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Impact of Maintenance Performance in Cable Manufacturing Industry: Cutix Cable Plc Hub Example

Godwin, Harold Chukwuemeka and Nsobundu, Martins Chinemelum

Department of Industrial/Production Engineering,
Nnamdi Azikiwe University, Awka, Anambra State, Nigeria
Corresponding Author: Godwin, Harold Chukwuemeka

Abstract
The maintenance expenditure accounts for 20-50% of the production cost for many asset-intensive industries depending on the level of mechanization which when reduced will lead to reduction in production cost. This paper aimed at integrating the efficiency and effectiveness of the production function into equipment and plant maintenance in Cutix Cable Manufacturing Plc. Nnewi, Nigeria through the review of their maintenance input for the year 2011. The objectives are to identify the lapses in their maintenance culture using the maintenance performance productivity model, to identify the effectiveness and efficiency of their production system using the overall equipment effectiveness/efficiency model (OEE) and as well establish the correlation between their performance and the productivity of their system using the statistical analysis technique. Findings revealed 98.8 hours of breakdown resulting to ₦990000 ($1.55B) being cost of breakdown repair. Equipment effectiveness/efficiency varies throughout the year 2011 with values between 81% and 86%. It is therefore recommended that Cutix Cable Plc should adopt and implement the total productive maintenance strategy to improve the Equipment Availability (EA) and its utilization, the Production Rate (PR), and the Quality Rate (QR). This research will help CUTIX Cable manufacturing Plc to adopt the most effective maintenance strategy.

Keywords: maintenance, equipment, efficient, production, breakdown, downtime

INTRODUCTION

Production facilities and equipment are subject to deterioration due to their use and exposure to environmental conditions. These deteriorations occur as a result of wear and tear of parts in relative motion and improper lubrication of the sliding parts. Nothing lasts forever and all equipment has predefined life expectancy or operational life associated with it. For instance, equipment may be designed to operate at full design load of 5,000 hours and may be designed to go through 15,000 start and stop cycles. Maintenance is the activity directed towards the upkeep and the repair of plant facilities/ equipment. Maintenance activities include: lubrication, cleaning, timely inspection, changing worn-out parts/ components and systematic maintenance (Stevenson, 2009; Mobley, 2002; Arditi and Nawakoraowit, 1999).

The need for maintenance is predicated on actual or impending failure – ideally, maintenance is performed to keep equipment and systems running efficiently and in good working condition for at least the design life of the component(s), and also to ensure the quality of products being produced (Martands, 1998). The design life of most equipment requires periodic maintenance. Belts need adjustment, alignment needs to be maintained, and proper lubrication on rotating equipment is required, and so on. Failure to perform maintenance activities intended by the equipment's designer shortens the operating life of the equipment (Stevenson, 2009).

For decades, industrial and other organizations concentrated most of their attention upon product production, generally ignoring the maintenance function, viewing it as a necessary evil. During the recent years, there has been a gradual attitude in how co-operate managers view the maintenance function. One of the most important factors forcing this change was that maintenance departments becomes major cost centres within these organizations. For many asset-intensive industries the maintenance costs are a significant portion of the operational cost, the maintenance expenditure accounts for 20-50% of the production cost for the industry depending on the level of mechanization (Parida, et al., 2007). If the right kind of maintenance strategy is rightly implemented, there should be a commensurate positive effect on the production.

Different approaches to how maintenance can be performed to ensure equipment reaches or exceeds its design life have been developed. In addition to waiting for a piece of equipment to fail (reactive maintenance), preventive maintenance, predictive maintenance, total productive maintenance or reliability-centred maintenance can be utilized (Das, 1999; Frangopol, 2000; Stevenson, 2009; Van Noortwijk and Frangopol, 2004; Mobley, 2002).

