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DECISION MAKING MODELS FOR QUALITY IMPROVEMENT

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ABSTRACT
The study of quality management is associated with improved quality. Improved quality also is basically related to the decision-making at every stage of the production process. The decisions made will determine the success rate of quality improvement can be achieved. To achieve optimal results, we need quality improvement model as a planning program. The impact is related to the cost. This paper reviews several models of quality improvement. The discussion begins with a list of some existing models. Afterwards the models are grouped into a model approach that surveys the impact of quality improvement on the stages in the production process. Analysis is carried out on several models in order to achieve a target of the desired quality. From the analysis and discussion on the models of product quality improvement, it was found that the commercial aspects need to be taken into account in improving the product quality.

Keywords: Product quality; Quality improvement; Quality model

1. INTRODUCTION
At present, competition between manufacturers in winning market share becomes increasingly fierce. Competition involves not only technical and commercial aspects, but also involves the management aspects of the business and all stages in the product life cycle. Therefore, everyone within the company needs to be involved because product quality improvement involves decision making at the stages of planning, production, and product delivery to consumers. It involves choosing between alternate options, taking into account the costs and the benefits. Decision making for quality improvement should be based on a systems approach. Therefore, in any decision made by the proper framework is required. The framework for proper decision-making and models plays a key role in this context. The models allow one to evaluate alternate options, choosing the best option.

The literature dealing with the use of models varies from simple static models to complex dynamic models. The outline of the paper is as follows. In the first section we commence with a brief review of the literature dealing with the use of models in product quality improvement. The models were classified based on their stage in the product life cycle, the variables that are used in the models, and the type of the models. The next five sections are subject to the nature of the model formulations. At each model we analyze the commercial, financial, and or technical aspects that interact with product quality improvement.

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2. BRIEF REVIEW OF LITERATURE

Table 1 is an illustrative sample of papers dealing with models for quality improvement. For each paper we highlight the following:

1. The stages of the PLC which are the focus of the model.
2. The variables indicate the system characterization used in the model building.
3. The type of model. Here we indicate whether the model is static or dynamic, deterministic or stochastic, and/or dealing with optimization etc.

Table 1 Small sample of literature on quality improvement

	PLC Stages					Variables										Type of Model				
	Front-end	Design and Development	Production	Marketing	Post-Sales	Product quality level	Costs	Time	Learning effects	Profits	Sales price	Market share	Warranty	Revenue	Customer satisfaction (Customer Behavior)	Static	Dynamic	Stochastic	Optimization	Conceptual / Framework
Levy (1965)			✓					✓	✓							✓				
Krishnan and Gupta (1967)				✓			✓				✓			✓		✓				
Bass (1969)				✓													✓			
Bell, et.al. (1975)				✓								✓				✓				
Robinson and Lakhani (1975)				✓							✓					✓				
Spence (1981)			✓						✓								✓			
Porteus (1986)			✓			✓											✓			
Fine (1986)			✓				✓		✓								✓		✓	
Buffa and Sarin (1987)			✓				✓		✓								✓			
Mamer (1987)					✓	✓	✓			✓			✓				✓			
Monahan (1987)				✓								✓								
Murthy and Nguyen (1987)		✓	✓		✓		✓											✓		
Wacker (1989)				✓						✓	✓						✓			
Armistead and Clark (1991)		✓		✓	✓	✓	✓								✓					
Kantor and Zangwill (1991)			✓			✓	✓		✓							✓				
Kohli and Mahajan (1991)				✓							✓					✓				
Djamaludin (1993)			✓			✓											✓			
Ghose and Mukhopadhyay (1993)						✓					✓	✓								

Table 1 Small Sample of Literature on Quality Improvement (continued)

