

SUSTAINABLE MANAGEMENT MODEL FOR PROCESS QUALITY EFFECTIVENESS MEASURE

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Abstract: The need to manage quality to enhance process effectiveness through elimination of wastes is a pointer to sustainable productivity. The factors that are affecting process quality management were harnessed from industrial experts. Process Quality Effectiveness (PE) was analyzed using Traditional Effectiveness measure, and then using developed modified version by incorporating dynamism that can enable effectiveness measures through combination and isolation of quality factors (manpower, machine, material, energy, management, information / communication, money and marketing) simultaneously. Decision on process quality acceptability of a plastic company was made by comparing quality effectiveness measured with the universal quality standards (sustainable quality trend, global acceptable quality standard and industrial revolution quality class. The results indicated varying quality measures in isolation against combination. From the results, machinery factor was identified as the root cause of reduced process quality effectiveness and hence needs to be concentrated upon to enhance process quality effectiveness.

Keywords: Management, Process, Quality, Sustainability, Effectiveness Measure.

1. INTRODUCTION

Increase in quality rate means that there is less scrap and rework, reduces costs, and hence better quality rate [1,2]. Traditional method of measuring process quality effectiveness requires modification in terms of introducing dynamism to enable measurements on the basis of isolation or combination of quality factors [3,4]. Emerging process quality management factors which include management, energy, information/communication, and marketing [5,6,7] are required to be considered along with other traditional factors - manpower, machine, material and money/funding [8] for a robust measure of quality effectiveness. For effective utilization of these resources to enhance process quality effectiveness, there is the need for a policy that ensures access to qualitative education and training in resources management.

2. LITERATURE REVIEW

Series of activities are undertaken in manufacturing industry. This includes the production of different items, machines, equipment etc. There are a range of sections in the manufacturing industry, from the managerial section down to production, maintenance and inspection departments [9]. Competition among corporations, industries, businesses, firms and organizations, demands the need for quality enhancement. Every firm must have a good process quality effectiveness programme in place to ensure favorable competitiveness [10,11]. Quality effectiveness of a process is determined on basis of contribution of process factors to wastes and losses [4]. Quality is most critical because it determines the whole system effectiveness due to direct link with consumers. Quality is affected mainly by wastes due to defect, rework, start-up and scrap [4]

Every industry should have a competent management in place to ensure that the production process is always produces quality goods and/or renders quality services that compete well in industrial environments [10]. A competitive process contributes to a sustainable development goal attainment [11,12,13], under good infrastructural facility by enabling process wastes elimination [9,14,15,16]. Therefore, process quality and infrastructural facility are inseparable [17,18].

Many studies have been tailored to eliminate wastes to enhance process quality effectiveness. Among them are: development of dynamic error-proof Overall Equipment Effectiveness (OEE) model for a complex production system operational optimization [9,19]; automation of industrial processes to improve efficiency by eliminating loss time [20]; application of lean workforce to eliminate non-value added activities [21]; digitalization of processes to eradicate rework, scrap, start-up losses [22,23]; and utilization of intelligent based Information and Communication Technologies (ICT) to eradicate wastes in the process [24,25]; re-designing quality measures through linking quality sustainability with accountability [26,27]. The weakness of these works is inability to compare their outputs with external (sustainable quality) standards; this study considered that.

The three sustainable quality standards called external standards on which process quality effectiveness is evaluated are enumerated in Table 1. The choice of sustainable process quality is based on the stated standards (Table 1), which are jointly considered. The evaluation is done on the basis of process quality effectiveness (PE) should not go below that of the standards' values [13] - global acceptable quality standard, $PE \geq 0.85$; sustainable trend quality standard, $0.5 < PE \leq 1.0$, and industrial revolution quality class, $0.85 \leq PE \leq 1.0$:

Table 1. Sustainable Standard Measures of Effectiveness.