This paper employed Maintenance Performance Productivity Model (Kumar et al, 2000), Overall Equipment Effectiveness/Efficiency Model (OEE) (Ljungberg, 1998; Dal et al, 2000), and Statistical Analysis Technique (Pearson, 1903) in analysing the effectiveness and efficiency of maintenance management and practices in Cutix Cables Ltd, bearing in mind the effects of ineffective maintenance practices on the production system and quality of products being produced. The essence is to minimize major industrial losses associated with shutdown (planned maintenance), production adjustment, equipment breakdown or failure, process failure, normal production loss, abnormal production loss, quality defects and reworking as well as scraping.

This paper aimed at ensuring effective integration of production function/activities into plant/equipment maintenance in CUTIX Cable Manufacturing Plc Nnewi, Nigeria. Hence, the following objectives were achieved: (1) identified the influence of equipment/ plant facilities over performance and productivity of a cable manufacturing system. (2) Reviewed the company's maintenance inputs/activities carried out from January to December, 2011. (3) Identified the lapses in the maintenance culture of the cable manufacturing system, through discreet analysis of its performance using maintenance performance productivity model. (4) Identified and evaluated the equipment effectiveness/ efficiency using overall equipment effectiveness model (a total productive maintenance model). (5) Established the correlation between the maintenance performances measured in terms of overall equipment effectiveness/efficiency performance (OEE) and the performance efficiency of the manufacturing system measured in terms of equipment availability, production rate and quality rate.

METHODOLOGY

Research Design

This analytical and case study research design is based on monthly maintenance data from January to December 2011 collected from the records in production and maintenance departments, and other information collected through direct observation and interviews with production, inventory and maintenance personnel of Cutix Cable Plc. Maintenance Performance Productivity Model, Overall Equipment Effectiveness/Efficiency Model (OEE) and Statistical Analysis Technique were utilized in analysis of maintenance data collected. The results are presented in tabular and graphical forms.

METHOD OF DATA ANALYSIS

Maintenance Performance Productivity Model

This model helps in the measurement, analysis and the evaluation of the performance of the maintenance system. It consists of various important components or elements designed to achieve its objectives. These elements are;

$$\text{Mean Time To Repair (MTTR)} = \frac{\text{Total Repair Time(TRT)}}{\text{Number of Breakdown (NOB)}} \quad (1)$$

$$\text{Mean Time Between Failure (MTBF)} = \frac{number\ of\ operating\ time\ (NOT)}{number\ of\ breakdown\ (NOB)} \quad (2)$$

$$\text{Maintenance Breakdown Severity (MBS)} = \frac{cost\ of\ breakdown\ repair\ (CBR)}{number\ of\ breakdown\ (NOB)} \quad (3)$$

$$\text{Maintenance Improvement (MI)} = \frac{\text{total maintenance man-hour on preventive maintenance job (MPM)}}{\text{total man-hours available (MPA)}} \times 100 \quad (4)$$

$$\text{Maintenace Cost Per Hour (MCPH)} = \frac{\text{total maintenance cost (TMC)}}{\text{total maintenance man-hours (TMM)}} \quad (5)$$

$$\text{Manpower Utilization (MU)} = \frac{\text{wrench time (WT)}}{\text{total time available (TA)}} \times 100 \quad (6)$$

$$\text{Material Usage Per Work Order (MUPO)} = \frac{\text{total material cost (TMC)}}{\text{number of work order (NWO)}} \quad (7)$$

$$\text{Maintenace Cost Index (MCI)} = \frac{\text{total maintenance cost (TMC)}}{\text{total production cost (TPC)}} \times 100 \quad (8)$$

Overall Equipment Effectiveness/Efficiency Model (OEE)