	PLC Stages					Variables										Type of Model				
	Front-end	Design and Development	Production	Marketing	Post-Sales	Product quality level	Costs	Time	Learning effects	Profits	Sales price	Market share	Warranty	Revenue	Customer satisfaction (Customer Behavior)	Static	Dynamic	Stochastic	Optimization	Conceptual / Framework
Rust and Metters (1996)					✓	✓	✓			✓					✓	✓				
Teng and Thompson (1996)	✓					✓			✓	✓	✓						✓			
Cohen, et.al. (1996)		✓				✓	✓	✓		✓							✓		✓	
Cohen and Whang (1997)					✓	✓	✓			✓	✓									
Crosby, et.al. (1990)				✓	✓						✓				✓					✓
Kingsman and de Souza (1997)	✓						✓				✓									✓
Martinez and Rodriguez (1997)					✓	✓	✓								✓					✓
DeCroix (1999)	✓					✓				✓			✓				✓			
Blischke and Murthy (2000)					✓								✓				✓			
Murthy and Kumar (2000)		✓	✓			✓				✓							✓			
Mallick and Mukhopadhyay (2001)		✓					✓			✓							✓		✓	
Shipley, et.al. (2001)	✓					✓				✓	✓									
Verma, et.al. (2001)		✓				✓				✓									✓	
Koksalan, et.al. (2003)		✓					✓										✓			
Souza, et.al. (2004)	✓						✓	✓											✓	
Ferguson (2009)			✓		✓	✓	✓						✓				✓			
Turner, et.al. (2010)			✓		✓										✓					✓

As can be seen, most models involve more than one variable as illustrated by the following examples. Fine (1986), Kantor and Zangwill (1991) and Buffa and Sarin (1987) examine the costs at the production stage taking into account the effects of learning during production. Armistead and Clark (1991), Rust and Metters (1996), Cohen and Whang (1997) and Martinez and Rodriguez (1997) study the interaction between product quality and after-sales service costs.

At the front-end stage, Teng and Thompson (1996) and DeCroix (1999) deal with profit models and quality. In DeCroix's model, the warranty period is taken into account. Kingsman and de Souza (1997) deal with a model to assist in cost estimation and pricing decisions, whilst the Shipley et al (2001) model examines the decision making with regards the type of product to be launched and the related price and quality issues. At this stage, decision-making related to quality improvement is also associated with new product development strategy. Souza (2004) conducted a study in shape optimization models in determining the right time to launch a new product. The model was built with consideration about the cost structure, competition, and market demand.

In the design and development stage, the quality under consideration is the quality of product performance. Armistead and Clark (1991) studied the link between the product quality performances as defined in the design and development stage with the quality of after sales product support. Verma et al., (2001) study product design complexity as this impacts the production process. While Koksalan (2003) deals with the influence of design problems with the cost of production. Mallick and Mukhopadhyay (2001) deal with a profit model as a function of sales volume whilst Cohen et al., (1996) deal with a similar model taking into account the cost of R&D and the total revenue generated.

In the production stage, Porteus (1986) and Djamaludin (1993) propose models to study quality of nonconformance under lot production. They discuss the optimal lot size taking into account the costs associated with the non-conforming items. Fine (1986), Kantor and Zangwill (1991), Buffa and Sarin (1987) and Spence (1981) study the effects of learning on outgoing product quality and production costs. Murthy and Kumar's (2000) model takes into account quality of performance (design stage), quality of conformance (production stage), and quality of service (post-sale stage) to determine the optimal strategies for design, quality control and servicing.

Models at the marketing stage include the following: Krishnan and Gupta (1967) deals with a static model to determine the revenue generated. Bass (1969) deals with a diffusion model to predict sales over time. Several researchers including Robinson and Lakhani (1975), Bell et al (1975), Monahan (1987), Wacker (1989) and Kohli and Mahajan (1991) have extended the model to incorporate additional variables. These additional variables include price, advertising, customer dissatisfaction etc.

In the post-sale stage, the bulk of the models proposed in the literature deal with the impact of product quality on the warranty servicing costs. Most manufacturers are keen to know how much they have to spend for warranty costs and the optimal warranty terms for items sold. The variables that need to be taken into account are product reliability (failure rate and distribution), usage mode, type of rectification action, cost of rectification etc. Murthy and Nguyen (1987) deal with three models concerning the trade-off between product quality (reliability) improvement and warranty servicing costs. Mamer (1987) deals with a model where the quality variations impact the expected warranty cost. Blischke and Murthy (2000) deal with post-sale decision issues.

2.1. Front-end stage models

At the front-end stage, models are needed to evaluate the costs and benefits of any improvements to product quality (in terms of its impact on various technical and commercial aspects of the business) and the optimal decisions with regards to quality improvement.

