INTERFACE OF QUALITY RELATED–COSTS WITH AUTOMATION IN NIGERIAN INDUSTRIES.

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ABSTRACT
The paper highlights Quality related Costs and how the costs can be extracted from an industry’s manufacturing and financial records.
The level of automation of industrial manufacturing systems was measured and interfaced with quality-related cost. The significance of the relationship between the two important industrial parameters was evaluated.
The results indicate that quality related costs increase with increase in the level of automation of industrial machines. However at very high automation levels, quality related costs become significantly lower.
Models depicting the relationship between quality-related cost and automation were developed and tested. The models can help in predicting quality-related costs of an industry given its level of automation.


INTRODUCTION
Quality costing is one of the numerous tools and techniques used in the introduction and development of Total Quality Management (TQM) in industrial organizations. While price competition will continue to be employed as both a tactical and strategic device, competition on the basis of sustained and proven quality will assume an increasingly significant role for both marketing and operation in the international scene Cheng and Podolsky,(1996). Total Quality Management has been, and arguably still is, the most significant approach to managing operations improvement over the last twenty years Nigel et al (2004)

In the process of implementing Total Quality Control (TQC) in an industry, all TQM factors need to be analyzed and their levels determined for the particular industry. The research is aimed at analyzing two TQM factors thus; Quality-Related-Costs (QRC), and Manufacturing System Automation (MSA) to determine the level of significance of their correlation and how QRC interfaces with MSA in Nigerian manufacturing industries.

Determining the level of QRC in a particular industry can provide useful information such as costs incurred in the prevention of production of defective items, appraisal of quality in a product, and producing below standard quality Plunkett and Dale (1986). Determining the level of Manufacturing System Automation (MSA), on the other hand will help management in planning employment, maintenance, production planning and control.

Made in Nigeria goods were looked down upon as inferior in quality and expensive, Nigerian markets were opened to international competitors with high quality products and rapid innovation, most machines in the industries were obsolete, exhaustively maintained and poorly operated, new and automated machinery was expensive and difficult to operate because of the low level of technology in the industries, and low-income levels and inflation have greatly reduced patronage.

Despite the problems stated above it was necessary for the industries to remain afloat for both the owners of the business as well as the nation. The aims and objectives of the research are to assess, collect, analyze data on the level of automation of the manufacturing systems in the industries and develop models for quality related costs and manufacturing systems automation.
The most significant aspect of the research was to have a clear view of quality-related costs in Nigerian industries and determine how the costs were related to automation in industry. This will enable an industry determine its quality related costs given its level of automation.

Measurement of QRC of an industry will enable it determine some inherent characteristics of quality as an element of continuous improvement. Models developed from the study can be used to determine the combination of manufacturing systems based on their automation that can reduce QRC. They can also be used to determine when to change automation in a scientific manner. The TQC factors determined could be used as a first step towards the effort of determining all the TQC factors in the industries with the objective of adopting TQM.

### REVIEW OF LITERATURE.

**QUALITY COSTS AND QUALITY-RELATED COST**


Quality cost is expenditure incurred by a producer for putting quality into a product, the user of the product for enjoying or otherwise the quality of the product, and the community for benefiting or otherwise from the quality of the product.

On the other hand, quality-related costs are costs incurred by the producer in his effort to prevent defects, appraise the product to detect defects that cannot be prevented, and the costs incurred in the form of internal and external failure when the defects could not be detected at the appraisal stage.

Constituents elements of QRC are to be found in BS6143: Part 2 (1990), and AS2561 (1982). However there are examples of disagreements to be found as to what to include under the cost categories of prevention, appraisal and failure. Papers by Garvin (1983), Schmidt and Jackson (1982), Abed and Dale (1987) and works of Dale and Plunkett (1996) writing on different types of industries, all make it clear that each case is different.

Prevention cost: The cost of any action taken to investigate, prevent or reduce the risk of non-conformity or defect. These elements include: Quality planning and Process control.

Appraisal cost: This is made up of Process appraisal and Final inspection

Internal failure cost: The costs arising within an organization due to non-conformities or defects at any stage of the quality loop.

External failure costs: The costs arising after delivery to customers, consumer/user due to non-conformance or defects.

