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QUANTITATIVE ANALYSIS OF THE FACTORS INFLUENCING EFFECTIVE MAINTENANCE AT A SELECTED TEXTILE FACTORY IN TANZANIA

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ABSTRACT

The study on quantitative analysis of the factors influencing maintenance effectiveness has been carried out for the purpose of investigation of factors, which in turn affect the production output in terms of quality and capacity for Tanzanian industries. The approach used to attain the study objectives is the Multiple Regressions Model. Eventually, a case study industry was selected. The stepwise regression was done by comparing the control and treatment data in order to test the reliability and validity of the model. By use of Durbin Watson test, R^2, and P-value test, the models were found to be valid, reliable and significant. The main result achieved was the quantified factors influencing the maintenance effectiveness. These are the factors related to spare parts, human resources, maintenance strategies, facilities and equipment as well as functional quality. Through a developed model, the identified critical factors were mentioned and strategies were proposed to be adopted for improving maintenance effectiveness for the case study industry. The recommended strategies were as follows: wages that can meet the basic living standard requirements, in-house and outside work training, reputable supplies of genuine spare parts to be selected among the main suppliers, use of set standard specifications for repetitive works, phase-out uneconomical old technology and emphasis on interactive quality so as to be able to offer consistent and reliable maintenance services.
Key words: maintenance effectiveness, quality, maintenance, multiple regressions, Tanzania.

1.0 INTRODUCTION

There are few authors who have discussed the effect of maintenance effectiveness on quality and quantity of product and services rendered. In Tanzania, studies carried out with regard to maintenance activities include the work of Mjema and Mweta, (2003), Bavu *et al.* (1997), Masanja and Kundi (1997). The contributions of these studies were based on Information technology, culture of maintenance and maintenance management designs, respectively. Maintenance effectiveness is very important for improving availability and reliability of equipment, machinery and other institutional infrastructure. According to Ling and Wang (2008), maintenance of equipment has strong impact on achieving a fully operational mode.

2.0 Aim

The aim of the paper is to quantitatively analyse the factors influencing maintenance effectiveness and their impact on products and services offered by the Tanzanian manufacturing industries.

2.1 Specific Objectives

a) To establish a quantitative relationship among factors influencing maintenance effectiveness by the Tanzanian industries.
b) To validate the maintenance effectiveness model with a view of assessing its predictive power of individual variables into the case study industry; and
c) To propose strategies to be adopted for improving maintenance effectiveness.

2.2 ESTABLISHMENT OF QUANTITATIVE RELATIONSHIP AMONG FACTORS INFLUENCING THE MAINTENANCE EFFECTIVENESS

This section attempts to develop mathematical relationship model among factors influencing the maintenance effectiveness. The identified factors influencing maintenance effectiveness during literature review were factors related to spare parts, human resources, the maintenance strategies, the facilities and equipment, as well as the functional or interactive quality. The method used to develop the model is the multiple regressions analysis.

2.2.1 Multiple Regressions

Multiple regressions are the progression of a regression model with two or more independent variables. They are methods of studying the effect and magnitude of more than one independent variable into dependent variable by using correlation and regression (Kothari, 2005; Saunders *et el*., 2007).

The method assumes linear relationship between factors influencing the maintenance effectiveness, and the effect of maintenance effectiveness (total) is given by its summation multiplied by its respective contributing weighting factors as shown in equation 1.

$$E_{M(TOT)} = A_i + \alpha_1 E_{M(SP)} + \alpha_2 E_{M(HR)} + \alpha_3 E_{M(STR)} + \ldots + \alpha_4 E_{M(F\&EQ)} + \alpha_5 E_{M(FQ)} + \varepsilon \ldots\ldots(1)$$

Where:

Dependent factor is: $E_{M(TOT)}$

$E_{M(TOT)}$ is a maintenance effectiveness (a total combined effect of factors affecting the maintenance effectiveness in the organization)

α_i is a weighting factor

α: is the contribution effect on total maintenance effectiveness

Independent factors are:

$E_{M(SP)}$: Factors relating to spare parts

$E_{M(HR)}$: Factors relating to human resources

$E_{M(STR)}$: Factors relating to maintenance strategies

$E_{M(F\&EQ)}$ Factors relating to facilities and equipment

$E_{M(FQ)}$: Factors relating to functional quality

Constants/Intercept

A_i = Constant value

α_i = Coefficients/intercepts (weighting factors)

ε = Error (Unpredicted variation/independent of variables)

The weighting factors α_i indicates the proportions contribution of the factors to the total maintenance effectiveness. They indicate the strength of the individual factor regarding maintenance effectiveness. It is impossible to mathematically deduce these weighting factors α_i. The only way to obtain the values is through an empirical study or by expert opinion. Although it can be assumed that, the values of α_i vary from one industry to another, it is possible to give out a general statement considering the values of α_1, α_2, α_3, α_4 and α_5.

The multiple regression method was used to formulate the models, which will be used in assessing the predictive power (ability) of individual variables. The main equation (model) interacts with all identified factors influencing the maintenance effectiveness.

2.2.2 Model Testing and Validation for a Case Study Industry at 21st Century Textiles Mills Ltd

The rationale of model testing and validation was carried out through a case study at the industry. It was done for the purpose of showing how the factors influencing the maintenance effectiveness would predict and explain the maintenance effectiveness of a particular industry.

2.2.3 Industry Background Information

21st Century Textiles Mills Ltd. is a privately owned textile manufacturing industry. The industry started its operation in 2004 after privatization of the previously renowned Morogoro Polyester Textiles Mills Ltd which was100 percent owned by the Government of Tanzania.
The textile industry inherited the old machines and installed few new modern machines in order to improve the production and subsequently the profitability. The industry employs more than 1000 labour force. The industry has the capacity to produce 4,400 metric tons of cotton and blended yarns and 16 million metres of grey and finished fabrics per year. This is the highest amount compared to any other textiles industries in the country.

3.0 METHODOLOGY

The methodology used to attain the study objective was through qualitative means, whereby questionnaires were prepared and distributed to different respondents in the industry, and thereafter the responses were collected, edited, tabulated and fed into the statistical software SPSS version 16 for analysis. The case study showed real life practical case implication of the developed model.

3.1 Sample Size

According to Maisel and Persel (1996) the appropriate sample size (n) can be calculated using the equation;

$$n = \left(\frac{Z \times STD.DEVIATION}{CONFIDENCE.INTERVAL} \right)^2$$

$$n = \left(\frac{1.96 \ x \ 0.5}{0.1} \right)^2 = 96$$

where
Z: is a constant which relates to the confidence level
n: is sample size
The calculated sample size was 96 at calculated confidence interval of 10%. In view of that 96 questionnaires were sent to the industry.

3.2 Response Rate

96 questionnaires were sent to the targeted respondents that included managers, engineers, supervisors, technicians, artisans and other experts in the field of maintenance engineering as shown in Table 1. A size of 86 responses was achieved. This is usual in surveys and is, therefore, understandable. Nevertheless, this receives 89% rate which compares reasonably with that achievement.

Table 1: Distribution of Respondents

S/N	Designation	Frequencies of the Targeted Respondents	Actual Responses
1	Production Manager	1	1
2	Maintenance Manager	3	1
3	Maintenance Engineers	6	5
4	Maintenance Planners	3	2
5	Engineers-Production	8	8
6	Supervisors	13	13
7	Technicians	15	12
8	Artisans	30	27
9	Others	17	17
	Total	**96**	**86**

3.3 Data Analysis

Of the received responses, 18 were set aside for model validation purposes and the remaining 68 were analysed and used for developing the model.

3.3.1 Production Processes in the Spinning Department

The study was conducted in the spinning department. The role of spinning department is to convert the raw fiber into twisted yarn (or thread). The characteristics and quality of the spun yarn vary depending on the material used, fiber length and alignment, quantity and quality of fiber as well as the degree of twist. Fig.1 shows the production process flow of yarn in the spinning mill. This involves the blow room, carding, draw frames, roving frames, ring frames and winding machines.