The objectives for improving product quality could be to maximize profits, increase sales (or market share) or total revenue. The following two models deal with improvements to maximize the total expected profits. In the first model, profit is defined as a function of product sale price and sales volume, whilst in the second model, profit is defined as a function of warranty, product reliability, and sale price.

2.1.1. Model 1 (Teng & Thompson, 1996)

In this model the product quality, *q(t)*, is continuously improving over time. The product quality impacts costs and sales. Let $C_T(q,t)$ denote the unit manufacturing cost at time *t*; *p(t)* the unit sale price and *s(t)* the total sales at time *t*. The sales rate at time *t* is modeled by an ordinary differential equation:

$$\dot{s}(t) = ds(t)/dt = f(p(t), q(t), s(t)) \tag{1}$$

Decision variables *p(t)* and *q(t)*, (which change over time), are to be selected optimally to maximise the discounted total profits over a time horizon *T* given by:

$$\max_{p(t),q(t)} \Pi = \int_0^T e^{-d_r t}[p(t) - C_T(q(t), s(t))]\dot{s}(t)dt \tag{2}$$

where d_r is the discount rate. The authors use results from optimal control theory to determine the optimal decision variables.

2.1.2. Model 2 (DeCroix, 1999)

This model deals with the case where there are *n* firms selling similar products. Firm i, $1 \le i \le n$, sells its product with unit sale price p_i and with warranty period w_i. The failure rate of the product produced by firm i is given by $r_i(t)$ and this characterises the reliability of the product. The unit manufacturing cost is $C_{MU}(r_i)$ which depends on the product's reliability (r_i) and the warranty cost per unit sold is $C_w(w_i, r_i)$ which is a function of the reliability and the warranty period. The demand for the product produced by firm i depends on the sale price and the perceived repair costs over the useful life of the product. The perceived costs for repair, $c_{ri}(w_i)$ is a function of the warranty period as customers view the warranty period as an indicator of reliability, with the longer warranty period conveying the message that the product is more reliable. As a result, the demand for firm i is given by a function $d_i(p + c_r(w))$. The decision variables that firm i needs to select the optimally are the sale price (p_i), warranty period (w_i), and reliability (r_i), to maximize the profit given by:

$$\max \Pi_i(w, r, p) = d_i(p + c_r(w))\left[p_i - C_{MUi}(r_i) - c_{Wi}(w_i, r_i)\right] \tag{3}$$

Note that in contrast to the previous case, this is a static optimization problem.

2.2. Design and development stage models

The main focus at this stage is to achieve the desired improvement in the quality of product performance. This is done through a proper design and development process. Quality at the design and development stage is determined by the number of variations of product design itself. The greater variety of product design leads to more diverse production processes. While more and more variations of the production process in all probability will lead to uncertainty in the production process. Therefore, we need a framework of robust design to ensure product quality from the design and development stage onwards (Kovach, 2008). The models at this stage deal with tradeoff decisions involving the speed of the design and development process as indicated by the following model. Decisions taken at the stage of design and development are mainly related to the selection of resources, which is owned by a company or other third parties

(Faes, 2009). In this case the optimization strategies in selecting and using any resources need to be done in order to achieve an optimal quality improvement at a lower cost.

2.2.1. Model 3 (Cohen, et.al., 1996)

Let t_{RD} and t_P denote the time needed for the completion of research and development (R&D) and production, respectively. Let L_{RD} and L_P be the wage of labour per hour per product unit for R&D and production and, c_{RD} and c_P variables are the labour rate cost per hour for R&D and production. Hence the total costs (C_T) of new product development (including production) is given by:

$$C_T(t_{RD}, t_P) = c_{RD} L_{RD} t_{RD} + c_P L_P (t_P - t_{RD}) \tag{4}$$

Suppose the quality of product performance is improved from q^o to q^n and let q^c denote the quality of the competitors' product. Let the demand be *M*, and the profit margin per unit for the existing and the new products be π^o and π^n, respectively. The total revenue is modelled as:

$$R(t_{RD}, t_P) = M\pi^o \frac{q^o}{q^o + q^c} t_P + M\pi^n \frac{q^n(t_{RD} t_P)}{q^n(t_{RD} t_P) + q^c}(T - t_P) \tag{5}$$

The total profit is given by:

$$\Pi(t_{RD}, t_P) = R(t_{RD}, t_P) - C_T(t_{RD}, t_P) \tag{6}$$

The decision variables related to completion times (for R&D and production) are to be selected optimally to maximise the total profits.