Sustainable Standards/Classes	Process Effectiveness PE range	Sources
Global Standard,	$PE \geq 0.85$	[19,28]
Sustainable Trend,	$0.5 < PE \leq 1.0$	[13,29]
Industrial Revolution class (4.0)	$0.85 \leq PE \leq 1.0$	[13,24]

3. METHODOLOGY

3.1. Framework for Model Development

Factors that influence management of process quality effectiveness (PE), are grouped into internal (that are within the processing unit) and external (that are outside the processing unit) factors. Manpower, money, machine, energy, management, information/ communication, material and marketing are considered as internal factors while quality standards- sustainable trend, industrial revolution, and global acceptable quality are external factors. Process quality effectiveness (PE) are acceptable if and only if it meets any or all of these quality standards, otherwise process improvement is desirable to satisfy customers' quality demands. Fig. 1 depicts the internal factors, external factors and improvement required for a processing unit. In traditional quality effectiveness measures the internal factors are combined in assessing the process quality, and the same time external quality standards are not considered in the measures. In order to meet global competition, there is the need to isolate those factors that are responsible for low quality effectiveness for early preventive treatment.

Traditionally, quality (Q) effectiveness is measured as a ratio that describes the ability of a processing unit to produce products according to set standards termed external factors and was mathematically expressed as:

$$Q = \frac{\text{Processed amount} - \text{defect amount}}{\text{Processed amount}} \quad (1)$$

Where, the defect amount represents the number of items rejected during processing that required rework or scrapped.

Then, process quality effectiveness (PE) can be estimated using Eqn. 2.:

$$PE = QM \quad (2)$$

Quality management (QM) is measured on the basis of:

$$PE = 1, \text{ quality is perfect or the process is excellent} \quad (3)$$

$$PE = 0, \text{ quality is poor or the process has collapsed,} \quad (4)$$

$$PE < 1, \text{ quality is gradually reducing but process can still survive} \quad (5)$$

By introducing external factors – sustainable trend, global standard and industrial revolution class a distinction is made between quality acceptability and rejection in a competitive marketing environment. On this basis, an acceptable QM is based on the following relations:

If $PE \geq 0.85$, quality is acceptable based on global standard (6)

If $0.5 < PE \leq 1.0$, quality is acceptable based on sustainable-trend standard, (7)

If $0.85 < PE \leq 1$, quality is acceptable based on industrial revolution class (8)

