. The variety of PAF activities this study addresses originates from a wide range of industrial sectors; QCC research by sector may produce unique industrial quality cost phenomena.

Practical implications – QCC will make it easier for managers to evaluate how strategically their departments or activities contribute to quality costs at the departmental or organizational level, as well as to effectively and efficiently improve quality cost performance.

Originality/value – The quality-related activity and quality cost issues are still rarely treated as subjects of research studies in the field of Strategic Cost Management. Even so, the discussion tends to be very broad, complex and difficult to apply. This study combines a simple diagrammatic and mathematical approach to simplify the discussion and, at the same time, manage the value of strategic quality management.

Keywords Competitiveness, Strategic management, Value chain, Quality cost

Paper type Conceptual paper

1. Introduction

Naturally, there is a cost associated with the activity (Blocher *et al.*, 2019; Cooper and Kaplan, 1992; Janatyan and Shahin, 2020; Shank, 1989). On the other hand, high and ineffective costs are a significant issue for any business. Decreased activity intensity will lower costs but not always enhance profitability, especially in the long run. Business requires better methods to reduce cost and increase their sustainability simultaneously. Strategic Cost Management (SCM) recommends three analytical pillars for these roles; they are Value Chain Analysis (VCA), Strategic Positioning Analysis (SPA) and Cost Driver Analysis (CDA) (Blocher *et al.*, 2019; Gliaubicas and Kanapickienė, 2015; Hertati and Sumantri, 2016; Li, 2018; Sedevich-Fons, 2018; Shank, 1989). Unfortunately, SCM did not explain a straightforward way to identify the

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starting point of this improvement (Li, 2018; Shank, 1989). Even the combination of Value Chain Analysis (VCA) and Cost Driver Analysis (CDA), the two of three pillars of SCM, did not clearly show the costs relationships among activities in a value chain (Li, 2018),

Meanwhile, quality is an essential source of competitive advantage, particularly for businesses that operate in highly competitive markets (Blocher *et al.*, 2019; Feigenbaum, 1983; Gliaubicas and Kanapickienė, 2015; Heizer *et al.*, 2017; Juran and Godfrey, 1999; Lakhal, 2009; Porter, 1998; Wood, 2013; Yasin *et al.*, 1999). Quality is no longer a function of day-to-day operations but rather of systemic and strategic performance, which is unrelated to the company's size (Gliaubicas and Kanapickienė, 2015). Internally, poor-quality products generate higher product costs due to inadequate design and production processes. Externally, this quality-based problem leads to safety problems, lawsuits and increased government regulation (Ames *et al.*, 2013; Heizer *et al.*, 2017). If undetected and persist in the long term, quality problems can erode the company's performance and reputation. Quality becomes a valuable source for growing sales, earnings and business image when handled quickly, properly and consistently (Blocher *et al.*, 2019; Heizer *et al.*, 2017; Li, 2018; Sailaja *et al.*, 2014; Wood, 2013). Companies that have not been quantifying quality costs might consider this activity as a step in their efforts to enhance the overall quality of their products and services (Pekanov Starcevic *et al.*, 2015).

Unfortunately, identifying and analyzing quality costs becomes a complicated task in the implementation stage. In the simulation of quality costs in Southeast Asian semiconductor businesses (Khaled Omar and Murgan, 2014) and quality cost estimation in PCB design (Gilbert *et al.*, 2005), apart from requiring a high degree of mathematical and statistical competence, quality costing tends to be partial and tactical in an organizational setting. A case study on aerosol canister quality has led to the integration of quality-related activities and costs; however, they are still far from effective because they directly place the inspection procedures in the manufacturing stage as the initial and main target of quality cost control (Farooq *et al.*, 2017). In Iraq, a textile company cannot effectively manage its quality management program because it does not completely understand the link between non-production operations and quality management activities in the production department (Ahmed Al-Dujaili, 2013). A previous conceptual study initiated integrating operational efficiency frameworks with strategic effectiveness. The use of optimal control theory in this study has shown which direction to improve quality and related costs but does not explain how to make it happen (Yasin *et al.*, 1999). Theoretically, out of 99 papers on quality cost analysis, only 45 articles discuss the components of quality costs in detail. Most only focus on the cost of poor quality. This finding supports the hypothesis that gathering quality costs in practical settings can be somewhat unclear and complicated while suggesting further studies on the interrelations of quality costs (Chatzipetrou and Moschidis, 2018). The other study shows that fear of implementing TQM indicates the lack of managerial competency related to quality management, at which quality costing is part of the problem (Bugdol, 2020). A recent study shows managers' lack of interest in new methods is still a significant obstacle to quality cost management (Biadacz, 2021). These studies confirm that companies still require simple but comprehensive techniques for analyzing quality-related activities and costs (Chatzipetrou and Moschidis, 2016; Cheah *et al.*, 2011; Schiffauerova and Thomson, 2006; Vaxevanidis *et al.*, 2009).

Surprisingly, research consistently shows that materials and procedures, not employee behavior, are at the core of about 85% of product quality concerns (Farooq *et al.*, 2017; Omachonu *et al.*, 2004; Wood, 2013). Other causes seem to hide under the iceberg (Purushothama, 2012). As a result, when nonconformities arise, quality is viewed as a partial problem and workers are not considered seriously as a contributing factor. Regardless of the neglect of engineering principles, violations of standard operating procedures, or the continuation of a sub-optimal process on these non-conformity problems, the fact is that there are various issues related to the ineffectiveness of workers behind it (Choi *et al.*, 2020; Schmitt, 2018). In the context of the value chain, employee empowerment means involving employees in every activity in each chain (Keller *et al.*, 2020; Nguyen *et al.*, 2020; Nikulin *et al.*, 2021). Employees are the organizational members who know best about the quality system's weaknesses because they deal with day-to-day operations. Employees have a huge role in quality formation from one chain to another. The facts prove that the involvement of workers has a considerable influence on variations in product quality (Letza and Gadd, 1994; Purushothama, 2012).

Product quality is a measure of a company's ability to meet the needs of its customers (Pekanov Starcevic *et al.*, 2015; Dapiran and Kam, 2017; Feigenbaum, 1983; Heizer *et al.*, 2017). Quality criteria and values for each customer can be different. Selecting certain consumer groups will affect the criteria and values of quality standards determined as the criteria and values of the company's quality standards. For example, in the e-Retail industry, IT infrastructure has a huge role in providing high-quality customer service as their core competency (Tsai *et al.*, 2013). In addition to maximizing transaction speed and accuracy, IT technology in e-retail is also crucial to identify external failures. For flake, flour, or other oat-based product manufacturers, the effectiveness of quality control in all primary chains will determine customer acceptability.

Comparing the purchase prices of many alternative suppliers forces companies to consider hidden charges in the acquisition cost risk (Gaudenzi *et al.*, 2021; Sato *et al.*, 2020). From a total cost of ownership (TCO) perspective, the quality cost is a hidden cost that arises when a company tries to reduce quality problems due to the price variability of raw materials supplied by its suppliers (Gaudenzi *et al.*, 2021). Due to the natural characteristics of the oat, criteria of quality conformance in oat-based products may have different complexity than non-agricultural products (Ames *et al.*, 2013). Quality cost is a strategic and systematic issue for a business. It requires a practical method to manage efficiently and effectively (Ahmed Al-Dujaili, 2013; Biadacz, 2021; Chatzipetrou and Moschidis, 2016; Chopra and Garg, 2012; Janatyan and Shahin, 2020; Kaplan, 1983; Sailaja *et al.*, 2014; Sedevich-Fons, 2018); without analytical records of quality expenditures, it would be impossible to establish a reliable estimation or assessment of a company's overall quality costs (Chatzipetrou and Moschidis, 2016; Chopra and Garg, 2012). Based on this, the PAF quality cost model was chosen as the starting point for this study. PAF provides a basic framework that is easy to understand and apply to identify causal relationships in a quality management system.

Activities and costs related to quality are no longer just operational issues but also a strategic issue that is increasingly important for every company today. Implementing strategic context, specifically strategic cost management, on the quality cost is the first contribution of this conceptual research. The second contribution, which is no less critical, is the new methodology approach. This study proposes a practical analysis technique related to gap research in previous studies regarding the failure of implementing an integrated quality cost measurement method. This study combines a simple mathematical and value chain model-based diagrammatic analysis method. This approach is expected to overcome the complexity of quality management in the company's internal and external value chain linkages. The development of this analytical tool begins by exploring the theoretical role of the value chain and quality costs in the context of SCM, examining the existence of various types of activities in the value chain and their impact on quality costs using a simple mathematical approach and performing several diagrammatic simulations to visualize and test the logic of the conceptual framework under consideration.