2.3. Production stage models

The quality notion under consideration in this stage is quality of conformance. Improving the quality of conformance can be achieved by increasing product and process quality. Improving the product and process quality is determined by many variables (Sahni, 2009). Therefore we need to analysis quality improvement models by considering those variables. In batch production, this depends on the lot size. As the lot size increases, the probability of producing non-conformance items increases. This can be reduced through smaller lot sizes, but this increases the unit manufacturing cost due to higher production costs resulting from more frequent setups. The following three models deal with optimal lot sizing which takes into account the effect of lot size on product quality. The first two models by Porteus (1986) and Djamaludin (1993) describe the relationship between lot size and unit production cost. The third model incorporates the effect of learning on product quality conformance and production costs.

2.3.1. Model 4 (Porteus, 1986)

Let *L* denote the lot size. The process is in-control when the lot production starts. The process can switch to out-of-control after an item is produced with probability q. Once the switch takes place it will stay in an out-of-control state until the lot is produced. All items produced with the process while it is in-control are conforming, whilst all items produced with the state out-of-control are non-conforming. As a result, the number of conforming items produced in a lot, $\tilde{N}$ is a random variable. The expected number of conforming items in a lot is given by:

$$E\left[\tilde{N}\right] = L\frac{q(1-q^L)}{1-q} \tag{7}$$

The outgoing quality is given by:

$$\frac{E\left[\tilde{N}\right]}{L} = 1 - \frac{q(1-q^L)}{(1-q)L} \tag{8}$$

Note that this decreases as q increases.

2.3.1. Model 5 (Djamaludin, 1993)

This model is similar to the previous model except that not all items produced when the process is in-control are conforming and similarly not all items produced are nonconforming when the process is out-of-control. Let φ_1 be the probability that an item produced is conforming when the process is in-control and φ_2 be the corresponding probability when the process is out-of-control.

$$E\left[\tilde{N}\right] = \left\{\frac{p(\varphi_1 - \varphi_2)(1-p^L)}{(1-p)}\right\} + \varphi_2 L \tag{9}$$

As a result, outgoing quality is given by:

$$E\left[\frac{\tilde{N}}{L}\right] = \left\{\frac{p(\varphi_1 - \varphi_2)(1-p^L)}{(1-p)L}\right\} + \varphi_2 \tag{10}$$

2.3.3. Model 6 (Fine, 1986)

This model shows the effect of learning on product quality and production costs. Let $x(t)$ and $q(t)$ denote production rate and quality of conformance achieved at time t. Learning results from the experience gained by production and is captured through a variable $z(t)$ and is modeled as follows:

$$z(t) = z(0) + \int_0^t x(s)q(s)ds \tag{11}$$

The unit sale price at time t depends on $x(t)$ and is given by $\phi(x(t))$. The costs associated with items produced at time t is comprised of the appraisal and prevention cost [$C_{ap}(q(t))$], failure cost [$C_f(q(t))$] and unit manufacturing cost [$C_{mu}(z(t))$]. The discounted total profit is given by:

$$J = \int_0^T e^{-rt}[\phi(x(t)) - C_{ap}(x(t)) - C_f(x(t)) - C_{mu}(z(t))]x(t)dt \tag{12}$$

The decisions variables are $x(t)$ and $q(t)$ which are selected to minimize J. Note that this is a dynamic optimal control problem.

2.4. Marketing stage models

Models at this stage relate product sales to sale price and product quality. The sale price depends on unit manufacturing cost, product quality and other costs which include transportation cost to markets, inventory holding, advertising and promotion etc. The demand for the product depends on quality and sale price. For a given price, it increases as quality improves and for a given quality, it decreases as sale price increases. However, when both of them increase, the net effect depends on buyer's tradeoff between quality and price. The notion of quality or "value for money" becomes important. At the marketing stage, the distribution of finished goods to consumers, also determines the value of the benefits to be gained by companies (Lenox, 2006). The longer the distribution channels the tendency exists to increase competition and risk in order to reduce profits.