This model is also known as total productive maintenance model. It is the product of equipment availability (EA), production rate (PR) and quality rate (QR). It is an effective and efficient model developed which utilizes total productive maintenance implementation procedures for observation, analysis and evaluation of the equipment effectiveness and efficiency. It is basically aimed at maximizing the production effectiveness and the effectiveness of production plant which depends on the efficiency with which it uses equipment, materials, people and method. This is actually achieved by examining and assessing the input to the production process and identifying, eliminating the losses associated with each in order to maximize production. The standard benchmark (world class benchmark) for overall equipment effectiveness model is +85% and above (Mckone et al., 1999). The components of this model are computed as follows;

$$\text{Equipment Availability (EA)} = \frac{\text{planned production time[PPT]} - \text{machine down time [MDT]}}{\text{planned production time [PPT]}} \quad (9)$$

$$\text{Production Rate(PR)} = \frac{\text{standard time per unit [STPU]} \times \text{unit produced non defective [UPND]}}{\text{number of operating time [NOT]}} \quad (10)$$

$$\text{Quality Rate (QR)} = \frac{\text{Total Unit Produced(TUP)} - \text{Defective Quantity(DQ)}}{\text{Total Unit Produced (TUP)}} \quad (11)$$

The Overall Equipment Effectiveness/ Efficiency (OEE) is then computed as shown below;

$$OEE = EA \times PR \times QR \quad (12)$$

Statistical Analysis Technique

This statistical tool is employed in testing the correlation between the maintenance performances and manufacturing system productivity of Cutix Cable Manufacturing Industry. This is achieved by using the data collected from the equipment effectiveness/efficiency since it is the function of input performance of the maintenance system, and the equipment availability (EA), production rate (PR) and quality rate (QR) also they are functions of manufacturing system performance.

The correlation between the parameters is determined using coefficient of correlation, r. This tool is used by statisticians to measure, determine and establish both the strength of the relationship and direction between two variables. The range of correlation coefficient is from -1 to +1. If there is a strong positive linear relationship between the variables, the value of r will be close to +1, If there is a strong negative linear relationship between the variables, the value of r will be close to -1, and when there is no linear relationship, the value of r will be zero (0).

The coefficient of correlation, r is computed as follows;

$$r = \frac{N(\sum XY) - (\sum X)(\sum Y)}{\sqrt{[N(\sum X^2) - (\sum X)^2][N(\sum Y^2) - (\sum Y)^2]}} \quad (13)$$

Where

r = coefficient of correlation

X = independent variable (Overall Equipment Effectiveness/Efficiency (OEE)

Y = dependent variable (equipment availability (EA) or production rate (PR) or quality rate (QR).

Since the value of r is computed from data obtained from samples, there are two possibilities: either the value of r is high enough to conclude that there is significant relationship between the variables, or the value of r is due to chance. In order to make this determination, a hypothesis testing procedure is used. In hypothesis testing, one of the following is true;

H_0; P = 0→ null hypothesis, which means that there is no correlation, between the variable X and Y in the population.

H_1: P ≠ 0→ alternative hypothesis, which means that there is a significant correlation between the variables X and Y in the population.

The formula for the correlation with degrees of freedom equal to N-2 is given as;

$$t = r\sqrt{\frac{N-2}{1-r^2}} \quad (14)$$

Where: t = computed test for significance of the correlation coefficient, N = number of variables and r = coefficient of the correlation.

For this study, the hypothesis test involves a two-tailed test at α = 0.05 level of significance and N – 2 degrees of freedom. From the standard t-test table, the critical value at 0.05 level of significance and N – 2 degrees of freedom is ±1.812.

RESULTS AND DISCUSSION

Maintenance Performance Productivity Model

Tables 1, 2 and 3 below represent maintenance performance measurement chart for year 2011 collected from the industry. Table 1 shows the machine downtime. The machine breakdowns are presented in form of mechanical, electrical, electronics and safety device faults. The total machine downtime is computed by summing all the losses due to machine faults, time losses due to setup or adjustment and other conditions, and the planned shutdown for preventive maintenance.