2. Literature studies

2.1 Strategic cost management

Strategic Cost Management (SCM) is a crucial companion instrument to the cost leadership strategy effectiveness in creating a competitive advantage (Gliaubicas and Kanapickienė, 2015;

Shank, 1989; Wang, 2019). Value Chain Analysis (VCA), Strategic Positioning Analysis (SPA) and Cost Driver Analysis (CDA) are three pillars of SCM (Blocher *et al.*, 2019; Gliaubicas and Kanapickienė, 2015; Hertati and Sumantri, 2016; Li, 2018; Sedevich-Fons, 2018; Shank, 1989). VCA is a method for breaking down company activities, externally and internally, into strategic activity groups, understanding their impact on cost behavior and competitive advantage creation (Bhargava *et al.*, 2018; Li, 2018; Shank, 1989). Activities in the value chain have a strategic impact on product costs (Blocher *et al.*, 2019; Li, 2018; Wouters and Morales, 2014). So basically, the value chain is also an essential input for pricing decisions (Blocher *et al.*, 2019; Kagermann *et al.*, 2015; Yilmaz and Bititci, 2006). Lower product prices than competitors should reflect the higher productivity of activities within the company (Ahmed Al-Dujaili, 2013; Blocher *et al.*, 2019; Hauck *et al.*, 2021; Jalali *et al.*, 2019; Li, 2018; Wouters and Morales, 2014). SPA recommends the company accomplish managerial accounting from a strategic perspective when making strategic decisions. The company's cost structure should be part of strategic positioning decisions that relate to competitive advantage creation. SPA helps companies evaluate the effectiveness of strategic positioning based on market and internal conditions, including analyzing value creation in the value chain related to its competitive advantage (Blocher *et al.*, 2019; Li, 2018; Shank, 1989). A cost driver is a factor that can change the amount of a cost (Kaplan, 1983). As the third pillar of SCM, CDA evaluates each cost driver in a strategic and organizational context. By CDA, SCM divides strategic cost drivers into structural and executional cost drivers. Depending on the selected strategic position, each group of activities in a company's value chain has a different strategic cost driver that is connected with varying complexity. Managing key cost drivers for companies that compete on a cost leadership basis is critical (Blocher *et al.*, 2019; Li, 2018; Shank, 1989).

From a managerial accounting perspective, the value chain concept reflects the process of accumulating costs and the flow of value from one activity to another, either from the primary activity to the following primary activity or from the supporting activity to other activities it supports (Li, 2018; Shank, 1989). Because the process of value creation in the primary activity absorbs costs in a specific composition and direction, the costs accumulated in the physical output of the operation activity will be more significant than inbound logistics and so on. In SCM, the value creation related to suppliers' activities and finished product deliveries to the end-user should be considered (Anthony Jnr, 2019; Li, 2018; Shank, 1989; Zhao *et al.*, 2017). High quality is impossible to attain without human engagement and deliberate engineering. This quality improvement, primarily concerned with cost-effectiveness, cannot be imposed solely on the operational activity (Feigenbaum, 1983; Juran and Godfrey, 1999). Quality issues in the R&D department might cause the product's time-to-market to be longer than planned. Outbound logistics quality issues might cause the goods to arrive late in customers' hands (Lakhal, 2009). Both can have a negative strategic impact on the company. Quality is an element of competitive advantage that must be built through a long and continuous process (Ames *et al.*, 2013; Gliaubicas and Kanapickienė, 2015).

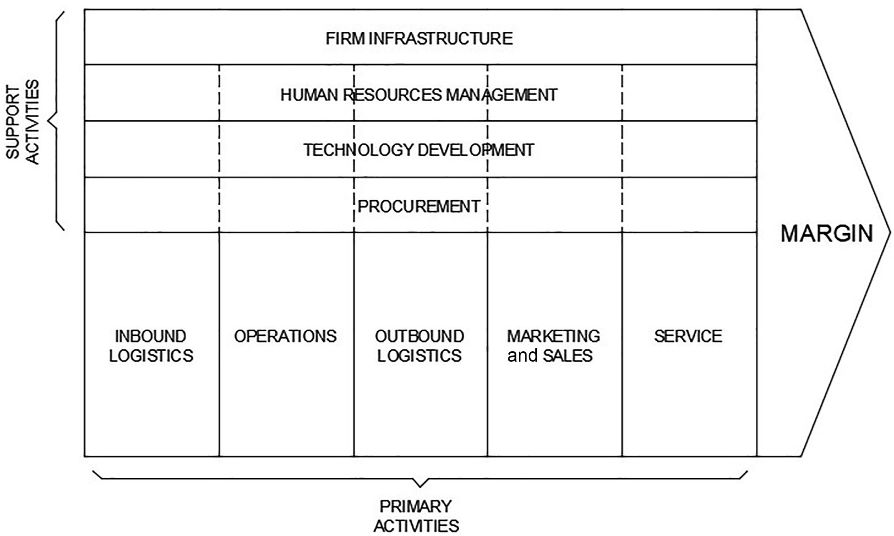
2.2 Value chain

A value chain reflects value propositions (Li, 2018; Turnbull and McCutcheon, 2019). Differences in value chains between a company with its competitors are a vital source of competitive advantage (Bhargava *et al.*, 2018; Porter, 1998; Tsai *et al.*, 2013). A value is the extent of money those customers are willing to pay for what they receive from the producers; the larger they are willing to pay, the higher the value (Blocher *et al.*, 2019; Dapiran and Kam, 2017; Janatyan and Shahin, 2020; Li, 2018; Porter, 1998). Consumer purchasing power is the constraint. A company needs to create customer value that exceeds the cost of producing the product. This cost should be lower than the competitors at an equal value (Blocher *et al.*, 2019; Li, 2018; Vaxevanidis *et al.*, 2009).

A company must be able to adapt to the current environmental conditions. The creation of competitive advantage needs to consider the value contribution of each activity inside the company (Anthony Jnr, 2019; Dapiran and Kam, 2017; Kagermann *et al.*, 2015). According to a study conducted in Australia, marketing and supplier management are linked significantly to product quality and innovation. Process management does not link to product innovation, but R&D management does. Instead, it has a strong connection to product quality. These two findings show that process management is primarily concerned with downstream processes, with the major focus on controlling processes to generate goods that meet predetermined requirements handled by the R&D division in upstream processes (Prajogo *et al.*, 2008). The activities should be separated or grouped. It can be based on differences in the economics of activities, technology, activity costs, or significance of potential value (Li, 2018; Porter, 1998; Zhang, 2005). Five generic primary activities are inbound logistics, operations, outbound logistics, marketing and sales and service. Four generic support activities are firm infrastructure, human resources management, technology development and procurement (Bhargava *et al.*, 2018; Porter, 1998).

The vertical dotted line indicates that supporting activities such as procurement, technology development and human resource management can be linked with a single primary activity or all of them. The line does not continue in the infrastructure section because this section supports the entire chain (Figure 1). In general, every activity related to value creation uses purchased inputs (materials, energy), human resources and some form of technology to carry out its functions (Bhargava *et al.*, 2018; Porter, 1998). Every activity absorbs costs (Blocher *et al.*, 2019; Cooper and Kaplan, 1992). Suppose the activity affects quality and so does the cost (Wood, 2013).

The value chain complexity of each company is different (Ames *et al.*, 2013; Bhargava *et al.*, 2018; Choi *et al.*, 2020; Janatyan and Shahin, 2020; Yilmaz and Bititci, 2006). The root cause of external failures experienced by e-retailers and customers can be purely from the delivery process in the service activity (Johnson and Whang, 2009; Tsai *et al.*, 2013), it can also come from the carelessness of the packaging department in the outbound logistics (Tsai *et al.*, 2013). Inadequate machine maintenance in the operation chain may result in a high proportion of defective products (Ahmed Al-Dujaili, 2013), otherwise inappropriate material



Source(s): Porter (1998)

Figure 1.
Value chain

handling in inbound logistics (Sawan *et al.*, 2018). According to contingency theory, the value chain is not static. It can change and should be changed due to environmental and situational uncertainty. No one best control system can be applied to the value chain in all organizations. Applying the proper control system needs to consider the involvement of contextual variables in which the organization exists (Gliaubicas and Kanapickienė, 2015; Schniederjans and Schniederjans, 2015; Tsai *et al.*, 2013).

2.3 Quality costs

Quality is a multi-dimensional concept (Feigenbaum, 1983; Lakhal, 2009; Zeng *et al.*, 2015). Quality can relate to performance, features, reliability, conformance, durability, serviceability, aesthetics, or perceived product quality from a customer perspective (Ames *et al.*, 2013; Choi *et al.*, 2020; Pekanov Starcevic *et al.*, 2015; Feigenbaum, 1983; Lakhal, 2009; Prajogo *et al.*, 2008; Purushothama, 2012). A quality problem arises when the customer feels one of their needs is unfulfilled by the product. Then the quality of the product is categorized as poor. This problem can generate additional costs for the customer and producer (Blocher *et al.*, 2019; Jalali *et al.*, 2019; Soares *et al.*, 2020; Sturm *et al.*, 2019).