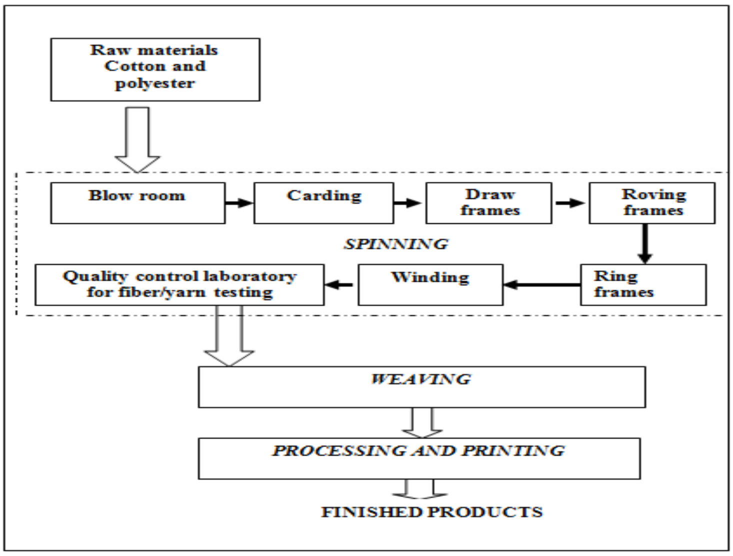

Fig. 1 Description of production flow process of yarn/fibre

3.3.2 Correlation Matrix of Factors Influencing Maintenance Effectiveness

Before using the data to test the model, it was important to see how closely the change in one variable influences the other variable and vice versa as well as also whether multicollinearity exists among the independent variables. In particular, variables that correlate highly with each other (i.e. r>0.9, where r is Pearson correlation coefficient) should be a source of concern

(Kothari, 2005; Field, 2005; Blaikie, 2003; Brace *et al.*, 2003). The Pearson's correlation r shows that there was a reasonable correlation among variables (i.e. $r<0.9$) and thus were rationally acceptable to be included in the stepwise regression analysis. The data shows that the Pearson correlation (by virtue of a 2-tailed test) demonstrated that a large number of variables were significant at $p<0.01$ This is an indication that generally the independent variables which correlate reasonably well with the dependent variable had to a greater extent been appropriately identified (see for instance Blaikie, 2003).
Drawing from factor analysis, an index for assessing the maintenance effectiveness was first developed. This involved numerical numbers from very low-1 to very high-5. This was necessary for providing a basis for converting the dependent variables into a single dependent variable in order to meet the requirement for multiple regression analysis.

3.3.3 Model Identification

It has been found that correlation analysis provides information on the relationship between variables (Kothari, 2005; Saunders *et al.,* 2007) but they provide little information about the predictive powers of independent variables to the dependent variable. In this regard, multiple regressions were applied to the data to try and identify the factors influencing the maintenance effectiveness with the most predictive power for each measure of maintenance effectiveness.

3.3.4 Regression Modelling Procedures and Results from 21st Century Textiles Mills Ltd

By the use of SPSS version 16 the variables were analysed with linear regression, whereby a procedure for variable selection was done in which all variables in block were entered into a single step which gave the initial regression results equation numbers 2; 3; 4; 5 and 6.
Durbin-Watson test value for factors related to human resources had a value of 2.119 and factors related to maintenance strategies were 2.319.
These were above Durbin-Watson test value of 2 indicating that their correlation is negative. On the other hand, Durbin-Watson test value for factors related to facilities and equipment was 1.879, factors related to spare parts was 1.610, and factors related to functional quality was 1.849. These factors had Durbin-Watson test value less than 2 indicating positive correlation.