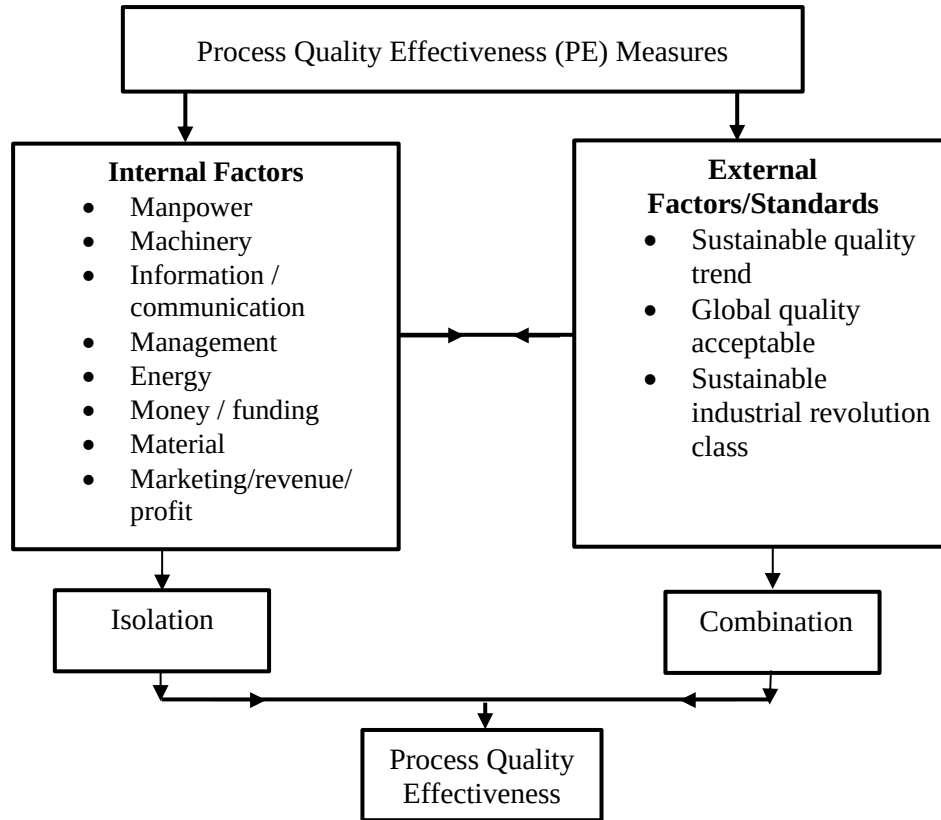


Figure 1. Factors Relationship to Process Quality Effectiveness.

The formulated models (Eqns 1- 8) considered the internal factors in combination. The effects of these internal factors on quality management can be best assessed by considering individual factor in isolation to enable good identification of actual factor that contributes to quality failure in the process. Therefore a new model is developed to isolate internal factors and incorporate dynamism into the quality management process. With internal factors considered in isolation, quality effectiveness managed on each factor using the following equation.

$$PE = Q_i = \frac{\frac{\sum_{i=1}^N t_i^P}{N_P} - \frac{\sum_{i=1}^N \sum_{j=1}^M t_{ij}^S}{N_L \times M}}{\frac{\sum_{i=1}^N t_i^P}{N_P}} \quad (9)$$

where:

N , is the number of internal factors, N_P , is number of processing time, N_L , number of loses time, M , number of loses identified, i , is a counter for internal factors, while j is a counter for types of loses.

Eqn. (9) is applied for determining contribution of each factor to process quality. Total number of eight (8) internal factors was considered- manpower, material, machinery, money/capital, management, energy, information/communication technology, and marketing.

Total Process Quality Effectiveness PE^T for combined factors is obtainable using Eqn 10.

$$PE^T = \frac{\sum_{i=1}^N Q_i}{N} \quad (10)$$

Where, Q_i is the Process Quality Effectiveness (PE) for each factor i count.

The quality management levels of the process effectiveness are determined using Eqns. (6-8). On this basis factors that contributed to process quality deficiency are isolated for possible improvement.

4. PROCESS QUALITY DATA AND ANALYSIS

Relevant data were collected using questionnaire and oral interview conducted in a selected company, producing plastic products. The data were collected on production process, working hours, downtime, product rejection rate, etc. These data were used for estimating relevant quality parameters as contained in the model. Overall Process Quality Effectiveness(PE), and decisions on process quality sustainability were made based on global quality standard ($PE \geq 0.85$), sustainable trend quality standard ($0.5 < PE \leq 1.0$) and industrial revolution quality class standard ($0.85 \leq PE \leq 1.0$) criteria. The summaries of the data collected from the plastic company are shown in Table 2. By treating factors in isolation the analysis id done as follows (Eqns. 1- 9):

$$PE = Q_i = \frac{\text{Process amount} - \text{Defect amount}}{\text{Process amount}}$$

$$PE = Q_i = \frac{\frac{\sum_{i=1}^N t_i^P}{N_P} - \frac{\sum_{i=1}^N \sum_{j=1}^M t_{ij}^S}{N_L \times M}}{\frac{\sum_{i=1}^N t_i^P}{N_P}}$$

where:

N , Number of internal factor considered ($i = 1, 2, \dots, 8$) = 8

N_P , Number of processing time = 1 (isolation)

N_L , Number of losses time = 1 (isolation)