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**Table 1: LINEAR Statistical Analysis Results for QRC against MSA**

<table>
<thead>
<tr>
<th></th>
<th>m5</th>
<th>M4</th>
<th>m3</th>
<th>M2</th>
<th>m1</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality</td>
<td>0.302768</td>
<td>0.003962</td>
<td>-0.03696</td>
<td>-0.14230</td>
<td>-0.39087</td>
<td>36.76578</td>
</tr>
<tr>
<td>Preventive</td>
<td>0.021675</td>
<td>0.043001</td>
<td>0.08243</td>
<td>0.192446</td>
<td>0.248737</td>
<td>27.34537</td>
</tr>
<tr>
<td>Appraisal</td>
<td>0.369501</td>
<td>0.151378</td>
<td>0.014274</td>
<td>0.019976</td>
<td>0.058306</td>
<td>0.105038</td>
</tr>
<tr>
<td>Failure</td>
<td>0.045059</td>
<td>0.104415</td>
<td>0.03120</td>
<td>0.030166</td>
<td>0.200441</td>
<td>9.315480</td>
</tr>
</tbody>
</table>

| Quality     | 0.32329  | 0.131419 | 0.091769 | 0.189131 | 0.445294 | 27.103163 |
| Preventive  | 0.102381 | 0.041618 | 0.029062 | 0.059895 | 0.141018 | 8.583187  |
| Appraisal   | 0.145006 | 0.058945 | 0.041161 | 0.084831 | 0.199728 | 12.156631 |
| Failure     | 0.257279 | 0.104585 | 0.073031 | 0.150513 | 0.354372 | 21.569135 |

| R2          | 0.630887 | 0.422084 | 2.051040 | 6        | 165.9593 | 97.097695 |
| Preventive  | 0.715098 | 1.273965 | 3.011986 | 6        | 24.441919 | 9.7379178 |
| Appraisal   | 0.71258  | 1.804356 | 2.975075 | 6        | 48.429746 | 19.534192 |
| Failure     | 0.524638 | 3.201412 | 1.324393 | 6        | 37.86881 | 61.494235 |

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Table 2: Polynomial Statistical Analysis Results for QRC against MSA

<table>
<thead>
<tr>
<th></th>
<th>m5</th>
<th>m4</th>
<th>m3</th>
<th>m2</th>
<th>m1</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality Related Cost</td>
<td>0.9903</td>
<td>0.9999</td>
<td>0.9989</td>
<td>0.9934</td>
<td>0.9834</td>
<td>36.8542</td>
</tr>
<tr>
<td>Preventive Cost</td>
<td>1.0264</td>
<td>0.9903</td>
<td>0.9825</td>
<td>0.9533</td>
<td>0.9404</td>
<td>602.8784</td>
</tr>
<tr>
<td>Appraisal Cost</td>
<td>0.9379</td>
<td>1.0267</td>
<td>1.0041</td>
<td>1.0009</td>
<td>1.0247</td>
<td>1.3868</td>
</tr>
<tr>
<td>Failure Cost</td>
<td>1.0074</td>
<td>0.9921</td>
<td>1.0035</td>
<td>1.0039</td>
<td>0.9879</td>
<td>7.0230</td>
</tr>
<tr>
<td></td>
<td>se5</td>
<td>se4</td>
<td>se3</td>
<td>se2</td>
<td>se1</td>
<td>seb</td>
</tr>
<tr>
<td>Quality Related Cost</td>
<td>0.0179</td>
<td>0.0073</td>
<td>0.0051</td>
<td>0.0105</td>
<td>0.0247</td>
<td>1.5008</td>
</tr>
<tr>
<td>Preventive Cost</td>
<td>0.0431</td>
<td>0.0175</td>
<td>0.0122</td>
<td>0.0252</td>
<td>0.0593</td>
<td>3.6092</td>
</tr>
<tr>
<td>Appraisal Cost</td>
<td>0.0303</td>
<td>0.0123</td>
<td>0.0086</td>
<td>0.0177</td>
<td>0.0418</td>
<td>2.5431</td>
</tr>
<tr>
<td>Failure Cost</td>
<td>0.0212</td>
<td>0.0086</td>
<td>0.0060</td>
<td>0.0124</td>
<td>0.0293</td>
<td>1.7809</td>
</tr>
<tr>
<td></td>
<td>R²</td>
<td>sev</td>
<td>F</td>
<td>If</td>
<td>ssreg</td>
<td>ssresid</td>
</tr>
<tr>
<td>Quality Related Cost</td>
<td>0.6274</td>
<td>0.2228</td>
<td>2.0209</td>
<td>6.0000</td>
<td>0.5014</td>
<td>0.2977</td>
</tr>
<tr>
<td>Preventive Cost</td>
<td>0.6332</td>
<td>0.5357</td>
<td>2.0719</td>
<td>6.0000</td>
<td>2.9729</td>
<td>1.7219</td>
</tr>
<tr>
<td>Appraisal Cost</td>
<td>0.7326</td>
<td>0.3775</td>
<td>3.2884</td>
<td>6.0000</td>
<td>2.3426</td>
<td>0.8549</td>
</tr>
<tr>
<td>Failure Cost</td>
<td>0.5210</td>
<td>0.2643</td>
<td>1.3051</td>
<td>6.0000</td>
<td>0.4559</td>
<td>0.4192</td>
</tr>
</tbody>
</table>