The quality of the salesperson and customer relationships also has an influence on the performance of product sales (Crosby, 1990). This is due to a good relationship between the salesperson to the consumer that will affect the perceived quality of the product. For products with a good perceived quality, it follows that this perception will automatically increase the sales of the products.

Product quality can be used as a promotional tool, either directly or through some associated variable, such as, a longer warranty period being used to promote a more reliable product. As a result, price and quality are the decision variables that impact sales, revenue and profit as improved quality involves higher unit cost due to greater investment in design and development.

2.4.1. Model 7 (Murthy & Kumar, 2000)

The total sales is modeled by static formulation given by:

$$S = kP^a q^b \tag{13}$$

where S is the total sales, P is the sale price and q is product quality (or some other variable which is related to quality such as warranty). k , a and b are parameters within which the last two, being the price and quality elasticity interact to affect the total sales S.

2.4.2. Model 8: Diffusion model (Bass, 1969)

The model is based on the diffusion theory. The product sale is modeled through a sales rate function $n(t)$ at a specific time t that changes dynamically over a specified time period. Let $N(t)$ denote the total sales until time t occurs so that $n(t) = dN(t)/dt$. The model is given by:

$$\frac{dN(t)}{dt} = [a + bN(t)][L - N(t)] \tag{14}$$

where L is the total market for sales and a and b are parameters. $N(0) = 0$ and $N(t) \to L$ as $t \to \infty$. L can be a function of price and quality as in Model 7. Similarly, a and b can also be function of price and advertising effort. Note that a represents the effect of direct advertising (such as on television or in newspapers) and b the "word-of-mouth" effect.

2.4.3. Model 9: Market share model (Krishnan & Gupta, 1967)

This model takes into account the effect of competition between two manufacturers selling a similar product. Let P_i and C_{ai} , $1 \le i \le 2$, denote the unit sale price and the promotional efforts for the two manufacturers, respectively. The market share for manufacturer i, $1 \le i \le 2$, is given by:

$$M_i = M_i = \frac{\alpha_i C_{ai}}{\alpha_1 C_{a1} + \alpha_2 C_{a2}} + k(P_1 + P_2 - 2P_i) \qquad (15)$$

where α_i, $1 \le i \le 2$, are the effectiveness of the promotional efforts of the two firms and k is a positive constant. As can be seen, if neither firm spends any money on promotion then the share depends solely on product price.

Let m_{pot} denote the total potential market potential. Let C_{MUi} ,$1 \le i \le 2$, denote the unit manufacturing costs for the two manufacturers. The profits for the two firms are given by:

$$\Pi_i = m_{pot} k(P_i - C_{MUi})^2 - C_{ai} \qquad (16)$$

for $1 \le i \le 2$.

2.4.4. Model 10: Profit model (Wacker, 1989)

This is a discrete time model where the price is altered in each period and as result the sales change from period to period. Let q denote the product quality and S_t , and P_t denote the sales and product price in period t. Let C_{MF_t} and C_{MV_t} denote the fixed and variable costs associated with the manufacturing of the product in period t. Then the model assumes that $S_t = f(P_t, q)$ and $C_{MT_t} = C_{MF_t} + C_{MV_i} S_t$. The profit in period t is given by:

$$\Pi_t = \Pi_t = (P_t - C_{MV_t}) S_t - C_{MF_t} \qquad (17)$$

The total profits over T time periods is given by:

$$\Pi = \sum_{t=1}^{T} \Pi_t = \sum_{t=1}^{T} (P_t - C_{MV_t}) S_t - \sum_{t=1}^{T} C_{MF_t} \qquad (18)$$

2.5. Post-sale stage models

At this stage models deal with the cost of servicing claims resulting from the product's failure to perform as expected. There are many models dealing with the claims under warranty and the resulting costs associated with the servicing of warranty. Other models deal with issues such as logistics needed for post-sale support including spares, service contracts etc.