Table 1: Machine Downtime for 2011

S/N	Months	Mechanical Breakdown (Hour)	Electrical Breakdown (Hour)	Electronic/Safety Device Breakdown (Hour)	Setup/ Adjustment and Other Conditions (Hour)	Planned Downtime For The Schedule Maintenance (Preventive Maintenance) (Hour)	Total Machine Downtime (TMD)
1	Jan.	45.2	11.3	2.5	9.4	10	78.4
2	Feb.	20.5	8.4	3.5	10	10	52.4
3	March	15.8	-	-	7.2	10	33
4	Apr	60.8	7.3	9.2	11.5	10	98.8
5	May	30.5	10.2	3.4	10.4	10	64.5
6	Jun.	3.5	11.2	7.8	11.2	10	43.7
7	Jul.	-	11.2	6.9	13.4	10	41.5
8	Aug.	40.2	7.7	2.3	5.2	10	65.4
9	Sept.	14.7	4.5	8.3	10.5	10	48
10	Oct.	30.2	6.3	7.5	11.00	10	65
11	Nov.	50.2	-	-	12.5	10	72.7
12	Dec.	12.5	-	10.5	15.2	10	48.2

Table 2: Maintenance Performance Measurement Chart for 2011

S/N	Total Maintenance Man Hr on Preventive Maintenance Job (TMMPM) (Hour)	Total Man Hr Available (TMA) (Hour)	Total Maintenance Cost (TMC) (₦)	Total Maintenance Man Hr (TMM) (Hour)	Wrench Time (WT) (Hour)	Total Time Available (TTA) (Hour)	Total Material Cost (TMC) (₦)	Number OF Work Order (NWO)
1	8.5	10	85000	33.9	25.4	78.4	4992000	6
2	7	10	70000	19.2	12.2	52.4	4647000	9
3	6.2	10	62000	17	10.8	33	5332500	4
4	9	10	90000	53	44	98.8	4659000	7
5	6	10	60000	28.5	22.5	64.5	5096250	5
6	5	10	50000	23.3	18.3	43.7	5072250	4
7	9.4	10	94000	25.5	16.1	41.5	5268750	7
8	9.6	10	96000	33.8	24.2	65.4	5089500	6
9	8.2	10	82000	20.7	12.5	48	5040000	8
10	7.6	10	76000	17.6	10.0	65	5220000	5
11	7.2	10	72000	24.2	17.0	72.7	4854750	5
12	6.4	10	64000	36.6	30.2	48.2	5218500	10

Table 3: Maintenance Performance Measurement Chart for 2011 Contd.

S/N	Total Repair Time (TRT)	Number of Operating Time (NOT) (Hour)	Number of Break downs (NOB)	Cost of Break down Repair (CBR) (₦)	Cost of Wrench Time (Productive Maintenance Time (COWT) (₦)	Cost of Preventive Maintenance (CPM) (₦)	Cost of Breakdown Time Losses (CBTL) (₦)	Cost of Machine Down Time (CMD) (₦)	Total Production Time (TPT) (Hour)	Planned Produc-tion Time (PPT) (Hour)
1	350400	665.6	2	571500	381000	85000	10260000	11760000	99840000	744
2	350400	619.6	2	274500	183000	70000	6360000	7860000	92940000	672
3	350400	711	1	243000	162000	62000	3450000	4950000	106650000	744
4	350400	621.2	4	990000	660000	90000	13320000	14820000	93180000	720
5	350400	679.5	2	506250	337500	60000	8175000	7675000	101925000	744
6	350400	676.3	2	411750	274500	50000	5055000	6555000	101445000	720
7	350400	702.5	1	362250	241500	94000	4725000	6225000	105375000	744
8	350400	678.6	1	544500	363000	96000	8310000	9810000	101790000	744
9	350400	672	2	281250	187500	82000	5700000	7200000	100800000	720
10	350400	696	1	225000	150000	76000	8100000	9750000	104400000	744
11	350400	647.3	3	382500	255000	72000	9405000	10905000	97095000	720
12	350400	695.8	1	679500	453000	64000	5730000	7230000	104370000	744

The mean time between failures (MTBF), maintenance breakdown severity (MBS), maintenance improvement (MI), maintenance cost per hour (MCPH), manpower utilization, material usage per work order (MUPO) and maintenance cost index (MCI) are computed using equations (2-8) respectively. The results obtained in each case for the months of January to December, 2011 are shown in table 4 below.