M , Number of losses identified = 4

(i) Man-power (mp) Input factor:

$$PE^{mp} = Q_1 = \frac{\frac{1200}{1} - \frac{\sum_{i=1}^4(25 + 10 + 5 + 2)}{1 \times 4}}{\frac{1200}{1}} = \frac{1200 - 10.5}{1200} = 0.9913$$

(ii) Machinery (*m*) Input factor:

$$PE^m = Q_2 = \frac{\frac{1000}{1} - \frac{\sum_{i=1}^4(50 + 22 + 12 + 3)}{1 \times 4}}{\frac{1000}{1}} = \frac{1000 - 21.75}{1000} = 0.9783$$

(iii) Info./Communication (*ict*) Input factor:

$$PE^{ict} = Q_3 = \frac{\frac{950}{1} - \frac{\sum_{i=1}^4(15 + 5 + 5 + 1)}{1 \times 4}}{\frac{950}{1}} = \frac{950 - 6.5}{950} = 0.9932$$

(iv) Management (*mg*) Input factor:

$$PE^{mg} = Q_4 = \frac{\frac{700}{1} - \frac{\sum_{i=1}^4(20 + 14 + 5 + 7)}{1 \times 4}}{\frac{700}{1}} = \frac{700 - 10.25}{700} = 0.9853$$

(v) Energy (*e*) Input factor:

$$PE^e = Q_5 = \frac{\frac{1500}{1} - \frac{\sum_{i=1}^4(22 + 12 + 5 + 4)}{1 \times 4}}{\frac{1500}{1}} = \frac{1500 - 10.75}{1500} = 0.9928$$

(vi) Money/funding (*mf*) Input factor:

$$PE^{mf} = Q_6 = \frac{\frac{2000}{1} - \frac{\sum_{i=1}^4(50 + 15 + 7 + 5)}{1 \times 4}}{\frac{2000}{1}} = \frac{2000 - 19.25}{2000} = 0.9904$$

(vii) Material (*ma*) Input factor:

$$PE^{ma} = Q_7 = \frac{\frac{1150}{1} - \frac{\sum_{i=1}^4(12 + 20 + 20 + 7)}{1 \times 4}}{\frac{1150}{1}} = \frac{1150 - 14.75}{1150} = 0.9872$$

(viii) Marketing (*mk*) Input factor:

$$PE^{mk} = Q_8 = \frac{\frac{1100}{1} - \frac{\sum_{i=1}^4(11 + 20 + 18 + 2)}{1 \times 4}}{\frac{1100}{1}} = \frac{1100 - 12.75}{1100} = 0.9884$$

Total Process Quality Effectiveness PE^T in combination can be evaluated from:

$$PE^T = \frac{\sum_{i=1}^N Q_i}{N}$$

$$PE^T = \frac{0.9913 + 0.9782 + 0.9932 + 0.9853 + 0.9928 + 0.9904 + 0.9872 + 0.9884}{8}$$

$$PE^T = \frac{7.9064}{8}$$

$$PE^T = 0.9883$$

5. RESULTS AND DISCUSSION

Analysis of the data collected, revealed varying contributions of processing factors to the output quantities (kg). Machinery performance and money/funding challenges contributed highest quantities, 87 and 77 kg respectively, as shown bolded in Table 2. Similarly, energy and money/funding availability have been highest contributors to output of 1500 and 2000 kg, bolded in Table 2, respectively. The poorest contributor to the output was management style (700 kg), while the best contributor to the realization of the least total quantity of defects (26 kg) was information/communication technology adopted by the company. Results in Table 2, generally revealed that number of rework was highest, followed by number of defects, start-up losses, while scrapped losses was the least. This shows that the company did more rework activities on wastes rather than scrapping them out. The results (Table 2) shown further that the company management needs to concentrate more at improving their machinery's quality performance in order to reduce amount of wastes (87 kg) generated in the process.