Many people still think that quality costs arise because of the presence of a poor product (Purushothama, 2012; Wood, 2013). Some experts consider calculating the quality costs, especially for poor products, is not advantageous for the company. This opinion can not last long. Research shows that; the proportion of poor quality ranges from 15 to 30% of product or period cost (Pekanov Starcevic *et al.*, 2015); the quality cost is about 5.64–14.42% of the sales revenue in a continuous-process manufacturing company (Cheah *et al.*, 2011). The high proportion of quality costs in the structure of overall company costs confirms that quality costs can not be ignored, followed by cost reduction actions. However, this process is not simple. About 90% of the quality cost icebergs are hidden underwater (Blocher *et al.*, 2019; Purushothama, 2012; Wood, 2013). Activity-Based Costing (ABC) can effectively identify these costs and quality-related activities (Cooper and Kaplan, 1992; Schiffauerova and Thomson, 2006; Soares *et al.*, 2020; Vaxevanidis *et al.*, 2009).

The other said a poor product indicates the need for corrective actions. Poor products make companies have to spend more money because they cannot sell the product or because they have to incur additional costs to repair the product so that it can be sold (Wood, 2013). If a product is perfectly made, there will be no quality costs. In other words, the cost of quality arises because of imperfections in the product. Many are increasingly doubtful. Facts show that perfect products or services require activities that absorb costs (Yasin *et al.*, 1999). Quality is economically valued (Blocher *et al.*, 2019; Wood, 2013).

Every cost must be justified in terms of its effectiveness. Even significant parts of the costs of prevention and appraisal, concerning the cost of failure and the total cost, are wastes that must be minimized to the extent feasible if they cannot be eliminated. The PAF quality cost model is chosen in this study due to the most extensively used quality costing classification, emphasizing the polar opposite behavior of preventive and appraisal costs on the one hand and failure costs on the other (Blocher *et al.*, 2019; Chatzipetrou and Moschidis, 2018; Feigenbaum, 1983; Heizer *et al.*, 2017; Juran and Godfrey, 1999; Schiffauerova and Thomson, 2006; Shank, 1989; Wood, 2013). Apart from the PAF quality cost model, several models have also been developed and used, such as the opportunity cost model, process cost model and Activity-Based Costing (ABC) model. The opportunity cost model incorporates the cost of intangible or opportunity losses into a typical PAF model (Schiffauerova and Thomson, 2006; Vaxevanidis *et al.*, 2009). The process cost model focuses on processes rather than products or services. This model recognizes the importance of measuring and ownership of process costs, where process costs are the total costs of conformity and non-conformance costs for a particular process (Khaled Omar and Murgan, 2014; Schiffauerova and Thomson, 2006; Vaxevanidis *et al.*, 2009). ABC tried to include overhead costs in the quality costing system because of the limitations of the PAF approach (Khaled Omar and Murgan, 2014; Schiffauerova and Thomson, 2006; Vaxevanidis *et al.*, 2009). ABC uses the two-stage procedure to achieve the correct costs of various cost objects, tracing resource costs to activities and then tracing the costs of activities to cost objects (Cooper and Kaplan, 1992; Khaled Omar and Murgan, 2014; Schiffauerova and Thomson, 2006; Soares *et al.*, 2020). Although several other points of view, modifications and criticisms of the cost of quality theory have been proposed in the literature against the original PAF quality cost model, the categorization of costs in the PAF quality cost model seems quite clear (Chatzipetrou and Moschidis, 2018; Kerfai *et al.*, 2016; Plewa *et al.*, 2016).

However, some cost components could potentially be included in each category. In addition, this categorization also depends on the researcher's objectivity in whether some costs will be classified under one or another category (Chatzipetrou and Moschidis, 2018). In the PAF quality cost model (Figure 2), prevention and appraisal activities are the cost of good quality (PAC), while internal and external failures are the cost of poor quality (FC). The core concept of the PAF quality cost model is that more spending on prevention activities should result in lower failure costs (Chopra and Garg, 2012; Duarte *et al.*, 2016; Soares *et al.*, 2020; Wood, 2013). An accurate assessment of quality costs and their benefits, the trade-off between conformance and non-conformance costs, should be regarded as an essential component of every quality initiative and, therefore, a critical problem for any manager (Schiffauerova and Thomson, 2006).

The activities related to the PAF quality model vary widely. New product reviews, quality planning, quality improvement project, quality training, education, equipment maintenance, product/process/service audit, supplier capability survey and supplier assurance are generic examples of prevention costs (Blocher *et al.*, 2019; Pekanov Starcevic *et al.*, 2015; Feigenbaum, 1983; Gaudenzi *et al.*, 2021; Heizer *et al.*, 2017; Juran and Godfrey, 1999; Lin, 1991; Wood, 2013). Material/process/equipment test and inspection activities are related to appraisal costs (Blocher *et al.*, 2019; Heizer *et al.*, 2017; Juran and Godfrey, 1999; Kaplan, 1983; Malik *et al.*, 2016; Wood, 2013; Yasin *et al.*, 1999). Scrap, rework, reinspection, retesting, downgrading, processing customer complaints, customer returns and warranty claims are parts of failure costs (Blocher *et al.*, 2019; Farooq *et al.*, 2017; Heizer *et al.*, 2017; Juran and Godfrey, 1999; Wood, 2013).

As Peter Drucker said, we cannot manage what we cannot measure. Quality costs are measurable even though the quality is not a static business element. Quality improvement is significant for company sustainability (Lakhal, 2009). Improvement of quality-related activities is part of the value chain redesign (Kagermann *et al.*, 2015). Research shows that the relative proportion of PAF cost is 10:30:60 (Cheah *et al.*, 2011; Malik *et al.*, 2016; Purushothama, 2012). In addition, some activities absorb and hide the quality cost. They include engineering and development, managerial jobs, break times, late delivery of raw materials, increased inventory, decreased capacity, repair of production facilities, late delivery, canceled orders and customers moving to competitors. Technically, tolerance limits on various quality parameters indicate that quality variations cannot be avoided (Gilbert *et al.*, 2005). Therefore, criteria of good quality must be defined in each activity.

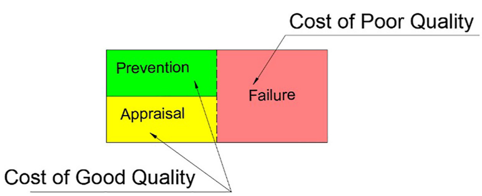


Figure 2. PAF model of quality cost

3. Discussion

The value chain has a significant role in mapping the activities within a business and its contribution to creating value for customers. Referring to the principle of Activity-Based Costing (ABC), which defines activity as a business element that absorbs costs, the value chain can also map the absorption of costs carried out by each activity (Blocher *et al.*, 2019; Cooper and Kaplan, 1992; Letza and Gadd, 1994; Li, 2018; Vaxevanidis *et al.*, 2009; Wood, 2013). Moreover, because quality costs are part of activity costs, the value chain should also map quality costs within a company.

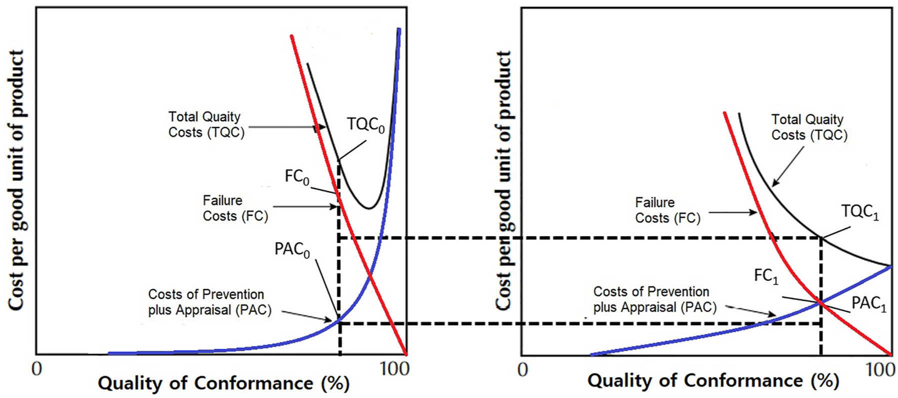


Figure 3.
Model of optimum quality costs

Source(s): Wood (2013)

Conceptually, the total quality cost (TQC) sums up good and poor quality costs (Janatyan and Shahin, 2020; Juran and Godfrey, 1999; Wood, 2013). Graphically, we can see the total quality cost is improved with the lower value of the new TQC ($TQC_1<TQC_0$) at quality conformance (Figure 3). Refers to this model; lower TQC_1 is the effect of a slight increase of new PAC and a considerable decrease of new FC. Meanwhile, PAC is the sum of prevention cost (PC) and appraisal cost (AC). In practice, while $PAC_1 = PAC_0$ ($\Delta PAC = 0$ possibly denotes no additional prevention and appraisal costs), the potential to reduce FC ($FC_1<FC_0$) may still exist. It means that PAC has a relevant range on TQC appropriateness. This relevant range refers to each PAC's maximum limit in averting a particular failure cost (relevant range ratio = FC/PAC). The higher this ratio, the more productive the PAC, but this is not unlimited. This proposed ratio is conceptually similar to process capability (Heizer *et al.*, 2017) or functional capability (Gilbert *et al.*, 2005). Another critical issue is the amount of FC in each chain. A primary activity closer to the ultimate value creation activity has greater TQC than the prior one. The TQC will be higher when an FC is identified in the sales and marketing activity than in outbound logistics (Janatyan and Shahin, 2020; Juran and Godfrey, 1999; Soares *et al.*, 2020). The FC-related prevention opportunities should be identified in the earlier activities, primary and supporting.