In the purchase of products, customers not only look at price and performance, but also post-sale support provided by the manufacturer. Warranty is one such post-sale issue of great interest to both buyers and manufacturers. For buyers it provides assurance and redress should the purchased item not perform satisfactorily. For manufacturers, it acts as the very tool to promote the reliability of their products. However, offering a warranty results in additional costs and these depend on the reliability of the product and the servicing strategies employed. In this section we shall discuss two models to determine the expected warranty servicing costs.

2.5.1. Model 11 FRW policy (Blischke & Murthy, 1994)

Under a FRW (Free-Repair/Replacement Warranty) policy the manufacturer rectifies all failures over the warranty period W subsequent to the sale, at no cost to the buyer. In the case of a non-repairable product (such as a computer chip) defective items need to be replaced by new ones. Let $N(W)$ denote the number of failures over the warranty period. This is a random variable and it is related to the reliability of the product. Let $M(W)$ denote the expected number of failures under warranty, as given by the following integral equation:

$$M(W) = F(W) + \int_0^W M(W-t)\, f(t)dt \tag{19}$$

where $F(t)$ is the failure distribution of the product. If the unit manufacturing cost is C_{MT}, then the total expected cost to the manufacturer for each item sold is given by:

$$E[C_m(W) = C_{MT}\left[1 + M(W)\right] \tag{20}$$

The unit sale price must be greater than this result to ensure positive profit in an expected sense.

2.5.3. Model 12 PRW policy (Blischke & Murthy, 1994)

Under a PRW (Pro-rata warranty) policy the manufacturer refunds a fraction of the sale price should an item fail within the warranty period. Let X denote the time to failure. The fraction refunded is given by a function $q(X)$ which is a monotonically decreasing function with $q(0) \le 1$ and $q(W) = 0$. The amount refunded is given by $Pq(x)$ where P is the sale price. As a result, the warranty cost per unit is $C_m(W) = C_{MT} + q(X)$ and the expected cost to the manufacturer per item sold unit is given by:

$$E[C_m] = C_{MT} + P\left[F(W) - \frac{\mu_W}{W}\right] \tag{21}$$

where μ_W is the partial expectation given by:

$$\mu_W = \int_0^W xf(x)d(x) \tag{22}$$

The unit sale price must be greater than this to ensure positive profit in an expected sense.

2.5.3. Model 13 Remanufacturing (Ferguson, et.al. 2009)

If the customer receives a non-conforming or defective product and the product is still under warranty, then the product will be returned to the manufacturer's premises. At the time when manufacturers rectify the products, then there will be cost incurred. Costs incurred are not always similar to the cost at the time of initial production. The cost of remanufacturing per unit for an item of quality grade *i = 1,…., 1*, for period *t* is given by:

$$c_{it} = \frac{\int_i^{q_i} c(q)\, f_t(q)dq}{F_t(q_{i+1}) - F_t(q_i)} \tag{23}$$

Whereas the number of defective product returns with quality grade *i* is given by:

$$B_{it} = R_t\left(F_t(q_{i+1}) - F_t(q_i)\right) \tag{24}$$

q is the quality of each defective product return, which is represented by a real number $q \in [0,1]$ where $q = 0$ is total scrap and $q = 1$ is the highest possible quality of non-conforming product returns. It is assumed that the number of non-conforming products probably occurred in the distribution stage with its cumulative distribution function set as time t by $F_t(q)$ and its probability density function set by $f_t(q)$. Also, the number of a non-conforming product returns in each period by R_t, is a random variable.

3. RESULTS AND DISCUSSION

This paper has presented and analyzed several mathematical models relating to quality improvement. The models are grouped into different categories based on the different stages of the product life cycle (Front-End, Design and Development, Production, Marketing, and Post-Sale). The paper also analyzed the aspects that have been related to product quality improvement, namely: technical, commercial, financial, and managerial aspects. They vary from simple static models to complex dynamic models. The paper also analyzed the aspects that have been related to product quality improvement, namely: technical, commercial, financial, and managerial aspects. Most of the models are related to commercial aspects, such as sales rate $\dot{s}(t)$ and profit Π_t.This is because product quality improvement is strongly correlated with the commercial aspects of the product itself. The main objective for improving quality of product is to win market share. Therefore, any costs associated with product quality improvement in total have to be less than the market product price expected. Therefore, some models are taking into account discount rate d_r and warranty costs as a function of warranty period and product reliability c_{wi} (at Front-End stage and Post Sale stage), profit Π_t and revenue R_t as a function of product quality q_i and total manufacturing costs C_m (at Design & Development and Production stages).