Table 2. Process Quality Analysis of Plastic Company.

Effectiveness factor	Amount processed (kg)	Waste / defective quantities in kg.				
		Rework quantity	Defective quantity	Start-up losses	Scrapped losses	Total quantity Defective
Manpower	1,200	25	10	5	2	42
Machinery	1,000	50	22	12	3	87
Info./comm	950	15	5	5	1	26
Management	700	20	14	5	2	41
Energy	1500	22	12	5	4	43
Money/fund	2000	50	15	7	5	77
Material	1150	12	20	20	7	59
Marketing	1100	11	20	18	2	51

In Table 3, it was revealed that information/communication technology contributed highest measure of process quality effectiveness (0.9932) as bolded, followed by energy, manpower, money/funding, marketing, material while machinery performance contributed the least (0.9783), as bolded, respectively. Poor performance of machinery could be attributed to the highest quantity of wastes generated through its operation. This machinery poor process quality performance calls for its isolation and application of sustainable improvement/maintenance strategy. The traditional or combined measure of process quality effectiveness yielded effectiveness result (0.9883) which cannot directly fitted to any of the factors' measures of effectiveness if they are treated in isolation (Table 3). On this basis, it could be difficult for industrial practitioners to identify the main root cause of ineffectiveness in a production system. The new approach has enabled the identification of cause of problem (machinery's

quality performance) without any stress. The evaluation of the process based on the two approaches has showcased flexibility of the new approach over the tradition one. As shown in Table 3, output from the traditional approach (0.9883) has revealed some variations (bias) when compared with the actual contributions of individual factors to the process quality effectiveness. It can be seen clearly that only marketing performance (0.9884) has a close effectiveness to traditional measure (0.9883) out of the eight (8) processes quality factors considered (Table 3).

Table 3. Process Quality Effectiveness Measure.

Effectiveness Factor	Process Quality Effectiveness in Isolation	Process Quality Effectiveness in Combination
	PE	PE^T
Manpower, PE^{mp}	0.9913	0.9883
Machinery, PE^m	0.9783	
Info./comm., PE^{ict}	0.9932	
Management, PE^{mg}	0.9853	
Energy, PE^e	0.9928	
Money/fund, PE^{mf}	0.9904	
Material, PE^{ma}	0.9872	
Marketing, PE^{mk}	0.9884	

However, process quality effectiveness outcomes for the company are all sustainable (Table 4) when compared with external factors called quality standards- acceptable trend, global standard, and industrial revolution class ($0.85 \leq PE, PE^T \leq 1.0$). It can be seen in Table 4 that the quality effectiveness measures under isolation, PE (range between 0.9783 and 0.9932) and combination PE^T (0.9883) are within the standards (Fig. 2). This shows that the company's process Quality Management (QM) is sustainable and hence acceptable (A) based on the three standards applied (Table 4).

Table 4. Process Quality Management Effectiveness Comparison.

Effectiveness factor	Process Quality Effectiveness in Isolation	Process Quality Effectiveness in Combination	Comparison with Acceptable Trend, Global Standard and Industrial Revolution Class	Quality Management (QM) Acceptance (A)/Rejection (R)
	PE	PE^T	$0.85 \leq PE, PE^T \leq 1.0$	A
Manpower, PE^{mp}	0.9913	0.9883	$0.85 \leq PE, PE^T \leq 1.0$	A
Machinery, PE^m	0.9783		$0.85 \leq PE, PE^T \leq 1.0$	A

Info./comm., PE^{ict}	0.9932		$0.85 \leq PE, PE^T \leq 1.0$	A
Management, PE^{mg}	0.9853		$0.85 \leq PE, PE^T \leq 1.0$	A
Energy, PE^e	0.9928		$0.85 \leq PE, PE^T \leq 1.0$	A
Money/fund, PE^{mf}	0.9904		$0.85 \leq PE, PE^T \leq 1.0$	A
Material, PE^{ma}	0.9872		$0.85 \leq PE, PE^T \leq 1.0$	A
Marketing, PE^{mk}	0.9884		$0.85 \leq PE, PE^T \leq 1.0$	A