Mathematically, TQC is the sum of Prevention Cost (PC) and Appraisal Cost (AC) and Failure Cost (FC) (Feigenbaum, 1983; Juran and Godfrey, 1999; Wood, 2013; Yasin *et al.*, 1999), formulated as follows;

$$TQC = PC + AC + FC$$

where:

TQC = Total Quality Cost

PC = Prevention Cost

AC = Appraisal Cost

FC = Failure Cost

Conceptually, PAC is the sum of PC and AC, so that:

$$TQC = PAC + FC$$

where:

$PAC = PC + AC$

FC = Failure Cost

Based on Figure 3, TQC_0 is the current total quality cost, while TQC_1 is the new total quality cost (Farooq *et al.*, 2017; Psomas *et al.*, 2018; Wood, 2013; Yasin *et al.*, 1999). Due to the inverse effect expected between the changes in PAC (ΔPAC) and FC (ΔFC) on TQC, the calculation of both should be treated differently (Omachonu *et al.*, 2004; Psomas *et al.*, 2018; Vaxevanidis *et al.*, 2009; Wood, 2013). ΔPAC is the difference between new and current Prevention and Appraisal Costs (PAC_1–PAC_0), while ΔFC is between current and new Failure Costs (FC_0–FC_1) (Omachonu *et al.*, 2004; Psomas *et al.*, 2018; Sawan *et al.*, 2018; Vaxevanidis *et al.*, 2009; Wood, 2013).

So that the relationship between TQC_0 and TQC_1 can be depicted as given:

$$TQC_0 = PAC_0 + FC_{0,} \text{ while } TQC_1 = PAC_1 + FC_{1.}$$

where:

TQC_0 = Current Total Quality Cost

PAC_0 = Current Prevention and Appraisal Cost

FC_0 = Current Failure Cost

TQC_1 = New Total Quality Cost

PAC_1 = New Prevention and Appraisal Cost

FC_1 = New Failure Cost

Because of the differing impacts of PAC and FC on TQC, the TQC improvement formula should take this conditional factor into account:

$$\text{If } \Delta PAC = PAC_1 - PAC_0 \text{ and } \Delta FC = FC_0 - FC_1 \text{ then :}$$

$$TQC_1 = (PAC_0 + \Delta PAC) + (FC_0 - \Delta FC) \text{ or;}$$

$$TQC_1 = (PAC_0 + FC_0) + (\Delta PAC - \Delta FC) \text{ or;}$$

$$TQC_1 = TQC_0 + (\Delta PAC - \Delta FC)$$

$$\text{If } \Delta PAC < \Delta FC \text{ then } TQC_1 < TQC_0, \text{ the } TQC_1 - \text{related PA activities can be applied.}$$

New and current preventive and appraisal (PA) activities may differ physically, but new and current failure (F) types will likely remain unaltered, indicating that quality increases as PAC increases. For this reason, if a company spends more on PAC for materials, the result will be an improved quality of material (Omachonu *et al.*, 2004; Sawan *et al.*, 2018). Given TQC1 equations reflect three alternative benchmarks for quality improvement in practice.

According to the SCM concept, $\Delta PAC < \Delta FC$ and $TQC_1 < TQC_0$ will be proposed as conditional references for PA activities improvement on the value chain. Recording activities and costs related to quality are crucial (Feigenbaum, 1983; Juran and Godfrey, 1999; Wood, 2013). PAC improvement should be identical to improving the quality of prevention or appraisal activities, which can be primary, supportive, or both. The logic is at least a root cause for each failure, the cause is preventable and prevention must be cheaper than failure (Ahmed Al-Dujaili, 2013; Soares *et al.*, 2020; Wood, 2013). The cost of poor quality is the best indicator of inefficient or ineffective activities (Ahmed Al-Dujaili, 2013; Chatzipetrou and Moschidis, 2016; Pekanov Starcevic *et al.*, 2015; Farooq *et al.*, 2017; Gilbert *et al.*, 2005; Kerfai *et al.*, 2016; Khaled Omar and Murgan, 2014; Omachonu *et al.*, 2004; Purushothama, 2012; Sawan *et al.*, 2018; Soares *et al.*, 2020). Therefore, to reduce TQC, the first target is to reduce FC.

Failure to meet the design specification is the most expensive error in the manufacturing sector. At first glance, the root of this failure mostly comes from the primary activity, namely operation or production (Table 1). Many predict this failure comes from component production or assembly; both are parts of operation activities. A mathematical model developed to calculate the total quality costs even still focuses on the operation activity (Farooq *et al.*, 2017; Gilbert *et al.*, 2005; Khaled Omar and Murgan, 2014).

In reality, this failure can start from the design process, where the design process is part of the supporting activities in the value chain (Gilbert *et al.*, 2005; Juran and Godfrey, 1999; Wang *et al.*, 2021). Unfulfilled specifications also stem from the difficulty of suppliers in providing consistent quality raw materials (Sato *et al.*, 2020). Manufactured agriculture, plantations and forestry products often face this problem (Ames *et al.*, 2013). This condition can even force producers to market products with lower quality. Although no studies have shown a significant relationship between wheat hull color, milled product color and groats color variation in oat products, this color difference is often an important criterion for consumers in determining the quality of oat products (Ames *et al.*, 2013). Components with excellent resistance to the applicable quality range will reduce failure rates and otherwise increase direct material costs and possibly subsequent processes.

Even in the same industry, especially in the service industry (Janatyan and Shahin, 2020; Yilmaz and Bititci, 2006), every company may have different references in determining the

Table 1.
Source of FC

		Source of FC								
		Primary					Supporting			
Author	Industry	IL	O	OI	SM	S	IS	HRM	TD	P
Soares *et al.* (2020)	Industrial manufacturers		√							
Sawan *et al.* (2018)	Construction	√								
Farooq *et al.* (2017)	Aerosol can manufacturer		√							
Chatzipetrou and Moschidis (2016)	Supermarket				√	√				
Kerfai *et al.* (2016)	Manufacturing industries		√		√					
Malik *et al.* (2016)	Wood-product manufacturer		√							
Pekanov Starcevic *et al.* (2015)	Multi-industries		√							
Khaled Omar and Murgan (2014)	Semi-conductor firm		√							
Gilbert *et al.* (2005)	Electronic manufacturer		√						√	
Omachonu *et al.* (2004)	Wire and cable manufacturer		√							

PAF quality cost relations, but all are detectable and relatively measurable. A company may place the cost of quality training, which is part of the prevention cost (PC), only on the operation chain. In another company, quality training becomes mandatory in every chain. The same situation can also apply to appraisal cost (AC) and FC. The red cells show the chains at which the activities-related quality cost is usually applied. In a deeper analysis, the yellow cells may have a strong relationship with the given quality costs (Table 2) (Blocher *et al.*, 2019; Choi *et al.*, 2020; Dapiran and Kam, 2017; Farooq *et al.*, 2017; Honarpour *et al.*, 2018; Purushothama, 2012; Soares *et al.*, 2020; Wood, 2013; Zeng *et al.*, 2015). Many research shows that an information system (IS) can be an infrastructure that supports all quality-related activities (Guimaraes *et al.*, 2007; Johnson and Whang, 2009; Kagermann *et al.*, 2015; Lin, 1991; Sahut *et al.*, 2020; Zhang, 2005). Quality Function Deployment (QFD) can be considered to find this relationship (Choi *et al.*, 2020).