Various departments/sections and cost centers are therefore affected with the issue of quality related costs. Amongst the departments and sections are; Quality control department (QC&A), Production (PROD), Sales (SALE), Marketing (MKT), Purchasing and materials handling (PSM), Transportation (TRSP), Research and development (R&D), Laboratory, (LAB) and gauge room engineering, (GI) etc. The cost centers include direct labor and direct material as well as overhead costs.

MANUFACTURING SYSTEMS TECHNOLOGY

Manufacturing systems in industries comprise all machines and equipment that may be manual or powered. Industries are rated in terms of their output and this depends to a large extent on the combination of their manufacturing systems. Amber and Amber (1962) classified manufacturing systems in order of their automaticity. They include; Hand tools and manual machines A_0, Powered machines A_1, Single –cycle automatic and self feeding machines A_2, Automatic repeat cycle machines A_3, Self measuring and adjusting, feedback machines A_4, and computer controlled and automatic cognition machines A_5.

This categorization agrees with Feigenbaum's (1983) though in his own case the categorization came under three, i.e. Manual machines; Mechanized machines; and Automatic machines.

Production efficiency of an industry will depend on the nature and age of the machinery. A Company operating with fully automated system may not necessarily perform better than another operating with manual machines and vice-versa. Most writers on the subject, however, urge that automatic system were more reliable when it came to precision and quality Schonberger (1987).

The ultimate development in the trend of mechanization is to have a completely integrated automatic sequencing beginning with the input of raw materials and ending with the final product without human labor or control other than to design and build the original equipment and process and maintenance.


METHODOLOGY

The research involved exploratory investigation and verification visits to map out the industries for the study. Secondary data collection and generation was from sources that included libraries, and industrial Organizations.

A sample of fifty Nigerian industries located in Kano, Kano State, Kaduna, Kaduna, and Lagos, Lagos State was targeted, however, useful data was gathered from twelve industries which included four textile companies, four food companies, two metal components manufacturing companies and two vehicle
assembly plants. The initial study was conducted between 1997 and 2001. Follow up and revalidation studies were conducted in 2005.

Fig. 1: Linear and Polynomial Graph for Quality Related Costs against Automation of Manufacturing Systems
Personnel/Time Expenditure Records, Labeling of Account Codes, Payroll Analysis, Operation Expenditure Reports and Others such as scrap reports, reworks or rectification authorizations/reports, travel expenses, claims, product cost information, field repairs, replacement and warranty cost reports, inspection and tests records and non-conformance costs were used in the data collection, Plunkett, and Dale (1985).

The quality-related cost for each activity was then evaluated using the information obtained.

Data obtained was analyzed using computer aided statistical tools for linear and curvilinear correlation as well as the F and t tests.

In order to determine the interference of the QRC with MSA, the first step was to set up a hypothesis: (H1) "that an industry’s Quality-related-costs are dependent on the automation of its manufacturing systems". If proved to be so, then industry’s quality-related costs will be dependent on automation of its manufacturing systems.