4. CONCLUSION

From the models that have been analyzed and discussed, it can be concluded that the high determinant in product quality improvement is the total costs C_T. These costs will effect the profit and revenue that can be generated by the producer. While the total cost is a function of several variables that have positive or negative impact on the total cost itself. Positive functions for the total cost are product quality q_i (including the number of conforming items produced in a lot, $\tilde{N}$) and sales rate $\dot{s}(t)$ (as the number of product sold increased, the unit manufacturing cost $C_{MU}(r_i)$ will decreased, and eventually the total costs will decrease). On the other hand, the negative functions for the total cost are failure cost, $C_f(q(t))$ and warranty cost per unit sold $C_w(w_i, r_i)$ which is a function of the number of non-conforming product returns B_{it} and the warranty period.

From all the models discussed it can also be concluded that there are two main values that need to be looked at for optimal values related to quality improvement. The two values are the value associated with the effort to fulfill the quality and the value that must be borne if the product fails to meet the desired quality. These two values can be expressed as the costs of appraisal and prevention [$C_{ap}(q(t))$], and the costs of failure cost [$C_f(q(t))$], for both internal and external failure costs.

From the models discussed above, the knowledge realized is that the improvement of product and process quality will bring a positive impact on company's business performance. Those impacts are the increase of revenue and sales, and at the same time the reduction of costs and losses. The models also show us specific quality control efforts that a company needs to work on in order to improve their product quality and what cost and loss reductions are involved for the company.

5. REFERENCES

Armistead, C., G. Clark, 1991. A Framework for Formulating After-Sales Support Strategy. *International Journal of Operations and Production Management, 11(3),* 111-124.

Bass, F.M, 1969. A new product growth model for consumer durables. *Management Science, 15(5),* 215-227.

Bell, D.E., and R.L. Keeney. 1975. A Market Share Theorem. *Journal of Marketing Research, 12(2),* 136-141.

Blischke, W.R., D.N.P. Murthy, 2000, *Reliability Modeling, Prediction, and Optimization*. Probability and Statistics, Brisbane, Australia: John Wiley and Sons, INC. xxvii, 812.

Buffa, E.S., R.K. Sarin, 1987. *Modern Production / Operations Management*: Wiley - New York.

Cohen, M.A., J. Eliashberg, T.H. Ho, 1996. New Product Development: The Performance and Time-to-Market Tradeoff. *Management Science, 42(2):* pp. 173-186.

Cohen, M.A. and S. Whang, 1997. Competing in product and service: a product life-cycle model. *Management Science, 43(4):* pp. 535-545.

Crosby, L.A., Evans, K.R., Cowles D., 1990. Relationship Quality in Service Selling. *Journal of Marketing, 54(3),* 68-81.

DeCroix, G.A., 1999. Optimal warranties, reliabilities and prices for durable goods in an oligopoly. *European Journal of Operational Research., 112(3):* pp. 554-569.

Djamaludin, I. 1993., *Quality Control Schemes For Items Sold With Warranty.* Unpublished Ph.D Thesis. The University of Queensland, Australia.

Faes, W., Matthyssens, P., 2009. Insights into the Process of Changing Sourcing Strategies. *Journal of Business and Industrial Marketing, 24/3/4,* 245-255.

Ferguson, M., Guide, V.D.; Koca, E., Souza, G.C., 2009. The Value of Quality Grading in Remanufacturing, *Production and Operations Management, 18(3),* 300–314.

Fine, C.H., 1986. Quality Improvement and Learning in Productive Systems. *Management Science, 32(10)*: pp. 1301-1315.

Ghose, S., S.K. Mukhopadhya., 1993. Quality as the interface between manufacturing and marketing: A conceptual model and an empirical study. *Management International Review, 33(1):* pp. 39-52.

Kantor, P.B., W.I. Zangwill. 1991. Theoretical Foundation for a Learning Rate Budget. *Management Science, 37(3):* pp. 315-330.