PAF Quality Costs			References:	Primary Activities					Supporting Activities			
Activities				IL	O	OL	SM	S	IS	HRM	TD	P
P	New product review		(Blocher *et al.*, 2019; Feigenbaum, 1983; Gilbert *et al.*, 2005; Juran and Godfrey, 1999; Malik *et al.*, 2016; Ramdeen *et al.*, 2007; Wood, 2013)		√		√	√	√		√	√
	Quality planning		(Blocher *et al.*, 2019; Chatzipetrou and Moschidis, 2017; Feigenbaum, 1983; Juran and Godfrey, 1999; Psomas *et al.*, 2018; Sawan *et al.*, 2018; Wood, 2013)	√	√	√	√	√	√	√	√	√
	Quality administration		(Blocher *et al.*, 2019; Feigenbaum, 1983; Juran and Godfrey, 1999; Wood, 2013)	√	√	√	√	√	√	√	√	√
	Quality improvement project		(Blocher *et al.*, 2019; Feigenbaum, 1983; Juran and Godfrey, 1999; Malik *et al.*, 2016; Wood, 2013)	√	√	√	√	√	√	√	√	√
	Training and education on quality		(Chatzipetrou and Moschidis, 2016; Feigenbaum, 1983; Juran and Godfrey, 1999; Malik *et al.*, 2016; Psomas *et al.*, 2018; Purushothama, 2012; Wood, 2013)	√	√	√	√	√	√	√	√	√
	Equipment maintenance		(Chatzipetrou and Moschidis, 2017; Feigenbaum, 1983; Juran and Godfrey, 1999; Omachonu *et al.*, 2004; Ramdeen *et al.*, 2007; Wood, 2013)	√	√	√			√	√	√	√
	Product, process, & service audit		(Blocher *et al.*, 2019; Feigenbaum, 1983; Juran and Godfrey, 1999; Kerfai *et al.*, 2016; Wood, 2013)		√	√	√	√	√		√	
	Supplier capability survey		(Blocher *et al.*, 2019, 2019; Chatzipetrou and Moschidis, 2016; Feigenbaum, 1983; Juran and Godfrey, 1999; Kerfai *et al.*, 2016; Psomas *et al.*, 2018; Sawan *et al.*, 2018; Wood, 2013)	√					√		√	√
	Supplier Assurance		(Blocher *et al.*, 2019; Chatzipetrou and Moschidis, 2016; Feigenbaum, 1983; Juran and Godfrey, 1999; Psomas *et al.*, 2018; Sawan *et al.*, 2018; Wood, 2013)	√					√		√	√
A	Incoming material Inspection		(Chatzipetrou and Moschidis, 2017; Farooq, 2017; Feigenbaum, 1983; Juran and Godfrey, 1999; Malik *et al.*, 2016; Omachonu *et al.*, 2004; Psomas *et al.*, 2018; Sawan *et al.*, 2018; Wood, 2013)	√	√				√	√	√	√
	Work in Process Inspection		(Farooq, 2017; Feigenbaum, 1983; Juran and Godfrey, 1999; Wood, 2013)		√				√	√	√	
	Finished Goods Inspection		(Chatzipetrou and Moschidis, 2016; Farooq, 2017; Feigenbaum, 1983; Juran and Godfrey, 1999; Omachonu *et al.*, 2004; Psomas *et al.*, 2018, 2018; Ramdeen *et al.*, 2007; Soares *et al.*, 2020; Wood, 2013)		√	√	√	√	√	√	√	
	Packaging Inspection		(Blocher *et al.*, 2019; Feigenbaum, 1983; Juran and Godfrey, 1999; Wood, 2013)		√	√	√	√	√	√	√	√
	Equipment test		(Blocher *et al.*, 2019; Feigenbaum, 1983; Juran and Godfrey, 1999; Omachonu *et al.*, 2004; Purushothama, 2012; Ramdeen *et al.*, 2007; Wood, 2013)	√	√	√		√	√	√	√	√
	Material test		(Blocher *et al.*, 2019; Feigenbaum, 1983; Juran and Godfrey, 1999; Wood, 2013)	√	√				√	√	√	√
	Product test		(Blocher *et al.*, 2019; Feigenbaum, 1983; Juran and Godfrey, 1999; Pasquini *et al.*, 2020; Ramdeen *et al.*, 2007; Wood, 2013)		√	√	√	√	√	√	√	√
F	Internal	Scrap	(Blocher *et al.*, 2019; Feigenbaum, 1983; Juran and Godfrey, 1999; Kerfai *et al.*, 2016; Malik *et al.*, 2016; Omachonu *et al.*, 2004; Psomas *et al.*, 2018; Sawan *et al.*, 2018; Wood, 2013)	√	√	√	√	√	√		√	
		Rework	(Blocher *et al.*, 2019; Feigenbaum, 1983; Juran and Godfrey, 1999; Kerfai *et al.*, 2016; Omachonu *et al.*, 2004; Soares *et al.*, 2020; Wood, 2013)		√		√	√	√		√	
		Reinspection	(Blocher *et al.*, 2019; Chatzipetrou and Moschidis, 2017; Farooq, 2017; Feigenbaum, 1983; Juran and Godfrey, 1999; Psomas *et al.*, 2018; Wood, 2013)	√	√	√	√	√	√		√	
		Retesting	(Blocher *et al.*, 2019; Feigenbaum, 1983; Juran and Godfrey, 1999; Wood, 2013)	√	√	√	√	√	√		√	
		Down-grading	(Feigenbaum, 1983; Juran and Godfrey, 1999; Kerfai *et al.*, 2016; Wood, 2013)	√	√	√	√	√	√		√	
		Loss of production	(Feigenbaum, 1983; Juran and Godfrey, 1999; Malik *et al.*, 2016; Wood, 2013)	√	√	√	√	√	√		√	
	External	Processing customer complaint	(Blocher *et al.*, 2019; Feigenbaum, 1983; Juran and Godfrey, 1999; Keller *et al.*, 2020; Kerfai *et al.*, 2016; Wood, 2013)	√	√	√	√	√	√		√	√
		Sales or Customer returns	(Blocher *et al.*, 2019; Chatzipetrou and Moschidis, 2016; Feigenbaum, 1983; Juran and Godfrey, 1999; Psomas *et al.*, 2018; Ramdeen *et al.*, 2007; Wood, 2013)	√	√	√	√	√	√		√	√
		Warranty claims/ field service	(Blocher *et al.*, 2019; Feigenbaum, 1983; Juran and Godfrey, 1999; Keller *et al.*, 2020; Wood, 2013)	√	√	√	√	√	√		√	√
		Sales allowance (due to quality problems)	(Blocher *et al.*, 2019; Feigenbaum, 1983; Juran and Godfrey, 1999; Wood, 2013)				√	√	√			
		Product liability lawsuits/claims	(Blocher *et al.*, 2019; Chatzipetrou and Moschidis, 2017; Juran and Godfrey, 1999; Wood, 2013)				√	√	√		√	
		Product recalls	(Blocher *et al.*, 2019; Feigenbaum, 1983; Juran and Godfrey, 1999; Psomas *et al.*, 2018; Wood, 2013)				√	√	√		√	

Table 2.
Activities in the PAF quality cost model

As the name implies, the function of PA activities is to minimize the poor quality output of an activity flowing into the following process. These activities should refer to critical quality attributes (CQA) targeted by the company. The complexities of the activities and CQA vary in different industries (Ames *et al.*, 2013; Gilbert *et al.*, 2005; Purushothama, 2012; Schmitt, 2018). However, when the meaning of poor quality is translated into the form of a tolerance range of quality values that is still acceptable, these quality management activities cannot prevent the closeness of the absolute quality value of a product to the specified tolerance limit (Ahmed Al-Dujaili, 2013; Jalali *et al.*, 2019). Practically, the easiest way to detect quality problems is to know the type and frequency of internal failures that occur in each primary activity and then convert them into monetary value (Khaled Omar and Murgan, 2014; Psomas *et al.*, 2018; Sailaja *et al.*, 2014). The next step can be prevention, appraisal, or a combination of both. The prevention and appraisal actions differ at each link in the chain and evolve (Ahmed Al-Dujaili, 2013; Sawan *et al.*, 2018; Soares *et al.*, 2020). Some methods are outdated. The worst-case design approach is no longer suitable for electronic products in this digital era (Gilbert *et al.*, 2005). Using this method as a prevention activity in the technology and development department is costly, potentially reducing competitiveness (Gilbert *et al.*, 2005).

On the other hand, product Platform Design (PPD) is highly recommended for filling a wide range of market niches while maintaining economies of scale and scope. A product platform is a collection of subsystems and interfaces that constitute a standard structure from which a stream of derivative goods can be efficiently produced and developed. Using PPD, component variations due to design diversity can be reduced; therefore, the potential for quality problems will automatically be reduced (Galizia *et al.*, 2020; Wei *et al.*, 2009).

As stated previously, many still think that FC is the only component of quality cost (Pekanov Starcevic *et al.*, 2015; Purushothama, 2012; Wood, 2013). If the failure is in the form of a product defect and occurs in the chain of operations, the conventional step to overcome it is to boost the production of good products. If the same failure occurs in the marketing and sales or service chain, the fastest solution is to replace it with a good product (Blocher *et al.*, 2019; Feigenbaum, 1983; Juran and Godfrey, 1999; Wood, 2013). The source of the problem is still present. In a better way, they map failure cost-main activities linkage inside the operation chain (Figure 4a) (Farooq *et al.*, 2017; Hauck *et al.*, 2021). Even though they are still focused on FC, several companies have begun to identify FC in each chain (Figure 4b) (Ames *et al.*, 2013; Gilbert *et al.*, 2005; Psomas *et al.*, 2018). In practice, it is possible to find this cost in supporting activities (Ahmed Al-Dujaili, 2013; Sawan *et al.*, 2018). The failure cost proportions among primary activities in Figure 4 are simulated.