Initial Regression Results for Maintenance Effectiveness Related Factors

$$E_{M(SP)} = 2.725 - 0.006\,Di_{SP} + 0.310\,Q_{SP} + 0.214\,S_{SP} - 0.140\,D_{SP} \quad (2)$$

$$E_{M(HR)} = -0.076M_{HR} + 0.114A_{HR} + 0.329W_{HR} - 0.131H_{HR} + 0.251E_{HR} + 0.098Q_{HR} + 1.868 \quad (3)$$

$$E_{M(STR)} = 0.528R_{STR} + 0.457M_{STR} - 0.060T_{STR} - 0.072O_{STR} + 0.258D_{STR} - 0.517 \quad (4)$$

$$E_{MF\&EQ} = -0.057C_{F\&EQ} + 0.173M_{F\&EQ} - 0.543A_{F\&EQ} - 0.094F_{F\&EQ} + 0.001S_{F7EQ} + e_{Q} \quad (5)$$

$$E_{M(FQ)} = 0.089\,Rs_{FQ} - 168\,E_{FQ} + 0.118\,T_{FQ} + 0.258\,\mathrm{Re}_{FQ} + 0.032\,Ra_{FQ} + 2.111 \quad (6)$$

Where:

$E_{M(SP)}$: The influence on maintenance effectiveness caused by factors related to spare parts

$E_{M(HR)}$: The influence on maintenance effectiveness caused by factors related to human resources

$E_{M(STR)}$: The influence on maintenance effectiveness caused by factors related to maintenance strategies

$E_{MF\&EQ}$: The influence on maintenance effectiveness caused by factors related to facilities and equipment

$E_{M(FQ)}$: The influence on maintenance effectiveness caused by factors related to functional-quality.

The total influence on maintenance effectiveness by initial regression model is shown by the equation 7. The initial modelling shows that maintenance effectiveness is influenced by factors related to human resources, facilities and equipment, functional quality, spare parts and maintenance strategies.

$$E_{M(TOT)} = 1.87 - 0.103E_{M(HR)} + 0.062E_{M(F\&EQ)} + 0.259E_{M(FQ)} + 0.359E_{M(SP)} - 0.008E_{M(STR)} \ldots\ldots\ldots\ldots (7)$$

The low negative coefficient of maintenance effectiveness factors related to human resources and maintenance strategies does not suggest that they are not important; this can be attributed to the reasons that some of their components (sub factors) have negative influence on maintenance effectiveness for example, human error. Furthermore, the reason could be that, data were not enough to capture the influence of the attributes.

3.3.5 The Regression Equations/ Models (Stepwise Selection of Variables)

The total number of independent variables which influence the maintenance effectiveness under this study was 25. Each variable was entered sequentially into the regression equation. The outcome of each variable was observed and the variable that contributes significantly to the dependent variable was retained, while the one contributing lesser was removed. The process went on until the economic model was achieved. Table 2 depicts the total number of independent variables that were entered into stepwise regression. The grey shaded factors were found to be reliable and valid.

Furthermore, the stepwise selection ensures that the regression model ends up with the smallest number of variables, the main advantage was that the most parsimonious model was achieved (Walliman, 2001; Brace *et al.,* 2003).

Table 2: Factors /Variables Influencing the Maintenance Effectiveness

S/N	Factors/Variables	S/N	Factors/Variables
1	Quality of spare parts	14	Duration of maintenance action
2	Durability of spare parts	15	Maintenance organization structure
3	Spare parts strength of materials	16	Age of facilities and equipment
4	Dimensional accuracy of spare parts.	17	Similarities of facilities and equipment
5	Motivation of maintenance personnel	18	Maintainability of facilities and equipment
6	Wages and salaries of maintenance personnel	19	Complexity of facilities and equipment
7	Work attitude of maintenance personnel	20	Failure rates of facilities and equipment
8	Human error of maintenance personnel	21	Reliability of maintenance services
9	Qualification of maintenance personnel	22	Responsiveness of maintenance personnel
10	Experience of maintenance personnel	23	Empathy of maintenance personnel
11	Types of maintenance actions	24	Reassurance offered by maintenance personnel
12	Timing of maintenance action	25	Appeal of tangibility of maintenance resources
13	Maintenance resource allocation		