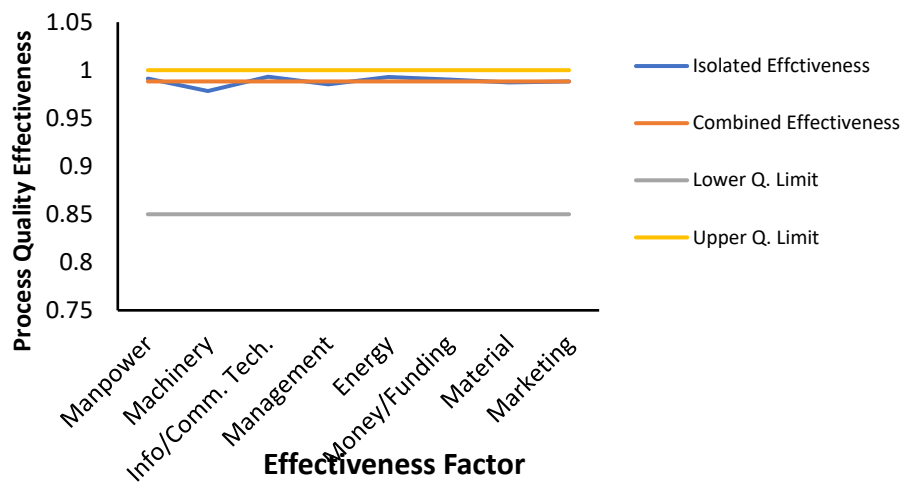


Figure 2. Process Effectiveness Quality Control.

6. CONCLUSION

A model that capable of resolving process quality sustainable challenges of production process was developed and applied to a plastic company. A traditional quality effectiveness measures was modified by isolating each of the factors responsible to quality effectiveness and then applied to a plastic company. The outcomes of the two measures- traditional and modified one are subjected to external (standard) factors comparison- acceptable trend quality, global quality standard, and industrial revolution quality class in order to evaluate the process quality management acceptability and sustainability of the company.

The results obtained by applying the models to a plastic company, revealed the following conclusions:

- i. Machinery performance and money/funding challenges contributed to highest wastes in the company.
- ii. Energy and money/funding availability were contributors to highest output, while management style contributed poorly to the output.
- iii. Information/communication technology adopted by the company enabled the company to generate least quantity of defective items.
- iv. Quantity of rework, defects, and start-up losses are relatively high as compared to scrap losses; and the company carried out more rework activities on wastes.
- v. The company management is requested to concentrate more at improving their machinery's quality performance in order to reduce amount of wastes in the process.
- vi. Information/communication technology contributed highest measure of process quality effectiveness out of quality effectiveness factors, while machinery performance contributed the least, due to high waste generation. This calls for isolation and improved maintenance to enhance performance.
- vii. Quality effectiveness measure using traditional and new techniques was not totally compatible, hence cannot directly be fitted to any of the factors' measures of effectiveness in isolation. An improved version of the model is provided to enable industrial engineer identify and isolate the main root cause of the process quality failure.
- viii. The modified approach has enabled identification of machinery's quality performance as the root cause of the company's process quality effectiveness challenge, and has showcased flexibility of this new approach over the traditional one.
- ix. Process quality effectiveness outcomes for the company are all sustainable under the influence of external factors (standards) - acceptable trend, global standard, and industrial revolution class, which means that the company's process quality effectiveness is acceptable.

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DATA AVAILABILITY STATEMENT

Data are readily available and adequately analyzed for and applied to this study.

DECLARATION OF INTEREST

There is no conflict of interest as regards the publication of this manuscript.

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