As the name implies, the function of prevention and appraisal activities is to minimize the poor quality output of an activity flowing into the following process (Ahmed Al-Dujaili, 2013; Chatzipetrou and Moschidis, 2017; Farooq *et al.*, 2017; Juran and Godfrey, 1999; Sawan *et al.*, 2018; Soares *et al.*, 2020). However, when the meaning of poor quality is translated into a tolerance range of quality indicators that is still acceptable, these activities cannot prevent the closeness of the absolute quality value of a product to the specified tolerance limit (Ahmed Al-Dujaili, 2013; Gilbert *et al.*, 2005; Yasin *et al.*, 1999). This condition increases the probability of internal failure in the following process.

When the proportion of FC in a chain is troublesome, $FC_{0\text{-}IL}$ in Inbound Logistics (IL), for example, meanwhile the performance of the main activity ($MC_{0\text{-}IL}$) is unchanged; the PAF quality cost model becomes a quality management model that is considered for quality cost reduction (Figure 5). In this case, the current main activity cost ($MC_{0\text{-}IL}$) is assumed to be the same as the main activity cost in the PAF model ($MC_{1\text{-}IL}$).

Due to FC reduction as the primary target, the first step in PAF quality cost model implementation is to identify the type of failure in each key-value creation chain (Soares *et al.*, 2020; Sturm *et al.*, 2019; Wood, 2013). The second is to determine the FC internally or externally. Internal FC is possibly found in all primary activities; external FC begins in the

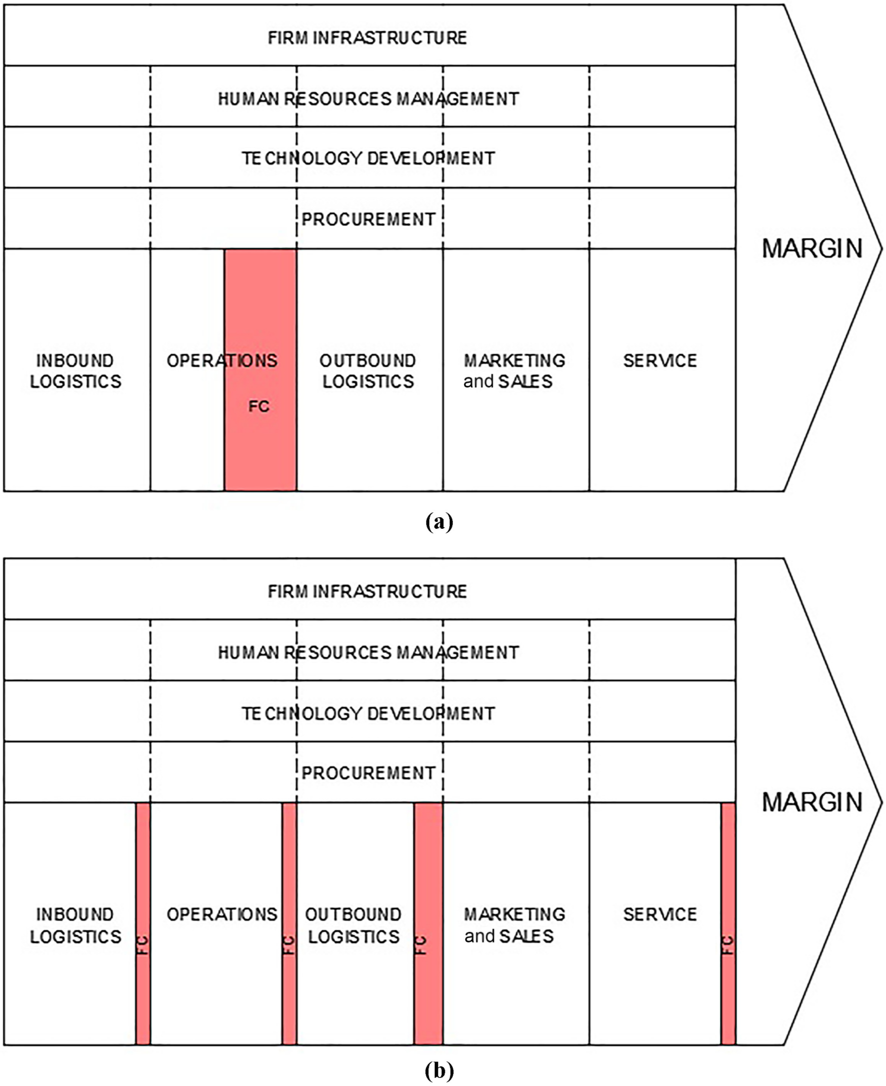


Figure 4.
Failure cost (FC) – main activities linkage

marketing/sales or service associated with the value chain (Table 2). The third step is to identify the preceding primary activity directly related to the failure and deploy it into sub-activities. The fourth step is charting each one's relationship to the other sub-activities. The fifth step is to identify appropriate prevention and appraisal initiatives. Then, inside and between primary and supporting activity categories, identify the related PC, AC, FC and important executional and operational cost drivers (Blocher *et al.*, 2019; Li, 2018; Soares *et al.*, 2020). After examining the existing quality problem-activity linkages, find a lower PAC. Finally, figure out how much FC is if failure happens. If the cost savings of the alternative FC are greater than the previous, suggest these additional PA activities or find a better

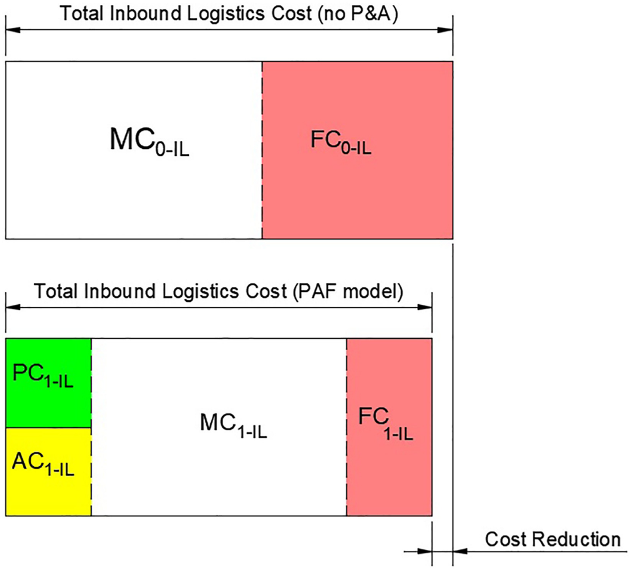


Figure 5.
Failure model vs PAF quality cost model

alternative. This PAF quality cost improvement map, the so-called Quality Cost Chain (QCC), can be classified as a value chain redesign (Kagermann *et al.*, 2015). QCC is a driver of innovation directly (Honarpour *et al.*, 2018; Zeng *et al.*, 2015) or indirectly (Schniederjans and Schniederjans, 2015).

It is nearly difficult for any company to ignore the presence of technology in every value-creation activity. Meanwhile, the wide range of technical capabilities accessible on the market significantly establishes competitive advantages, particularly quality-related ones. These technologies can be specifically designed to improve the performance of specific primary or supporting operations and serve as a connection across activities to optimize value (Bhargava *et al.*, 2018). Quality-related activities, which can be primary, supportive, or both, should be improved with PAC improvement. In the inbound logistic (IL) case, ΔPAC may reflect the increases in PC_{IL} and AC_{IL}. At the same time, ΔFC indicates a decrease in FC_{IL}. The improvement of TQC in Inbound Logistics is confirmed if the new TQC_{IL} is lower than the previous. The PAF activities improvement can be centralized as a single sub-activity in primary or supporting activities (Figure 6).

The PAF activities improvement is also possibly distributed in many sub-activities in the Inbound Logistics (IL) chain, such as $TQC_{1\text{-}IL}$, $TQC_{2\text{-}IL}$, $TQC_{3\text{-}IL}$ and so on (Figure 7). For example, the total cost of an inbound logistics sub-activity ($TC_{1\text{-}IL}$) consists of $PC_{1\text{-}IL}$, $AC_{1\text{-}IL}$, $MC_{1\text{-}IL}$ and the internal $FC_{1\text{-}IL}$. Some generic main sub-activities in inbound logistics cases are receiving raw materials from suppliers, transporting, storing and releasing them from the warehouse, scheduling vehicles and maintaining warehouses. Zero defect may happen, but not zero quality cost or free as stated in some literature (Plewa *et al.*, 2016). PC and AC will happen even minimum. Theoretically, the minimum TQC in the PAF model consists of PAC (FC = 0). In the SCM, the number of activities related to poor quality and PA activities related to the good product can be defined as executional cost drivers. Test capability is an essential parameter in the technology development chain, categorized as support activities (Gilbert *et al.*, 2005). This parameter can be set as one of the prevention activities cost-drivers in the technology and development chain.