RESULTS
LINEAR REGRESSION, F and t TESTS.
The test were based on the three basic elements of quality related costs i.e., QRC, preventive, appraisal and failure costs. Table 1 shows the results of QRC, preventive, appraisal and failure costs against MSA.

QRC against MSA
It indicated a moderate correlation between the two factors $R^2 = 0.63$. The $f$ and $t$ statistics values returned are however lower than the critical values ($f = 2.05 < Fc = 4.39$) $t$ is between 0.03 to 1.36 (tc = 1.943) for confidence interval $a = 0.05\%$. This indicate that there is a moderate correlation between the dependent and the independent variables, however, this could result by chance and the slopes for the linear equations returned cannot effectively predict failure costs. The linear model from the result showing the contribution of each level of automation is given by equation 1 while equation 2 shows the linear relationship between quality related cost ($Y$) and automation ($A$).

$$Y_{QRC} = -0.0303A_5 + 0.004A_4 - 0.037A_3 - 0.142A_2 - 0.39A_1 + 36.77 \ldots \ldots \ldots [1]$$

The model depicting the relation of automation generally with quality related costs is

$$Y_{QRC} = 0.0696A + 3.84 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots [2]$$

Preventive Cost against MSA.
The results returned indicated that there exists a high correlation between the two variables $R^2 = 0.72$. However, the linear model given by:

$$Y_{PREV} = 0.0216A_5 - 0.043A_4 - 0.082A_3 - 0.192A_2 - 0.249A_1 + 27.345 \ldots \ldots [3]$$

and the model depicting the relation of automation generally with preventive costs

$$Y_{PREV} = 0.01A + 0.743 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots [4]$$

cannot predict preventive cost because the correlation may happen by chance ($f = 1.9 < Fc = 4.39$) and ($t$ is between 0.212 to 3.213 (tc = 2.02) for $a = 0.05\%$.

Appraisal Cost against MSA.
With an $R^2 = 0.71$, there exist a very high relationship between appraisal cost and MSA. The result returned an $f = 2.975$ and values of $t$ between 0.01 to 2.568 for the various slopes at $a = 0.05\%$. These are all less than the critical values, therefore despite the high correlation, the relationship could have happened by chance and the linear model cannot effectively predict value of appraisal cost.

$$Y_{APPR} = -0.370A_5 + 0.151A_4 + 0.0143A_3 + 0.0200A_2 + 0.058A_1 + 0.105 \ldots \ldots [5]$$

The model depicting the relation of automation generally with appraisal costs is
Y_{APPR} = 0.029A – 2.19 ......................................................[6]

Failure Cost against MSA.
The test returned $R^2 = 0.53$, $f = 1.32$ and $t$ is between 0.20 to 1.0 at $a = 0.05\%$. This means that there exist a moderate correlation between the two variables however, this could also happen by chance and that the linear equation cannot be used to predict further values of failure cost.

$Y_{FAIL} = 0.045A^5 - 0.104A^4 + 0.0312A^3 + 0.0302A^2 - 0.2004A + 9.316 ........[7]

The model depicting the relation of automation generally with failure costs is

$Y_{FAIL} = 0.0304A +5.291 ..................................................[8]$

The foregoing results indicated that there is a strong linear relationship between Quality –Related cost and Manufacturing Systems Automation, thus the automation in an industry have a significant effect on it’s quality costs.

However the relationship is stronger in the cases of preventive and appraisal costs than with failure cost.

CURVILINEAR REGRESSION, F and t TESTS.

QRC against MSA
The test returned $R^2 = 0.63$ and $f = 2.02$ ($f < Fc$). The $t$ values returned for all the slopes are greater than $tc$ indicating that the curvilinear equation can be used to predict quality related costs. The results are shown in Table 2. The curvilinear models are:

$Y_{QRC} = 36.85(0.99A^5)(1.00A^4)(1.00A^3)(0.983A^1) .......[9]$

$Y_{QRC} = -0.0008A^2 + 0.42A –32.65 ...........................................[10]$

Preventive, Appraisal and Failure Costs against MSA.
The results returned are $R^2 = 0.63$, 0.73, 0.52 for preventive, appraisal, and failure respectively against MSA. It shows that a moderate correlation exists between the dependent and the independent variables.