Table 4: Maintenance Performance Results for the Year 2011

S/N	Month	MTBF (Hrs)	MBS (Naira Per Breakdown)	MI (%)	MCPH (Naira per Hour)	MPU (%)	MUPW (naira per Order)	MCI (%)	MD (HRS)
1	Jan.	332.8	285750	85	2507.37	32	832000	0.085	78.4
2	Feb.	309.8	137250	70	3645.83	23	516333.33	0.075	52.4
3	Mar.	711.0	243000	62	3647.06	33	1333125	0.058	33.0
4	Apr.	155.3	247500	90	1698.11	45	665571.43	0.097	98.8
5	May	339.75	253125	60	2105.26	35	1019250	0.059	64.5
6	Jun.	338.15	205875	50	2145.92	40	1268062.5	0.049	43.7
7	Jul.	702.5	362250	94	3686.27	39	752678.57	0.089	41.5
8	Aug.	678.6	544500	96	2846.23	37	848250	0.094	65.4
9	Sept.	336.0	140625	82	3961.35	26	630000	0.081	48.0
10	Oct.	696.0	225000	76	4318.18	15	1044000	0.073	65.0
11	Nov.	215.78	127500	72	2975.21	24	970950	0.074	72.8
12	Dec.	695.8	679500	64	1748.63	63	521850	0.061	48.2

From table 4 above, it can be observed that mean time between failures (MTBF) which provides information about the maintenance performance efficiency fluctuates throughout the year 2011, with the highest value of 711hours in March, and lowest value of 155.3hours in April. To ensure effective utilization of the production equipment which has a direct effect on the productivity of the manufacturing system, the benchmark is to always have a high MTBF. Also, the result obtained for maintenance breakdown severity (MBS) which provides information about the financial (cost) resources spent on maintenance services, shows that the company spent the highest amount of money (₦ 679,500) for maintenance services in December, and the lowest cost of ₦ 127,500 in November. Table 4 also shows very low values of maintenance cost index, with the lowest value of 0.049% in June and, the highest value of 0.097% in April. Maintenance cost index is the ratio of maintenance cost to the production cost of the equipment. The lower the maintenance cost index, the more effective and efficient the manufacturing system.

Overall Equipment Effectiveness/Efficiency Model (OEE)

Table 5 shows the data for the total machine downtime, standard time per unit, total unit produced, defective quantity, unit produced non defective, number of operating time and planned production time for the year 2011 obtained from production and maintenance departments.

Table 5: Overall Equipment Effectiveness Measurement Chart for 2011

Month	Total Machine Downtime (TMD)	Standard time per unit (STPU) (hrs/coils)	Total unit produced (TUP) (coils)	Defective quantity (DQ) (coil)	Unit produced non defective (UPND) (coil)	Number of operating time (NOT) (hrs)	Planned production time(PPT) (hrs)
Jan	78.4	0.03	20800	229	20571	665.6	744
Feb	52.4	0.03	19363	445	18918	619.6	672
Mar	33	0.03	22219	561	21883	711	744
Apr	98.8	0.03	19413	679	18737	621.2	720
May	64.5	0.03	21234	255	20979	679.5	744
Jun	43.7	0.03	21134	564	20765	676.3	720
Jul	41.5	0.03	21953	520	21755	702.5	744
Aug	65.4	0.03	21206	121	21085	678.6	744
Sep	48	0.03	21000	441	20559	672	720
Oct	65	0.03	21750	207	21543	696	744
Nov	72.7	0.03	20228	263	19965	647.3	720
Dec	48.2	0.03	21744	544	21200	695.8	744

Applying equations (9 -12) using the data in the table 5, the equipment availability (EA), production rate (PR), quality rate (QR) and overall equipment effectiveness (OEE) are respectively obtained. The results obtained are shown in table 6 below.