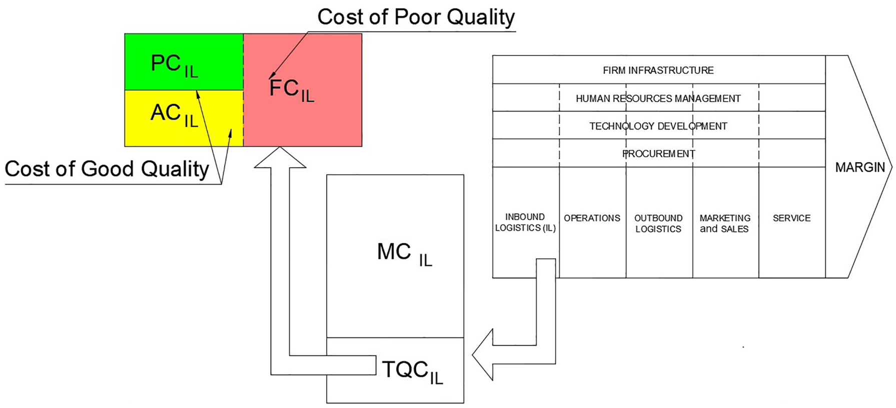


Figure 6.
PAF as centralized activity and cost

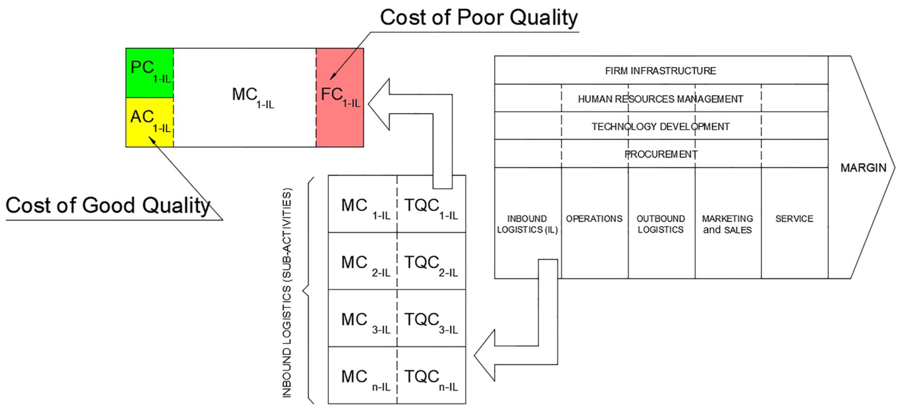


Figure 7.
PAF as distributed activities and cost

The model of optimum quality costs (Figure 3) does not indicate the effect of TQC improvement on the total cost of the activity (TC). After all, a successful PAF improvement will also improve Total Cost (TC) (Chatzipetrou and Moschidis, 2016; Omachonu *et al.*, 2004; Sawan *et al.*, 2018). A mathematical approach based on centralized PAF activities (Figure 6) shows the way a new TQC improved the total cost of the inbound logistic (TC_{IL}):

$$TC_{IL\_0} = (PC_{IL\_0} + AC_{IL\_0}) + MC_{IL\_0} + (FC_{IL\_0}) \text{ or;}$$

$$TC_{IL\_0} = PAC_{IL\_0} + MC_{IL\_0} + FC_{IL\_0} \text{ or;}$$

$$TC_{IL\_0} = TQC_{IL\_0} + MC_{IL\_0}$$

where:

TC_{IL_0} = Total cost of the inbound logistic activity (0 indicates current TC on inbound logistics)

PC_{IL_0} = The prevention cost of the inbound logistic (current)

AC_{IL_0} = The appraisal cost of the inbound logistic activity (current)

MC_{IL_0} = The main cost of the inbound logistic activity (current)

$$FC_{IL\_0} = \text{The internal failure cost of the inbound logistic activity (current)}$$

$$PAC_{IL\_0} = PC_{IL\_0}+AC_{IL\_0}$$

$$TQC_{IL\_0} = PAC_{IL\_0}+FC_{IL\_0}$$

The total cost of inbound logistics after improvement is $TC_{IL\_1}=(PC_{IL\_1}+AC_{IL\_1})+MC_{IL\_1}+(FC_{IL\_1})$. The explanation of each notation in TC_{IL_1} is similar to TC_{IL_0}.

The arrangement of PAF activities and the main activity related to each other, the so-called QCC (Quality Cost Chain), will facilitate the analysis process (Figure 8). This example assumes no modification in the main activity, so the cost is unchanged ($MC_{1L\_0} = MC_{1L\_1}$). 0 and 1 refer to current and new PAF activities, respectively.

Mathematically;

$$\text{If }\left(\left(PC_{1L\_1}+AC_{1L\_1}\right)-\left(PC_{1L\_0}+AC_{1L\_0}\right) < \left(FC_{IL\_0}-FC_{IL\_1}\right)\right)\text{ then }\left(TQC_{IL\_1} < TQC_{IL\_0}\right).$$

$$\text{If }\left(TC_{IL\_1}=TQC_{IL\_1}+MC_{IL\_1}\right)\text{ while }\left(MC_{IL\_0}=MC_{1L\_1}\right)\text{ then }\left(TC_{IL\_1}=TQC_{IL\_1}+MC_{IL\_0}\right)$$

Finally, if $(TQC_{IL\_1} < TQC_{IL\_0})$ then $TC_{IL\_1} < TC_{IL\_0}$, the total cost has decreased in Inbound Logistics.

A lower total cost of the activity (TC), primary or supporting, results from lower total quality cost (TQC) or higher ratio FC to PAC ($FC_{current}/PAC_{current} < FC_{new}/PAC_{new}$). In practice, this lower TQC potentially improves product return rate, lower inventory, lower manufacturing cost, higher perceived value, more satisfied customers and faster throughput time (Blocher *et al.*, 2019; Kagermann *et al.*, 2015; Schniederjans and Schniederjans, 2015; Zhang, 2005). QCC helps businesses lower TQC, which is related to strategic performance.

According to Table 2, in the e-retailer case (Johnson and Whang, 2009; Tsai *et al.*, 2013), prevention and appraisal capabilities can be centralized in the IT infrastructure chain or distributed among primary activities (Figure 9). PAF cost proportion and distribution in this

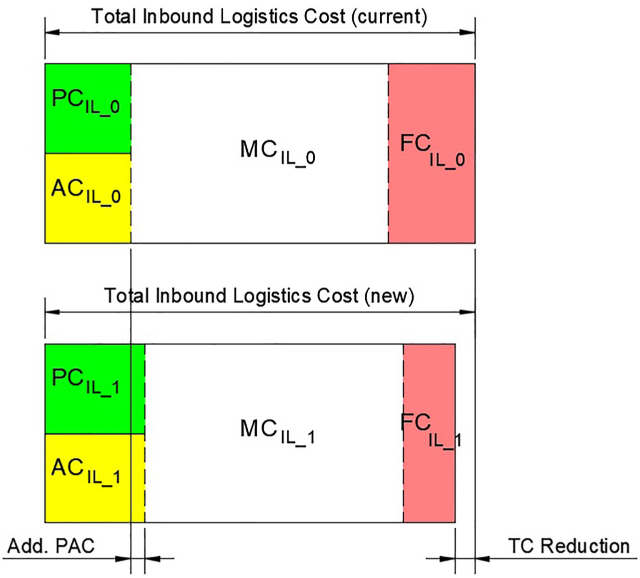


Figure 8.
PAF improvement and total cost (TC) reduction

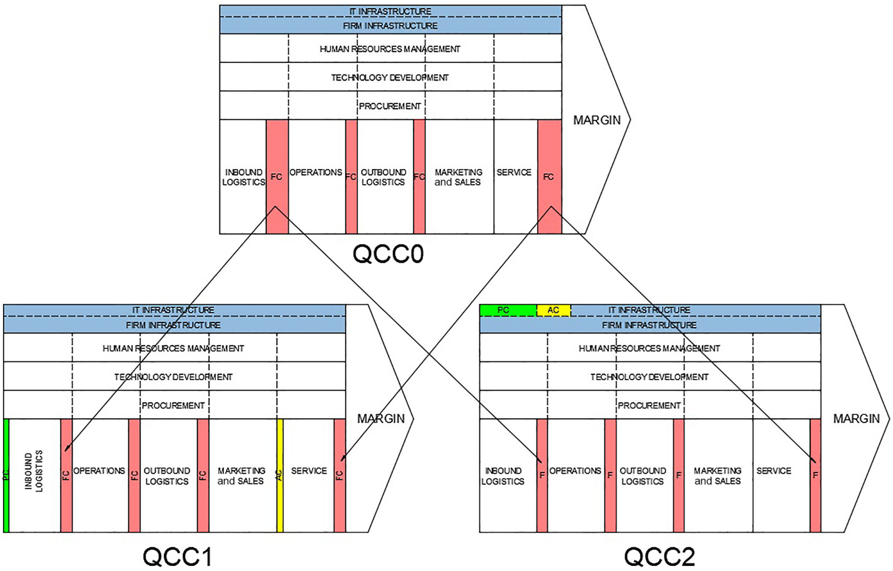


Figure 9. Various QCCs with equal TQC

example is just a simulation. Both alternative QCCs, QCC1 and QCC2, have different consequences from the SCM point of view, so does the competitive advantage (Blocher *et al.*, 2019; Schniederjans and Schniederjans, 2015; Zhang, 2005). In this case, the goal of the new quality management system is to lower FC in inbound logistics and service chains. QCC1 develops prevention activities directly at the inbound logistic and appraisal activities throughout the service chain. During their time at QCC2, the company implements prevention and evaluation modules into their IT infrastructure. These new modules are linked to an inbound logistics and services inspection hardware system.