Kingsman, B.G., A.A. de Souza., 1997. A knowledge-based decision support system for cost estimation and pricing decisions in versatile manufacturing companies. *International Journal of Production Economics.*, 53(2): pp. 119-139.

Kohli, R., V. Mahajan., 1991. A Reservation-Price Model for Optimal Pricing of Multi-attribute Products in Conjoint Analysis. *Journal of Marketing Research, 28(3):* pp. 347-354.

Koksalan, M., R.D. Plante., 2003. Interactive Multi-criteria Optimization for Multiple-Response Product and Process Design. *Manufacturing and Service Operations Management,* 5(4): pp. 334-347.

Kovach, J., Cho, B.R., Antony, J., 2008. Development of a variance prioritized multi-response robust design framework for quality improvement. *International Journal of Quality and Reliability Management. 26(4)*; pp: 380 – 396.

Krishnan, K.S., S.K. Gupta., 1967. Mathematical Model for a Duopolistic Market. *Management Science, 13(7):* pp. 568-583.

Lenox, M.J., Rockart, S.F., and Lewin, A.Y., 2006. Interdependency, Competition, and the Distribution of Firm and Industry Profits. *Management Science. 52(5),* 757-772.

Levy, F.K., 1965. Adaptation in the Production Process. *Management Science, 11(6):* pp. B136-B154.

Mallick, D.N., S.K. Mukhopadhyay, 2001. Local design vs. global design: a strategic business choice. *European Journal of Operational Research, 131(2):* pp. 389-399.

Mamer, J.W. (1987). Discounted and Per Unit Costs of Product Warranty. *Management Science, 33(7):* pp. 916-930.

Martinez, R., J.F. Rodriguez., 1997. Quality services model oriented to customers. *Computers and Industrial Engineering, 33(1-2):* pp. 153-156.

Monahan, G.E., 1987. The Structure of Equilibria in Market Share Attraction Models. *Management Science, 33(2):* pp. 228-243.

Murthy, D.N.P., D.G. Nguye., 1987. Optimal Development Testing Policies for Products Sold with Warranty. *Reliability Engineering, 19(1987):* pp. 113-123.

Murthy, D.N.P. and K.R. Kumar., 2000. Total product quality. *International Journal of Production Economics., 67(3):* pp. 253-267.

Porteus, E.L., 1986. Optimal Lot Sizing, Process Quality Improvement and Setup Cost Reduction. *Operations Research., 34(1):* pp. 137-144.

Robinson, B. and C. Lakhani, 1975. Dynamic Price Models for New-Product Planning. *Management Science, 21(10):* pp. 1113-1122.

Rust, R.T., R. Metters. 1996. Mathematical models of service. *European Journal of Operational Research., 91(3):* pp. 427-439.

Sahni, N.S., Piepel, G.F., 2009. Product and Process Improvement Using Mixture-Process Variable Methods and Robust Optimization Techniques. *Journal of Quality Technology, 41(2),* 181-197.

Shipley, M.F., A. de Korvin, and K. Omer, 2001. A Fuzzy Logic-Based Decision Model to Satisfy Goals for Successful Product / Service Introduction. *European Journal of Operational Research, 135(1):* pp. 209-219.

Souza, G.C.; B.L. Bayus, and H.M. Wagner, 2004. New-Product Strategy and Industry Clockspeed. *Management Science, 50(4):* pp. 537-549.

Spence, A.M., 1981. The Learning Curve and Competition. *The Bell Journal of Economics, 12(1):* pp. 49-70.

Teng, J.T., G.L. Thompson, 1996. Optimal strategies for general price-quality decision models of new products with learning production costs. *European Journal of Operational Research., 93(3):* pp. 476-489.

Turner, K.F.; Bienstock, C.C.; and Reed, R.O., 2010. An Application of the Conceptual Model of Service Quality to independent Auditing Services. *Journal of Applied Business Research, 26(4),* 1-7.

Verma, R., et al., 2001. Effective Design of Products / Services: An Approach Based on Integration of Marketing and Operations Management Decisions. *Decision Sciences, 32(1):* pp. 165-193.

Wacker, J.G., 1989. Integrative theory of strategic quality management: A cost-benefit framework for evaluating quality improvement programmes. *International Journal of Production Research., 27(1):* pp. 53-71.