The $f$ values returned are 2.071, 3.29, and 1.31 respectively. All the values are a bit lower than the $Fc$. The $t$ test values returned are much higher than the $tc$ for all the three cases, hence, the curvilinear relationship can be used to evaluate further values of the dependent variables. The curvilinear models are:

Preventive cost against MSA;

$Y_{PREV} = 602.88(1.03A^5)(0.99A^4)(0.98A^3)(0.95A^2)(0.94A_1) ........[11]$

$Y_{PREV} = 0.0003A^2 + 0.14A – 12.81 ...........................................[12]$

Appraisal cost against MSA

$Y_{APPR} = 1.39(0.94A^5)(1.03A^4)(1.00A^3)(1.00A_2)(1.03A_1) ........[13]$

$Y_{APPR} = 0.00001A^2 + 0.23A – 1.55 .................................[14]$

Failure cost against MSA

$Y_{FAIL} = 7.02(1.00A^5)(0.99A^4)(1.01A^3)(1.01A_2)(0.99A_1) ........[15]$

$Y_{FAIL} = -0.0005A^2 +0.258A –18.275.................................[16]$
Figure 1 shows the linear and polynomial graph of QRC against MSA.

**CONCLUSIONS.**
The essence of interfacing Quality Related Costs with MSA was based on the understanding that the manufacturer to a large extent has control over MSA. The industries can see how MSA is related to quality related costs in the industry. The industries can make adjustments on MSA to reduce quality costs in the industry.

The data analysis therefore developed two types of models. The first model shows the interface of QRC, Preventive, Appraisal and Failure costs with the various levels of MSA. These models show the contribution of each level of automation and each level of in the overall quality cost formula linearly and in a curvilinear form.

The models in each of the two cases (linear and curvilinear) were tested to determine the level of correlation between the dependent and independent at variables. The correlation was tested using the F-test to determine whether it happened by chance or not. Further, the models developed were also tested using the t-test to determine whether they can be reliably used to determine further values of the dependent variables.

However, the F-test that followed the linear correlation gave values that were less than the critical values thus indicating that the correlation that exists between the variables could have happened by chance. Likewise the t-test revealed that the linear models could not effectively predict further values of the dependent variables given the values of the independent variables.

The curvilinear analysis on the other hand showed high correlation between QRC, Preventive, Appraisal and Failure costs and the independent variables and second order polynomial models were developed. Both the F and t tests gave values above the critical values thus indicating that the correlation could not have happened by chance and that the curvilinear relationship could be used to predict further values of the dependent variables given values of the independent variables. Therefore the hypothesis that quality related costs are dependent on an industry’s level of automation has been proved.

The results also showed that preventive and failure costs reduction can be achieved with higher levels of automation. However, appraisal costs will definitely increase with increase in the levels of automation because higher levels of automation need far stricter methods of checking and inspecting before defects could be detected. Likewise it will entail using highly advanced quality control tools for checking and inspection. All these factors come under appraisal cost.

The models developed from the data analysis can be used by the industries to determine the trend in their quality related costs. However, the problem the industries may likely face was the fact that tremendous amount of financing will be required to enable them bring about the needed upgrading in their levels of automation and it appears that the financing was not forth coming.

**REFERENCES**


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Industrial automation can and will generate explosive growth with technology related to new inflection points: nanotechnology and nanoscale assembly systems; MEMS and nanotech sensors (tiny, low-power, low-cost sensors) which can measure everything and anything; and the pervasive Internet, machine to machine (M2M) networking. The future belongs to nanotech, wireless everything, and complex adaptive systems. Major new software applications will be in wireless sensors and distributed peer-to-peer networks — tiny operating systems in wireless sensor nodes, and the software that allows nodes to communicate with each other as a larger complex adaptive system. That is the wave of the future. The fully-automated factory. technicians working with automation in industry. Since the respondents needed for the second study, could not be obtained for a face-to-face group. Increased efficiency. Improved quality. Increased comparativeness. Cost-cuts. Several related applications such as processes time performances evaluating, time savings, productivity assessment, lines balancing, and cost estimating are proposed as well as other possible future applications presented as perspectives and future works that can be supported by the defined environment dedicated to early phase assembly systems design and automation decision.