By assuming the failure cost reduction (ΔFC) may be equal between QCC1 and QCC2 implementation, then;

$$\Delta FC_{QCC1} = \Delta FC_{QCC2}, \text{ so that } FC_{QCC0} - FC_{QCC1} = FC_{QCC0} - FC_{QCC2}.$$

Either; the total of PAF activities improvement at QCC1 is equal to the total of PAF improvement at QCC2, or:

$$TQC_{QCC1} = TQC_{QCC2}, \text{ then;}$$

$$TQC_{QCC1} = PAC_{QCC1'} + FC_{QCC1}, \text{ and } TQC_{QCC2} = PAC_{QCC2} + FC_{QCC2}.$$

$$\text{So that } PAC_{QCC1'} + FC_{QCC1} = PAC_{QCC2} + FC_{QCC2}.$$

Another alternative of QCC can be developed so that the generic equation will be:

$$PAC_{QCC1'} + FC_{QCC1} = PAC_{QCC2} + FC_{QCC2} = PAC_{QCC3} + FC_{QCC3} = PAC_{QCCn} + FC_{QCCn}$$

This equation confirms that the different QCCs with equal TQC can be generated to solve the same quality problems. Similar to the previous e-retailer case, internal failure due to the assembly-disassembly process in the chain of operations, sales and marketing and service may be overcome by implementing PPD in the technology development chain (Galizia *et al.*, 2020; Gliaubicas and Kanapickienė, 2015; Wei *et al.*, 2009). In SCM, the PPD method can be a prevention activity applied in the supporting activities. Generally speaking, from a quality cost in the short-run perspective, we can choose one with equal financial consequences or slightly different. However, the system development complexity can be very different when it becomes a strategic matter. Quality factors of the end product at the consumer level will ultimately determine the value and marketability. Quality is not just an operational or manufacturing industrial problem. The entire value chain must be considered to secure a reliable and consistent flow of quality that fulfills finished product specifications (Ames *et al.*, 2013), including marketing and sales and service chains (Lakhal, 2009).

The responsibility for implementing and achieving quality improvement targets in QCC1 applies to specific chains or sections. Prevention is a matter for inbound logistics, while appraisals are for the service department. Cost Driver, both executional and operational, in the two chains, of course, will be different. On QCC2, the IT infrastructure chain handles prevention and appraisal matters directly. These activities may still be implemented by workers in the inbound logistics chain and service chain. Nevertheless, the responsibility of the PAF remains on the IT infrastructure developer. This way, these two activities' executional and operational cost drivers will now be fully embedded in the IT infrastructure chain.

The selection of prevention and appraisal activities can be a strategic decision in quality management. Practically, prevention activities can significantly reduce appraisal costs (AC) (Chatzipetrou and Moschidis, 2016; Chopra and Garg, 2012; De, 2009; Farooq *et al.*, 2017; Pasquini *et al.*, 2020; Purushothama, 2012; Ramdeen *et al.*, 2007; Wang *et al.*, 2021). Table 2 can be an initial reference to find the relationship between the prevention and appraisal activities relation optimization. For example, quality management activities and cost administration are essential for the quality improvement program. If performed manually, it will be resource exhausted. An integrated quality management information system is highly recommended (Guimaraes *et al.*, 2007; Johnson and Whang, 2009; Lin, 1991; Sahut *et al.*, 2020). It will potentially reduce AC, TQC and TC simultaneously in a chain (Figure 10). Slightly different from Figures 5–8, PC and AC in

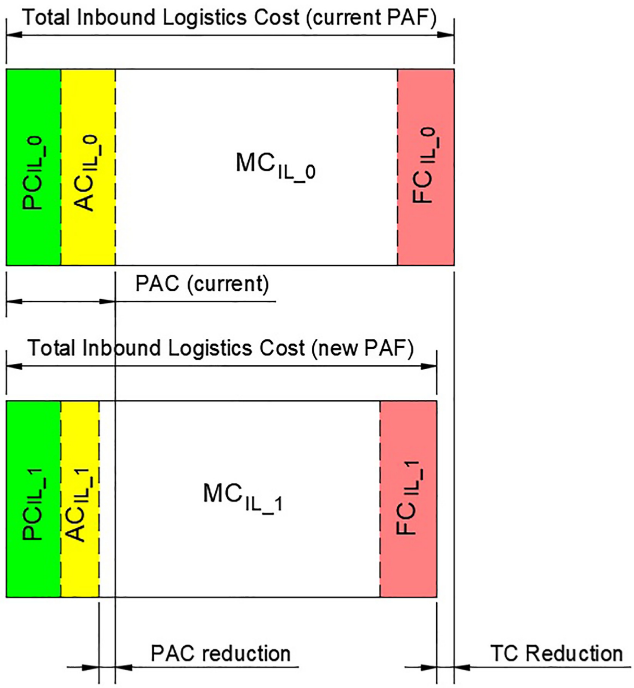


Figure 10.
PAC and TC reduction

Figure 10 are drawn vertically to make it easier to visualize the impact of changes in PAC, TQC and TC. Following FC/PC, a lower AC/PC ratio might be the second quality improvement criterion based on this PAC depiction.

New product design and customization, new materials, new machine operators, new process setups and new technologies will result in new quality issues (Chatzipetrou and Moschidis, 2016; Choi *et al.*, 2020; Galizia *et al.*, 2020; Wei *et al.*, 2009). The old quality issues may be resolved by implementing new conditions, but a new one may emerge. The one-time cost of prevention is no longer effective. The expense of prevention lasts a lifetime. The organization must re-create a new QCC map to investigate such new relationships.

4. Conclusions and implications

4.1 Conclusions

The Quality Cost Chain (QCC) is the sub-set of an internal business Value Chain. QCC effectively maps the linkages between activities and quality cost, making Strategic Cost Management applicable. Conceptually these linkages can be modified to develop valuable sources for innovation, competitive advantage and sustainability. The primary executional goal of strategic quality improvement is to reduce internal and external failure costs in the long run. The relationship between failure cost and all activities in the value chain that contribute to failure prevention must be mapped by a business. This activity is a dynamic process that might be unique to each firm.

Due to its strategic consequences, a business needs to identify, manage, evaluate carefully and modify the economics of quality in its value chain. The focus of strategic quality improvement is creating practical prevention activities. The ratio between potential failure costs (FC) and prevention and appraisal costs (PAC) can be considered for altering prevention and appraisal activities and applying new quality processes or technology with the condition that the new total quality cost is lower than the current. The second important consideration is the lower AC/PA ratio at equal FC/PAC. Although the costs of the primary value-added activities may stay unchanged, a higher FC/PAC ratio following the new executional quality management activities might lower the total cost of a value chain. Last, it is crucial to conduct a long-term investigation of the new possible quality concern.

4.2 Implications

This study has practical implications. Company managers can quickly analyze the strategic contribution of their departments or activities to quality costs at the departmental or organizational level using the QCC map. This map helps managers identify the linkage between activities and quality cost in all value chains, improve it in a centralized or distributed manner by considering FC/PAC, TQC, FC/PC and AC/PA, respectively and monitor them. Of course, as an inter-departmental analysis instrument, the detail and the completeness of related information, such as costs and activities, have a vital role.

This research has limitations. This study only discusses the relationship between quality costs and activities related to quality management in the PAF quality cost model, not cost behavior. This limitation opens up opportunities for future research that intends to link QCC with cost behavior in the context of managerial accounting and Strategic Cost Management. The use of QCC in certain industrial areas is the next research opportunity. The variety of PAF activities this study addresses originates from a wide range of industrial sectors; QCC research by sector may produce unique industrial quality cost phenomena.

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