3.3.6 Refined Stepwise Regression Results

Stepwise regression is the most complicated technique of the multiple regression analysis when large independent variables are involved (Brace *et al.,* 2003). In a stepwise regression each variable is entered sequentially and its value is assessed. The purpose is to retain the variables contributing significantly to the model (predictive quality) and exclude those variables which do not contribute significantly, hence, the final stepwise regression models were depicted by equations 8; 9; 10; 11 and 12 as shown in table 4.

$$E_{M(SP)} = 3.040 + 0.317E_{SP} \quad (8)$$
$$E_{M(HR)} = 0.376W_{HR} + 0.270E_{HR} + 1.719 \quad (9)$$
$$E_{M(STR)} = 0.507R_{ALL} + 0.441M_{ACT} + 0.260D_{ACT} - 0.895 \quad (10)$$
$$E_{MF\&EQ} = 0.209M_{F\&EQ} - 0.623A_{F\&EQ} + 0.483 \quad (11)$$
$$E_{M(FQ)} = 0.279R_{REL} + 2.303 \quad (12)$$

3.3.7 Statistical Tests Results on Stepwise Regression

Table 3 depicts the summary of statistical tests given by SPSS version 16 result on equations (model generated) where: F -Test statistics which have and F-distribution and S -Standard error; R^2 (coefficient of determination) for the model generated; Durbin-Watson test for independent of the error terms, its values is close to 2 for all variables indicating that the assumptions of normality have not been violated.
Tests results show that, whether or not the model is a useful predictor of maintenance effectiveness, and whether it gives a highly significance result ($P<0.01$) indicating that this model significantly improves the prediction of maintenance effectiveness for all factors.

Table 3: Statistical Test Results on Stepwise Regression

EQUATION NO.	QUALITY OF MAINTENANCE	F	DURBIN-WATSON	P SIGNIFICANCE	R^2	S (ERROR)
4.1	Spare parts	6.437	1.998	0.014	0.190	0.714
4.2	Human resources	7.601	1.640	0.001	0.435	0.089
4.3	Maintenance strategies	30.428	2.350	0.000	0.493	0.487
4.4	Facilities and Equipment	12.531	1.943	0.001	0.588	0.527
4.5	Functional quality	4.900	1.859	0.030	0.069	0.682

In the final output for the total maintenance effectiveness, the factors related to "human resources, maintenance strategies and facilities and equipment" were not statistically significant and may not be needed in the model. However, it was needed to drop one term after the other so as to monitor the changes in the magnitude of coefficients of other determinants. The final significant model was achieved by equation 13.

$$E_{M(TOT)} = 1.704 + 0.278E_{M(FQ)} + 0.314E_{M(SP)} \quad (13)$$

The final regression model shows that maintenance effectiveness is only influenced by factors related to spare parts and functional quality. This is not, however, to suggest that the other factors like human resources, maintenance strategies and facilities and equipment are not important. This does only indicate that there was insufficient evidence to establish their degree of influence.

4.0 THE CONCEPT OF MODEL VALIDATION

Validity of the model can be said simply as the measure of the quality of the developed model. The validity of the model can be split into the following parts: internal validity, external validity, construct validity and conclusion validity.

There are five ways of doing external validation in the regression analysis. Among them the most preferred in our situation is by dividing the sample size into two groups as control and treatment blocks whereby the collected data were divided into two parts, while keeping a quarter of it for validations purposes (Snee, 1977; Good and Hardin, 2003; Field, 2003).

4.1 Reliability Test of the Developed Model for Maintenance Effectiveness

The sample was divided into two parts, the control block was having 68 respondents and the treatment block was having 18 respondents. The result equations were then checked, the result shows that for reliability (the control and treatment block) through which their R-Square, R-Square (adjusted) and standard errors were compared for consistence, the equations were valid and reliable as depicted in Table 4:

Table 4 Validity and Reliability Test Results

S/N	Quality of maintenance	Control Block (68 cases)	Treatment Block (18 cases)
1	Influence of Factors Related to Maintenance Strategies	$E_{M(STR)} = 0.507R_{STR} + 0.441M_{STR} + 0.260D_{STR} - 0.895$ Durbin Watson=2.350 S=0.489 R-sq =0.588 R-sq (adj)= 0.569	$E_{M(STR)} = 0.544R_{STR} + 0.219D_{STR} + 1.008$ Durbin Watson=2.671 S=0.507 R-sq =0.509 R-sq (adj)= 0.483
2	Influence of Factors Related to Facilities and Equipment	$E_{MF\&EQ} = 0.209M_{F\&EQ} - 0.623A_{F} + 0.483$ Durbin Watson=1.943 S= 0.527 R-sq =0.493 R-sq (adj)= 0.478	$E_{MF\&EQ} = 0.491M_{F\&EQ} - 0.391A_{F\&EQ} + 0.302$ Durbin Watson=2.023 S= 0.499 R-sq =0.568 R-sq (adj)= 0.545
3	Influence of Factors Related to Functional Quality	$E_{MF/Q} = 2.303 + 0.279\,\mathrm{Re}_{FQ}$ Durbin Watson=1.859 S=0.682 R-sq = 0.069 R-sq (adj)=0.055	$E_{MF/Q} = 1.676 + 0.390\,\mathrm{Re}_{FQ}$ Durbin Watson=2.418 S=0.637 R-sq = 0.182 R-sq (adj)=0.143
4	Influence of Factors Related to Spare Parts	$E_{M(SP)} = 3.040 + 0.317Q_{SP}$ Durbin Watson=1.998 S= .714 R-sq = .190 R-sq (adj)= .165	$E_{M(SP)} = 2.642 + 0.384Q_{SP}$ Durbin Watson=2.045 S= 0.515 R-sq = 0.123 R-sq (adj)= 0.023
5	Influence of Factors Related to Human Resources	$E_{M(HR)} = 0.376W_{HR} + 0.270E_{HR} + 1.719$ Durbin Watson=1.640 S= 0.089 R-sq = 0.075 R-sq (adj)= 0.623	$E_{M(HR)} = 0.932W_{HR} + 0.418E_{HR} + 0.384$ Durbin Watson=1.642 S= 0.599 R-sq = 0.315 R-sq (adj)= 0.280

The areas that were observed during the model testing should be of great importance. If the method for improvement was sought, the areas that were mainly noted were as shown in Table 5.

5.0 CONCLUSION

The study successfully tested the regression models. Tests were done in order to verify whether or not the data fit the model. The analysis indicates that, to a great extent, nine factors fit the model. This paved way for interpretation of the results. Normally, the model is used to predict or explain and describe the result of a process. Therefore, the maintenance effectiveness models can be used to predict and explain the maintenance effectiveness as the outcome in the 21st Century Textiles Mills Ltd. Furthermore, it has determined the significant relationship that exists among factors influencing maintenance effectiveness by using Pearson's correlation and stepwise multiple regression method.

6.0 RECOMMENDATION

6.1 Specific Recommendation to 21st Century Textiles Mills Ltd

By using the maintenance effectiveness model, the company should strive to improve the critical factors influencing the maintenance effectiveness, and keep on assessing them regularly for further improvement of the maintenance effectiveness as shown in Table 5.

Table 5 Recommendations to 21st Century Textiles Mills Ltd on critical factors

S/N	Factors Influencing Maintenance Effectiveness	Intervention / Recommendation
1	Wages of maintenance personnel	Recommend for minimum wage increase. Wage that can meet the basic living standard requirements.
2	Work experience of maintenance personnel	Recommends in-house and outside work training
3	Quality of spare parts	Reputable supplies of genuine spare parts to be selected among the main suppliers
4	Proper maintenance resources allocation	Use set standard specifications for repetitive works
5	Correctness of allocation of maintenance action	Use set standard specifications for repetitive works
6	Correctness of duration allocation for maintenance action	Use set standard specifications for repetitive works
7	Age of facilities and equipment	Phase-out uneconomical old technology
8	Maintainability of facilities and equipment	More training and use of modern maintenance diagnostic tools
9	Reliability of maintenance services	Emphasis on interactive quality and be able to offer consistent and reliable maintenance services

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