Table 6: Overall Equipment Effectiveness/ Efficiency (OEE) Results

s/n	Month	Equipment Availability (EA)	Production Rate (PR)	Quality Rate (QR)	Machine Downtime (MD)	Overall Equipment Effectiveness/Efficiency (OEE) (%)
1	Jan.	0.89	0.93	0.98	78.4	81
2	Feb.	0.92	0.92	0.98	52.4	83
3	Mar.	0.96	0.92	0.98	33	86
4	Apr.	0.86	0.90	0.91	98.8	75
5	May	0.91	0.93	0.99	64.5	84
6	Jun.	0.94	0.93	0.99	43.7	86
7	Jul.	0.74	0.93	0.99	41.5	86
8	Aug.	0.91	0.93	0.99	65.4	84
9	Sept.	0.93	0.92	0.98	48	84
10	Oct.	0.91	0.93	0.99	65	84
11	Nov.	0.89	0.93	0.99	72.8	82
12	Dec.	0.93	0.91	0.98	48.2	83

From table 6, it can be observed that the monthly Overall Equipment Effectiveness/ Efficiency vary throughout the year with values ranging from +81% to +86%. The values for months of March, August, September and October are +84% each which is 1% below the standard (world class) benchmark of +85% (Mckone et al., 1999), while that of March, June and July are +86% each which is 1% above +85%. Others fall very close to the benchmark. This simply shows that overall equipment effectiveness/efficiency of the company is relatively good but, more effort needs to be put in place so as to improve the Equipment Availability (EA) and its utilization, the Production Rate (PR), and the Quality Rate(QR) so as to push more of the monthly overall equipment effectiveness above the standard benchmark of +85%. This will further improve the overall equipment effectiveness/efficiency in the company.

Statistical Analysis Technique

The results in table 6 are used to test the relationship between the maintenance performances and manufacturing system productivity of Cutix Cable Manufacturing Industry. The equipment effectiveness/efficiency (OEE) which is a function of

input performance of the maintenance system is used as the independent variable. The equipment availability (EA), production rate (PR) and quality rate (QR) are all functions of manufacturing system performance. Therefore, any of them can be used as the dependent variable to represent the manufacturing system performance. Applying equation (13) and the values in table 6, the coefficient of correlation in each case is obtained, and the significance of the relationship in each case is tested using equation (14) as shown below.

For relationship between equipment availability (dependent variable, y) and overall equipment effectiveness/ efficiency (independent variable, x), we have: N=12, $\sum x$= 9.88, $\sum x^2$= 8.1416, $\sum y$= 10.79, $\sum y^2$ =9.7371. Therefore, the coefficient of correlation between EA and OEE is;

$$r = \frac{12(8.8896)-(9.88)(10.79)}{\sqrt{[12(8.1416)-(9.88)^2][12(9.7371)-(10.79)^2]}} = 0.4\ 88$$

The value of t is;

$$t = 0.488 \sqrt{\frac{12-2}{1-(0.488)^2}} = 1.768.$$

The computed value (1.768) is less than the critical value from t-test table; therefore, there is no significant relationship between equipment availability (EA) and the overall equipment effectiveness/efficiency (OEE).

For the relationship between the production rate (dependent variable, y) and the overall equipment effectiveness/ efficiency (independent variable, x), we have: N=12, $\sum x$= 9.88, $\sum x^2$= 8.1416, $\sum y$= 11.08,

$\sum y^2$ =10.2316. Therefore, the coefficient of correlation between PR and OEE is;

$$r = \frac{12(9.1242)-(9.88)(11.08)}{\sqrt{[12(8.1416)-(9.88)^2][12(10.2316)-(11.08)^2]}} = 0.8$$

The value of t is; t = $0.8\sqrt{\frac{12-2}{1-(0.8)^2}} = 4.216$

The computed value (4.216) is greater than the critical value from t-test table; therefore, there is a significant relationship between production rate (PR) and the overall equipment effectiveness/efficiency (OEE).

For the relationship between the quality rate (dependent variable) and the overall equipment effectiveness/ efficiency (independent variable), we have: N=12, $\sum x$= 9.88, $\sum x^2$= 8.1416, $\sum y$= 11.75, $\sum y^2$ =11.5107. Therefore, the coefficient of correlation between QR and OEE is;

$$r = \frac{12(9.6797)-(9.88)(11.75)}{\sqrt{[12(8.1416)-(9.88)^2][12(11.5107)-(11.75)^2]}} = 0.1171$$

The value of t is, t = $0.1171\sqrt{\frac{12-2}{1-(0.1171)^2}} = 0.388$

The computed value (0.388) is less than the critical value from t-test table; therefore, there is no significant relationship between quality rate (QR) and the overall equipment effectiveness/efficiency (OEE).

From the foregoing, it can be said that there is correlation between maintenance performances measured in terms of overall equipment effectiveness/efficiency performance (OEE) and the performance efficiency of the manufacturing system measured in terms of production rate (PR).

CONCLUSION

Maintenance of production facilities goes a long way to determine the level of quality and efficiency of a production system. The relevance of maintenance practice is measured in the productivity of the manufacturing system using various indicators. Depending on the system of production, level of automation and schedule of a production system, different maintenance strategies are being practiced; these strategies could be reactive, proactive or aggressive in nature.

In this study, maintenance practice in Cutix Cable Manufacturing Plc Nnewi, Nigeria was reviewed and evaluated using Maintenance performance productivity Model, Overall Equipment Effectiveness/efficiency Model (OEE) and a statistical tool (co-efficient of correlation). The Maintenance Performance Productivity Model was used to measure, analyse and evaluate the performance of the maintenance practice while Overall Equipment Effectiveness/Efficiency Model was used to analyse and evaluate the effectiveness and efficiency of the production system. The statistical tool - the co-efficient of correlation was used to measure, determine and establish the strength of the relationship between maintenance performance and the productivity of the manufacturing system. The study reveals that the maintenance practice in this industry is effective, and makes more use of preventive maintenance method than others.

REFERENCES

Arditi, D. and Nawakoraowit, M. (1999). Issues in Building Maintenance, Property Managers and Prospective. Journal of Architectural Engineering, 5(4).

Dal, B., Tugwel, P. and Greatbanks, R. (2000). Overall Equipment Effectiveness as a Measure for Operational Improvement: A Practical Analysis. International Journal of Operations and Production Management, 20(12), Pp 488-502.

Das, P.C. (1999). Prioritization of Bridge Maintenance Needs, Case Studies in Optimal Design and Maintenance Planning of Civil Infrastructure Systems, ASCE, Reston, Virginia, Pp 26-44.

Frangopol, D.M. (2000). Optimum Maintenance Strategies for Different Bridge Types: Project Description and Steel/Concrete Composite Bridges, Vol.1, Final Report to Highways Agency, London.

Kumar, A., Singh, H. and Motwani, J. (2000). A Review and Analysis of the State of the Art Research on Productivity Measurement. Ind. Management and Data System, 100(5), Pp 234-241.

Ljungberg, O. (1998). Measurement of Overall Equipment Effectiveness: Effectiveness as a Basic for TPM Activities. International Journal of Operation and Production Management, 18(5), Pp 495-507.

Mobley, R.K. (2002). An Introduction to Preventive Maintenance, 2nd Ed., Elsevier Science, USA.

Stevenson, W. J. (2009). Operations Management, 10th ed., The McGraw-Hill Companies, New York.

Van Noortwijk, J.M. and Frangopol, D. M. (2004). Two Probabilistic Life-Cycle Maintenance Models for Deteriorating Civil Infrastructures. Probabilistic Engineering Mechanics, Vol. 19, No 4, Pp 345-359.